

07-AB-1632

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RECD. OCT 27 2008

AB 1632 ASSESSMENT OF CALIFORNIA'S OPERATING NUCLEAR PLANTS

FINAL REPORT

Prepared For:

CALIFORNIA ENERGY COMMISSION

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FINAL CONSULTANT REPORT

October 2008

CEC-100-2008-005-F

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DISCLAIMERS

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AB 1632 (Chapter 722, Statutes of 2006) authorizes the California Energy Commission to work with other public entities and agencies, including the California Seismic Safety Commission, to gather and analyze information related to the vulnerability of the state's largest baseload power plants to a major disruption due to a seismic event or plant aging. In places where this report contains input from staff of the Seismic Safety Commission, it does not reflect input from the full California Seismic Safety Commission nor have the Commissioners approved the report. While Seismic Safety Commission staff members are licensed professionals familiar with certain aspects of seismic systems, they do not perform engineering, geological or other licensed work. Consequently, their input does not constitute work by licensed professionals on the Seismic Safety Commission or its staff. The Seismic Safety Commission does not assume responsibility for the accuracy, integrity or reliability of any aspect of the contractor's report nor does the Seismic Safety Commission regulate, certify, approve or disapprove of this report.

The Consultant Team

This report is the product of a collaborative effort by individuals at MRW & Associates, Inc. (MRW), ABS Consulting (ABS), Aspen Environmental Group (Aspen), Ventyx (formerly Global Energy Decisions), and EllerStone D’Paul, Inc. collectively referred to as the “Consultant Team.” Individuals from these companies provided expertise for various aspects of this interdisciplinary report. MRW provided policy and economic expertise as well as overall project management; ABS provided expertise in nuclear plant engineering, geology, and seismology; Aspen contributed environmental and socioeconomic expertise; Ventyx assisted with the resource planning analysis; and EllerStone D’Paul provided research and editorial support. A list of the individuals that contributed to this report is provided below.

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Acknowledgements

The Consultant Team thanks all those who contributed to the preparation and review of this report or participated in the AB 1632 process.

Assemblyman Sam Blakeslee initiated this review of policy and reliability issues associated with the use of California's operating nuclear plants. The Energy Commission's Electricity and Natural Gas Committee and 2008 IEPR Committee, led by Commissioners James Boyd, Jeffrey Byron, and Jackalyne Pfannenstiel, spearheaded the project and provided guidance and insight on the project scope and objectives.

The Seismic Vulnerability Advisory Team provided valuable feedback on multiple drafts of the report. Their expertise provided the Consultant Team new perspectives on the seismic literature, and their careful reviews sharpened the text and conclusions of the seismic vulnerability assessment. The Seismic Vulnerability Advisory Team was comprised of Richard McCarthy, Bob Anderson, and Fred Turner of the California Seismic Safety Commission; Mark Johnsson of the California Coastal Commission; Michael Reichle, Bill Bryant, and Chris Wills of the California Geological Survey; and Matt Silver and Bob Strand from the California Energy Commission.

Several Energy Commission staff members assisted in planning and reviewing the report. Michael Jaske took the lead on the reliability implications of nuclear plant outages. He helped plan and then interpret the production simulation modeling, and he provided helpful feedback on the report text. Karen Griffin provided insightful comments on the replacement power analysis and other policy issues. Eugenia Laychak contributed to the reviews of once-through cooling and the seismic vulnerability assessment.

Bob Emmert of the California Independent System Operator and members of the public who participated in the public workshops or submitted written comments provided useful information and added important perspectives.

Pacific Gas & Electric and Southern California Edison provided extensive information in response to California Energy Commission data requests and also provided comments on the study plan and the draft report. This information was invaluable to the Consultant Team.

Finally, many Energy Commission staff, including Suzanne Korosec, Chris Marxen, Joe O'Hagen, Dave Vidaver, Claudia Chandler, and Susanne Garfield-Jones, provided valuable technical and editorial advice. We would also like to thank Susanne Garfield-Jones and her staff, including Bob Aldrich, Nancy Hassman and Carol Greenwood, for helping with the final production of the report and web team support. Donna Parrow provided administrative and logistical support to the project and Jerome Lee helped with managing the audio visual equipment during the workshops.

Abstract

This consultant report was prepared in response to Assembly Bill 1632 (“AB 1632” - Blakeslee, Chapter 722, Statutes of 2006), which directed the California Energy Commission to assess the potential vulnerability of the state’s two operating nuclear power plants to a major disruption due to a seismic event or plant aging; to assess the impacts of such a disruption on system reliability, public safety, and the economy; to assess the costs and impacts from nuclear waste accumulating at these plants; and to evaluate other major issues related to the future role of these plants in the state’s energy portfolio. The report considers the seismic vulnerabilities of the nuclear plant sites, structures, and spent fuel storage facilities and the vulnerability of the plants to age-related degradation. The report also considers the impacts of a major disruption at the plants on the reliability of California’s transmission grid and power supply. Finally, the report considers a number of policy areas related to California’s operating nuclear plants, including the cost, land use, and local economic impacts of nuclear waste accumulation at the plant sites; the economic and environmental tradeoffs among alternative power supply options; and potential implications of renewing the operating licenses of the nuclear plants.

Keywords

Nuclear energy, nuclear power, California Energy Commission, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Hosgri Fault, seismic, earthquake, tsunami, operating basis earthquake, safe shutdown earthquake, design basis, Kashiwazaki-Kariwa, Nuclear Regulatory Commission, NRC, nuclear waste, nuclear waste storage, nuclear waste disposal, nuclear waste transport, Department of Energy, DOE, spent fuel, safety culture, Independent System Operator, CAISO, production simulation, outage, replacement power, reliability, low-level waste, renewable power, life cycle, once-through cooling, license renewal, relicensing, electricity, dry cask, independent spent fuel storage installation, ISFSI, greenhouse gas emissions, GHG emissions, USGS, US Geological Survey

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Executive Summary

In 2006 the California Legislature passed Assembly Bill 1632 (AB 1632).¹ The legislation directed the California Energy Commission (Energy Commission) to assess the potential vulnerability of the state's largest baseload power plants, which are the two operating nuclear plants, to a major disruption due to a seismic event or plant aging.² The Energy Commission was also directed to assess the impacts that such a disruption would have on system reliability, public safety, and the economy; assess the costs and impacts from nuclear waste accumulating at these plants; and evaluate other major issues related to the future role of these plants in the state's energy portfolio.

The state's two operating nuclear plants, Pacific Gas & Electric's (PG&E) Diablo Canyon Power Plant (Diablo Canyon) and Southern California Edison's (SCE) San Onofre Nuclear Generating Station (SONGS), account for 12 percent of the state's electricity supply and, by some measures, 24 percent of the state's low-carbon electricity supply.³ A major disruption of California's operating nuclear plants could result in a shutdown of plant operations for several months to more than a year or even cause the retirement of one or more of the plants' reactors. Because these plants are so important to the state's electricity supply, California requires a long-term plan to prevent major disruptions and to be ready should a disruption occur.

This report provides information to policymakers and stakeholders about Diablo Canyon and SONGS to assist energy policy planning. It also provides the analytical foundation for the findings and recommendations of the AB 1632 assessment in the Energy Commission's 2008 *Integrated Energy Policy Report Update* to the State Legislature.

A key element of the report is a review of existing scientific studies regarding the potential vulnerability of SONGS and Diablo Canyon to a major disruption due to a seismic event or plant aging.

Study Approach

This assessment, as directed in AB 1632, relies on existing literature, studies, and data where possible. The interdisciplinary Consultant Team reviewed materials that include academic and scientific journal articles, reports, and studies; federal, state, and local governmental studies, reports, bulletins, planning documents, and budgets; federal and state regulatory proceeding filings and rulings; data provided by the nuclear plant owners; and many scientific articles and reports. Despite the depth and breadth of data and literature reviewed, the Consultant Team in

¹ AB 1632 (Blakeslee, Chapter 722, Statutes of 2006).

² AB 1632 directs the Energy Commission to assess "large baseload generation facilities of 1,700 megawatts or greater." Besides Diablo Canyon and SONGS, there are two generating facilities (Alamitos and Moss Landing) that have a nameplate capacity greater than 1,700 MW. However, because both of these facilities operate below a 60% capacity factor, they are not considered baseload generation and were therefore excluded from the study.

³ California Energy Commission. "2007 Net System Power Report." CEC-200-2008-002-CMF. April 2008, pages 4-5. <<http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>>.

some instances found areas where data are either limited or unavailable. For these areas, the report identifies questions and issues that merit additional review and analysis.

For the seismic vulnerability assessment, the Consultant Team provided early drafts to several seismic staff experts at the California Energy Commission, the California Seismic Safety Commission, the California Coastal Commission, and the California Geological Survey. These experts reviewed the drafts and provided comments on the literature reviewed by the Consultant Team and the team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS. Staff experts from the California Energy Commission and the California Independent System Operator (ISO) also reviewed early drafts and provided comments on other sections of the report.

The public and stakeholders, including the plant owners, also contributed to this assessment by identifying studies for review and providing comments on a draft study plan.⁴ To maintain the independence of the assessment, the Consultant Team did not meet with the nuclear plant owners or other interested parties during the development of the draft report. The plant owners, members of the public, and interested stakeholders were also provided the opportunity to submit written comments on a preliminary draft of this report.

Seismic Vulnerability Assessment

The seismic vulnerability assessment undertaken for this study was performed in two steps. In the first step, the Consultant Team considered the geology and seismic hazards in the vicinity of Diablo Canyon and SONGS. In the second step the Consultant Team assessed the seismic design of the power plants, the spent fuel storage facilities located at the plants, the transmission systems leading to and from the plants, and the access roadways for the plants. From these reviews, the Consultant Team developed an assessment of the plants' vulnerabilities to earthquakes and secondary seismic hazards.

The main findings of the seismic vulnerability assessment are:

1. PG&E, through its Long-Term Seismic Program (LTSP), has extensively explored the seismology and geology of the Diablo Canyon site. SCE does not have a program similar to PG&E's LTSP, and much less is known about the SONGS seismic setting. New information on ground motion and blind thrust faulting has eroded the perceived safety margins of SONGS. The vulnerability of the plant to seismic hazards cannot be determined without further investigations into the plant's seismic setting and an assessment of the implications of new research on seismology, geology, and ground motion for the plant's safety and reliability.
2. The Hosgri Fault dominates the seismic hazard at Diablo Canyon. For many years there has been uncertainty regarding the regional tectonic setting of this fault zone and the nature of the Hosgri Fault. Current published data, much of which has been developed through PG&E's LTSP, support the interpretation that the Hosgri Fault is predominantly

⁴ See the Energy Commission's AB 1632 web site at: < <http://www.energyca.gov/ab1632/index.html>>.

a strike-slip fault.⁵ A minority of scientists disagrees with this characterization and believes that the Hosgri Fault is predominantly a thrust fault. If displacement on the fault is predominantly thrust, the seismic hazard at Diablo Canyon could be greater than currently anticipated.

3. Diablo Canyon is located within the San Luis-Pismo structural block. There is a need to better define the deep geometry of bounding faults of this block and to better understand the lateral continuity of these fault zones. Although these fault zones are unlikely to replace the Hosgri Fault as the dominant source of seismic hazard at the plant, improved characterizations of these fault zones would refine estimates of the ground motion that is likely to occur at different frequencies. This would be significant for future engineering vulnerability assessments.
4. The geometry of faults bounding the San Luis – Pismo block suggests that the occurrence of an earthquake directly beneath Diablo Canyon, similar to the 2003 San Simeon earthquake is possible. Although PG&E has considered such an earthquake in the context of probabilistic seismic hazard analyses, PG&E has not assessed the expected ground motions and vulnerabilities of plant components specifically from such an earthquake. If such an assessment is conducted, it should include the vulnerabilities of plant components that might be sensitive to enhanced long-period motions in the near field of an earthquake rupture.
5. Updates to the Diablo Canyon probabilistic seismic hazard assessment have concluded that the plant was built with sufficient safety margin to accommodate ground motions from the Hosgri Fault, assuming up to 33 percent thrust faulting. Future study with newer technologies, such as three-dimensional geophysical seismic reflection mapping, could resolve questions about the characterization of the Hosgri Fault and might change estimates of the seismic hazard at the plant. Similarly, such imaging at strategically chosen locations could prove or disprove the existence of subsurface faults in the San Luis–Pismo tectonic block and could also help refine knowledge of the deep geometry, continuity, and interaction of poorly expressed faults that comprise the structural boundaries of the San Luis–Pismo Block.
6. A modern global positioning system (GPS) in the central California coastal area could provide insight to tectonic block movements in this region and might alter fault parameters that are used in existing seismic hazard assessments. PG&E, through the LTSP, is pursuing this objective.
7. The major uncertainties regarding the seismology of the SONGS site relate to the continuity, structure, and earthquake potential of a nearby offshore fault zone that connects faults in the Los Angeles and San Diego regions. There is also uncertainty regarding the potential for unknown (“blind thrust”) faults near the plant. Well planned, high-quality three-dimensional seismic reflection data at strategically chosen locations

⁵ This interpretation was adopted in a recent consensus report by the U.S. Geological Survey, the California Geological Survey, and the Southern California Earthquake Center.

may resolve many of the remaining uncertainties and might change current estimates of the seismic hazard at the plant.

8. New seismologic and geologic information that has emerged since SONGS was built in the 1970s and early 1980s indicates that SONGS could experience larger ground motions from earthquakes than had been anticipated at the time the plant was designed. This does not necessarily imply that the plant is unsafe; however, it raises safety and reliability concerns that warrant further study.
9. In the decades since Diablo Canyon and SONGS were built, scientists have learned more about the ground motions that could result from an earthquake rupture. One important finding is that ground motion can be highly variable in the region near a rupture, with significant amplification of ground motion in some areas. These effects have already contributed to a higher revised seismic hazard assessment at SONGS. It will be important for PG&E and SCE to continue to evaluate the implications of new approaches to modeling the variability of ground motion in the region near a fault rupture.
10. The U.S. Geological Survey (USGS), California Geological Survey, and the Southern California Earthquake Center have developed a detailed, updated database of faults and rupture probabilities in California (the Uniform California Earthquake Rupture Forecast – “UCERF-2”). This database, used in conjunction with USGS models, would provide additional useful information regarding the seismic hazards at Diablo Canyon and SONGS. To obtain accurate seismic hazard data, the USGS models must be modified to reflect site-specific conditions at the plants.
11. In addition to the direct hazard from earthquake ground motion, there are secondary seismic hazards that could impact the nuclear plants. Liquefaction and landslides do not appear to be significant hazards at Diablo Canyon or SONGS. There is less certainty regarding the tsunami hazards at the sites because currently available tsunami studies for both plants are at least 10 years old and do not take advantage of modern tools and updated information that could improve the quality of the assessments, such as second-generation tsunami run-up maps being prepared by the University of Southern California and new data from the National Oceanic and Atmospheric Association.

Updated tsunami hazard assessments are important for both plants, but are most critical for SONGS. This is because the SONGS seawall is only three feet higher than the largest tsunami that was thought to be possible at the site based on the original tsunami hazard studies conducted during the plant’s design. These studies did not consider the hazard from submarine landslides, which could be large events. PG&E is currently reassessing the tsunami hazard at Diablo Canyon; SCE is not planning a reassessment of the tsunami hazard at SONGS.

12. The non-safety related systems, structures, and components (SSCs) of the plants are the greatest sources of seismic-related vulnerability for SONGS and Diablo Canyon. The electrical switchyards are particularly vulnerable to damage. Damage to these systems would not pose a safety hazard to the public; however, it could result in outages of weeks or months for repairs.

13. Seismic design standards of non-safety related SSCs have evolved significantly since Diablo Canyon and SONGS were designed and licensed. Given the evolution of seismic design standards, non-safety related SSCs at Diablo Canyon and SONGS may be less seismically robust than if those same SSCs were built to current standards. A full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of seismic design changes that have occurred since these plants were designed and built. Such an analysis should consider any retrofits to SSCs that PG&E and SCE may have undertaken.
14. The estimated times to repair or replace components within a nuclear power plant may range from one week to as much as several years. The determining factors most likely would be the location of the damage (i.e., whether the repair is on the nuclear side or the non-nuclear side of the power plant) and the time required to obtain suitable replacement parts. One implication of the plant shutdown at the Kashiwazaki-Kariwa nuclear plant in Japan following an earthquake in 2007 is that plant shutdowns are not only tied to equipment repair times but also can be driven by regulatory and political concerns.
15. The spent fuel pools and dry cask storage facilities at Diablo Canyon and SONGS have been designed to sustain a design basis (“safe shutdown”) earthquake at the plants, and they are unlikely to release radioactive materials due to an earthquake. In addition, the dry cask storage facilities were built to accommodate newly characterized effects that can amplify earthquake ground motion and which could impact the seismic hazard of the facilities. Of the two types of storage, spent fuel pools are associated with a higher degree of overall risk, and they are also known to experience “sloshing” – the spillage of water from the pool – during earthquakes.

Seismic Hazards at Diablo Canyon

The offshore Hosgri Fault zone, 4.5 kilometers west of Diablo Canyon, creates the primary seismic hazard at the plant site. For many years there has been uncertainty regarding the tectonic setting of this fault zone with much of the scientific discussion centering on whether the fault is a lateral strike-slip fault or a thrust fault. The distinction is significant for the ground motion hazard at the Diablo Canyon site: a strike-slip fault is steeply (i.e. close to vertically) inclined, and a thrust fault has a shallower angle and extends diagonally beneath the surface. If the Hosgri Fault were a thrust fault with an eastward dip, the fault would extend closer to the Diablo Canyon site, and the ground motion resulting from an earthquake could be greater.

Current geologic and seismologic research literature supports the interpretation that the Hosgri Fault is predominantly characterized by strike-slip faulting. Experts with the USGS, the California Geological Survey, and the Southern California Earthquake Center have accepted the strike-slip characterization for the Hosgri Fault. A minority of scientists, however, disagrees with this characterization and believes that the Hosgri Fault is a thrust fault.

The implications of a thrust fault characterization for the seismic vulnerability of Diablo Canyon are uncertain. PG&E and the NRC separately evaluated the seismic hazard at Diablo Canyon from the Hosgri Fault for probabilities of up to 33 percent thrust faulting. They found that there

was sufficient safety margin in the plant design to accommodate the resulting ground motion, even though this motion was greater than had been anticipated when the plant was designed. PG&E has not published an analysis showing the implications of 100 percent thrust faulting on the safety of the plant, and such an interpretation is extreme in the context of the current professional consensus.

Another potential seismic hazard at Diablo Canyon occurs from the possibility of an earthquake directly beneath the plant. Based on seismologic interpretations and conclusions from investigations of the 2003 San Simeon earthquake that occurred approximately 35 miles north of the Diablo Canyon site (magnitude 6.5), the tectonic setting where this earthquake occurred appears similar to the local tectonic setting of Diablo Canyon. The deep geometry of faults that bound the San Luis-Pismo block, where Diablo Canyon sits, is not understood sufficiently to rule out a San Simeon-type earthquake directly beneath the plant. It is necessary to better define the deep geometry of bounding faults of the San Luis-Pismo block and to better understand the lateral continuity of these fault zones. Although these fault zones are unlikely to replace the Hosgri Fault as the dominant source of seismic hazard at the plant, improved characterizations of these fault zones would refine estimates of the ground motion that is likely to occur at different frequencies. This information may be significant for engineering vulnerability assessments.

The Diablo Canyon seismic setting has been extensively studied, mostly under PG&E's Long-Term Seismic Program.⁶ Further study using advanced technology may help resolve remaining uncertainties. For example, high quality three-dimensional geophysical seismic reflection mapping could resolve questions about the characterization of the Hosgri Fault and might change estimates of the seismic hazard at the plant. Similarly, direct imaging of the subsurface structure at Diablo Canyon could determine if faults exist near the site that do not break to the surface and could also help refine knowledge of the deep geometry, continuity, and interaction of poorly expressed faults that comprise the structural boundaries of the San Luis-Pismo Block. A permanent GPS array in the onshore region surrounding the plant (currently under development) could refine models of tectonic movements in the plant vicinity. Results of these surveys might alter fault parameters that are used in existing seismic hazard assessments.

Finally, since Diablo Canyon was built, scientists have learned more about the ground motions that could result from an earthquake rupture. One important finding is that ground motion can be highly variable in the region near a rupture, with significant amplification of ground motion in some areas. This could be important at Diablo Canyon since the plant lies within five kilometers of the Hosgri Fault.

Seismic Hazards at SONGS

In contrast to the Diablo Canyon site, a recent review by the California Coastal Commission in connection with the construction of a proposed spent fuel storage facility states "there is credible reason to believe that the design basis earthquake approved by U.S. Nuclear

⁶ The Long-Term Seismic Program is a unique program developed in response to the discovery of the Hosgri Fault during the licensing of Diablo Canyon.

Regulatory Commission (NRC) at the time of the licensing of SONGS 2 and 3 ... may underestimate the seismic risk at the site.”

As newer seismologic and geologic data become available, the emerging concern appears to be the perception of an eroding safety margin at the SONGS site. The estimated frequency of an earthquake equivalent to the design basis (“safe shutdown”) earthquake decreased from 1 in 7,194 years in a 1995 study to 1 in 5,747 years in a 2001 study. Underground (“blind thrust”) faults in the vicinity of SONGS have been postulated since the plant was built. This new information does not necessarily mean that the facility is unsafe. Since the plant was engineered with a large margin of safety, it likely will withstand earthquakes of greater magnitude and frequency than originally expected. However, the possibility that the safety margin is shrinking suggests that further study is necessary to characterize the seismic hazard at the site, especially since much less is known about the seismic setting of SONGS than the seismic setting of Diablo Canyon. While SCE periodically evaluates the implications of new seismic data that become available, there is no ongoing seismic research program at SONGS similar to PG&E’s Long-Term Seismic Program at Diablo Canyon.

The major uncertainties regarding the seismology of the SONGS site relate to the continuity, structure, and earthquake potential of the South Coast Offshore Fault zone and the faulting that connects the Newport-Inglewood Fault in the Los Angeles region with the Rose Canyon Fault in the San Diego region. Similar to the Diablo Canyon area, direct high-quality subsurface imaging of the offshore zone is lacking. There is also uncertainty regarding the potential for blind thrust faults near the plant. Well planned, high-quality three-dimensional seismic reflection data at strategically chosen locations may hold potential for resolving many of the remaining uncertainties and might change current estimates of the seismic hazard at the plant.

Similar to Diablo Canyon, SONGS is located within 10 kilometers of a fault, and new research on ground motion near an earthquake rupture is relevant to the seismic hazard of the plant. When SCE incorporated some of these developments into the seismic hazard assessment for SONGS, SCE found that the safety margins at the plant are less than previously believed. SCE is currently assessing the applicability of updated ground motion modeling for the SONGS site.

Tsunami Hazards at Diablo Canyon and SONGS

PG&E is currently conducting a study to reassess the tsunami hazard at Diablo Canyon. The most recent study, from the early 1990s, concluded that the plant was designed to sustain the largest tsunami that can be expected at the site.

SCE has not reassessed the tsunami hazard at SONGS since the plant was designed. Since then, scientists have learned that submarine landslides can generate large local tsunamis. Tsunami run-up maps that are being prepared by the University of Southern California will incorporate expected hazards from such near-to-shore landslides. Currently, it is not possible to determine whether these new maps will result in significantly revised estimates of the tsunami hazard at SONGS. An increase in the estimated maximum tsunami run-up of a few feet could raise significant concerns about the adequacy of the site’s seawall.

For both plants, the currently available tsunami hazard assessments do not take advantage of recently developed tools that could provide more accurate assessments. The use of probabilistic hazard assessments, inundation modeling, and data from the National Oceanic and

Atmospheric Administration's Short-Term Inundation Forecast for Tsunamis system could improve the quality of future assessments.

Vulnerability of Power Plant Buildings and Structures

The safety-related systems, structures, and components (SSCs) of Diablo Canyon and SONGS are designed to remain safe during earthquakes of magnitudes as large as 7.5 on the Hosgri Fault and 7.0 on the South Coast Offshore Fault Zone, respectively. These earthquakes ("safe-shutdown earthquakes") are expected to be the largest magnitude earthquakes that could impact the plants given what is currently known about the geology of local faults. Nevertheless, Diablo Canyon and SONGS would incur some damage in the event earthquakes occurred at or near the plant sites.

Earthquakes with magnitudes equivalent to the safe-shutdown earthquakes would likely cause serious damage to Diablo Canyon or SONGS with the damage centered on the non-nuclear areas of the plants. The safety-related portions of the plants – the reactor, primary steam supply, containment, and associated equipment – are expected to withstand safe-shutdown earthquakes without damage that would impact safety. Notably, the largest earthquakes experienced at SONGS and Diablo Canyon have been significantly less than the plants' safe-shutdown earthquakes.

The non-safety related SSCs of the plants are most vulnerable to damage from earthquakes. Damage to non-safety related SSCs could pose risks of injury and loss of life to plant workers and occupants. Damage would not pose a direct safety hazard to the public; however, it could result in extended outages for repairs lasting weeks or months. The seismic-related reliability risk of non-safety related SSCs is not well understood in part because the nuclear industry and the NRC historically have focused on safety-related SSCs.

The switchyards of the plants could be particularly vulnerable to earthquake damage because the equipment configuration and the dispersed and interconnected nature of the switchyard facilities make them vulnerable to ground motion. Diablo Canyon's 500 kV switchyard, through which the plant's energy is transmitted to the grid, is built on deep fill making it particularly vulnerable to subsidence and ground motion amplification. In part, the degree of damage that could be sustained will depend on the extent to which SCE and PG&E have upgraded their plants' switchyard equipment to meet the newest seismic design standards. Failure of a switchyard could result in a loss of power from the plants even if the reactor units remain safe and undamaged.

Seismic design standards of non-safety related SSCs have evolved significantly since Diablo Canyon and SONGS were designed and licensed in the 1970s and early 1980s. Non-safety related SSCs at Diablo Canyon and SONGS may therefore be less seismically robust than if those same SSCs were built to current standards. A full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of the evolution of seismic design standards since these plants were designed and built. Such an analysis should consider any retrofits to SSCs that PG&E and SCE may have completed.

Diablo Canyon or SONGS could be shut down following earthquakes for as little as one week to as much as several years for repairs or component replacement. Estimates of time to repair or

replace nuclear plant components are very uncertain since this information is not readily available. The determining factors most likely would be the extent and location of the damage (i.e., whether the repair is on the nuclear side or the non-nuclear side of the power plant) and the availability of replacement parts. Other factors affecting the duration of a shutdown include the amount of time needed to investigate the plant for damage and the need for design and backfitting efforts. Public or regulatory concerns also could delay the restart of the power plant.

There are many lessons to be learned from the experience of the Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP) and the 2007 Niigata Chuetsu-Oki earthquake. The KK NPP experienced ground motions significantly higher than the design basis ground motion and yet suffered no significant damage to safety-related components. Nevertheless, more than a year after the earthquake, the KK NPP remains shut down. Extensive investigations and a re-evaluation of the seismic design standards for the plant appear to be the primary cause of the lengthy shut down, suggesting that repairing or replacing damaged components may be just one factor in how long a nuclear power plant is shut down following a major seismic event.

Vulnerability of Spent Fuel Storage Facilities

There are two general types of spent nuclear fuel storage, pool and dry cask storage. Diablo Canyon and SONGS currently use primarily pools for spent fuel storage; however, they have also constructed or are constructing dry cask storage facilities to accommodate the increasing amount of spent fuel stored on site. The greatest risk for spent fuel pools is the loss of water or the loss of active cooling. A loss of cooling event could be precipitated by earthquakes or a terrorist event. If not mitigated, such an event could result in overheating of the stored spent fuel, melting of the fuel cladding, and the subsequent release of radioactive material. Because of this risk, spent fuel storage pools are designed to reduce the possibility of drainage leading to water levels lower than the tops of the spent fuel assemblies. In the case of Diablo Canyon and SONGS, the spent fuel pools are designed to the highest safety classification and are supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis. The spent fuel pools are not expected to suffer a catastrophic loss of cooling as the result of earthquakes.

Because of the lack of a permanent spent fuel disposal facility, the spent fuel pools at Diablo Canyon and SONGS have been “re-racked” to provide increased storage capability by placing the fuel assemblies closer together. The more densely configured spent fuel pools are considered to have a higher degree of risk than a spent fuel pool that has a more open racking arrangement. For example, a loss-of-coolant event precipitated by a terrorist attack in a re-racked spent fuel pool could result in extensive radiation release and contamination. Reconfiguring the spent fuel in the pools to distribute decay heat loads more evenly appears to help reduce the vulnerability of spent fuel pools.

An earthquake or other impact to a spent fuel pool could result in the spread of radioactivity if contaminated water spills from the pool, as occurred during the July 2007 Niigata Chuetsu-Oki earthquake in Japan. The earthquake’s ground motion caused water to slosh in the spent fuel pool at the KK NPP and spill in one of the nuclear plant’s reactor buildings, and the contaminated water leaked into the Sea of Japan from conduit leaks in the reactor building floor. The SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of

sloshing. However, in light of the leak at the KK NPP, PG&E is investigating the water-tightness of conduits in the Diablo Canyon auxiliary building where the spent fuel pool is housed.

In general, a dry cask storage facility is considered to have a lower degree of overall risk than a spent fuel pool. Over the last 20 years, there have been no radiation releases from a dry cask storage facility that have affected the public, no radioactive contamination, and no known or suspected attempts of sabotage. A major study on the risks of dry cask storage by Robert Alvarez, a Senior Scholar of Nuclear Policy at the Institute for Policy Studies, suggested that the use of dry cask storage at a nuclear power plant has the potential to reduce the overall risk associated with at-reactor storage of spent fuel, including the risk of seismic and terrorist events, since dry cask storage would allow the spent fuel pools to be returned to their original configuration and design loading.

Dry cask storage probabilistic risk analyses performed by the NRC and the Electric Power Research Institute (EPRI) concluded that there is a greater risk of an event leading to public harm during cask loading and transportation, which occur primarily during the first year of operation, than from routine operations. During the cask loading process, spent fuel is exposed and in motion, which increases the possibility for accidents.

The design of Diablo Canyon's dry cask storage facility incorporated a number of seismic safety features. These features were included after analysis of near-source fault ruptures showed the potential for types of ground motion to which the dry cask storage facility is more sensitive than the power plant. The SONGS dry cask storage facility was built to higher than required seismic standards at all frequencies. In reviewing the facility's seismic design, the California Coastal Commission concluded that even an earthquake much larger or closer than the design earthquake would not produce ground shaking that would exceed the design of the facility.

Limited information is available on the vulnerability of dry cask storage to sabotage, which is consistent with the National Academies' finding in its 2006 study of spent fuel storage safety and security. While terrorist scenarios have been postulated that could release a significant amount of cesium into the environment, an assessment of the likelihood of such scenarios occurring has not been publicly released.

Vulnerability of Roadways and Transmission Systems

The primary concern with seismic vulnerability of roadways serving Diablo Canyon and SONGS is reduced ability for emergency personnel to reach the plants and for the local community and plant workers to evacuate.

Diablo Canyon is served by a two-lane asphalt road and a separate emergency access road. During an emergency, this restricted access could result in traffic congestion and increase the potential for traffic accidents and further congestion. At SONGS, access roadways have a large capacity to bring in emergency supplies and relief personnel, but, if the emergency impacts nearby residents, there could be an unprecedented amount of traffic traveling through this corridor to escape a threatening situation. To avert such a situation, SCE and state and local authorities have developed emergency plans. For example, during the October 2007 wildfires in southern California, state and local authorities coordinated access to the SONGS site for plant personnel.

The distributed nature of the transmission system makes the transmission system relatively more vulnerable than a nuclear plant to terrorist attack, but such an attack would not result in high human or environmental risk. Transmission towers and poles are not very susceptible to earthquake damage. However, as discussed above, switchyards are likely to be damaged during large earthquakes.

Plant Aging and Reliability Assessment

The AB 1632 Consultant Team assessed the vulnerability of California's nuclear plants to extended outages caused by plant aging-related degradation and evaluated the reliability implications of an extended outage. The main findings of the Consultant Team are:

1. To maintain a safe and reliable nuclear power supply, aging plant components must be adequately monitored and maintained and, when defective, either repaired or replaced with appropriate components. To date, PG&E and SCE have adequately managed aging at their nuclear plants, as evidenced by the high reliability of the plants. Unchecked age-related degradation could have significant long-term implications for safety and plant reliability.
2. Effective maintenance and a strong safety culture are critical to keeping Diablo Canyon and SONGS operating safely and reliably. The NRC has raised concerns about the safety culture at SONGS and has required SCE to create a plan to improve safety culture at the plant. Diablo Canyon appears to have a relatively effective safety culture. In this regard, Diablo Canyon may benefit from the oversight of the Diablo Canyon Independent Safety Committee, which investigates concerns that do arise, and from the participation of the local community. No independent safety committee oversees SONGS, and historically there has been less active participation from the local community near this plant.
3. The workforces at Diablo Canyon and SONGS are aging, and large numbers of staff will soon retire. It is critical to the ongoing reliability and safety of the plants that adequate staffing levels are maintained, that programs to transfer knowledge from retiring workers to new workers are successful, and that strong safety cultures are maintained throughout this shift in the plants' workforces.
4. Under most circumstances, replacement power would be available during extended outages at Diablo Canyon and SONGS. However, an outage at either plant could exacerbate supply-demand imbalances during peak demand and adverse supply conditions, potentially to critical levels. In addition, adequate replacement power may not be available in areas with local transmission constraints that limit power imports. This issue merits further study.
5. Replacement power for either plant would be supplied mostly by combined cycle natural gas-fired plants, which are more expensive to operate and which emit more carbon dioxide than nuclear plants.
6. SONGS is an integral part of the southern California transmission system, and imported power flows are restricted when the plant is shut down. In the event of a long-term SONGS shutdown, modifications to the transmission system would likely be required. Diablo Canyon does not appear to have the same critical impact on reliable operations of

the transmission system, and transmission modifications would likely not be required due to an extended outage at the plant.

Vulnerability to Plant Aging-Related Degradation

Diablo Canyon and SONGS are reliable sources of power, and continued vigilance is required to ensure that they remain reliable as the plants approach and then enter their fourth decade of operation. If plant components are not properly monitored, maintained, repaired, and replaced, as needed, age-related degradation could result in extended plant outages and impaired safety.

There is a clear correlation between the age of a nuclear plant and the number of degradation occurrences at the plant. Effective maintenance programs and regulatory oversight are critical to ensure that aging plant equipment and components are identified and either repaired or replaced with appropriate components before the reliability and safety of the plant are jeopardized. Unchecked age-related degradation could have significant long-term implications.

Nuclear plants are baseload units and are planned to operate as much as possible. Any increase in the amount of time a plant is unavailable or is forced to operate at less than full capacity is reflected in a reduced capacity factor.⁷ Reductions in capacity factor over time may thus indicate that degradation is impacting plant reliability. Capacity factors at Diablo Canyon and SONGS have increased significantly since the early years of plant operation, and both plants achieved five-year average capacity factors of approximately 90 percent. This does not necessarily indicate the absence of plant degradation, but it suggests that PG&E and SCE have adequately managed aging at their nuclear plants such that operational improvements and reductions in down time for plant maintenance and refueling have more than compensated for degradation-related operational losses.

Researchers generally agree that age-related degradation is of greater concern for passive rather than active components. In the 1990s, NRC-sponsored research found that piping, steam generators, and passive components of the reactor pressure vessel comprised over half of nearly 500 reported degradation occurrences at nuclear plants in the U.S. Problems with reactor coolant systems and reactor vessels/internals have contributed to the greatest losses in energy production at nuclear plants nationwide. Careful monitoring of these components is crucial. In addition, EPRI's groundwater protection guidelines should be followed to prevent inadvertent releases of tritium from degraded materials or operational failures.

Plant component aging problems at some U.S. nuclear plants have raised safety or reliability concerns. For example, Davis-Besse, Vermont Yankee, Oyster Creek, and Indian Point have all received scrutiny by the NRC, government agencies, and/or watchdog groups concerned that different types of age-related degradation are eroding plant safety. The implications for Diablo Canyon and SONGS are twofold. First, the same unanticipated age-related degradation of some plant components or systems could be occurring at the California plants. Second, a serious incident or the identification of a safety hazard at one plant could result in a regulatory

⁷ The capacity factor is defined as the total energy production divided by the total possible energy production from the plant in the given period.

requirement for more extensive inspections, repairs, and even outages at similar plants nationwide.

Maintenance plays a central role in mitigating age-related degradation and component failure. All units at Diablo Canyon and SONGS have achieved the highest level of the NRC's maintenance-related performance indicators since the second quarter of 2006, when a new performance-tracking system was initiated. A key element of an effective maintenance program is the plant's safety culture (a strong "safety-first" dedication and accountability among plant workers). However, the NRC has raised concerns about the safety culture at SONGS and has required SCE to create a plan to improve safety culture at the plant. The Institute for Nuclear Power Operations (INPO), an industry-funded oversight agency, has also identified safety concerns at SONGS, including an unusually high rate of employee injury.⁸ A strong safety culture is a key element of an effective maintenance program, and problems with safety culture have been linked to the high profile operational difficulties at the Palo Verde Nuclear Generating Station and the extensive degradation uncovered at Davis-Besse. Diablo Canyon, which has had no NRC violations since 1995, appears to have a relatively effective safety culture. In this regard, Diablo Canyon may benefit from the oversight of the DCISC, which investigates concerns that do arise, and from the participation of the local community. There is no similar independent safety committee that oversees SONGS, and historically there has been less active participation from the local community near this plant.

Effective maintenance programs and safety cultures require well-trained workforces at the plants. The average age of the workforces at Diablo Canyon and SONGS is increasing, and large numbers of staff will soon retire. Both utilities have instituted programs for the retiring staff to pass on their institutional knowledge to newer staff. It is critical to the ongoing reliability and safety of the plant that adequate staffing levels are maintained, that programs to transfer knowledge from retiring workers to new workers are successful, and that strong safety cultures are maintained throughout this shift in the plants' workforces.

Impacts of a Major Disruption at Diablo Canyon and SONGS

If earthquakes, age-related plant or equipment failure, or other events lead to an outage at one or both of the nuclear plants, the power from the impaired units would need to be replaced with power from other sources. Actions at other plants not directly related to the in-state nuclear plants could also result in a shutdown. For example, a major safety-related event at a nuclear power plant elsewhere in the country could lead to a general shutdown of other nuclear plants for an indefinite period of time. The reliability, cost, and environmental implications of

⁸ The results of Institute for Nuclear Power Operations (INPO) reviews are confidential, and the Energy Commission and the California Public Utilities Commission usually do not have access to information about these reviews. (Recent limited information releases by SCE and PG&E are exceptions.) In *Nuclear Power in California: 2007 Status Report*, MRW & Associates recommended that the Energy Commission "work with federal and state regulators, nuclear plant owners, and the Institute for Nuclear Power Operations to develop a means for usefully incorporating results of Institute for Nuclear Power Operations review and ratings of reactor operations into a meaningful public process while maintaining the value of these reviews as confidential and candid assessments." The Consultant Team agrees with this recommendation.

an extended outage would depend on what time of the year the outage occurred and what replacement power was available.

When any of California's nuclear reactors are not operating, the power they produce must be replaced with power from other sources. PG&E and SCE generally schedule refueling outages and other planned maintenance shutdowns to avoid periods of peak electric demand and reduce the cost of replacement power. Unplanned outages can occur at anytime. The experiences of nuclear plants nationwide indicate that most unplanned outages last just a few days, although many plants have experienced significant operational disruptions lasting a year or longer, mostly from component degradation.

To assess replacement power options in the event of a lengthy, unplanned outage at one or both of California's nuclear plants, the Consultant Team simulated the operations of the electricity market for the year 2012 with and without one or both of the nuclear plants operational. The Consultant Team also considered the results of a study of future supply and demand conditions conducted by the Western Electricity Coordinating Council (WECC). These studies indicate that adequate replacement power would be available in the event of extended outages at Diablo Canyon and SONGS during typical conditions or winter peak demand conditions in the near term. The studies differ in their assessments of the adequacy of replacement power during summer peak demand conditions: the production simulation modeling indicates that in the event of an extended outage at either nuclear plant in 2012, sufficient replacement power would be available to meet California's 15 percent reserve margin requirement, while the WECC study indicates that the loss of the plants would reduce reserve margins to six or seven percent.

The difference between these results is primarily a consequence of input assumptions about supply conditions. The production simulation modeling assumed that there is currently excess capacity on the system and that new generation capacity will be added to the system as needed in order to maintain a 15 percent reserve margin. In contrast, the WECC study assumed adverse supply conditions and limited new generation projects coming on-line in future years. Together, the studies suggest that while replacement power would be available under most circumstances, the outage of either plant could exacerbate supply-demand imbalances during peak demand and adverse supply conditions. Both studies will need to be revisited in the coming years to reflect updated supply and demand conditions. In addition, more detailed study would be needed to assess the availability of replacement power at the local level given transmission constraints that could restrict the deliverability of replacement power to some areas.

The production simulation modeling indicates that replacement power during a year-long outage at either Diablo Canyon or SONGS in 2012 would be supplied mostly by combined cycle natural gas-fired plants. Approximately 55 to 62 percent of the replacement power would come from in-state gas-fired plants, while the remainder would come from out-of-state gas-fired plants or, to a much lesser extent, out-of-state coal plants. Over the course of a year, the cost to generate or procure replacement power would increase the cost of power by \$470 million, with additional costs required to repair the plant.

An outage would also pose environmental consequences, since the replacement power would be largely natural gas-fired. The simulations found that a year-long outage at either nuclear

plant would increase in-state greenhouse gas emissions from power generation by seven to eight percent, or roughly 4.3 to 4.7 million tons of CO₂. Out-of-state replacement generation would add an additional 2.2 to 2.8 million tons of CO₂, for a total greenhouse gas impact of approximately 7 million tons of CO₂.

Previous studies have shown that while Diablo Canyon represents a significant generation resource and supports power flows through transmission Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. However, SONGS is a more integral part of the southern California transmission system, and imported power flows are restricted when it is shut down. Consequently, there would likely need to be modification to the transmission system in the event of a long-term SONGS shutdown. The extent of the transmission system changes would depend on the transmission configuration in place at the time of the shutdown.

Economic, Environmental, and Policy Issues Assessment

The AB 1632 Consultant Team assessed the costs and impacts from nuclear waste accumulating at Diablo Canyon and SONGS and evaluated other major issues related to the future role of these plants in the state's energy portfolio. The main findings of the Consultant Team related to these areas are:

1. The accumulation of nuclear waste at Diablo Canyon and SONGS is a long-term concern in the absence of a federal repository for disposing of spent fuel. If delays continue and spent fuel from SONGS has not been transferred to a repository within 40 years and from Diablo Canyon within 50 years, the spent fuel stored in dry casks on-site may need to be repackaged or the current spent fuel storage containers may need to be bolstered. This waste ultimately must be transported off-site, and spent fuel could require additional repackaging prior to transport. The long-term storage, packaging, and transport of this waste add to the expense and the risk of nuclear power in California.
2. Currently, there is no low-level waste disposal facility in the U.S. available for California low-level waste except for the least radioactive grade ("Class A") of waste. Other classes of low-level waste (Class B and C), therefore, must remain at the nuclear plant sites until a new or existing facility agrees to accept this waste. This does not pose a significant problem at present because the volume of this waste is relatively small, and the waste can be safely stored on site. However, the plants cannot be fully decommissioned until the waste is removed from the plant sites. In addition, given the scarcity of disposal options for low-level waste, the cost to dispose of the waste during plant decommissioning could be higher than currently anticipated. Indeed, low-level waste disposal costs have risen significantly in recent years, and costs may be substantially higher than estimated in the most recent regulatory proceeding on decommissioning costs in 2005.
3. The experiences of several communities in other parts of the U.S. suggest that a dry cask storage facility at a plant site should not prevent the full decommissioning of the remainder of the plant site and the conversion of most of the site to alternative, productive uses. More study is required to assess the impact of a dry cask storage

facility on local property values, business, and tourism, as current academic research into this issue is very limited.

4. California has substantial potential for renewable energy resources, and in the long term, renewable resources could be suitable replacement power options if either Diablo Canyon or SONGS were to be shut down, assuming the resolution of key operational and cost issues. However, most current renewable energy technologies cannot replace the operational characteristics of baseload nuclear plants and therefore would require support of some natural gas-fired units to replace all the attributes of the nuclear plants. In addition, sufficient planning, siting, and construction time would be needed to develop these resources and any necessary transmission infrastructure. Based on current prices and technologies, replacing power from Diablo Canyon and SONGS primarily with renewable power would increase the overall cost of power to consumers. It would also replace certain environmental impacts, such as the adverse impacts from once-through cooling and nuclear waste generation, with other adverse impacts, such as avian mortality from wind towers, habitat fragmentation and risks of soil and water contamination from solar thermal plants, and greenhouse gas emissions from backup natural gas-fired plants. A more detailed study of power generation options is needed to quantify the reliability, economic, and environmental impacts of replacement power options.
5. One of the challenges in replacing the nuclear plants with renewable power generating facilities would be the impacts of this decision on different communities. If the new plants were built in California, the total economic benefit from employment and taxes statewide could be comparable to the benefits currently provided by the nuclear plants. However, many of these benefits would likely be transferred from the coastal communities near Diablo Canyon and SONGS to communities in inland southern California and throughout the state.
6. Some of the lost jobs and reduced tax revenue from closing Diablo Canyon could be offset by economic gains from alternate uses of the plant site, other commercial or industrial development elsewhere in the county, or a potential increase in property values as a result of the plant closure. Without such offsets, the loss of the plant would have a significant impact on the county's economy. The loss to the San Diego and Orange County economies from a closure of SONGS would be much less significant since these economies are more diversified and less dependent on the nuclear plant.
7. A key uncertainty in assessing the economic benefits to keeping Diablo Canyon and SONGS operating through a 20-year license extension is the reliability of the plants as they age. If the plants continue to operate reliably and do not require significant repairs or capital additions, the cost should remain comparable to current levels. However, significant equipment failures or extended outages could result in much higher costs. As discussed earlier, effective plant maintenance and a strong safety culture are critical to keeping the plants operating safely and reliably as they age.

Nuclear Waste Accumulation at Diablo Canyon and SONGS

Diablo Canyon and SONGS produce significant quantities of radioactive waste in the form of spent fuel and other radioactively contaminated materials. These wastes must be carefully handled, stored, transported, and disposed of in order to protect humans and the environment from exposure to radioactive materials. Spent nuclear fuel, which remains extremely radioactive for thousands of years, must be stored in a water-filled pool for a minimum of five years following removal from the reactor core to shield plant workers against high levels of radiation.

As previously discussed, Diablo Canyon and SONGS lack sufficient spent fuel pool capacity to store the quantity of spent fuel that will be produced during their current operating licenses, which extend into the 2020s. As a result, PG&E and SCE have been forced to increase the on-site storage capacity for spent fuel by constructing dry cask storage facilities.

PG&E and SCE have taken different approaches for the design and use of dry cask storage at Diablo Canyon and SONGS, respectively. PG&E has designed and permitted a dry cask storage facility for Diablo Canyon that will allow the utility to store most of the spent fuel to be produced during the current operating license. With the additional storage capacity in the Diablo Canyon spent fuel pool, PG&E will not run out of storage capacity during the current license period. SCE has designed and permitted and is constructing a dry cask storage facility for SONGS with a capacity to store 36 percent of the spent fuel generated during the current license period. Even with the additional storage available in the SONGS spent fuel pool, SCE will need to develop additional on-site storage or secure offsite storage to store all the spent fuel to be produced during the plant's current operating license.

In June 2008 the U.S. Department of Energy (DOE) filed a license application with the NRC for a permanent geologic repository for spent fuel at Yucca Mountain, Nevada. If the license is granted, Yucca Mountain will begin operations most likely after 2020, more than 20 years after the January 1998 statutory and contractual deadline for the federal government to begin accepting spent fuel from utilities. PG&E and SCE have sued DOE for reimbursement of their dry cask storage costs, claiming that this delay represents a breach of contract. PG&E received a favorable judgment that provides for reimbursement of certain dry cask storage costs while denying other claims. PG&E is currently appealing the decision. A trial date to hear SCE's claim has not been set.

Utility dry cask storage is an interim solution for waste disposal. PG&E's facility is designed for a lifetime of 50 years, and the canisters used in SCE's facility are designed for a lifetime of 40 years. If the spent fuel is not transported off-site within the design lives of the dry cask storage facility components, the spent fuel may need to be repackaged on-site and transferred into new storage canisters, or the current canisters or other cask storage facility components may need to be bolstered. The long-term storage, packaging, and transport of this waste add to the expense and the risk of nuclear power in California. At this time there are no estimates as to how long the spent fuel will remain in interim dry-cask storage, and no additional off-site or on-site interim fuel storage facilities are being considered by either PG&E or SCE.

If a federal repository is established, spent fuel will need to be packaged for transport, aging, and disposal (TAD) at a repository. DOE has proposed designing and developing a new TAD canister packaging system but has not yet established federal TAD packaging requirements.

This has forced PG&E and SCE to move forward with dry cask storage cask designs that may not be compatible with federal TAD requirements. The costs for transport of spent fuel to off-site storage or disposal facilities will be substantial, including costs for security, accident prevention, and emergency preparedness. Policies are being developed to federally fund state and county emergency response preparation for repository shipments; however, California has claimed that the proposed federal program may be insufficient, both in the planned timing of the grant program and the amount of the proposed grants for state planning and for training emergency response personnel to respond to potential accidents involving California's spent fuel shipments.

Low-level radioactive waste also requires care in handling, transport, and disposal. There are only three facilities in the U.S. that accept low-level waste for disposal and, as of June 30, 2008, only the Energy Solutions facility in Clive, Utah, accepts low-level waste from Diablo Canyon and SONGS. It is expected that Class A waste will continue to be shipped to Clive, Utah, but that Class B and C wastes (waste with higher levels of radioactivity) will be stored on-site at Diablo Canyon and SONGS until a new or existing facility agrees to accept this waste. This does not pose a significant problem at present because the volume of this waste is relatively small, and the waste can be safely stored on site. However, the plants cannot be fully decommissioned until the waste is removed from the plant sites. The NRC is currently reviewing its policies regarding on-site low-level waste storage and expects to complete this task by the end of 2008.

Low-level waste disposal costs are relatively modest during ongoing plant operations. However, a substantial quantity of low-level waste will need to be disposed of when the plants are decommissioned, and the cost to transport and dispose of this waste, presuming a disposal facility is available, is expected to be hundreds of millions of dollars or more. Low-level waste disposal costs have been rising in recent years, and costs may be substantially higher than estimated during the most recent California Public Utilities Commission (CPUC) review in 2005.

Land Use and Economic Implications of On-Site Waste Storage

There is much uncertainty as to when and if a geologic repository or other interim waste storage facility will allow the removal of spent fuel from the Diablo Canyon and SONGS plant sites. This raises questions about the land use and local economic implications of extended on-site waste storage. It is widely assumed that long-term storage of spent fuel at the plant sites will have a negative effect on future land uses, local property values, business, and tourism. Underlying this presumption is the perception that spent fuel storage creates health and safety risks that preclude certain land uses or depresses economic conditions.

The experience of several communities where nuclear power plants have been shut down and decommissioned but a dry cask storage facility remains does not support this presumption. Indeed, local communities near the Rancho Seco plant outside of Sacramento, California, and the Maine Yankee nuclear power plant have successfully converted the land once used for the power plant and immediately around it into areas that provide recreational or economically-productive mixed uses. The Connecticut Yankee nuclear plant site may also be developed soon. Accordingly, the presence of dry cask storage facilities at Diablo Canyon and SONGS after the plants are decommissioned should not prevent alternate uses from being established.

Voters in San Luis Obispo County have expressed a strong preference to convert the Diablo Canyon to recreational use; however, PG&E has not indicated publicly how it would use the decommissioned plant site. In the case of SONGS, the plant site, which is located on military land, will remain under the control of the U.S. Navy. The Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use. As long as spent fuel remains stored at their respective plant sites, PG&E and SCE will need NRC licenses.

Even with a plant site converted to alternate uses, the question remains as to whether the continued presence of the spent fuel has a negative impact on property values, business, and tourism in the area. Academic research does not lead to a strong conclusion that a dry cask storage facility would negatively affect nearby property values. However, the available analytical studies are extremely limited and only partially relevant, and surveys can be unreliable economic predictors. An analysis of property sales data and other economic indicators in areas where a dry cask storage facility is operating would provide a useful starting point to assess potential economic impacts of extended spent fuel storage at California's nuclear plants.

Power Generation Options

The California legislature, through Assembly Bill 32 (AB 32, 2006), has mandated greenhouse gas reductions statewide. The California Air Resources Board, the California Public Utilities Commission, and the Energy Commission are integrating this mandate into the state's energy policies. As the Energy Commission stated in the *2007 Integrated Energy Policy Report*, "AB 32 forces California to determine how to meet its electricity needs in a way that leaves an ever-shrinking *greenhouse gas* footprint."⁹

State policy sets a "loading order" for meeting California's growing energy demand while lowering greenhouse gas emissions. Energy efficiency, renewable resources, and distributed generation are at the top of the order.¹⁰

California has substantial potential for renewable energy resources, and, in the long term, renewable resources could be suitable replacement power options if either Diablo Canyon or SONGS were to be shut down, assuming the resolution of key operational and cost issues. However, most current renewable energy technologies cannot replace the operational characteristics of baseload nuclear plants without support from natural gas plants for backup power and ancillary services. Operational and local transmission issues must be studied more carefully to identify which attributes of the nuclear plants would need to be replaced if the plants shut down, and sufficient planning, siting, and construction time would be needed to develop these resources and any necessary transmission infrastructure.

⁹ California Energy Commission. *2007 Integrated Energy Policy Report*. CEC-100-2007-008-CMF, page 35.

¹⁰ California law (Public Resources Code 25524) prohibits the permitting of land-use for a new commercial nuclear power plant until a federally approved means for the permanent disposal of spent fuel is available. This effectively excludes nuclear power as a means to meet California's growing energy demand.

No power generation technology is free of environmental impacts. A comparison of the life cycle greenhouse gas emissions for nuclear power, wind, solar photovoltaics, geothermal, and biomass shows that these technologies have comparable levels of life cycle greenhouse gas emissions.¹¹ In addition, each of these technologies has some impact on the environment, affecting land, water, or wildlife. Moreover, the fossil fuel power plants needed to support many renewable units emit greenhouse gases and cause additional environmental impacts. Nuclear energy generation also imposes adverse impacts, including impacts from nuclear waste storage, transport, and disposal and from a potential major plant accident or terrorist event.

Life cycle analyses can provide decision-makers a clearer and more complete understanding of the health and environmental impacts of different generating technologies. However, the usefulness of these analyses in comparing technologies is constrained by widely varying methodologies and assumptions and, in many cases, limited data. Extreme care must be taken to interpret the results of such analyses in light of these limitations.

Local economic impacts of generating facilities can also be important factors in policy decisions about resource options. Replacing the nuclear plants with an equal mixture of in-state wind, solar thermal, geothermal, and biomass power could result in roughly the same overall tax and employment benefits to the state as provided by the nuclear plants. However, these benefits may be conferred to different localities. The communities currently benefiting from the nuclear plants would lose jobs and revenue unless the nuclear plants were replaced by other income-generating facilities. Notably, several large-scale solar projects are currently being planned in San Luis Obispo County.

Preliminary analysis suggests that replacing the state's two operating nuclear plants with renewable generation and using existing fossil-fuel units for reliability support could incur significant costs. Additional modeling is needed to fully understand the economic and environmental tradeoffs, as well as the implications on the California power grid, of permanently retiring Diablo Canyon and SONGS.

License Renewal Issues for State Policymakers

Diablo Canyon and SONGS have been operating for approximately half of their 40-year initial license periods, and PG&E and SCE are exploring the feasibility of seeking 20-year license renewals for the plants. If granted, license renewals could keep Diablo Canyon and SONGS in operation until the early to mid 2040s.

The decision whether or not to renew the Diablo Canyon and SONGS operating licenses will have a significant impact on the state's power supply portfolio and on the communities located near the reactors. The full implications of this decision are unknown. Even the most straightforward question of how much power would be impacted by this decision cannot be answered with certainty. While current production levels from the plants are known, it is unclear how performance will change as the plants age – no commercial reactor has yet operated for a full 60 years.

¹¹ MRW & Associates, Inc. Nuclear Power in California: 2007 Status Report. Prepared for the 2007 Integrated Energy Policy Report. October 2007, page 186.

The cost of power from the nuclear plants over the license renewal period will be linked to the performance of the plants. If the plants maintain high levels of performance and safety and do not require significant repairs or capital additions, the costs could remain comparable to current levels with relatively minor increases due to higher nuclear fuel costs and potentially stricter security requirements. However, significant equipment failures or extended outages could result in much higher costs. In addition, prior to a license renewal the plants may be required to retrofit their once-through cooling systems at a cost of several billion dollars.

It is also important to consider the environmental impacts from plant operations over an extended 20-year license period, including once-through cooling ocean impacts and impacts from continuing waste accumulation at these plants. The extent of the impacts will depend on the outcomes of state and federal policies and requirements for once-through cooling and on whether a long-term solution to the waste disposal problem is found.

The impact that shutting down one or both of the plants would have on the reliability of California's electricity grid is unclear at this time. The impact will depend on what other generating and transmission resources are built or retired over the next two decades and on the pattern of population growth in the regions near the plants. This is an area that needs to be investigated further prior to any decision on license renewal.

The loss of the plants would mean the loss of jobs and tax revenues for the communities located near the plants. This loss would be felt more strongly in San Luis Obispo County following the closure of Diablo Canyon than it would be in the much larger San Diego and Orange Counties following the closure of SONGS. Some of the lost jobs or reduced tax revenues could be recouped over time by the use of the reclaimed land for other income-generating enterprises or by the development of renewable energy facilities elsewhere in the county to replace the nuclear units. It is also possible that some of this loss could be offset by a rise in property values, if current property values are depressed by the presence of the plants. However, additional study is required to assess whether this is the case and whether the closure of the plants would reverse this impact, especially if nuclear waste remains on-site.

CHAPTER 1: Introduction

In 2006 the California Legislature passed Assembly Bill 1632 (AB 1632), introduced by Assemblyman Sam Blakeslee.¹² The legislation directed the California Energy Commission (Energy Commission) to assess the vulnerability of the state's largest baseload power plants to a major disruption due to a seismic event or plant aging.¹³ In California the two largest baseload power plants are the nuclear plants: Diablo Canyon Power Plant (Diablo Canyon) and San Onofre Nuclear Generating Station (SONGS) (shown in Figure 1 and Figure 2). The Energy Commission was also directed to assess the impacts that such a disruption would have on system reliability, public safety, and the economy; assess the costs and impacts from nuclear waste accumulating at these plants; and evaluate other major issues related to the future role of these plants in the state's energy portfolio.

Background

Diablo Canyon and SONGS provide the state with reliable baseload power that has relatively low CO₂ emissions and low operating costs. They supply 12 percent of the state's electricity supply and, by some measures, 24 percent of the state's low-carbon electricity supply.¹⁴ Should a major disruption occur at these plants, plant operations could be shut down for several months to more than a year, and one or more of the plants' reactors could even be permanently retired. Because these plants are so important to the state's electricity supply, California requires a long-term plan to prevent major disruptions and to be ready should a disruption occur.

Seismic activity is one source of potential vulnerability. Diablo Canyon and SONGS are both located near multiple faults in seismically active areas of the state. The plants were designed to be able to withstand large earthquakes without significant plant damage or release of radiation. However, the scientific understanding of seismicity and the coastal fault zones and improvements in structural materials and engineering have developed over the decades since the plants were designed.

Plant degradation due to aging is another risk factor for Diablo Canyon and SONGS. The two plants came online in the mid 1980s and are now approaching their fourth decade of operation. As the plants age, their systems, structures, and components are all subject to degradation, which, if unchecked, could lead to a loss of function and impaired safety and reliability.

¹² AB 1632 (Blakeslee, Chapter 722, Statutes of 2006).

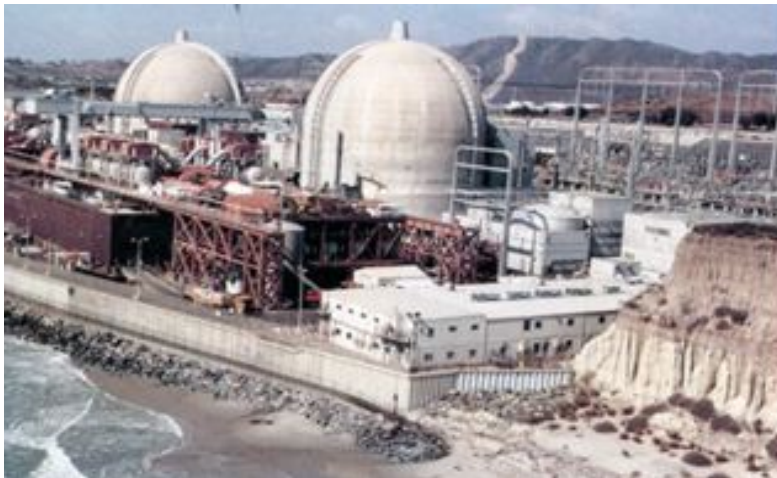
¹³ AB 1632 directs the Energy Commission to assess "large baseload generation facilities of 1,700 megawatts or greater." Besides Diablo Canyon and SONGS, there are two generating facilities (Alamitos and Moss Landing) that have a nameplate capacity greater than 1,700 MW. However, because both of these facilities operate below a 60 percent capacity factor, they are not considered baseload generation and were therefore excluded from the study.

¹⁴ California Energy Commission. "2007 Net System Power Report." April 2008: 4-5.

Figure 1: Diablo Canyon Power Plant¹⁵



Figure 2: San Onofre Nuclear Generating Station (SONGS)¹⁶



If earthquakes, age-related plant or equipment failure, or other events lead to an outage at one or both of the nuclear plants, the power from the impaired units would need to be replaced with power from other sources. Actions at other plants not directly related to the in-state nuclear plants could also result in a shutdown. For example, a major safety-related event at a nuclear power plant elsewhere in the country could lead to a general shutdown of other nuclear plants for an indefinite period of time. The reliability, cost, and environmental implications of

¹⁵ Lawrence Berkeley National Laboratory. <http://www.lbl.gov/LBL-Programs/physics/assets/img/research/theta_diablo_canyon_reactor.jpg>.

¹⁶ United States Marine Corps Base Camp Pendleton. <<http://www.pendleton.usmc.mil/cpao/pages/about/history/images/SONGS.jpg>>.

an extended outage would depend on what time of the year the outage occurred and what replacement power was available.

AB 1632 also directed the Energy Commission to consider the costs and impacts of nuclear waste accumulating at Diablo Canyon and SONGS. There is currently no federal repository for disposing of spent fuel from nuclear reactors; thus, the reactor sites have become de facto long-term waste storage sites. The nuclear waste must eventually be transported off-site, and it could require repackaging prior to transport. The failure of the federal government to develop a repository and clarify the means of ultimate disposal of nuclear waste makes it difficult to quantify the costs of transporting the waste. Nevertheless, it is clear that the storage, packaging, and transport of this waste will add to the expense to the state and increase the risks associated with nuclear power. Some of the costs will be reimbursed by the federal government but additional costs may fall on ratepayers and taxpayers.

Nuclear power plants impact their nearby communities in numerous ways. The plants provide economic benefits in the form of tax payments and jobs, but they could lead to lowered property values if the public perceives these areas to be unsafe because of the plants. Reactor operations and the accumulation of significant quantities of nuclear waste at the plant sites might also pose radiological risks to local communities, particularly in the event of a terrorist attack, sabotage or a large seismic event.

The role played by the existing nuclear power plants in the coming decades will depend in large part on whether or not the plants continue to operate after their current operating licenses expire in the early to mid 2020s. Many reactor operators throughout the U.S. have sought and received 20-year extensions of their initial 40-year operating licenses; California's reactor operator-utilities are considering similar action. There are a number of policy and planning issues that will inform the decisions on whether to seek license extensions. Key among these are the reliability, economic, and environmental impacts of replacing the power from the nuclear plants with a replacement power portfolio, the implications of the State's requirement for achieving statewide greenhouse gas reduction goals, and the implications of a potential state requirement that the plants' once-through cooling systems be retrofitted with alternative cooling systems.

Approach

The overarching objective of this report, *AB 1632 Assessment of California's Operating Nuclear Plants*, is to provide information to policymakers and stakeholders about California's two operating nuclear power plants, Diablo Canyon and SONGS. A guiding principle for this assessment, as directed in AB 1632, was to rely on existing literature, studies, and data where possible. The scope of information reviewed for this study was extremely broad. Moreover, large bodies of work exist for some of the issue areas evaluated for this study. The interdisciplinary Consultant Team reviewed materials that include academic and scientific journal articles, reports, and studies; federal, state, and local governmental studies, reports, bulletins, planning documents, and budgets; federal and state regulatory proceeding filings and rulings; data provided by the nuclear plant owners; and many scientific articles and reports.

Despite the depth and breadth of data and literature reviewed, in some instances the Consultant Team found areas where data are either limited or unavailable. For these areas, the report identifies questions and issues that merit additional review and analysis.

For the seismic vulnerability assessment, the Consultant Team provided early drafts to several seismic staff experts at the California Seismic Safety Commission, the California Coastal Commission, and the California Geological Survey. These experts reviewed the drafts and provided comments on the literature reviewed by the Consultant Team and the team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS. Staff experts from the California Energy Commission and the California Independent System Operator (ISO) also reviewed early drafts and provided comments on other sections of the report.

Public Involvement

Nuclear power has been and continues to be a controversial technology; supporters and opponents are both vocal and impassioned. The Energy Commission and the Consultant Team solicited input from stakeholders on all sides of the issue at several occasions during the study process.

A public workshop was held at the Energy Commission on December 12, 2007, to review a draft study plan prepared by the Consultant Team. Comments on the draft study plan were submitted by a number of parties.¹⁷ The Consultant Team and Energy Commission staff reviewed and considered all comments in preparing a final Study Plan, which was posted on the Energy Commission's website. The Energy Commission also established an email address through which members of the public could submit suggested studies to be reviewed by the Consultant Team. To maintain the independence of the assessment, the Consultant Team did not meet with the nuclear plant owners or other interested parties during the development of the draft report.

A public workshop was held on September 25, 2008, at which the Consultant Team presented a draft of this report. The public and interested stakeholders were provided the opportunity to submit written comments on the draft report until October 2, 2008.

Report Structure

The remaining chapters of this report on the various assessments called for in AB 1632. The nine chapters address the following information:

- Chapter 2 provides an assessment of the seismic hazards at the Diablo Canyon and SONGS sites based on the current understanding of site-specific geology.
- Chapter 3 assesses the current state of knowledge on the seismic vulnerability of the power plant buildings and structures.

¹⁷ Comments on the draft study plan were received by Pacific Gas & Electric (PG&E), Southern California Edison (SCE), the Alliance for Nuclear Responsibility, the Santa Lucia Chapter of the Sierra Club, Scott Fielder, and Russell Hoffman.

- Chapter 4 reviews the vulnerability of the Diablo Canyon and SONGS spent fuel storage facilities, access roadways, and transmission systems to seismic events or terrorist attack.
- Chapter 5 examines plant aging issues as well as regulatory oversight, safety culture at the plants, and the implications of an aging work force.
- Chapter 6 assesses the impacts of a major disruption at Diablo Canyon or SONGS, including the potential economic and environmental impacts of a replacement power portfolio that might substitute for the nuclear plants in the event of an extended plant outage.
- Chapter 7 provides an assessment of the growing amounts of spent fuel and low-level waste accumulating at Diablo Canyon and SONGS and evaluates the costs of spent fuel and low-level waste storage and transport.
- Chapter 8 evaluates the land use and economic implications of long-term storage of spent fuel at the reactor sites.
- Chapter 9 presents an assessment of replacement power alternatives and a comparison of the costs and environmental impacts of nuclear power and alternative sources of power.
- Chapter 10 investigates some of the major policy questions from the state's perspective that could arise in considering license extensions for the nuclear plants.

CHAPTER 2: Seismic Hazards at the Diablo Canyon and SONGS Sites

The Diablo Canyon Power Plant (Diablo Canyon) and the San Onofre Nuclear Generating Station (SONGS) are located in seismically active areas of coastal California. Both plants are therefore vulnerable to seismic and tsunami events that could potentially disrupt plant operations.

The first step in assessing the extent of this vulnerability is to understand the severity of the hazard. For this assessment, knowledge is needed of the following key elements: 1) possible seismic sources, 2) size and frequency of possible earthquakes, and 3) distance and orientation of each seismic source with respect to the site. Once these geologic and seismologic inputs are determined, the seismic hazard of a site can be evaluated.

This chapter leads the reader through this assessment. It begins with an overview of geologic concepts to assist the lay reader in understanding the technical discussion in the remainder of the chapter. It then presents descriptions of the seismic settings of Diablo Canyon and SONGS, highlighting areas of uncertainty. As part of this discussion, the Consultant Team presents their own assessment, based on a thorough literature review, of the sources and resolutions of these areas of disagreement. The chapter concludes with brief discussions of tsunami and other seismic hazards at the plants and advances in scientific knowledge and technological capabilities that could impact the assessment of seismic safety at the plants.

This chapter sets the stage for the next two chapters: Chapter 3, which presents an analysis of the seismic design and construction of the plants, and Chapter 4, which presents an analysis of seismic and other vulnerabilities of spent fuel storage facilities, transmission systems, and access roadways.

Overview of Geologic Concepts

Geology and the science of earthquakes and seismic hazards are technical fields of study. The Consultant Team has attempted to summarize the technical knowledge to be accessible to lay readers. However, certain key concepts are important for a lay understanding of the seismic hazards of the sites. These concepts are: types of faults, slip rates, and fault zone segmentation. General information on these concepts is provided in the main text below. More technical information is provided in technical notes at the end of the chapter.

Types of Faults

There are three basic types of faults: strike-slip faults, thrust faults (and the closely related reverse faults), and normal faults (Figure 3).¹⁸ Movement along a strike-slip fault is lateral (i.e. to the left or to the right). In a strike-slip fault with right (left)-lateral displacement, one side

¹⁸ Thrust faults have angles less than 45 degrees (shallow dipping). A fault with the same type of movement as a thrust fault but with an angle greater than 45 degrees (steeply dipping) is called a reverse fault.

moves to the right (left) relative to the opposite side. The San Andreas Fault is an example of a right-lateral strike-slip fault.

Thrust, reverse, and normal faults are generally referred to as dip-slip faults. Predominant movement on these types of faults during earthquake rupture is in the vertical direction. In thrust and reverse faulting, one side of the fault is pushed up and over the other side. In normal faulting, one side moves down and away from the other side. Faults reflect the stress environment in which they move. In areas of normal faulting, the earth's crust is being pulled apart (tensional stress environment). In areas of thrust and reverse faulting, the earth's crust is being compressed (compressive stress environment).¹⁹

Component movements in both the horizontal and vertical directions can occur during an earthquake. This combined movement along a fault plane is referred to as oblique faulting, such as right-oblique thrust or left-oblique normal. Earthquakes are often a combination of the primary types of motion.

The ground motion from earthquakes decreases with increasing distance from the site to the fault. Depending on the type of fault, this distance may be equal to or less than the surface distance to the fault. A strike-slip fault is steeply inclined to the earth's surface (i.e. close to vertical), so the closest distance from a site (represented by the blue triangle in Figure 3) to the fault is at the surface. However, thrust and normal faults extend diagonally beneath the surface, so subsurface portions of the fault may be closer to the site than the surface fault.

The angle (dip) of a fault can be an important parameter in determining the level of hazard at a site. For example, as discussed later in this chapter, the seismic hazard at Diablo Canyon would be greater if the Hosgri Fault dipped eastward than if the fault were vertical or steeply dipping. This is because an eastward dipping Hosgri Fault would be closer to the Diablo Canyon site in the subsurface than would be a vertical or steeply dipping fault.

Slip Rate and Seismic Moment Rate

Slip rates measure the average long-term activity of a fault. A fault's average annual slip rate is the total displacement on a fault divided by the period of time over which the total displacement occurred. Slip rates generally are used as a method to compare the relative activity of one fault to another. Yet, slip rates are not a direct expression of the earthquake potential on a given fault, and faults with high or low slip rates may both generate large earthquakes. However, there would be longer intervals between large earthquakes for a fault with a low slip rate.

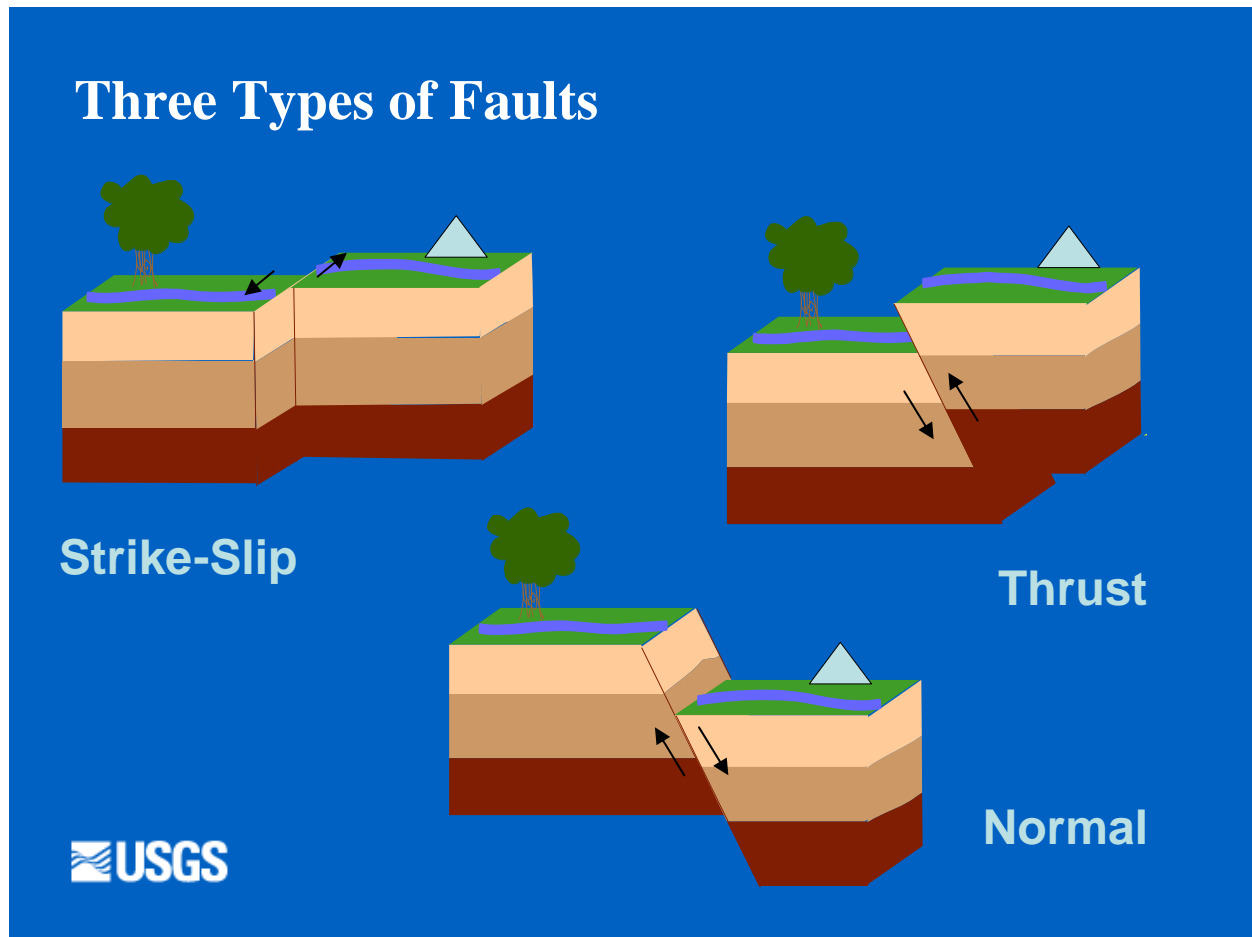
Two other important values are the average seismic moment rate and the earthquake occurrence frequency curve. The average seismic moment rate is a measure of the area of a fault plane multiplied by a value of the average rigidity of crustal rocks and the average annual slip rate. When combined with an assessment of the maximum earthquake magnitude that is

¹⁹ Strike-slip faulting also reflects a compressive stress environment, but one in which the horizontal primary compressive stress axis is at an oblique angle to the nearly vertical strike-slip fault plane. This is referred to as a transpressive stress environment. In the case of oblique-normal faulting, it would be considered a transtensional stress environment.

physically possible on a fault and a statistical distribution of earthquakes across a range of magnitudes up to this maximum, the average seismic moment rate can be used to develop a distribution of earthquake magnitudes versus time. This distribution is called the earthquake occurrence frequency curve (see Technical Note 1 at the end of the chapter).

The estimate of the maximum earthquake is very important to evaluating the seismic hazard posed by a fault. The larger the maximum earthquake, the lower will be the frequency of occurrence of smaller earthquakes and vice-versa.

Figure 3: Three Types of Faults

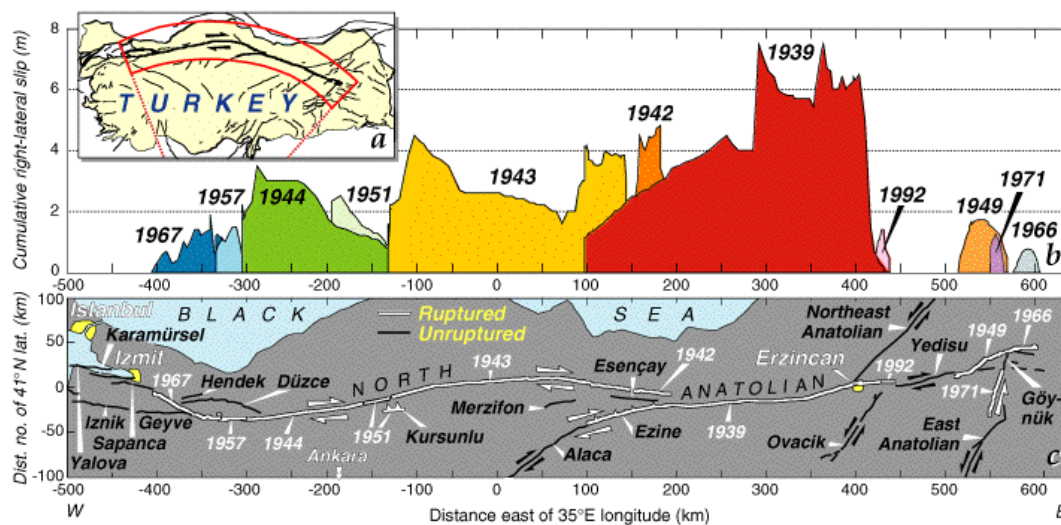


Fault-Zone Segmentation

Historical observations of earthquakes in long fault zones indicate that these fault zones tend not to rupture along their entire length during a single earthquake. Rather, only some fraction of the total length tends to rupture at one time. If these ruptures coincide with observable geometrical or mechanical boundaries along a fault and if there is a history of repeated ruptures between these boundaries, then the fault zone is said to be segmented. A classic example of a long fault zone rupturing in segments is the North Anatolian Fault in northern Turkey (Figure 4).

Identifying segments of a long fault zone, where appropriate, is important for earthquake hazard evaluation because the length of a segment is directly related to the anticipated magnitude of future earthquakes in that segment. Scientists use data on geologic features within the fault zone and measurements that show a difference in these features over long periods of time to identify the segments. The best data for this type of analysis are historic earthquake ruptures and their relationship to physical changes along a fault zone or geologic features of the fault zone. Historic earthquakes can then be compared to paleoseismological recurrence data for the fault zone.

Figure 4: Segment Ruptures of the North Anatolian Fault²⁰



Studies of many segmented fault zones show that fault segments terminate at changes in surface geology and/or changes in fault geometry. These changes are surface expressions of the rupture process of a fault at seismological depths, and they can be identified using geologic, geophysical, and seismological data. However, available data do not preclude the possibility of adjacent segments rupturing in the same earthquake. Therefore, plausible scenarios of multi-segment ruptures are typically used to constrain estimates of maximum earthquake magnitudes that are physically possible (see Technical Note 2). PG&E and SCE considered such scenarios in the probabilistic seismic hazard analyses for Diablo Canyon and SONGS.

Ground Motion

The amplitude of ground motion caused by an earthquake is directly linked to the earthquake magnitude: in general, smaller earthquake magnitudes produce smaller ground motions, and larger earthquake magnitudes produce larger ground motions.²¹ Ground motions are thus the

²⁰ Stein, R.S., A. A. Barka and J. H. Dieterich. "Progressive Failure on the North Anatolian Fault Since 1939 by Earthquake Stress Triggering." *Geophysical Journal International*, Vol. 128. 1997, pages 594-604.

²¹ Due to the large variability of ground motion, this is not always the case.

link between the geologic knowledge of earthquakes (i.e. the hazard) and knowledge of the consequences of the earthquakes on the built environment (i.e. the risk).

The study of earthquake ground motions is complex since a large number of physical variables affect the severity of ground motions at any given site. Some of these variables are regional in nature, such as the vibration transmission properties of the earth's crust, while others are very local, such as the thickness and firmness of the soil at a particular site. In addition, earthquake motions present a spectrum of vibration frequencies. Some of these vibrations are high frequency, which generally affect short, stiff structures. Other vibrations are low frequency, which affect tall, flexible structures. High frequency vibrations diminish relatively rapidly with distance from the earthquake rupture, whereas low frequency vibrations extend to much greater distances. Mathematical formulas called "strong ground motion attenuation relationships" describe the manner in which ground motion severity diminishes (attenuates) with distance from an earthquake fault rupture (see Technical Note 3).

Peak ground acceleration (PGA) has traditionally been the most common measure of earthquake ground motion hazard since it is easy to obtain and it can be directly used to establish the force imparted to a structure by an earthquake.²² Higher PGA values naturally imply higher ground motion hazard. However, PGA measures only the very high frequency ground motions, and many types of structures do not vigorously respond to these motions. To fully assess the potential damage to a structure, a more in-depth analysis that accounts for the vulnerability of a structure relative to the entire spectrum of earthquake motions is required. Such spectral analyses are most commonly used in seismic design of important facilities (see Technical Note 4). For example, spectral analyses were used in the seismic design of Diablo Canyon and SONGS.

Methodology and Sources for Literature Review

The Consultant Team conducted an extensive literature review related to the geology and seismology of the regions surrounding Diablo Canyon and SONGS. As part of this review, the Consultant Team reviewed, assessed, and summarized nearly fifty scientific papers (see summaries in Appendix C). In addition, the Consultant Team reviewed many other supporting documents. A list of all cited works is provided at the end of the chapter.

There is voluminous literature on the geology and seismology of the region surrounding Diablo Canyon. PG&E is required under the terms of the Diablo Canyon operating license to maintain a Long-Term Seismic Program (LTSP). The purpose of the LTSP is to evaluate the seismic design of the plant in light of new geologic and seismologic information from seismic events around the world. With each new event, PG&E updates the geologic, seismologic, and ground motion data for Diablo Canyon and reevaluates the seismic design basis for the plant. The work of the LTSP is reviewed by the U.S. Nuclear Regulatory Commission (NRC) and published in peer-reviewed journals. It forms an important basis for the seismotectonic knowledge of the region today.

²² The force imparted to the structure is equal to the mass of the structure times the peak ground acceleration.

The geologic and seismologic literature pertaining to the region surrounding the SONGS site is quite different from that for Diablo Canyon. Since SONGS does not have a counterpart to the Diablo Canyon Long-Term Seismic Program, there is much less published literature on the seismology and geology of the site area.

Generally, the Consultant Team has focused on major published works or individual published papers that provide significant insights into, or have had a significant impact on, the perceived seismic hazard of the power plant sites. Because of the volume of peer-reviewed research available for the Diablo Canyon site, secondary sources of information, such as meeting abstracts, field guides, and worldwide web postings, in most cases have not been included in this effort.

Seismic Setting of Diablo Canyon

The Diablo Canyon site is located in coastal south-central California in the Coast Ranges physiographic province. More specifically, the plant site sits within a triangular-shaped region of the Coast Ranges named the Los Osos domain. This region extends south from Point Piedras Blancas to nearly Point Arguello and eastwards to the Oceanic–West Huasna fault zone.²³ The Los Osos domain is characterized by a series of elongated, northwest-southeast-trending crustal blocks that alternate between uplift and subsidence. The alternating blocks of uplift and subsidence are reflected in the trends of the central California coastline. The uplifted blocks jut seaward forming the points of the coastline, and the structurally lower blocks occupy the bays. One of these blocks is known as the San Luis – Pismo block, more commonly known as the San Luis Range, and it is within this specific block of the Los Osos domain that the Diablo Canyon plant sits.

Relative movement among the blocks in the Los Osos domain is accommodated along their intervening fault zones.²⁴ Some deformation also occurs within the northwestern half of the San Luis – Pismo block.²⁵ Shallow small earthquakes in proximity to the Hosgri Fault zone exhibit strike-slip movement perhaps related to shear stresses near the Hosgri Fault, while earthquakes further east in the block exhibit reverse motion perhaps related to overall block uplift.²⁶

The faults of primary importance to seismic hazard at the Diablo Canyon site are the boundaries of the San Luis-Pismo block. These faults are the Los Osos Fault, the offshore Hosgri Fault, and the Southwest Boundary fault zone (Figure 5). The geologic evidence supporting the

²³ Lettis, W.B. and K.L. Hanson, et al. "Quaternary Tectonic Setting of South-Central Coastal California." USGS Bulletin No. 1995, *Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province*. Chapter AA. 2004, page 21.

²⁴ Lettis, W.B. and K.L. Hanson, et al. 2004; Slemmons, D.B. and D.G. Clark, U.S. Nuclear Regulatory Commission (USNRC), Office of Nuclear Reactor Regulation. "Independent Assessment of the Earthquake Potential at the Diablo Canyon Power Plant, San Luis Obispo County, CA." NUREG-0675, Supplement No. 34, Appendix D. 1991.

²⁵ Lettis, W.B. and K.L. Hanson, et al. 2004; McLaren, M.K. and W.U. Savage. "Seismicity of South-Central Coastal California: October 1987 through January 1997." 2001; Bulletin of the Seismological Society of America, Vol. 91, pages 1629-1658.

²⁶ McLaren, M.K. and W.U. Savage. 2001.

formal categorization of all of these faults as active, or capable, faults (see Technical Note 5) is summarized in the following section, “Major Faults.”²⁷ Faults within the San Luis-Pismo block have not moved within the last 500,000 years and are therefore considered inactive faults.²⁸ Finally, the southeastern end of the San Luis -Pismo block is marked by the West Huasna Fault at the base of the San Rafael Range, approximately 50 km to the southeast of the Diablo Canyon site.

There are two main sources of information on seismic faults in the vicinity of Diablo Canyon. PG&E researchers have developed most of the detailed local data through the geologic and seismologic research efforts of the LTSP. Researchers outside of this program, funded by state and federal agencies, have studied the geology and seismology of the larger region. Members of these two groups have developed differing perspectives regarding the nature of important seismic sources in proximity to the Diablo Canyon site. They differ in particular in their interpretations of the faulting style and subsurface geometry of faults in the region, which can generally be described as “thin-skinned” versus “thick-skinned” types of tectonic models (see discussion of Hosgri Fault below and Technical Note 6).

Major Faults

Knowledge of active faults in the vicinity of Diablo Canyon has grown significantly since the plant was initially licensed. The Nacimiento Fault that originally was thought to be the primary influence on seismic hazard at the plant now is thought to be of minor importance for seismic hazard at the plant.²⁹ Instead, scientists now believe that seismic hazard at the plant site is dominated by the offshore Hosgri Fault zone, which was discovered in 1972. Faults of the Los Osos domain that are in close proximity to the plant are secondary to the Hosgri Fault zone because of their smaller earthquake potentials and longer recurrence intervals between earthquakes. Table 1 summarizes basic information about the major active faults in proximity to the Diablo Canyon plant site. The geologic and seismologic knowledge of each of these faults is discussed further below.

²⁷ Pacific Gas & Electric. “PG&E Final Report of the Diablo Canyon Long Term Seismic Program.” PG&E Diablo Canyon Power Plant Docket No. 50-275 and 50-323. 1988; Slemmons, D.B. and D.G. Clark, USNRC, Office of Nuclear Reactor Regulation. 1991.

²⁸ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. “Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2.” NUREG-0675, Supplement No. 34. Docket No. 50-275 and 50-323, 1991.

²⁹ U.S. Nuclear Regulatory Commission, “Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2.” Docket Numbers 50-275 and 50-323, NUREG-0675, Supplement No. 34.

Table 1: Major Active Faults in the Vicinity of Diablo Canyon

	Slip Rate (mm per year)³⁰	Maximum Earthquake (magnitude)
Los Osos Fault	0.13-0.80	6.81 ± 0.28
Southwest Boundary Fault	0.01-0.14	6.15 ± 0.22
Hosgri Fault	≤ 1.0-3.0	6.96 ± 0.27

Los Osos Fault

The Los Osos Fault zone extends a distance of 49 kilometers (km) from its termination offshore in Estero Bay by the Hosgri Fault, southeastward to the Lopez Reservoir.³¹ The fault may be as long as 57 km; however, its southeastern termination is obscured by sediment in the Santa Maria Valley. The fault zone is divided into four segments that vary between eight and approximately 19 km in length.³² These segments are divided by geologic discontinuities along the fault zone and by variations in the elevation and topography of the San Luis-Pismo block that it bounds.

The Los Osos Fault zone is characterized by reverse faulting that dips towards the southwest. The dip angle of the fault zone is uncertain: shallow geologic features of the fault suggest a very low dip to the main fault plane, but focal mechanisms of small earthquakes at depth indicate steep dips of 60 degrees and higher. In characterizing the earthquake potential of the zone, PG&E and the NRC's consultant evaluated the fault with a weighted average dip value of 51 degrees to the west with a range of dip angles between 30 and 60 degrees.³³ The fault zone may have accommodated right-lateral horizontal displacement early in its history; however, the most recent movements have been nearly pure dip-slip. This is evidenced by striations preserved on the fault plane and the lack of laterally offset surface geomorphic features that cross the fault.

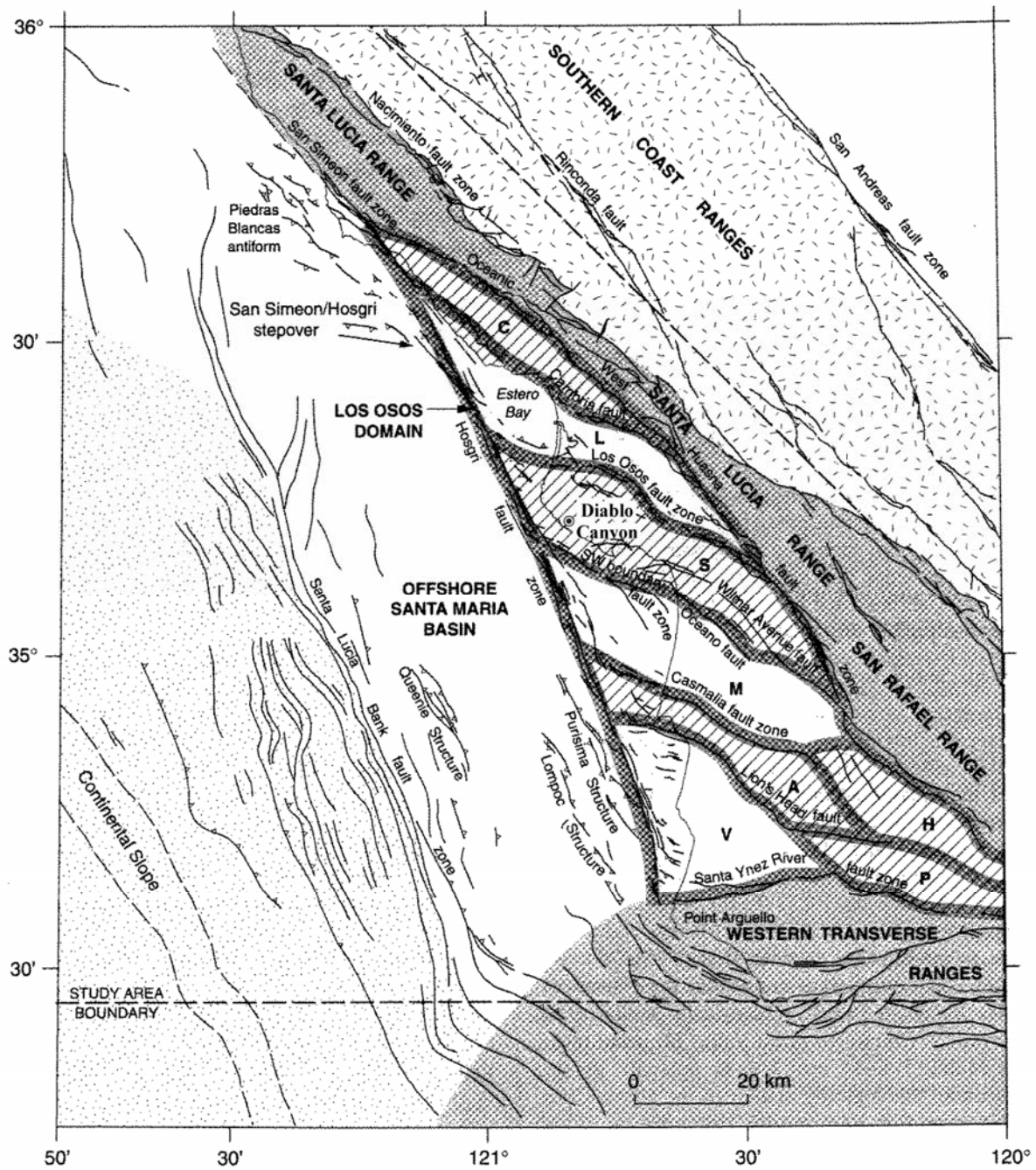
³⁰ Final Report of the Diablo Canyon Long Term Seismic Program, 1998, PG&E; Slemmons, D.B. and D.G. Clark, U.S. Nuclear Regulatory Commission (USNRC), Office of Nuclear Reactor Regulation. "Independent Assessment of the Earthquake Potential at the Diablo Canyon Power Plant, San Luis Obispo County, CA." NUREG-0675, Supplement No. 34, Appendix D. 1991.

³¹ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark, USNRC, Office of Nuclear Reactor Regulation. 1991; Lettis, W.R. and N.T. Hall. "Los Osos Fault Zone, San Luis Obispo County, California." Geological Society of America Special Paper 292. 1994.

³² Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991; Lettis, W.R. and N.T. Hall. 1994.

³³ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

Figure 5: Los Osos Domain



Location map of central California Coast Ranges showing crustal blocks and fault boundaries of the Los Osos domain with the general location of the Diablo Canyon site in the western part of the San Luis – Pismo block.³⁴ Letter designations of blocks are as follows: A, Casmalia; C, Cambria; H, Solomon Hills; L, Los Osos; M, Santa Maria Valley; P, Purisima; S, San Luis – Pismo; V, Vandenberg – Lompoc. Ruled pattern indicates blocks of relative uplift. No fill pattern indicates blocks of relative subsidence or no movement. Other patterns indicate limits of geographic regions labeled in the figure.

³⁴ McLaren, M.K. and W.U. Savage. 2001.

The average, long-term slip rate of the fault can only be estimated within a relatively wide range of values since the dip of the fault zone is an integral part of this estimate, and the specific dip value is uncertain.³⁵ Shallow trench investigations suggest a slip rate of 0.13-0.33 millimeters (mm) per year, while alternative estimates based on the timing and uplift of marine terraces that are deformed by the fault indicate rates of 0.25-0.80 mm per year. Similarly, the displacement of the fault that might be expected in an earthquake is not well constrained due to the uncertainty in the fault's dip angle. PG&E estimated a maximum value of 2.1 meters, which is consistent with an average 50 km-long fault rupture length. While the USGS did not consider this to be a conservative estimate, the USGS agreed with PG&E and the NRC's consultant that the maximum credible earthquake for the fault zone is 6.81 ± 0.28 .³⁶

Southwestern Boundary Fault

A southwestern boundary of distributed faults separates the San Luis-Pismo block from the onshore Santa Maria basin to the south. Onshore, this array of moderate-to-steeply northeast-dipping reverse faults includes the Wilmar Avenue, Oceano, San Luis Bay, Pecho, and Olson faults. Offshore, this zone of faulting is generally not very well expressed in the seafloor and has been referred to simply as the Southwest Boundary fault zone.³⁷ Assuming an average fault dip of 45 degrees to the northeast, the net dip-slip rate of displacement for the boundary zone is about 0.2 mm per year. In its closest approach to the Diablo Canyon site (4-8 km), marine terrace ages and offsets suggest that about 0.14 mm per year of slip occur on the onshore San Luis Bay and Olson Faults and about 0.06 mm per year or more occur on the offshore fault.³⁸ The slip rate on the offshore reverse Pecho Fault has been estimated at 0.01-0.02 mm per year.³⁹

The southeastern part of the southwestern block boundary is comprised of the Wilmar Avenue and Oceano Faults. The Wilmar Avenue Fault extends along the base of the San Luis Range from offshore of Pismo Beach southeastwards to the Santa Maria River for a distance of approximately 30 km.⁴⁰ There are at least two ways to partition this fault into discrete segments.⁴¹ One study identified four segments ranging from 5.2 km to 10 km, and another study identify only two segments of approximately 12 km and 17 km. Part of the eastern segment of this fault is blind, meaning that it does not reach the surface.⁴² The fault is interpreted to be continuous at depth, however, because of a fold structure that follows along

³⁵ Pacific Gas & Electric. 1988; Slemmons. 1991; Lettis, W.R. and N.T. Hall. 1994.

³⁶ The maximum credible earthquake is the largest earthquake considered to be physically possible on the fault; Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

³⁷ McLaren, M.K. and W.U. Savage. 2001.

³⁸ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

³⁹ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

⁴⁰ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991; Nitchman, S.P. and D.B. Slemmons. "The Wilmar Avenue Fault: A Late Quaternary Reverse Fault Near Pismo Beach, California." Geological Society of America Special Paper 292. 1994.

⁴¹ Slemmons, D.B. and D.G. Clark. 1991.

⁴² Slemmons, D.B. and D.G. Clark. 1991; Nitchman, S.P. and D.B. Slemmons. "The Wilmar Avenue Fault: A Late Quaternary Reverse Fault Near Pismo Beach, California." 1994.

the projection of the fault trace where it is exposed at the surface. The fault is exposed in a sea-cliff at Pismo Beach, where it dips between 45 degrees and 60 degrees to the northeast. Striations along the fault plane indicate the movement is reverse faulting. Using the age and offset of displaced marine terraces along with the fault dip gives an estimated long-term slip rate of 0.04 to 0.07 mm per year.⁴³

The Oceano Fault lies generally parallel to and southwest of the Wilmar Avenue Fault at the northern margin of the Santa Maria Basin (Figure 6). The fault is not exposed at the surface but its location is known from borehole and geophysical data.⁴⁴ Onshore and offshore geophysical data indicate that the fault is at least 15 km long. Poorly constrained data onshore suggest that the vertical slip rate may decrease from about 0.04-0.13 mm per year to 0.01-0.05 mm per year towards the west, which is consistent with termination of the fault to the west in geophysical data. Offshore long-term vertical slip rates of this fault are estimated to be 0.01 to 0.03 mm per year.⁴⁵

Evaluation of the seismic potential of the southwestern boundary to the San Luis – Pismo block is difficult due to the low fault slip rates and the discontinuous and relatively poor expression of the faults. Of the faults comprising the boundary zone, the San Luis Bay (including the Olson trace) and Wilmar Avenue faults are defined as active according to regulatory definitions. The remaining faults are principally defined by geophysical data and lack displacement data qualifying them as active.

In the probabilistic seismic source model of the San Luis Bay Fault, PG&E modeled fault lengths of 6, 12, and 19 km, weighted with probabilities of 40 percent, 25 percent, and 35 percent, respectively. PG&E assigned a probability of 41 percent to the fault's not extending to 7 km deep, meaning that it is not considered seismogenic according to PG&E's rupture criteria. PG&E also modeled fault depths of 9 and 12 km, assigning higher probability to the 9 km value. Measured dip values of the San Luis Fault near Avila Beach range between 15 to about 40 degrees but PG&E judged the fault to steepen with depth. In addition, borehole data in the offshore require a steep fault dip and seismic reflection data, although poorly constrained, also suggest a steep dip. Based on these data, PG&E assigned a 70-degree dip value 80 percent weight and a 40-degree dip value 20 percent weight. Various alternative assumptions of the lengths of possible rupture segments in an earthquake and an integrated boundary zone model suggest that maximum credible magnitudes are between 5.8 and 6.6 with a mean of 6.1.⁴⁶

⁴³ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991; Nitchman, S.P. and D.B. Slemmons. 1994.

⁴⁴ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

⁴⁵ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

⁴⁶ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

Hosgri Fault

The offshore Hosgri Fault zone bounds the San Luis–Pismo block on the northwest. A number of earthquake hazard assessments have shown it to be the dominant source of ground motion hazard for Diablo Canyon.⁴⁷

The Hosgri Fault is approximately 110 km long and forms the southern section of a regional fault zone that is over 400 km long, extending along and near the California coast from the San Andreas Fault near Bolinas in the north to just north of Point Pedernales in the south.⁴⁸ The northern and central sections are the San Gregorio,⁴⁹ Sur, and San Simeon fault zones,⁵⁰ respectively. The entire zone is generally referred to as the San Gregorio–Hosgri Fault zone or fault system (Figure 6).

Although the Hosgri Fault is recognized as an important element in the geologic development of the region over the last 23 million years, details of its evolution through prior tectonic regimes and its contemporary offset style (lateral strike-slip vs. thrust) have not been conclusively determined (see “Characterization of the Hosgri Fault” below). Estimates of the total right-lateral horizontal offset on the San Gregorio–Hosgri Fault over time – using various interpretations of offset rock types and their corresponding ages – have varied from approximately 10 km to over 200 km.⁵¹ However, other interpretations of offshore geophysical

⁴⁷ Blume, J.A. “Diablo Canyon Plant: Plate-Boundary and Diffused Areal Probabilistic Considerations.” Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site. PG&E, Volume VII, USNRC Docket No. 50-275 and 50-323, Appendix D, D-LL 45. 1977, pages 45-1 to D45.11; Blume, J.A. “Probabilities of Peak Site Accelerations Based on the Geologic Record of Fault Dislocations.” Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site. PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 41. 1977, pages 41-1 to D41.28; Pacific Gas & Electric. 1988; U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. “Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2.” 1991.

⁴⁸ Hanson, K.L. and W.R. Lettis et al. “Style and Rate of Quaternary Deformation of the Hosgri Fault zone, Offshore South-Central California.” USGS Bulletin No. 1995, *Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province*. Chapter BB. 2004, page 33.

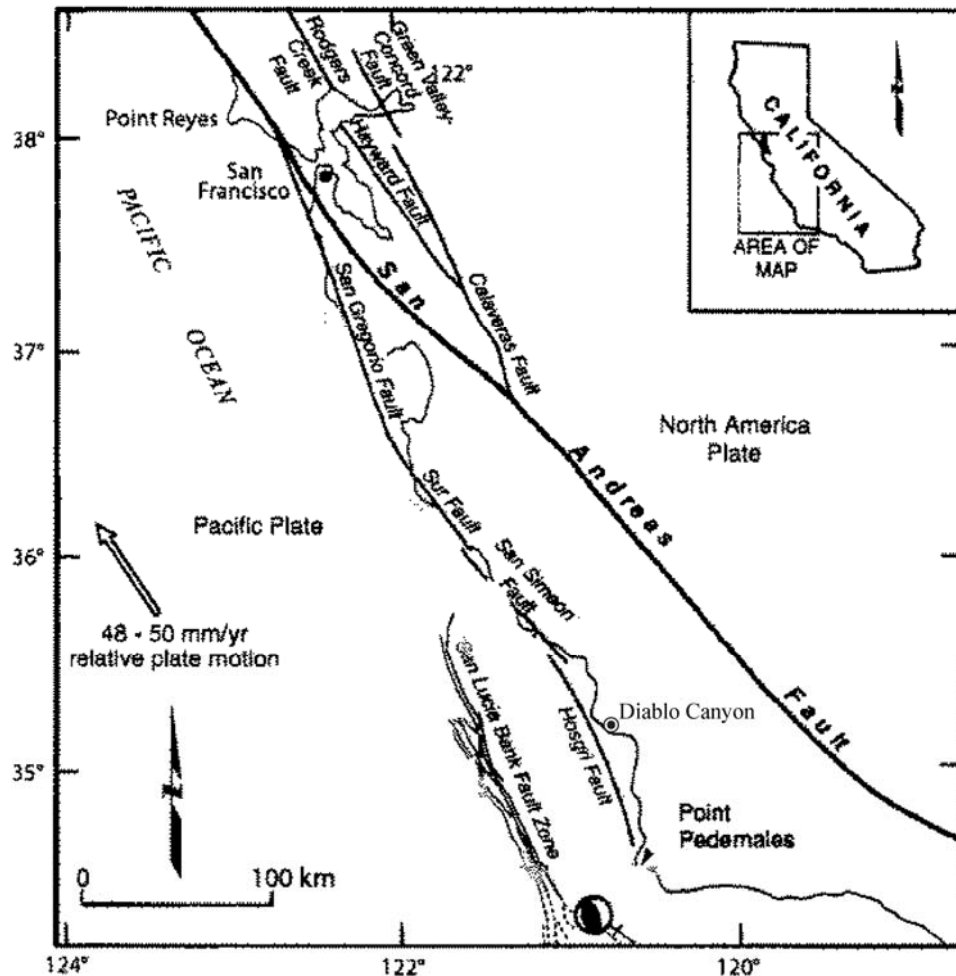
⁴⁹ Coppersmith, K.J. and G.B. Griggs. “Morphology, Recent Activity, and Seismicity of the San Gregorio Fault Zone.” California Division of Mines and Geology Special Report 137, *The San Gregorio – Hosgri Fault zone, California*. 1978, pages 33 – 43.

⁵⁰ Hanson, K.L. and W.R. Lettis. “Estimated Pleistocene Slip Rate for the San Simeon Fault Zone, South-Central Coastal California.” Geological Society of America Special Paper 292. 1994; Hall, N.T. T.D. Hunt, and P.R. Vaughan. “Holocene Behavior of the San Simeon Fault Zone, South-Central Coastal California.” Geological Society of America Special Paper 292. 1994; Steritz, J.W. and B.P. Luyendyk. “Hosgri Fault zone, Offshore Santa Maria Basin, California.” Geological Society of America Special Paper 292. 1994.

⁵¹ Silver, E.A. “The San Gregorio – Hosgri Fault zone: An Overview.” California Division of Mines and Geology Special Report 137, *The San Gregorio – Hosgri Fault zone, California*. 1978, pages 1 – 2; Graham, S.A. and W.R. Dickinson. “Apparent Offsets of On-Land Geologic Features Across the San Gregorio – Hosgri Fault Trend.” California Division of Mines and Geology Special Report 137, *The San Gregorio – Hosgri Fault zone, California*. 1978, pages 13 – 23; Dickinson, W.R. M. Ducea, L.I. Rosenberg, H.G. Greene, S.A. Graham, J.C. Clark, G.E. Weber, S. Kidder, W.G. Ernst, and E.E. Brabb. “Net Dextral Slip, Neogene San-Gregorio-Hosgri Fault Zone, Coastal California: Geological Evidence and Tectonic Implications,” 2005, Geological Society of America Special Paper 391, 43 pages.

data across the fault and the development of folds in the region have been taken to suggest that in the contemporary tectonic episode (which began approximately three to five million years ago) the fault may move with dominant thrust displacement.⁵²

Figure 6: Elements of the San Gregorio-Hosgri Fault System⁵³



The Hosgri Fault System shown in relation to other faults of western California and the offshore November 4, 1927, magnitude 7.0 Lompoc earthquake. The arrow shows the rate and direction of relative movement between the North America and Pacific tectonic plates.

Offshore in the vicinity of Point Arguello, the Hosgri Fault and associated splay faults turn southeastward and accommodate block rotation and left-lateral movement associated with

⁵² Crouch, J.K. S.B. Bachman, and J.T. Shay. "Post-Miocene Compressional Tectonics Along the Central California Margin." *Tectonics and Sedimentation Along the California Margin*: Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM), Vol. 38. 1984, pages 37 – 54; Namson, J. and T.L. Davis. "Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California." *The American Association of Petroleum Geologists Bulletin*. Vol. 74, No. 4. 1990, pages 467-492.

⁵³ Hanson, K.L. and W.R. Lettis et al. 2004: 33.

east-west trending faults and folds of the western Transverse Ranges.⁵⁴ The remaining horizontal displacement on the fault zone is absorbed by folding and overlapping thrust faulting at its intersection with structures of the western Transverse Ranges.

Slip-rate data is not directly available for the Hosgri Fault. However, the fault is structurally linked to the San Simeon Fault to the north, for which abundant slip-rate geologic data is available.⁵⁵ The transfer of slip occurs via a right step-over between the two faults. The step-over is an area of extensional separation and faulting (termed a pull-apart basin) over the last one million years, as indicated by sediments deposited in the small basin. Net slip of one to three mm per year is transferred from the San Simeon Fault to the Hosgri Fault through the step-over. The slip rate may decrease southward as the differential movement across the Hosgri Fault dissipates among northwest-trending folds and faults of the Los Osos domain.⁵⁶

Five potentially controlling rupture segments ranging in length from about 12 to 30 km have been identified along the Hosgri Fault.⁵⁷ Each segment mostly corresponds to the northwestern side of the structural block that it bounds (Figure 7). For the Diablo Canyon probabilistic seismic hazard assessment, PG&E modeled fault rupture scenarios between 20 and 110 km, with rupture lengths of 20 km and 45 km carrying the majority of weight in the modeling procedure. The average displacement in an earthquake is estimated to be one to two meters based on evidence from the San Simeon Fault.⁵⁸ The maximum earthquake based on the geologic evidence has been estimated to range between magnitude 6.5 and 7.5, with the majority of weight given to a maximum earthquake of magnitude 6.75 to 7.25.

The 1927 Magnitude 7.0 Lompoc Earthquake

The November 1927 Lompoc earthquake is the largest earthquake to occur off the central California coast. However, since the earthquake occurred prior to the establishment of regional seismograph networks in California, there has been considerable uncertainty regarding the earthquake's location and rupture mechanism.

Byerly originally positioned the earthquake approximately 80 km west of Point Arguello near the edge of the continental shelf.⁵⁹ Later work by Gawthrop placed the earthquake close to the coast near Point Sal, which suggested an association with the southern end of the Hosgri Fault

⁵⁴ Steritz, J.W. and B.P. Luyendyk. "Hosgri Fault zone, Offshore Santa Maria Basin, California." 1994; Cummings, D. and T.A. Johnson. "Shallow Geologic Structure, Offshore Point Arguello to Santa Maria River, Central California." 1994, Geological Society of America Special Paper 292; Sorlien, C.C. J.J. Kamerling and D. Mayerson. "Block Rotation and Termination of the Hosgri Strike-Slip Fault, California, from Three-Dimensional Map Restoration." 1999, *Geology*, Vol. 27, No. 11. pages 1039-1042.

⁵⁵ Hanson, K.L. and W.R. Lettis. 1994; Hall, N.T. T.D. Hunt, and P.R. Vaughan. "Holocene Behavior of the San Simeon Fault Zone, South-Central Coastal California." 1994.

⁵⁶ Hanson, K.L. and W.R. Lettis et al. 2004: 33.

⁵⁷ Hanson, K.L. and W.R. Lettis et al. 2004.

⁵⁸ Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

⁵⁹ Byerly, P. "The California Earthquake of Nov. 4, 1927." *Bulletin of the Seismological Society of America*, Vol. 20. 1930, pages 53-66.

zone.⁶⁰ However, Hanks located the earthquake at an intermediate location between Byerly's and Gawthrop's locations.⁶¹ Most recently, analyses of travel-time data from the tsunami that was generated by the earthquake⁶² as well as waveform analysis and modeling⁶³ indicate that the earthquake was located approximately 40 km to the west of Point Conception and had a reverse fault mechanism (66° dip) along a N20° W trend. The earthquake, therefore, has been shown rather conclusively to not be associated with the Hosgri Fault zone.

The assessment of the magnitude of the earthquake has also been revised from the original estimations. Helmberger et al. explain that the original magnitude of 7.3 for the earthquake that was cited in many older earthquake catalogs was based on long-period body waves and not on surface waves that are typically used to determine magnitudes of earthquakes of this size.⁶⁴ Going back to the original worksheets that were developed for the earthquake, they established a surface wave magnitude of 7.0 for the Lompoc earthquake.

Characterization of the Hosgri Fault

Two models of the deformation of the central California Coastal Ranges lead to conflicting pictures of regional tectonic motion. One is a thick-skinned model built up from detailed data on the local faults and the other is a thin-skinned model derived from a larger-scale picture of regional tectonic motion (see Technical Note 6). The two models lead to characterizations of the Hosgri Fault, either as a strike-slip fault or as a thrust fault, respectively.

Models of Regional Tectonic Motion

The faults of the Central Coastal Ranges are part of a broad region of shearing and related deformation between the Pacific and North American tectonic plates (Figure 7). Movement between the plates drives the observed faulting as well as aspects of the region's topography. For example, the northwest-trending fault zones accommodate horizontal movement between the plates. In addition, a component of compression that is transmitted across the plate boundary causes the uplift of the Coastal Ranges and results in folding of the crustal rocks and in reverse and thrusting fault styles. The resulting deformation of the brittle crust is complex since the faulting and folding occur at the same time, and the relative degree of horizontal or compressive (vertical) deformation along a fault changes with the trend of the fault relative to

⁶⁰ Gawthrop, W.H. "Seismicity and Tectonics of the Central California Coastal Region." California Division of Mines and Geology Special Report 137, *The San Gregorio – Hosgri Fault zone, California*. 1978, pages 45 – 56; Gawthrop, W.H. Comments on, "The Lompoc, California, Earthquake (November 4, 1927; M=7.3) and its Aftershocks" by Thomas C. Hanks. *Bulletin of the Seismological Society of America*, Vol. 20. 1981, pages 557-560.

⁶¹ Hanks, T.C. "The Lompoc, California, Earthquake (November 4, 1927; M = 7.3) and its Aftershocks." *Bulletin of the Seismological Society of America*, Vol. 69. 1979, pages 141-462.

⁶² Satake, K. and P.G. Somerville. "Location and Size of the 1927 Lompoc, California, Earthquake from Tsunami Data." *Bulletin of the Seismological Society of America*, Vol. 82. 1992, pages 1710--1725.

⁶³ Helmberger, D.V. P.G. Somerville, and E. Garnero. "The Location and Source Parameters of the Lompoc, California, Earthquake of 4 November 1927." *Bulletin of the Seismological Society of America*, Vol. 82. 1992, pages 1678-1709.

⁶⁴ Helmberger, D.V. P.G. Somerville, and E. Garnero. 1992: 1678-1709.

the compressive stress direction. In addition, some of the faults that are active today have been inherited from prior tectonic regimes, and their current movement is overprinted on movements from earlier tectonic episodes.

There are two primary models that describe the deformational style of the central California Coastal Ranges. The dynamics of the LTSP model builds upon earlier studies in the western Transverse Ranges. These earlier studies concluded that the older rocks of the Transverse Ranges had been systematically rotated in a clockwise direction more than the younger rocks.⁶⁵ This rotation results from north-south crustal shortening and ubiquitous east-west trending thrust faulting of these ranges over the last 22 million years. According to the LTSP team, this tectonic rotation is propagated northward into the Los Osos domain, in which the crustal blocks alternately subside or uplift to accommodate the rotational motion in a thick-skinned style of tectonic deformation (Figure 7).⁶⁶ The shortening in the Los Osos domain from the reverse faulting is accommodated by strike-slip displacement along the Hosgri Fault zone. Slip on the Hosgri Fault increases northward towards the San Simeon Fault as the accommodative reverse block-faulting style of the Los Osos domain diminishes, and the only accommodation style remaining north of the Los Osos domain is more purely strike-slip motion along the San Simeon Fault.⁶⁷

Researchers outside of the LTSP team developed a second model based on larger-scale studies of the regional geology and seismology. This model invokes nearly pure compressive stress and thrust faulting across the plate margin in a thin-skinned style of tectonic deformation.⁶⁸ An underlying assumption of this model is that virtually all the horizontal Pacific – North America plate shearing motion is accommodated by the San Andreas Fault. The interpretations are based on a geometric analysis of geologic folds in the region that are six million years old and younger.⁶⁹ The method uses vertical cross sections of known shallow geology, field mapping, and borehole data to infer the deeper locations and geometry of possible thrust faults. The method geometrically restores the shallow geologic structure to its pre-deformed state along the line of tectonic transport and considers sections to be “balanced” as long as the length of the bedding planes of rock strata used in the cross section are the same before and after deformation (balanced cross sections).

⁶⁵ Hornafius J.S. “Neogene Tectonic Rotation of the Santa Ynez Range, Western Transverse Ranges, California, Suggested by Paleomagnetic Investigation of the Monterrey Formation.” *Journal of Geophysical Research*, Vol. 90, No. B14. 1985, pages 12,500 –12,522.

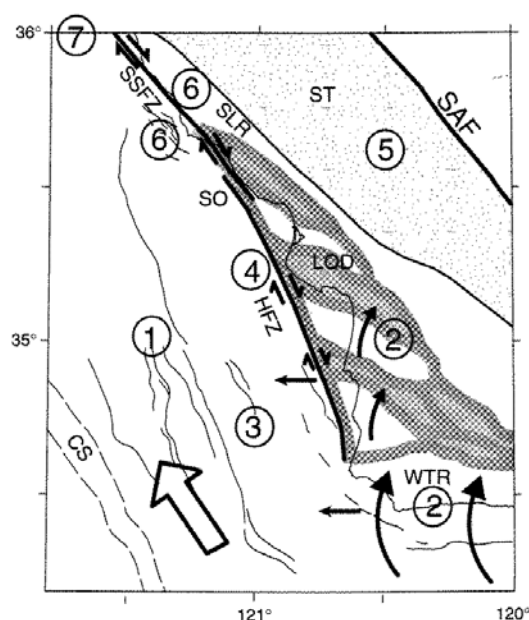
⁶⁶ McLaren, M.K. and W.U. Savage. “Seismicity of South-Central Coastal California.” 2001; Lettis, W.B. and K.L. Hanson, et al. 2004.

⁶⁷ Lettis, W.B. and K.L. Hanson, et al. 2004; Hanson, K.L. and W.R. Lettis et al. 2004.

⁶⁸ Crouch, J.K. S.B. Bachman, and J.T. Shay. “Post-Miocene Compressional Tectonics Along the Central California Margin.” 1984; Namson, J. and T.L. Davis. “Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California.” 1990.

⁶⁹ Namson, J. and T.L. Davis. 1990.

Figure 7: Kinematic Block Model of the Los Osos Domain⁷⁰



Kinematic block model of the Los Osos domain (LOD) with respect to clockwise rotation of the western Transverse Ranges (WTR). Shaded patterns indicate structurally high blocks. Abbreviations are as follows: CS, Continental slope; HFZ, Hosgri Fault Zone; LOD, Los Osos domain; SAF, San Andreas Fault; SLR, San Luis Range; SO, San Simeon – Hosgri step-over region; SSFZ, San Simeon fault zone; ST, Salinian terrain; WTR, Western Transverse Ranges. Large open arrow indicates the direction of Pacific plate motion. Large curved arrows indicated clockwise rotation of the WTR. Smaller curved arrows indicate continued rotation into the Los Osos domain. West-point arrows indicate westward crustal escape. Arrows either side of the Hosgri Fault zone indicate right-lateral strike-slip motion. Decrease in arrow sizes along the fault indicates diminishing slip rate southward along the fault. Circled numbers refer to numbered paragraphs in the original report that provide further information on the model.

There are several limitations to this geometrical analysis. First, the result of any balanced cross section is non-unique, and there are always alternative interpretations that could yield different amounts of shortening and different interpretations as to the exact location and extent of the thrust faults at depth.⁷¹ In addition, the method cannot account for the effects of lateral, strike-slip faulting in and out of the plane of the cross sections that are balanced, nor can it account for crustal block rotations. To the extent that these lateral and rotational motions exist in the area of the balanced cross section, errors will be introduced into the final, undeformed geometrical solution and the inferred structural elements.

Hosgri Fault: Thrust vs. Slip-Strike

Most geologists and seismologists that have evaluated the Hosgri fault believe that it is a strike-slip fault; however, some geologists believe that the Hosgri Fault could be a thrust fault. The distinction between strike-slip and thrust displacement is significant because strong ground motions from a thrust fault tend to be greater at a specified source-to-site distance and source magnitude than for pure strike-slip earthquakes.

⁷⁰ McLaren, M.K. and W.U. Savage. 2001.

⁷¹ Yeats, R.S. K. Sieh and C.R. Allen. The Geology of Earthquakes. Oxford University Press. 1997, page 568.

Offshore geophysical data indicates that the Hosgri Fault typically consists of a high-angle eastern trace, a high-angle western trace within about two km of the eastern trace, and a low-angle east-dipping trace, which may merge with the western trace at depths of about two to four km. Accommodation of strain by the fault may be different between the two main traces, with the western trace perhaps accommodating more compressive movement than the eastern trace, which may accommodate most of the horizontal movement.⁷² An alternative interpretation is that the steep fault strands observed in the relatively shallow geophysical data decrease in dip with increasing depth, and all of the strands become low-angle faults that primarily accommodate pure thrust movement.⁷³ The basis of these thrust interpretations for the Hosgri Fault is derived primarily from regional deformation models that infer a primary compressive stress across the plate margin, as described in the previous section. A difficulty with the thrust-fault interpretation is that detailed LTSP seismological data from small earthquakes located along the fault show a nearly vertical distribution of earthquakes to at least 12 km, which is the depth below which brittle deformation of the crust ceases to exist in many areas of California. The vertical distribution of associated seismicity therefore indicates that no shallow-dipping seismogenic faulting is currently occurring within the Hosgri Fault zone. In addition, focal mechanisms of these earthquakes, which are developed from seismologic analyses that are independent of any shallow geologic or geophysical information, indicate right-lateral horizontal slip along the fault zone with little or no vertical thrust component.⁷⁴

Most recently, the fault has been interpreted to be a steeply dipping, convergent right-lateral (transpressional) fault that exhibits varying compressive and tensional deformation styles along its length consistent with slight changes in trend relative to the northeast-directed regional compressive stress direction.⁷⁵ According to this interpretation, shallow thrust type folds and faults are formed where the fault bends slightly to the left of its regional trend, and tensional features are formed where the fault bends slightly to the right of its regional trend. The basic mechanics of this model can be demonstrated by cutting a sheet of paper lengthwise along a mild “S” curve. When the two halves are slid past each other in opposite directions, areas of compression are indicated where the two halves overlap and areas of tension are indicated where the two halves separate. Where the cut is parallel to the sliding direction, area is conserved and only pure horizontal displacement occurs. This transpressional fault model is compelling in its ability to integrate previous, seemingly contradictory data and observations of faulting style, not only along the length of the Hosgri Fault, but also along the entire San Gregorio-Hosgri Fault system.

As part of the LTSP, PG&E developed a probabilistic seismic hazard analysis (PSHA) for the site assuming that the Hosgri Fault had a 65 percent probability of being a strike-slip fault, a 30 percent probability of being an oblique right-slip fault, and a five percent probability of being

⁷² Slemmons, D.B. and D.G. Clark. 1991.

⁷³ Crouch, J.K. S.B. Bachman, and J.T. Shay. “Post-Miocene Compressional Tectonics Along the Central California Margin.” 1984; Namson, J. and T.L. Davis. “Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California.” 1990.

⁷⁴ McLaren, M.K. and W.U. Savage. 2001.

⁷⁵ Hanson, K.L. and W.R. Lettis et al. 2004.

a thrust fault (see Chapter 3 for more information about PSHA analyses). Consultants to the NRC that reviewed this analysis believed that PG&E's probabilities underestimated the potential for thrust faulting along the Hosgri Fault.⁷⁶ The NRC subsequently conducted its own evaluation of the ground motion from the Hosgri Fault using 67 percent strike-slip and 33 percent thrust faulting, a different ground motion model, and a somewhat more shallow eastward dip to the fault.⁷⁷ They found an increased long period content as compared to the PG&E model, which was largely due to the alternative ground motion model. The NRC required PG&E to consider the envelope of both the PG&E spectrum and their own spectrum for defining the LTSP spectrum. PG&E concluded that while long period ground motion estimates were somewhat higher with these changes, there was sufficient safety margin in the plant design to accommodate the higher ground motion. Subsequently, the NRC concluded that the Diablo Canyon design safely accommodates the maximum credible earthquake on the Hosgri Fault.⁷⁸

The San Simeon Earthquake and Implications for Diablo Canyon

On December 22, 2003, a magnitude 6.5 earthquake struck 35 miles north-northwest of Diablo Canyon. This earthquake, with an epicenter seven miles northeast of San Simeon, became known as the San Simeon earthquake. Early seismologic analyses by the USGS concluded that the earthquake had reverse displacement and that it ruptured over a distance of 20 km in a northwest-southeast direction.⁷⁹ The nearest mapped fault to the epicenter is the Oceanic Fault zone, but the USGS noted that the reverse motion of the earthquake is inconsistent with the motion of the Oceanic Fault. According to the USGS, the earthquake did not occur on the Oceanic Fault but rather on an unknown blind thrust fault in the area.⁸⁰ Blind thrust faults could also be responsible for prior earthquakes in the immediate area, which have also exhibited thrust or oblique-thrust motion. Such unknown faults have been responsible for a number of significant earthquakes in California, including the 1983 Coalinga earthquake, the 1985 Kettleman Hills earthquake, the 1987 Whittier Narrows earthquake,⁸¹ and the 1994 Northridge earthquake.⁸²

⁷⁶ U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2." 1991; Slemmons, D.B. and D.G. Clark. 1991.

⁷⁷ U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2." 1991.

⁷⁸ Slemmons, D.B. and D.G. Clark. 1991.

⁷⁹ U.S. Geological Survey Earthquake Summary Map: M6.5 San Simeon, California. December 22, 2003.

⁸⁰ U.S. Geological Survey Earthquake Summary Map: M6.5 San Simeon, California. December 22, 2003.

⁸¹ Stein, R. and R.S. Yeats. "Hidden Earthquakes." *Scientific American*, Vol. 260. 1989, pages 48-57.

⁸² Teng, T-L and K. Aki, eds. "Special Issue on the Northridge, California Earthquake of January 17, 1994." *Bulletin of the Seismological Society of America*, Vol. 86, No. 1, Part B Supplement. 2006.

A recently published detailed seismologic analysis of the earthquake indicates a considerably more complex faulting process than was evident in the early seismologic data.⁸³ These analyses indicate that the mainshock occurred as faulting that initiated at a depth of 9.7 ± 0.7 km. Blind faulting propagated southeastwards along an approximately 30-km-long northeast-dipping thrust fault. In the epicentral area at the northwest end of the zone, rupture also occurred along an approximate 10-km-long southwest dipping backthrust (opposite dip from the main thrust fault), but it is not clear if the backthrust ruptured as part of the mainshock or was a triggered response to the main rupture. Mainthrust and backthrust features also occur at the southeast end of the rupture zone. However, backthrust features are absent from the central part of the zone where coseismic slip on the main fault plane was the greatest (Figure 8). No surface faulting was caused by the earthquake, but uplift of the Santa Lucia Range by about 72 mm in the central part of the rupture zone and about 45 mm on both ends was documented using satellite imagery. In the epicentral region at the northwest end of the rupture, the surface projection of the main thrust plane is a few km west of the mapped location of the Oceanic fault. The authors therefore interpreted the Oceanic fault in this area as a secondary feature to the main fault. The southeastern end of the rupture, however, projects more closely to the surface trace of the Oceanic fault, and the authors therefore suggest that either much of the slip during the earthquake was on this fault at this location or that the fault accommodated post-seismic slip in order to produce the observed uplift in this area.

Implications for Diablo Canyon

Although the majority of earthquakes around Diablo Canyon have had lateral movements, which are consistent with strike-slip faults, small earthquakes with thrust mechanisms of unknown origin have occurred in the central San Luis–Pismo block.⁸⁴ These have been interpreted as perhaps associated with internal block stresses related to vertical uplift,⁸⁵ which is consistent with the present geologic data. However, location and depth uncertainty of these small earthquakes is on the order of two and five km, respectively, and no specific fault planes can therefore be resolved by the data.⁸⁶ Conversely, due to the uncertainty in the locations, the seismologic data does not prove that these small earthquakes are not associated with coherent fault planes.

The coseismic uplift of the Santa Lucia Range at the northwestern and southeastern ends of the San Simeon earthquake rupture zone (Figure 8) appears similar to PG&E's proposed vertical uplift of the San Luis-Pismo block in which Diablo Canyon is located. The USGS has assigned dips of 45 degrees each to the Los Osos Fault and the San Luis Bay fault, with each fault dipping

⁸³ McLaren, M.K. J.L. Hardebeck, N. van der Elst, J.R. Unruh, G.W. Bawden, and J.L. Blair. "Complex Faulting Associated with the 22 December 2003 Mw 6.5 San Simeon, California Earthquake, Aftershocks, and Postseismic Deformation," *Bulletin of the Seismological Society of America*, Vol. 98. 2008, pages. 1659-1680.

⁸⁴ McLaren, M.K. and W.U. Savage. "Seismicity of South-Central Coastal California." 2001.

⁸⁵ McLaren, M.K. and W.U. Savage. "Seismicity of South-Central Coastal California." 2001.

⁸⁶ McLaren, M.K. and W.U. Savage. "Seismicity of South-Central Coastal California." 2001.

toward the other.⁸⁷ This paired fault geometry is virtually identical to that shown in Figure 8 for the mainthrust and backthrust faults of the San Simeon earthquake. The implication from this fault geometry is that an earthquake similar to the San Simeon earthquake is possible beneath the Diablo Canyon site.

A formal assessment of ground motions from a magnitude 6.5 earthquake directly beneath the Diablo Canyon site is beyond the scope and purposes of the present study. Nonetheless, some indication of the level of ground motion severity relative to the Hosgri Fault design spectrum for Diablo Canyon appears warranted if only to indicate whether this may pose a pressing plant safety issue. The Consultant Team has therefore constructed the following approximate model of a main-fault rupture at the Diablo Canyon site that is grossly similar to the San Simeon earthquake and evaluated the resulting ground motion spectra from this deterministic model.⁸⁸

The Irish Hills sub-block at the northwestern end of the San Luis-Pismo block is approximately 12 km wide between the southwest-dipping Los Osos Fault and the northeast-dipping Southwest Boundary Fault. Hypothetically, if each of these faults dips at 45 degrees towards each other in the subsurface, then their idealized intersection is six km deep below the center of the Irish Hills subblock. The Diablo Canyon site lies approximately four km from the surface trace of the Southwest Boundary Fault, which is the main fault rupture zone in our model. The fault beneath the site in this model is therefore four km deep. We model a magnitude 6.5 thrust earthquake rupture on a 45-degree, northeast-dipping fault plane with a rupture extending from zero km to six km deep. The average shear-wave velocity of the foundation material at Diablo Canyon is approximately 1,070 m/sec, as derived from data in the facility's FSAR. We estimated 84th percentile, five percent-damped acceleration response spectra as the average of the five "Next Generation Attenuation Relationships."^{89, 90}

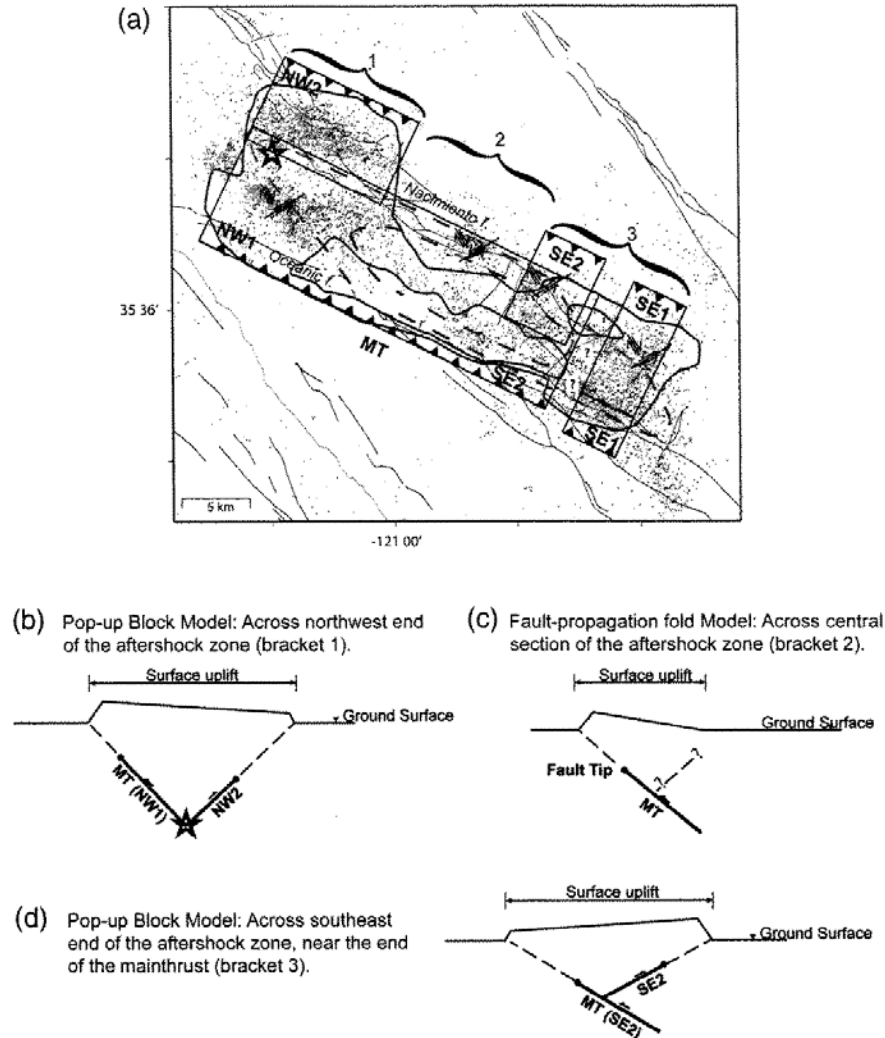
⁸⁷ Wills, C.J. R.J. Weldon II, and W.A. Bryant, 2008, "Appendix A: California Fault Parameters for the National Seismic Hazard Maps and Working Group on California Earthquake Probabilities 2007," U.S. Geological Survey Open File Report 2007-1437A; CGS Special Report 2003A, and SCEC Contribution 1138A, 48 pages.

⁸⁸ This postulated earthquake falls within the range of sources considered by PG&E in the Probabilistic Seismic Hazard Assessment for Diablo Canyon. However, PG&E has not considered the implications of such an earthquake on a deterministic basis (probability of 1).

⁸⁹ Power, M. B. Chiou, N. Abrahamson, Y. Bozorgnia, T. Shantz, and C. Roblee, 2008, "An Overview of the NGA Project," *Earthquake Spectra*, Vol. 24, pages 3-21.

⁹⁰ Directivity rupture effects were not addressed in this simple test (See Technical Note 7), but these effects would only affect spectral amplitudes beyond about 0.6-second period (1.7 Hz).

Figure 8: Summary Map of Complex Faulting from the 2003 San Simeon Earthquake⁹¹

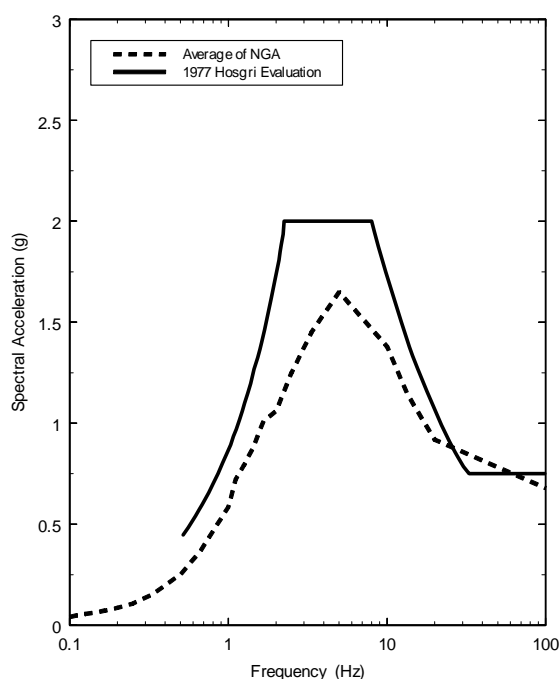


Summary map of inferred blind thrust faulting during the San Simeon earthquake. (a) The top figure shows the rupture planes of the earthquake in two-dimensional map view. Thrust fault planes are shown with barbs pointing down dip. The main thrust plane of the earthquake is labeled "MT" and dips towards the northeast (plane NW 1). Secondary backthrust planes are shown in the northwest (NW 2) and southeast (SE 1 and SE 2) regions of the rupture area and dip towards the southwest. Dashed lines are slip contours on the main fault plane. Solid contours are the edges of the mapped areas of Santa Lucia Range uplift. Strike-slip symbols indicate subordinate fault planes that were defined in the upper part of seismicity clusters in the aftershock zone. (b) Cross-section vertical sketch of a block "pop-up" model for bracket area 1 in the top figure. (c) Cross-section vertical sketch of a thrust fault and fold model for bracket area 2 in the top figure. (d) Cross-section vertical sketch of a block "pop-up" model for bracket area 3 in the top figure. Labels on the faults of the cross-section models correspond to those in the top figure. Faults are dashed where they are projected to the surface from their deeper rupture zones that are defined by the seismological data.

⁹¹ Figure is from McLaren, M.K. J.L. Hardebeck, N. van der Elst, J.R. Unruh, G.W. Bawden, and J.L. Blair, 2008, "Complex Faulting Associated with the 22 December 2003 Mw 6.5 San Simeon, California Earthquake, Aftershocks, and Postseismic Deformation," *Bulletin of the Seismological Society of America*, Vol. 98, pages 1659-1680.

The results are shown in Figure 9 in comparison to the Diablo Canyon 1977, five percent-damped Hosgri spectrum evaluation that was taken from the site FSAR. This comparison suggests that average, 84th percentile ground motions from a scenario M 6.5 thrust earthquake beneath the Diablo Canyon site are generally well accommodated by the 1977 Hosgri spectrum. High-frequency motions at around 30 Hz (0.03-second period) are, on average, in-line with the 1977 spectrum with the remainder of the deterministic spectrum well below the 1977 Hosgri spectrum. Nonetheless, this simple test case cannot be taken as conclusive, and more rigorous and formal testing of this hypothesis should be considered, particularly for plant components that might be vulnerable to pulse-type long-period ground motions that are not represented in this simple test.

Figure 9: Comparison of Scenario M 6.5 Earthquake Spectra (dashed line) with the “1977 Hosgri Evaluation” Spectrum (solid line)



84th-percentile, 5%-damped acceleration response spectrum (dashed line) is the averaged result of five NGA attenuation relationships for a magnitude 6.5 earthquake on the Southwest Boundary Fault zone (i.e. San Luis Bay Fault).

There is certainly a need to better define the deep geometry of bounding faults of the San Luis-Pismo block and to refine the understanding of the lateral continuity of these fault zones. Although these fault zones are unlikely to unseat the Hosgri Fault as the dominant source of seismic hazard at the plant, important shifts in ground-motion frequency content may accompany improved characterizations of these fault zones and be significant to future engineering vulnerability assessments.

Better resolution of the geologic structure at depth below the San Luis – Pismo block using newer geophysical methods could improve the understanding of the small thrust earthquakes that have been observed within the block and the dips of the bounding fault zones (see “Technological Advances for Assessing Geologic Structure and Tectonics”). Such advances in

understanding would reduce modeling uncertainty and result in a better definition of the ground motion hazard at the Diablo Canyon site.

Seismic Setting of SONGS

The SONGS site is located in close proximity to the southwestern boundary of the onshore Peninsular Ranges Geomorphic Province of southern California. The Peninsular Ranges Province extends south of the Transverse Ranges into Baja California. The region is characterized by elongated ranges and intervening valleys whose trends are controlled by faults that branch southward from, or are parallel to, the San Andreas Fault. Just offshore, the Peninsular Ranges Province is neighbored on the west by the Continental Borderland Province, which extends from Point Conception southward to central Baja California. This geomorphic province is generally characterized by so-called “ridge-and-basin” topography in which the islands and banks offshore form the topographic highs that are separated by intervening topographically low basins. The continental slope forms the western boundary of the Continental Borderland, which is more than 185 km (100 nautical miles) west of SONGS. Geophysical studies by Vedder et al. indicated a higher concentration of faults and seismicity on the ridges of the Borderland Province.⁹² Junger suggested that the ridges of the Borderland Province are a product of deep, convergent right-lateral faults that are not necessarily present at or near the surface.⁹³

Within the near-shore area of the Borderland Province, a nearly collinear, quasi-continuous deformational zone of folds and faults extends within 10 km of the coast for a distance of approximately 100 km between Long Beach and San Diego. From north to south, this zone is comprised of the offshore Newport-Inglewood Fault Zone (NIFZ), the South Coast Offshore Fault Zone (SCOFZ), and the Rose Canyon Fault Zone (RCFZ) (Figure 10). The NIFZ is the southern continuation of the onshore Newport-Inglewood Fault, south of the San Joaquin Hills. The onshore northern extension is the Newport-Inglewood fault zone that extends through the western Los Angeles metropolitan area and which ruptured in the 1933 magnitude 6.3 Long Beach earthquake. Southward, the RCFZ extends onshore through the San Diego metropolitan area.

Parallels exist between the Diablo Canyon and SONGS sites in terms of their proximity to near-shore fault zones:

- Seismic hazard investigations at both sites have concluded that the dominant source of ground motion hazard derives from these near-shore fault zones that are within approximately 8-10 km of the plant sites.

⁹² Vedder, J.G. and L.A. Beyer, et al. “Preliminary Report on the Geology of the Continental Borderland of Southern California.” *U.S. Geologic Survey Miscellaneous Field Studies Report* 624. 1974.

⁹³ Junger, A. “Tectonics of the Southern California Borderland,” in D.G. Howell, ed. Aspects of the Geologic History of the California Continental Borderland. American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24. 1976, pages 486-598.

- The structural nature and faulting style of these offshore fault zones has been debated in the geologic research literature as characterized by either predominantly strike-slip or thrust movement.
- The continuity of the offshore zones with known onshore fault zones has been controversial. In the case of SONGS, the USGS expressed an opinion that the NIFZ, SCOFZ, and RCFZ zones cannot be dissociated into separate fault zones. SCE believes that these three zones are distinct structural zones and should not be considered a single, through-going structural feature.⁹⁴

Major Faults

Major faults of southern California include the Whittier-Elsinore (37 km [23 miles] east of SONGS), San Jacinto (70 km [43 mi] northeast of SONGS) and the southern San Andreas fault zone (92 km [57 mi] northeast of SONGS) (Figure 10). While these faults are very important in regard to the seismic hazard and risk of southern California in general, their potential earthquake magnitudes and associated recurrence frequencies, along with their distances from SONGS, combine to make them secondary sources of ground motion hazard at the site when compared to the NIFZ-SCOFZ-RCFZ zone. The hypothesis of a nearby offshore zone of faulting, whether or not connected to the Newport-Inglewood Fault to the north and the Rose Canyon Fault zone to the south, dominates the hazard at SONGS for the larger ground motions.⁹⁵ While the SCOFZ has been shown to be the dominant source of ground motion hazard at SONGS, it is not the closest fault. The Cristianitos Fault is the closest fault to the power facility, being located only 0.8 km (0.5 mi) east of Units 2 and 3.

Cristianitos Fault

The Cristianitos Fault trends north-northwesterly from a coastal exposure in the San Onofre Bluff for a distance of 32 km (20 mi) and passes within 0.8 km (0.5 mi) of SONGS Units 2 and 3.⁹⁶ Where exposed in the sea cliff, the fault is overlain by undisturbed marine deposits that have been dated as 125,000 years old.⁹⁷ Since the fault does not offset these marine deposits, it can be inferred that the fault has not moved in at least the last 125,000 years. The Cristianitos Fault is therefore not an active fault, as defined by federal regulations (see Technical Note 5).

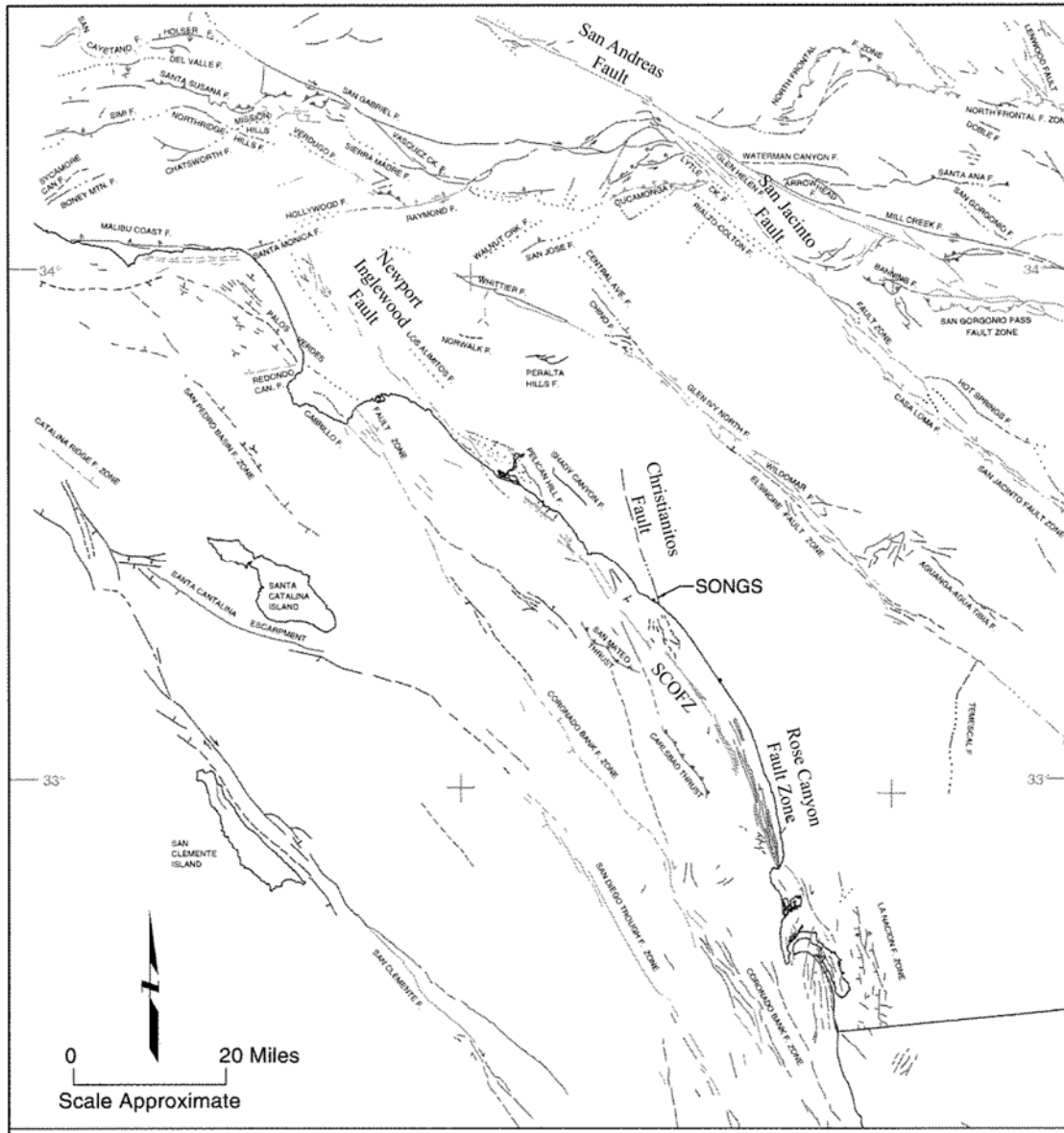
⁹⁴ Southern California Edison. "San Onofre 2&3 FSAR (Updated)." *San Onofre 2&3 UFSAR, 2.0 – Site Characteristics*. 2005, pages 2.5-1 - 2.5-281.

⁹⁵ Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005; Risk Engineering, Inc. "Seismic Hazard At San Onofre Nuclear Generating Station." Report for Southern California Edison. 1995.

⁹⁶ Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

⁹⁷ Shlemon, R. J. "The Cristianitos Fault and Quaternary Geology, San Onofre State Beach, California." 1992.

Figure 10: Location of SONGS Site⁹⁸



NIFZ-SCOFZ-RCFZ

The SCOFZ has been defined by offshore geophysical investigations as a zone of en-echelon faults 67 km (42 mi) long that extend from approximately 8 km (5 mi) south of Newport Beach to a southern terminus southwest of Oceanside. The closest approach of the zone is approximately seven km (4.5 mi) southwest of the San Onofre site.⁹⁹ The deep structure of the

⁹⁸ Geomatrix Consultants and GeoPentech. "San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults." Report for Southern California Edison, 2001.

⁹⁹ Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

zone consists mainly of branching, N-NW-trending, discontinuous faults and folds in rocks that are approximately 20 million years old.¹⁰⁰ These structures are less continuous in younger rocks at shallower depths. The current compressive style of deformation exhibited in the shallower structures of the zone are probably superimposed upon extensional faults that are exhibited in the deeper, older rocks. Although the SCOFZ locally intersects the sea floor, it is not extensively overlain by young geologic sediments.¹⁰¹ Evidence of geologically young movement mostly comes from geophysical investigations along the offshore extensions of the NIFZ and the RCFZ.¹⁰² The structure of the zone is consistent with a steeply dipping zone of strike-slip faulting with shallow branching thrust faults and folds (so-called “flower structure”).¹⁰³ Although significant earthquake activity is not associated with the zone, seismologic analysis of two small-earthquake clusters, one located offshore of Newport Beach and the other northwest of Oceanside, define nearly vertical planes of faulting to 13 km and 7 km deep, respectively.¹⁰⁴

The structural continuity of the SCOFZ with the NIFZ to the north and the RCFZ to the south has been a matter of debate. SCE considers the offshore SCOFZ to be distinct from the NIFZ and the RCFZ based on different fault styles and timing of movements reflecting different strain patterns among the three zones.¹⁰⁵ However, more recent investigations have considered the entire NIFZ-SCOFZ-RCFZ to be continuous and to perhaps be part of a regional strike-slip fault system that extends 300 km from the western Los Angeles region southeastward to Punta Banda in Baja California.¹⁰⁶ Hypothetically, strain release in earthquakes along this system may load neighboring segments and prime them for future earthquakes.¹⁰⁷

The southern approximately 13-15 km of the SCOFZ overlaps with the northern end of the RCFZ. The RCFZ is located about three to five km east (shoreward) of the SCOFZ in the area offshore of Carlsbad. However, the separation of the two fault zones at the surface has been shown to result from a wide flower structure that propagates upward from the same fault zone at depth.¹⁰⁸ The SCOFZ and NIFZ have therefore been shown rather conclusively to be part of

¹⁰⁰ Southern California Edison. “San Onofre 2&3 FSAR (Updated).” 2005.

¹⁰¹ Southern California Edison. “San Onofre 2&3 FSAR (Updated).” 2005.

¹⁰² Fischer, J.P. and G.I. Mills. “The Offshore Newport-Inglewood-Rose Canyon Fault Zone, California: Structure, Segmentation and Tectonics,” in P.L. Abbott and W.J. Elliott, eds. Environmental Perils, San Diego Region. San Diego Association of Geologists for the Geologic Society of America Meeting, San Diego Region. 1991, pages 17-36.

¹⁰³ Fischer, J.P. and G.I. Mills. 1991.

¹⁰⁴ Grant, L.B. and P.M. Shearer. “Activity of the Offshore Newport-Inglewood Rose Canyon Fault Zone, Coastal Southern California, from Relocated Microseismicity.” *Bulletin of the Seismological Society of America*, Vol. 94, No. 2. 2004, pages 747-752.

¹⁰⁵ Southern California Edison. “San Onofre 2&3 FSAR (Updated).” 2005.

¹⁰⁶ Fischer, P.J. D.S. Gorsline and R.J. Shlemon. “Late Quaternary Geology of the Dana Point-San Onofre-Carlsbad Margin, California.” 1992; Fischer, J.P. and G.I. Mills. 1991.

¹⁰⁷ Grant, L.B. and T.K. Rockwell. “A Northward-Propagating Earthquake Sequence in Coastal Southern California?” *Seismological Research Letters*, Vol. 73, No. 4. 2002, pages 461-469.

¹⁰⁸ Fischer, P.J. D.S. Gorsline and R.J. Shlemon. 1992; Fischer, J.P. and G.I. Mills. 1991.

the same fault zone. In addition, the fault zone offshore and onshore the San Diego area exhibits offsets from the last 10,000 years, qualifying them as active faults.¹⁰⁹

SCE initially located the northern termination of the SCOFZ approximately eight km south of Newport Beach and recently updated this location to a site a few kilometers north where there is a marked left step in the fault zone and an abrupt increase in seismicity northwards.¹¹⁰ North of this location, the NIFZ extends a distance of 65 km (42 mi) along the western margin of the Los Angeles basin to the Santa Monica Mountains. The NIFZ is characterized by short discontinuous NW-trending en-echelon,¹¹¹ right-lateral faults, shallow anticlines, and subsidiary normal and reverse faults that are the surface expressions of a through-going strike-slip fault at depth.¹¹² Seismicity extends to 11 km deep, and at least five earthquakes of magnitude 4.9 and larger have been associated with the fault zone since 1920, including the 1933 magnitude 6.3 Long Beach earthquake. The southern half of the zone exhibits strike-slip earthquake focal mechanisms with some normal mechanisms, while strike-slip mechanisms with some reverse mechanisms occur in the northern half of the zone as the zone approaches the Santa Monica Mountains.¹¹³

Slip-rate data is not directly available for the SCOFZ, so SCE has inferred a range of possible slip rates based on the slip rates of the NIFZ and RCFZ (Table 2). Although well-constrained slip-rate data does not exist for the NIFZ, a horizontal slip rate along the offshore extension of the NIFZ over approximately the last 2 million years was estimated between 0.8 and 1.3 mm per year based on displacements observed on submarine canyons that cross the fault.¹¹⁴ Slip rate estimates for the onshore segment of the NIFZ range from a minimum strike-slip rate of 0.34-0.55 mm/yr, based on the assumption that the displacement associated with paleoearthquakes identified near Huntington Beach were similar to the displacement at depth reported for 1933 Long Beach earthquake.¹¹⁵ Grant, et al stated that the slip rate may be several times larger than their estimated minimum rate of 0.34-0.55 mm/yr and could be as high as the slip rate of the Rose Canyon Fault.¹¹⁶ Shlemon, et al estimated a slip rate for the NIFZ of 1.5 to 2.5 mm/yr, based on apparent vertical separation and assumptions of the ratio of horizontal to vertical

¹⁰⁹ Fischer, P.J. D.S. Gorsline and R.J. Shlemon. 1992; Fischer, J.P. and G.I. Mills. 1991; Lindvall, S.C. and T.K. Rockwell. "Holocene Activity of the Rose Canyon Fault Zone in San Diego, California." *Journal of Geophysical Research*, Vol. 100, No. B12. 1995, pages 24,121 – 24,132.

¹¹⁰ Geomatrix Consultants. "Appendix A (to Title 43) - Seismic Source Characterization." Report for Southern California Edison. 1995.

¹¹¹ En-echelon faults are subparallel faults that are offset from the overall structural trend.

¹¹² Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

¹¹³ Hauksson, E. "Seismotectonics of the Newport-Inglewood Fault Zone in the Los Angeles Basin, Southern California." *Bulletin of the Seismological Society of America*, Vol. 77, No. 2. 1987, pages 539-561.

¹¹⁴ Fischer, J.P. and G.I. Mills. "The Offshore Newport-Inglewood-Rose Canyon Fault Zone, California: Structure, Segmentation and Tectonics." 1991.

¹¹⁵ Grant, L.B. J.T. Waggoner, T.K. Rockwell and C. von Stein. "Paleoseismicity of the North Branch of the Newport-Inglewood Fault Zone in Huntington Beach, California, from Cone Penetrometer Test Data." *Bulletin of the Seismological Society of America*, Vol. 87, No. 2. 1997, pages 277-293.

¹¹⁶ Grant, L.B. J.T. Waggoner, T.K. Rockwell and C. von Stein. 1997.

displacement (6 to 10) at a site near the Santa River.¹¹⁷ At the southern end of the SCOFZ, minimum slip rate estimates for the onshore part of the RCFZ range between 1-2 mm per year with a best estimate of 1.5 mm per year.¹¹⁸ In consideration of the available slip rate estimates, their uncertainties, and their likely applicability to the offshore SCOFZ, SCE applied slip rates to the SCOFZ ranging between 0.8 and 3.0 mm per year (with a median value of 1.5 mm per year) for the 1995 NRC-required PSHA.

Table 2: NIFZ-SCOFZ-RCFZ Slip Rates

	Slip Rate (mm per year)
Offshore NIFZ	0.8-1.3 ¹¹⁹
Onshore NIFZ	≥ 0.34-0.55 ¹²⁰
RCFZ	1.0-2.0 ¹²¹
SCOFZ (inferred)	0.8-3.0 (median value: 1.5) ¹²²

For the PSHA, SCE identified three segments of the SCOFZ consisting of the NIFZ, SCOFZ, and RCFZ (Figure 11). These correspond to the Dana Point segment, the San Onofre segment, and the Oceanside segment. As indicated in the figure, SCE identified additional segments and subsegments based on more recent offshore geophysical work.¹²³ Earthquake rupture lengths on the SCOFZ based on the segmentation model ranged between 32 and 115 km. Maximum earthquake magnitudes associated with the SCOFZ in this model range from 6.5 -7.6 with a median value of approximately 6.8.¹²⁴

¹¹⁷ Shlemon, R.J., Elliott, P., and Franzen, S. "Holocene displacement history of the Newport-Inglewood, North Branch fault splays, Santa Ana River floodplain, Huntington Beach, California." Geological Society of America Abstracts with Programs, Fall Meeting. 1995.

¹¹⁸ Lindvall, S.C. and T.K. Rockwell. "Holocene Activity of the Rose Canyon Fault Zone in San Diego, California." 1995.

¹¹⁹ Fischer, J.P. and G.I. Mills. 1991.

¹²⁰ Grant, L.B. J.T. Waggoner, T.K. Rockwell and C. von Stein. 1997.

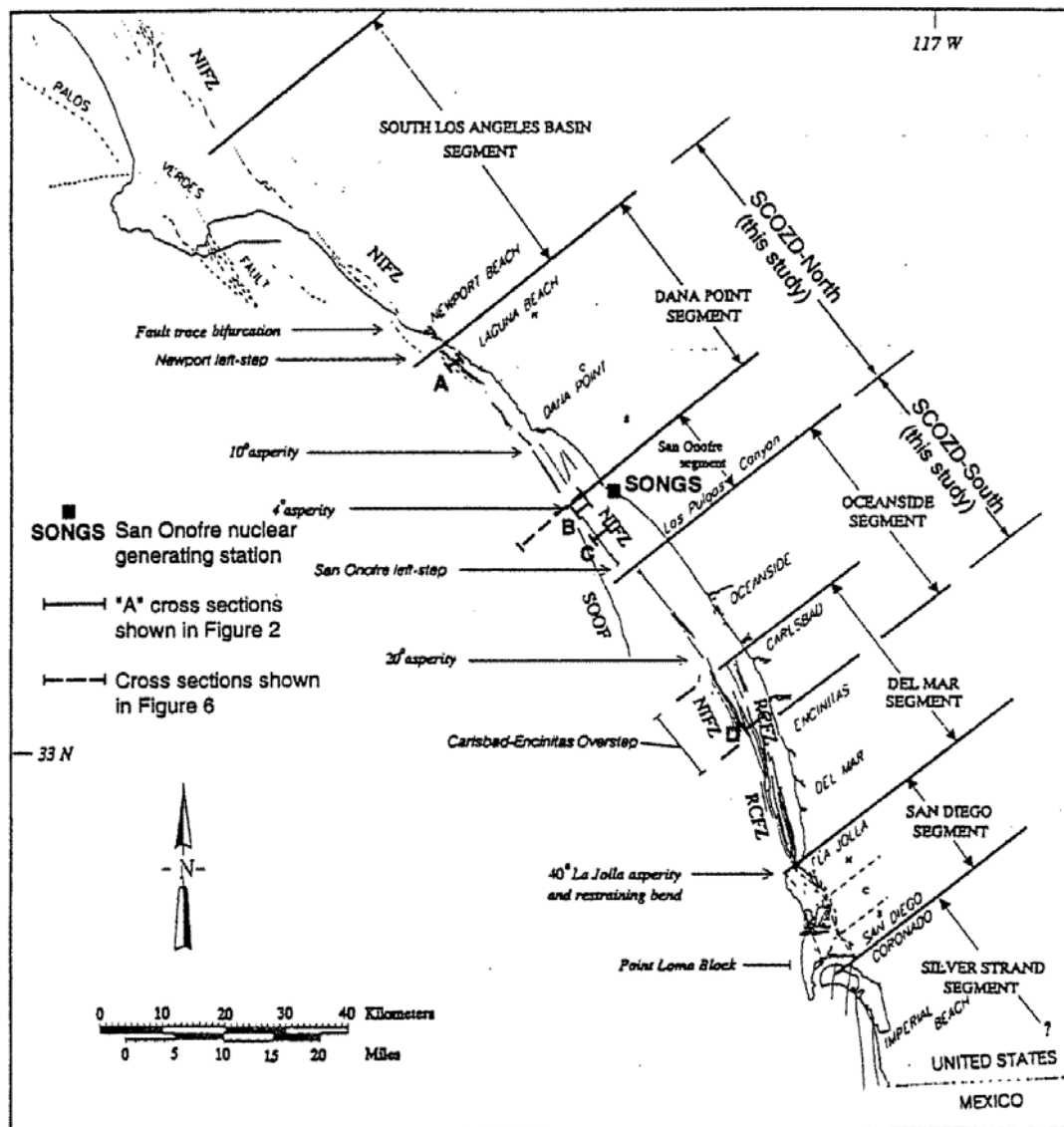
¹²¹ Lindvall, S.C. and T.K. Rockwell. "Holocene Activity of the Rose Canyon Fault Zone in San Diego, California." *Journal of Geophysical Research*, Vol. 100, No. B12. 1995, pages 24,121 – 24,132

¹²² Geomatrix Consultants. "Appendix A - Seismic Source Characterization." Report for Southern California Edison. 1995.

¹²³ Geomatrix Consultants. "Appendix A - Seismic Source Characterization." 1995.

¹²⁴ Geomatrix Consultants. "Appendix B - Maximum Magnitude Distributions." Report for Southern California Edison. 1995.

Figure 11: Segmentation Model of the NIFZ - SCOFZ ("SCOZD") - RCFZ Fault Zone^{125, 126}



¹²⁵ The South Coast Offshore Fault Zone is identified as the South Coast Offshore Zone of Deformation (SCOZD) in this image.

¹²⁶ Geomatrix Consultants. "Appendix A - Seismic Source Characterization." 1995.

Blind Thrust Faults in the Regional Tectonic Setting

A complication to the overall regional strike-slip faulting model in the region of SONGS and southern California in general has been the interpretation of blind thrust faults in the offshore Continental Borderland Province and their associated implications for earthquake hazards in the region.^{127, 128} While such faults have long been postulated to exist in the Continental Borderland,¹²⁹ only recently have two such regional faults been interpreted to exist: the Oceanside thrust fault and the Thirtymile Bank thrust fault.¹³⁰ Both faults extend southward from Laguna Beach and Catalina Island, respectively, to at least the international border with Mexico.¹³¹ The Thirtymile Bank thrust fault lies seaward of the Oceanside thrust fault. These faults formed in a prior extensional tectonic episode that affected the entire southern California margin,¹³² but some scientists postulate that they have been reactivated in the contemporary transpressional stress regime as thrust faults. Notably, the location, aftershock pattern, and thrust mechanism of the magnitude 5.3, 1986 offshore Oceanside earthquake have been interpreted to be consistent with a rupture source on the down-dip extension of the Thirtymile Bank blind thrust fault.¹³³

The Oceanside thrust fault is postulated to come on shore at the San Joaquin Hills, which is a local uplift of late Quaternary age located to the east of where the NIFZ crosses the coastline and heads southward offshore west of Laguna Beach. The faulting style of the intersection of the NIFZ (strike-slip) with the Oceanside thrust fault at San Joaquin Hills uplift has been a topic of research and debate. Grant et al. suggested that the uplift is caused by compressive movement along a blind thrust fault that dips 30 degrees to the southwest.¹³⁴ This geometry characterizes the fault as a “backthrust” to the main east-dipping Oceanside thrust. Bender suggested, however, that the mechanism of uplift is more likely related to fault blocks being “squeezed upward” within the NIFZ in a form of compressive deformation related to

¹²⁷ Lettis, W.R. and K.L. Hanson. “Crustal Strain Partitioning: Implication for Seismic-Hazard Assessment in Western California.” *Geology*, Vol. 19. 1991, pages 559-562; Weldon, R. and E. Humphreys. “A Kinematic Model of Southern California.” *Tectonics*, Vol. 5, No. 1. 1986, pages 33-48.

¹²⁸ Legg, M. C. Nicholson, and C. Sorlien. “Active Faulting and Tectonics of the Inner California Continental Borderland: USGS Lines 114 and 112.” *EOS, Transactions of the American Geophysical Union*, Vol. 73. 1992, page 588; Rivero, C. J.H. Shaw and K Mueller. “Oceanside and Thirty-mile Bank Blind Thrusts: Implications for Earthquake Hazards in Coastal Southern California.” *Geology*, Vol. 28, No. 10. 2000, pages 891-894.

¹²⁹ Junger, A. “Tectonics of the Southern California Borderland,” in D.G. Howell, ed. Aspects of the Geologic History of the California Continental Borderland. American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24. 1976, pages 486-598.

¹³⁰ Legg, M. C. Nicholson, and C. Sorlien. 1992; Rivero, C. J.H. Shaw and K Mueller. 2000.

¹³¹ Rivero, C. J.H. Shaw and K Mueller. 2000.

¹³² Bohannon, R.G. and E. Geist. “Upper Crustal Structure and Neogene Tectonic Development of the California Continental Borderland.” *Geological Society of America Bulletin*. 1998, Vol. 110, pages 779-800.

¹³³ Rivero, C. J.H. Shaw and K Mueller. 2000.

¹³⁴ Grant, L.B. and K.J. Mueller, et al. “Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California.” *Geology*, Vol. 27, No. 11. 1999, pages 1031-1034.

northwest-southeast transpression.¹³⁵ It is also possible that combined blind thrust faulting with vertical strike-slip faulting contribute to the uplift of the area.¹³⁶ From seismic reflection profiling data offshore, Rivero confirmed the existence of a southwest-dipping backthrust as postulated by Grant but also noted that the feature is restricted to the hanging wall of the larger Oceanside thrust fault.¹³⁷ Rivero interpreted that the backthrust merges at a shallow depth with the main Oceanside thrust fault and that movement on the larger, regional thrust fault is responsible for the uplift at San Joaquin Hills. This interpretation implies that the Oceanside thrust would be similarly active far to the south of San Joaquin Hills in the offshore area.

The nature of the intersection of thrust faults with the NIFZ at San Joaquin Hills has important implications as to which style of faulting is dominant in the area and how the dimensions of the active faults are determined for seismic moment rate calculations.¹³⁸ These parameters, in turn, can impact seismic hazard estimates at SONGS, which is within approximately 30 km of the southern San Joaquin Hills.

Implications for Seismic Design Basis

The design basis for SONGS is based on a safe-shutdown earthquake (SSE) of magnitude 7.0 at a distance of 8 km on the SCOFZ. Following NRC review, modification, and adjustment, SCE calculated the maximum bedrock acceleration from this earthquake at 0.67g.¹³⁹ This ground motion estimate was a deterministic value and unrelated to any specific annual probability (or return period). As part of the subsequent PSHA, SCE evaluated the SSE value of 0.67g to be associated with an annual probability of 0.00014, corresponding to a return period of 7,194 years. (The standard for nuclear plant design is a return period of 10,000 years.) A more recently updated PSHA,¹⁴⁰ which accounted for blind thrust faults, newer ground motion attenuation relationships, and near-source ground motion effects (i.e. rupture directivity and “fling” - see discussion of “Advances for Assessing Site-Specific Seismic Characteristics” later in this chapter), evaluated the return period associated with the SSE bedrock acceleration to be 5,747 years. In other words, advances in seismology have revealed that the SONGS site could

¹³⁵ Bender, E.E. “Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California: Comment.” *Geology*, Vol. 28. 2000, page 383.

¹³⁶ Grant, L.B., K.L. Mueller, E.M. Gath, R. Munro, “Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California: Reply” *Geology*, Vol. 28. 2000, page 384.

¹³⁷ Rivero, C. J.H. Shaw and K Mueller. 2000.

¹³⁸ Barrie, D., T.S. Tatnall and E. Gath. “Neotectonic Uplift and Ages of Pleistocene Marine Terraces, San Joaquin Hills, Orange County, California.” 1992; Grant, L.B. and K.J. Mueller, et al. “Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California.”, 1999; Rivero, C., J.H. Shaw and K Mueller. “Oceanside and Thirty-mile Bank Blind Thrusts.” 2000; Grant, L.B., L.J. Ballenger and E.E. Runnerstrom. “Coastal Uplift of the San Joaquin Hills, Southern Los Angeles Basin, California, by a Large Earthquake Since A.D. 1635.” *Bulletin of the Seismological Society of America*, Vol. 92, No. 2. (2002), pages 590-599.

¹³⁹ Southern California Edison. “San Onofre 2&3 FSAR (Updated).” 2005.

¹⁴⁰ Geomatrix Consultants and GeoPentech. “San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults.” 2001.

experience larger and more frequent earthquakes than had been anticipated when the plant was designed.

The California Coastal Commission (Coastal Commission), in review of SCE's application for an on-site spent fuel storage facility, evaluated this information and concluded that there has been an increase in the apparent seismic hazard at SONGS. However, they cautioned that this does not necessarily indicate that the plant is unsafe since SONGS was presumably built with sufficient safety margins to accommodate larger than anticipated ground motion. As explained by the Coastal Commission:¹⁴¹

The [Coastal] Commission thus finds that there is credible reason to believe that the design basis earthquake approved by NRC at the time of the licensing of SONGS 2 and 3...may underestimate the seismic risk at the site. This does not mean that the facility is unsafe – although the design basis earthquake may have been undersized, the plant was engineered with very large margins of safety, and would very likely be able to attain a safe shutdown even given the larger ground accelerations that might occur during a much larger earthquake.

The Coastal Commission did not review the seismic design of SONGS to evaluate whether the safety margins at the plant are indeed sufficient to accommodate the maximum ground motions that are now thought to be credible at the site. Given that there remain significant uncertainties regarding the seismic hazard at SONGS, such an assessment is warranted. This assessment should consider the plant's original design standards, the current condition of key plant components, and an updated assessment of seismic hazard at the plant in order to determine whether safety margins remain under credible seismic hazard scenarios.

The Uniform California Earthquake Rupture Forecast

In early 2008, the 2007 Working Group on California Earthquake Probabilities released a major report titled, "The Uniform California Rupture Forecast, Version 2 (UCERF 2)."¹⁴² The report is a joint publication of the USGS (USGS Open-File Report 2007-1437), the California Geological Survey (CGS Special Report 203), and the Southern California Earthquake Center (SCEC Contribution No. 1138) and is the culmination of a three-year effort to assemble a detailed, uniform model of faults and associated rupture probabilities over the next 30 years for the entire State of California. The primary purpose of this work was to provide a consensus database of active fault parameters for the State of California as a basis for the 2008 state update in the U.S. national seismic hazard maps.¹⁴³ The fault definitions and parameters were

¹⁴¹ California Coastal Commission. "W15a – Revised Findings." Application File No. E-00-014, Southern California Edison Company, San Diego Electric Company, City of Anaheim and City of Riverside, Construction of San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 Temporary Spent Nuclear Fuel Storage Facility. 2001, page 20.

¹⁴² Field, E.H. and T.E. Dawson, et al. "The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2)." USGS Open File Report 2007-1437; CGS Special Report 203, SCEC Contribution #1138. 2008, page 95 + Appendices.

¹⁴³ Petersen, M.D. and A.D. Frankel, et al. "Documentation for the 2008 Update of the United States National Seismic Hazard Maps." U.S. Geologic Survey Open-File Report 2008-1128. 2008, page 60 + Appendices and Maps.

developed through a consensus-building process. This process consisted of a review by an internal Scientific Review Panel, which in turn reported to a Management Oversight Committee. External reviews were provided by the National Earthquake Prediction Evaluation Council and the California Earthquake Prediction Council as well as the California Earthquake Authority's Multidisciplinary Research Team. Input from the scientific and engineering community at large was invited through open meetings and workshops during the course of the project.

Inspection of the UCERF-2 report and databases for faults in proximity to the power plant sites revealed that none of these faults have sufficient data from which time-dependent earthquake forecasts might be derived. Such forecasts are reserved for only the most significant faults of the San Andreas system (Class A faults), which have sufficient data and research to support well constrained earthquake recurrence intervals and known times since the last fault-rupturing earthquake. The Hosgri and Newport-Inglewood offshore faults, which have the largest impact on earthquake hazard at the Diablo Canyon and SONGS sites, respectively, are referred to as Class B faults. Since the slip rates and dimensions of these faults are established with at least a fair level of confidence, calculations can be made of the average annual moment rate. These values can be transformed into estimates of earthquake rupture frequencies given assumptions on the distribution of the moment rate with respect to earthquake magnitude (See Technical Note 1). Although the precision of the fault parameters for Class B faults is generally not as well constrained as with Class A faults due to the lesser amount of relevant data, consensus UCERF-2 values were developed for these faults.

The UCERF-2 database characterizes the Hosgri Fault zone as a strike-slip zone of faulting with an estimated maximum magnitude of 7.2 -7.3, a slip rate of 2.5 mm per year, and a steep dip of 80 degrees to the east. These fault parameters are consistent with the range of values established for the Hosgri Fault as part of PG&E's LTSP and reflect the current professional consensus that the Hosgri Fault is not a shallow east-dipping thrust fault in the brittle crust. Indeed, the UCERF-2 parameterization of faults relied heavily on research performed through the LTSP in the coastal area of central California.¹⁴⁴

Similarly, the UCERF-2 Newport-Inglewood Fault, both offshore and in connection with onshore segments, reflects recent research on this fault zone that was incorporated into the fault models of the most recent probabilistic seismic hazard assessment of the SONGS site.¹⁴⁵ The UCERF-2 models include multi-segment ruptures of the Newport-Inglewood Fault and the San Joaquin Hills blind thrust fault that are in close proximity to the SONGS site. The Newport-Inglewood Fault offshore is characterized as a vertical strike-slip zone of faulting with an estimated maximum magnitude of 6.8 - 7.0 and a slip rate of 1.5 mm per year. A multi-segment rupture of the fault zone is estimated to have a maximum magnitude of 7.1 - 7.2, which is associated with a slip rate of one mm per year.

Except for the San Joaquin Hills blind thrust fault, the UCERF-2 database does not specify any blind thrust faults in proximity to the power plant sites along the coastal areas of central and

¹⁴⁴ Lettis, W.B. and K.L. Hanson, et al. 2004; Hanson, K.L. and W.R. Lettis et al. 2004.

¹⁴⁵ Geomatrix Consultants and GeoPentech. 2001.

southern California. This reflects the fact that, while such hypotheses might be found in the geologic research literature, pertinent data are presently too sparse to allow a professional consensus on the existence of these faults.

Use of USGS National Map Values for Hazard Analyses

The UCERF-2 database of active fault parameters in California provides important information for seismic hazard analyses. However, the use of the USGS national seismic hazard maps for evaluating nuclear plant seismic hazards is not straightforward. Currently, the NRC is examining the database and the models that underlie the USGS maps, but not the maps themselves, to evaluate whether the calculated seismic risk at nuclear plants is impacted by these models. In the eastern and central U.S. the NRC is also working with the USGS to determine how the USGS analysis can be used in reviewing new reactor license applications and in reassessing the earthquake risk at existing plant sites.¹⁴⁶ Notably, the NRC is not currently using the USGS maps directly in seismic hazard analyses for nuclear plants and has not compared the map values to the seismic hazard values used in nuclear plant applications. This is because of the conceptual difficulties in applying the seismic hazard maps to site-specific nuclear plant investigations. Some of these difficulties, as applied to Diablo Canyon and SONGS, are as follows:¹⁴⁷

- The USGS national seismic hazard data for the western U.S. are distributed on a 0.05° grid of values. Neither of the power plants is located at one of these grid points, and errors are immediately introduced by accepting the USGS results of grid points closest to the sites as representing the sites themselves.¹⁴⁸ Both Diablo Canyon and SONGS are in close proximity to active faults, and ground motion calculations are sensitive to the distance of the site from the nearest active fault. Therefore, the USGS ground motion values that are available in the vicinity of the power plant sites should not be considered exact values for the sites themselves.
- The purposes of the studies are different. The primary purpose of the USGS national seismic hazard project is to provide a basis for seismic design criteria in building codes for non-nuclear facilities. (The USGS maps are not used for developing standards for nuclear plants.¹⁴⁹ Instead, the Code of Federal Regulations (CFR) is the ultimate guide

¹⁴⁶ Personal communication between Annie Kammerer, U.S. Nuclear Regulatory Commission, and Barbara Byron, California Energy Commission. August 13, 2008; Nuclear Regulatory Commission. "Fact Sheet on Seismic Issues for Existing Nuclear Power Plants." June 2008. Accessed: October 20, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-seismic-issues.html>>.

¹⁴⁷ Petersen, M.D. and A.D. Frankel, et al. "Documentation for the 2008 Update of the United States National Seismic Hazard Maps." U.S. Geologic Survey Open-File Report 2008-1128. 2008, page 60 + Appendices and Maps; Frankel, A.D. M.D. Petersen, et al. "Documentation for the 2002 Update of the National Seismic Hazard Maps," U.S. Geological Survey Open-File Report 02-420. 2002.

¹⁴⁸ At the latitude of Diablo Canyon, 0.05° of longitude corresponds to approximately 4.5 km in distance.

¹⁴⁹ U.S. Nuclear Regulatory Commission. "Screening Analysis for GI-199, 'Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants.'" ML073400504. February 1, 2008, page 1.

for nuclear power plant standards.¹⁵⁰⁾ Design standards for non-nuclear facilities are based on annual exceedance probabilities of 10 percent and two percent in 50 years (i.e. return periods of 475 and 2,475 years, respectively). In contrast, the primary purpose of the site-specific ground motion hazard analyses that have been performed for the power plant sites is to provide earthquake ground motion estimates targeted at 0.5 percent annual exceedance probability in 50 years (i.e. 10,000 year return period) and lower. The beginning assumptions of the ground motion investigations are therefore different, and it is not clear that the USGS values are valid for site-specific applications requiring very low annual probabilities of exceedance.

- The reference earth materials for the USGS national maps and the power plant sites are different. The shear-wave velocity of near-surface earth material has a large effect on the amplification, or de-amplification, of earthquake ground motions. The USGS national seismic hazard data is developed for an average shear-wave velocity in the top 30 meters of earth material of 760 m/sec. The average shear-wave velocity of the foundation material at Diablo Canyon is approximately 1,070 m/sec as derived from data in the facility's FSAR. Therefore, the reference shear-wave velocity of the USGS national ground motion hazard maps does not reflect the foundation material at Diablo Canyon. This makes any direct comparison of results unreliable.

The USGS models can be restructured to allow for site-specific adjustments, such as changes to location, return period, and ground characteristics, as described above. Once these adjustments are made, the model can be used to elicit relevant information on the seismic hazard of the site considered. There is no public information on any such analyses being performed for the Diablo Canyon and SONGS sites. Such analyses could provide additional information on the seismic hazard at the nuclear plants.

Other Seismic Hazards

The primary seismic hazards to Diablo Canyon and SONGS are from the ground motions that could result from major earthquakes at nearby faults. Other potential seismic hazards are liquefaction and landslides, which could result from local earthquakes, and tsunamis, which could be generated from offshore faults, both near and far, and from submarine landslides. These hazards are discussed briefly in this section.

Liquefaction Hazard

Liquefaction occurs in saturated sandy soil due to the oscillatory motions of the ground during earthquake shaking. Over repeated ground oscillations, water pore pressure builds up in the soil. At sufficiently high pore pressures, the cohesion between the sand particles is destroyed, resulting in a slurry of sand and water that erupts to the surface. This compromises the strength

¹⁵⁰ All other building standards, such as the California Building Code or the ASCE 31 (Seismic Evaluation of Existing Buildings), are superseded by the standards in the CFR. Personal communication between Annie Kammerer, U.S. Nuclear Regulatory Commission, and Barbara Byron, California Energy Commission. August 13, 2008.

of the deposit, and structures on the surface can sink and tilt due to the loss of the soil's bearing capacity.

Liquefaction effects beneath the Diablo Canyon containment building and other important safety-related structures are not a concern since the foundations of these structures are placed on bedrock, and the groundwater level lies well below the final building grade. A small, localized zone of medium dense sand that could be subject to liquefaction is located under a portion of buried piping. However, this does not present a safety hazard since the piping is not connected to the cooling water system, and the potential for liquefaction was accounted for in its design.

At SONGS, the plant and offshore areas are underlain to a depth of about 275 m by very dense, well-graded sands of the San Mateo Formation. Extensive geotechnical testing of induced shear stresses from earthquake motions and strength tests of the sands were conducted in designing the plant to obtain factors of safety against liquefaction. No adverse effects from liquefaction are therefore expected at the site.

Landslide Hazard

The only potential landslide hazard at Diablo Canyon is a slope east of the plant's building complex. Field and laboratory analyses of the soil and rock conditions of the slope and analyses of the impact of an earthquake striking after prolonged periods of precipitation did not identify any landslide hazards from this slope to the containment building and other important safety-related structures at the plant. However, potential landslides could temporarily block the access road at several locations. If this were to occur, emergency traffic would be rerouted to an alternate access route. However, as discussed in Chapter 4, Diablo Canyon is located in a remote location with limited road access. PG&E has an annual slope stability and shoreline erosion monitoring program to identify possible landslide hazards.¹⁵¹

All natural near-vertical bluffs and cut slopes at SONGS Unit 2 and 3 sites are at a sufficiently great distance so as not to affect the safety of these structures. Switchyard slopes northeast of Units 2 and 3 are the only permanent slopes in the vicinity of plant structures. These slopes were studied and cut-slopes were designed in detail for plant safety, in particular, with regard to stability during the safe shutdown earthquake. No adverse consequences to structures or equipment are expected from a landslide during such an earthquake.

Tsunami Hazard

In addition to the direct hazard from earthquakes discussed above, as coastal plants, the nuclear plants are also faced with possible flooding risk from tsunamis.¹⁵² The tsunami hazards at the

¹⁵¹ Pacific Gas & Electric. "PG&E's Comments on the Draft Consultant Report, 'AB 1632 Assessment of California's Operating Plants,' dated September 2008." October 2, 2008, page 4.

¹⁵² Flooding can also occur from the overflow of local creeks; however, based on the site hydrospheres, topologies, and designs described in the Final Safety Analysis Reports and the utility reports to the NRC, the risks posed to the plants do not appear to be extreme.

Diablo Canyon is located alongside Diablo Creek, and PG&E has maintained a site specific record of flows on Diablo Creek since 1968. In addition, the USGS maintains data on the Los Berros Creek, which is located 21 miles southeast of the site.

plants do not originate solely from the local faults — tsunamis can be generated locally, but they can also be generated from events at great distance. Nearly two-thirds of California’s historic tsunami events and all but one damaging event were generated by distant sources. These tsunamis have come from all around the Pacific basin including from South America and Alaska.

Local tsunamis can be triggered by offshore faults or by coastal and submarine landslides. Scientists have identified undersea landslides in submarine canyons, on continental slopes, adjacent to seamounts, and off the flanks of oceanic volcanoes. Evidence suggests that submarine mud flows and debris avalanches may have initiated tsunamis in southern California in the geologic past.¹⁵³

Submarine landslides have spanned a range of five orders of magnitude in volume: from less than 0.01 km³ to more than 1,000 km³. These landslides can generate both local and distant tsunamis. Locally generated tsunamis have the potential to cause greater wave heights in the vicinity than most distant earthquake sources. The largest historic local-source tsunami on the west coast was caused by the 1927 Lompoc earthquake, which produced waves of about six feet in the nearby coastal area.

Diablo Canyon Tsunami Design Basis

The Diablo Canyon tsunami evaluation and design evolved as a result of a number of studies and analyses during the original plant design period, during the operating license review period, and following breakwater damage in a 1981 storm. The plant’s design assumes that the worst tsunami ever documented on the California coast occurs during the worst tide and storm-induced wave conditions, resulting in a combined wave run-up of 34.6 feet.¹⁵⁴ The site has been designed to sustain this wave run up without damage to the plant.

PG&E re-evaluated external flood hazards in response to an NRC requirement in the early 1990s.¹⁵⁵ PG&E considered flooding from the maximum probable hurricane, tsunami, high tide, storm waves, and precipitation and from a severely degraded breakwater and concluded that the Diablo Canyon site conforms to NRC Standard Review Plan criteria.

SONGS is located alongside the San Mateo and San Onofre Creeks. SCE determined that the local topography precludes the San Mateo Creek as a flood source and that the San Onofre Creek Basin does not pose a flooding hazard for the SONGS site but that the foothill drainage area east of the plant could pose a flooding hazard. In response, prior to plant construction SCE constructed a berm to divert water from the foothill drainage area towards San Onofre Creek, which has a drainage area of 43 square miles.

¹⁵³ Pacific Marine Environmental Laboratory. “Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites.” NOAA Technical Memorandum OAR PMEL-136. May 2007, page 32.

¹⁵⁴ The design basis maximum combined wave run-up is the greater of that determined for near-shore tsunamis and for distantly-generated tsunamis. For Diablo Canyon these values are 34.6 feet for near-shore tsunamis and 30 feet for distantly-generated tsunamis.

¹⁵⁵ U.S. Nuclear Regulatory Commission. Generic Letter 88-20, Supplement 4.

In 2006 PG&E told the state Seismic Safety Commission that they would once again reassess tsunami scenarios at Diablo Canyon and determine whether any facility upgrades are required.¹⁵⁶ PG&E expects to complete this study in December 2008.

SONGS Tsunami Design Basis

The tsunami design basis for SONGS appears to be based on the original engineering studies from 1972. This hypothetical tsunami is the result of an earthquake with a 7.07-foot vertical displacement of the sea floor five miles offshore from the plant. SCE estimated that a tsunami generated from this earthquake that occurred during high tide and storm-induced wave conditions could increase water levels to elevation 27 feet above Mean Lower Low Water.¹⁵⁷ SCE constructed a reinforced concrete seawall to elevation 30 feet above Mean Lower Low Water to protect SONGS from such a tsunami. SCE officials maintain that this seawall is sufficient. They are not planning a reassessment of the tsunami risks.

The Coastal Commission believes that further study is warranted. The Coastal Commission noted in 2001 hearings on the SONGS dry cask spent fuel storage facility that SCE has only analyzed tsunamis generated by earthquakes, not those generated by submarine landslides. According to the Commission:

Several recent tsunamis have been generated by massive submarine landslides. These tsunamis are often localized, but very large events. There have been a number of studies in recent years which appear to demonstrate that massive underwater landslides have occurred off the Southern California coast, particularly in Santa Monica Bay, in the recent geologic past...

It is likely that large underwater landslides would be triggered by severe earthquakes, and the possibility of both tectonic displacement and landslide inducement of tsunamis exists. Maximum expected run-up maps for locally generated tsunami are being prepared for coastal San Diego County. These studies suggest that large local-source tsunamis could be generated by mechanisms other than those considered during licensing for SONGS 2 and 3.

Based on a review of the public literature, it appears that local run-up studies based on the close-to-shore landslide mechanism have not been performed for the SONGS site. The University of Southern California is preparing tsunami run-up maps in conjunction with the California Governor's Office of Emergency Services, but these maps are not yet available.

Advances in Tsunami Hazard Assessments

At the request of the NRC, the NOAA Center for Tsunami Research headed a scientific review group to update the framework for assessing the tsunami hazard at potential new nuclear plant sites. The review group noted that a probabilistic hazard assessment "would provide a more realistic and scientifically rigorous framework for decision-making during NRC reviews of

¹⁵⁶ Statement of Lloyd Cluff to the Seismic Safety Commission in June 2006.

¹⁵⁷ Southern California Edison. "SONGS Units 2 and 3 Final Safety Analysis Report Update." Amended June 2005, pages 2.4-40.

[nuclear plant] applications [than current methods of assessment], since such reviews would be based on quantitative hazard level estimates.”¹⁵⁸ They stopped short of recommending that probabilistic assessments be used since these are relatively new instruments that are just now being considered for adoption by government agencies.

Instead, the review group recommended that inundation modeling be conducted to show how waves from possible tsunami sources would interact with the shoreline.¹⁵⁹ They recommended that all possible sources be considered, including earthquakes, submarine and subaerial landslides, and volcanoes. They cautioned that current hazard models are not able to accurately assess the hazards from debris transported by tsunamis and from tsunami-induced erosion and sedimentation, since these hazards are not yet well understood.¹⁶⁰

A new tool that may provide improved input for seismic hazard assessments is NOAA’s Short-Term Inundation Forecast for Tsunamis (SIFT) system. SIFT uses data from tsunami sensors that detect offshore tsunami waves to predict where a tsunami will hit the coastline and the wave height, speed, and extent of inundation.¹⁶¹ In addition to its primary use as an early warning system, SIFT can also be used to evaluate tsunami hazards from hypothetical events at particular sites.¹⁶²

Updates to Seismic Safety Studies

The seismic hazards for Diablo Canyon and SONGS were assessed during the plant design and design review processes in the 1970s and early 1980s. However, the scientific understanding of seismology and geology has continued to evolve since that time. The regulatory requirements for updating seismic safety studies and the major advances in science and technology that could impact these assessments are discussed below. A summary of the utilities’ current seismic research efforts is also presented.

Regulatory Requirements

The Diablo Canyon operating license includes a condition (License Condition 2.C.7) that requires PG&E to maintain a seismic design basis re-evaluation program and to assess “additional new data...to assure adequacy of seismic margins.” New data would include new information from the USGS on unanalyzed faults in the vicinity of Diablo Canyon.

¹⁵⁸ Pacific Marine Environmental Laboratory. May 2007: 105.

¹⁵⁹ Pacific Marine Environmental Laboratory. May 2007: 1-2.

¹⁶⁰ Pacific Marine Environmental Laboratory. May 2007: 77.

¹⁶¹ Tsunami sensors were placed strategically through the oceans as part of the Deep-ocean Assessment and Reporting of Tsunamis (DART) program. As of March 2008, there are two DART buoys located off the coast of California. One is located 190 nautical miles west-southwest of San Diego, and the other is located 260 nautical miles northwest of San Francisco; National Oceanic and Atmospheric Administration Center for Tsunami Research. “DART Locations Map.” March 10, 2008. Accessed: July 9, 2008. <<http://nctr.pmel.noaa.gov/Dart/>>.

¹⁶² Gica, Edison, et. al. “Development of the Forecast Propagation Database for NOAA’s Short-Term Inundation Forecast for Tsunamis (SIFT).” NOAA Technical Memorandum OAR PMEL-139. March 2008, page 11.

In addition, per NRC Safety Evaluation Report Supplement 34 regarding the Diablo Canyon Long-Term Seismic Program, PG&E made the commitment to continue to keep abreast of new geologic, seismic, and seismic engineering information and to evaluate the significance of new information for Diablo Canyon. Should an analysis indicate that a new hazard exists that is outside the existing license basis for the facility, PG&E would be required to make a prompt report of that situation to the NRC with a proposal addressing how PG&E intended to continue to safely operate the plant. The NRC would then determine whether or not to allow the facility to continue to operate. The NRC has the authority to immediately modify or suspend the operating license.

SCE does not have a similar program to PG&E's LTSP and is not required to update the seismic studies for SONGS on an ongoing or routine basis. Instead, SCE reassesses the seismic hazard at SONGS when required by the NRC or when "new credible seismic information becomes available."¹⁶³ SCE was last required to update the SONGS seismic studies in response to the NRC's 1991 requirement (updated in 1995) that nuclear plant owners conduct probabilistic risk assessments for their plants.¹⁶⁴ SCE subsequently updated the probabilistic hazard assessment in 2001 to account for new information on the site seismology.

Advances in Assessing Site-Specific Seismic Characteristics

The most significant technological advancements with regard to earthquake ground motion characterization at the Diablo Canyon and SONGS sites have been the characterization of amplified motions near earthquake fault ruptures.¹⁶⁵ These near-source effects are manifested in two ways: (1) as spatial variability that increases the ground motion amplitudes in the direction of the fault rupture, and (2) as horizontal polarization that increases ground motion amplitude of the strike-normal component and decreases the ground motion amplitude of the strike-parallel component, relative to the average of the two horizontal components of strong ground motion (see Technical Note 7).

The spatial variability in ground motion amplitude due to rupture directivity is period dependent above about 0.6 seconds, with rupture towards a site causing increases in ground-motion amplitudes that grow with increasing ground motion period. This period dependence of amplitude variation indicates a transition from coherent source radiation and wave propagation conditions at long periods to incoherent source radiation and wave propagation at short periods. The effect is typically modeled empirically in ground motion studies as being

¹⁶³ Southern California Edison. "Southern California Edison Company's (SCE) Comments to the Draft Consultant Report: AB1632 Assessment of California's Operating Nuclear Plants (07-AB-1632)." October 2, 2008.

¹⁶⁴ In 2007 the American Nuclear Society published a standard for external event probabilistic risk assessments, and the NRC requires utilities that wish to submit risk-informed assessments to meet the relevant requirements found in the standard. This provides the utilities an incentive—but not a requirement—to update their analyses.

¹⁶⁵ Somerville, P.G. N.F. Smith, R.W. Graves and N.A. Abrahamson. "Modification of Empirical Strong Ground Motion Attenuation Relations to Include the Amplitude and Duration Effects of Rupture Directivity." *Seismological Research Letters*, Vol. 68. 1997, pages 199-222.

negligible below about a 0.6 second period. The effects of forward rupture directivity are most significant when two conditions are met: (1) the rupture front propagates toward the site, and (2) the direction of slip on the fault is aligned with the site. For strike-slip faults, these conditions are met when the fault slip is oriented in a direction parallel to the trend of the fault, and the rupture propagates horizontally along the fault strike either unilaterally or bilaterally.

Strike-normal refers to the horizontal component of motion normal to the strike of the fault and strike-parallel refers to the horizontal component of motion parallel to the strike of the fault. Empirical strong motion data indicates that ground motions in the strike-normal direction are on average larger than in the strike-parallel direction for vibration periods longer than about 0.6 seconds. For strike-slip faults, the polarity of the strike-normal displacement is opposite for rupture in opposite directions, whereas for strike-parallel displacement, the polarity is the same for rupture in either direction.

Fault “fling” also results in amplified long-period motions close to fault ruptures, similar to that of the directivity effects just described. However, fault fling results from the inertial effect of the tectonic displacement on a fault whereas the directivity effects result from constructive and destructive interference of the ground motions. Fault fling effects need to be incorporated into a hazard estimate outside of standard ground motion attenuation relationships since these relationships do not incorporate the fling effect. Rupture directivity effects, while not originally addressed in design considerations for the power plant sites, have been included in the more recent PSHA models for the plants’ dry cask spent fuel storage facilities.¹⁶⁶

Ground motion recordings for the magnitude 6.0 earthquake that struck Parkfield, California, in September 2004 indicate that the large variability in ground motion observed in empirical ground motion models is also applicable to the near-fault region for a single earthquake.¹⁶⁷ These recordings are the best recordings ever taken within 10 km of a fault rupture, and the large variability that they exhibit is stimulating new thinking on ground motion attenuation models.¹⁶⁸ Researchers are constantly updating and refining these strong ground motion attenuation models. For example, under the auspices of the Pacific Earthquake Engineering Research (PEER) Center, a multi-institution, multi-investigator, multi-sponsor collaborative program was undertaken to develop the next generation of strong ground motion attenuation relationships for the western United States, which were published during the course of this project.¹⁶⁹

¹⁶⁶ Since rupture directivity and fault fling affect long-period motion, these effects are likely to be important for the design of the spent fuel storage facilities, which respond to long period earthquake motions to a greater degree than the power plants.

¹⁶⁷ Shakal, A.F. H. Haddadi, V. Graizer, K. Lin and M. Huang, “Some Key Features of the Strong-Motion Data from the M 6.0 Parkfield, California, Earthquake of 28 September 2004.” *Seismological Society of America Bulletin*, 2006. Vol. 96, pages S90 – S118.

¹⁶⁸ Harris, R.A. and J.R. Arrowsmith, “Introduction to the Special Issue on the 2004 Parkfield Earthquake and the Parkfield Prediction Experiment.” *Seismological Society of America Bulletin*, 2006. Vol. 96, pages S1 - S10.

¹⁶⁹ Stewart, J.P. R.J. Archuleta, M.S. Power, eds. “Special Issue on the Next Generation Attenuation Project” *Earthquake Spectra*, Vol. 24, 2008, 341 pages.

The potential amplification of ground motion near a fault rupture is important for Diablo Canyon and SONGS, since both plants are located near active faults. PG&E, a partial sponsor of the PEER Center project, is involved with several projects to refine ground motion modeling in the Diablo Canyon region (see below). As described above, SCE has already updated the SONGS PSHA to account for potential ground motion amplification and other advances. The results revealed that there is a greater seismic hazard at SONGS than previously believed.

Technological Advances for Assessing Geologic Structure and Tectonics

There are two primary technological advances that have recently had profound impact on the resolution of deep geologic structure and on resolving the movements of the Earth's crust. These are the collection and processing of three-dimensional geophysical seismic data (3D seismic) and the collection and interpretation of global positioning system data (GPS data). When combined, these data types can augment existing data sources to provide refined resolution of shallow Earth structure and the movement on, or across, these structures.

Collection of offshore 3D seismic geophysical data is now commonplace in the oil and gas industry to obtain better resolution of potential oil and gas trapping structures and to pinpoint drilling objectives in the subsurface. The collection process is data intensive and relatively expensive. It consists of numerous closely-spaced acoustic geophysical lines that measure the reflectivity of subsurface rock layers. In the offshore environment, acoustic vibrations are imparted to the surface layer using high-intensity air guns and receivers record the reflected waves from the various rock layers at depth. Onshore, the vibrations are imparted in direct contact with the ground through mechanical means. The seismic lines are laid out in a closely-spaced grid pattern. Computer processing of the large amount of collected data is intensive and highly specialized. In properly processed data sets, laterally continuous reflection "events" can be viewed in their proper vertical and horizontal positions in the subsurface and can be "sliced" and rotated in any desired direction while fidelity to the true subsurface structure is retained. 3D seismic data thereby provides detailed information on subsurface fault distribution and their three-dimensional geometry, as well as on folded rocks and rock layers within the surveyed area. These types of investigations, if properly planned and executed, hold high potential for resolving uncertainty concerning the presence and geometry of faults at depth.

GPS surveys can provide data and information on the relative movement of blocks across fault zones, and they have been used extensively in this capacity over the last decade. Data collection is quick and efficient, although an elapsed period of time is required between repeated surveys in order to define differences in the rate and direction of movement on either side of a fault. The GPS method is based on triangulation between a receiver site on the ground and time signals transmitted by satellites that circle the earth in very precise orbit.

Extensive analysis of regional GPS data was used in the 2001 seismic hazard study of postulated blind thrust faults in the vicinity of SONGS.¹⁷⁰ The data was used primarily to evaluate the implications of compressive strain across southern California that could drive thrust components on northwest-trending faults of the region. The results were used to assign weights to various models of seismic sources that incorporated thrust faulting.

¹⁷⁰ Geomatrix Consultants and GeoPentech. 2001.

Similar GPS evaluations for the Diablo Canyon site are currently in progress through PG&E's LTSP. As discussed below, the existing, relatively sparse GPS network in the central California coastal area is being resurveyed and augmented with additional stations to provide more accurate measurements of tectonic block movements in the Los Osos domain. However, because there are no islands off the central California coast, it is not possible to have the GPS network span the Hosgri Fault zone.

Current Geologic Investigations by Plant Owners

PG&E has a number of ongoing research activities.¹⁷¹ PG&E is currently supporting a major update of the seismic hazard in the central California coastal region for the purpose of developing new seismic source characterization models and ground motion models, including improved characterization of near-fault ground motions. Considerable new geophysical and geological data are being collected in support of these models. The purpose of this work is to update models of the probabilistic seismic hazard analysis at Diablo Canyon. PG&E expects to complete this work in 2012.

Additional geological and geophysical research is being conducted under a cooperative research agreement between PG&E and the USGS:

- The USGS is compiling all existing GPS data for coastal central California and is augmenting the existing GPS network with up to 20 new stations. PG&E estimates that approximately three to five years of observations will be required to obtain high-precision rate estimates due to the relatively low level of tectonic motion in the region.
- The USGS is using satellite imagery (Synthetic Aperture Radar, or, "SAR") to characterize the spatial extent and temporal variability of surface deformation in the region. While SAR does not have the accuracy of GPS, it provides similar types of observations over a larger area.
- The USGS collected geophysical aero-magnetic data along the central California coastal area in 2008. Interpretation of this data will improve understanding of subsurface geologic structures.
- Offshore, the USGS is currently collecting high-resolution bathymetric and magnetic data to help pinpoint the location of offshore faults.
- Onshore, the USGS is reprocessing geophysical data (regarding seismic line J-6¹⁷²) to help constrain three-dimensional tectonic models of the area.
- Beginning in 2009, the USGS will conduct field studies to improve the mapping of warped marine terraces. This research, together with PG&E-sponsored research addressing the uncertainties in balanced cross-sections for the central coastal region (also planned to begin in 2009) potentially holds insights for thin-skinned versus thick-skinned tectonic models.

¹⁷¹ Pacific Gas & Electric. "PG&E's Comments on the Draft Consultant Report, 'AB 1632 Assessment of California's Operating Plants,' dated September 2008." October 2, 2008, pages 22-34.

¹⁷² Seismic line J-6 extends from the Pacific Ocean to the San Andreas Fault at a latitude of about 35° 30'.

PG&E is also involved with several seismology and ground motion research projects:

- PG&E is updating the seismic instrumentation of the central coastal region. Data from the network is provided to the USGS and used for locating earthquakes in the region.
- PG&E is one of the sponsoring organizations for the Pacific Earthquake Engineering Center's Next Generation Attenuation (NGA) project, which recently published a set of new empirical ground motion models for California and other active tectonic regions.
- PG&E is supporting the development of improved numerical simulations of ground motion at the USGS and SCEC. In addition to supplementing the recently published empirical ground motion models, this work will be used for new site-specific numerical simulations of motion at Diablo Canyon by 2010.
- PG&E is conducting a study on the spatial coherence of ground motion over short distances. This information is used as part of the input to soil/structure interaction analyses for Diablo Canyon structures. The new research will be used to update models developed by the Electric Power Research Institute in 2005, which were based on very limited data. PG&E expects to complete this project by 2009.

Finally, PG&E is completing an update to the tsunami hazard at Diablo Canyon. This new update is a probabilistic analysis that considers tsunamis triggered by local and distant earthquakes, as well as submarine landslides. PG&E expects to complete this study by December 2008.

Ongoing seismic research by SCE pertaining to SONGS is more limited. The only research project that SCE reported to the Consultant Team is an evaluation of the implications for SONGS of the new ground motion models that were developed through the NGA project.¹⁷³

Conclusions: The Diablo Canyon Site

The Diablo Canyon seismic setting has been extensively studied, and a majority scientific opinion has developed regarding the tectonic setting of the Hosgri Fault zone, which is the primary contributor to seismic hazard at the plant. The geologic and seismologic research literature for the Diablo Canyon site, much of which has been developed through PG&E's LTSP, support the interpretation that the Los Osos domain is characterized by high-angle, reverse-oblique faulting and that the Hosgri Fault system is characterized by transpressional strike-slip faulting. The hypothesis that shallow-dipping thrust faults exist in this region, which could imply a greater seismic hazard at Diablo Canyon than currently assumed, is not supported by the models developed under the LTSP. Indeed, this was the consensus of the USGS, California Geological Survey, and Southern California Earthquake Center in their recent UCERF-2 report.

However, a minority of scientists disagrees with this characterization, and additional study is required to definitively resolve the true dip and structure of the Hosgri Fault zone at depth.

¹⁷³ Southern California Edison. "Southern California Edison Company's (SCE) Comments to the Draft Consultant Report: AB1632 Assessment of California's Operating Nuclear Plants (07-AB-1632)." October 2, 2008.

High quality three-dimensional seismic data collected along the offshore Hosgri Fault zone could be useful in resolving this issue. Furthermore, direct 3D imaging of subsurface structure within the San Luis – Pismo Block may hold the potential to definitively prove or disprove the existence of faults near the site that do not appear at the surface. Finally, such imaging at strategic locations could help refine knowledge of the dip, continuity, and interaction of the array of faults that bound the San Luis – Pismo Block on the northeast and southwest, including the Los Osos and Southwest Boundary faults, respectively.

To date, assessments of the tsunami hazard at Diablo Canyon have concluded that the plant is designed to withstand without damage the maximum anticipated wave run-up. PG&E plans to complete an updated assessment by the end of 2008.

Conclusions: The SONGS Site

The SONGS seismic setting has been studied much less than the Diablo Canyon seismic setting, and much uncertainty remains regarding the structure of nearby fault zones. In addition, newer seismologic and geologic data indicate that safety margins at the plant are smaller than they were thought to be 10 years ago, and the risk of a design basis earthquake is larger.¹⁷⁴

In response to this situation, a recent review by the California Coastal Commission in connection with the proposed spent fuel storage facility at the SONGS sites states:

There is credible reason to believe that the design basis earthquake approved by NRC at the time of the licensing of SONGS 2 and 3 ... may underestimate the seismic risk at the site. This does not mean that the facility is unsafe – although the design basis earthquake may have been undersized, the plant was engineered with very large margins of safety, and would very likely be able to attain a safe shutdown even given the larger ground accelerations that might occur during a much larger earthquake.

The Consultant Team agrees with the Coastal Commission that current data do not necessarily indicate a safety hazard at the plant. However, the Consultant Team believes that further study of the SONGS seismic setting is warranted and that an active program similar to PG&E's LTSP should be strongly considered.

One area that could be resolved via more active seismic study at SONGS is the continuity, structure, and earthquake potential of the offshore fault zone that extends from the Newport-Inglewood Fault in the Los Angeles region with the Rose Canyon Fault in the San Diego region. This is an issue of high consequence to the seismic hazard at the plant. Similar to the Diablo Canyon area, however, direct high-quality subsurface imaging of the offshore zone is lacking, particularly at the critical intersection of this strike-slip fault zone with the onshore termination

¹⁷⁴ Risk Engineering, Inc. "Seismic Hazard At San Onofre Nuclear Generating Station." Report for Southern California Edison, 1995; Geomatrix Consultants and GeoPentech. "San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults." Report for Southern California Edison, 2001.

of the Oceanside thrust fault at San Joaquin Hills.¹⁷⁵ Continuity of the offshore zone of faulting with onshore segments affects the maximum magnitude of potential earthquakes on the fault. Whether or not compressive stress is occurring across the coast affects the type of faulting that is to be expected, which ultimately affects the ground motion hazard at SONGS.¹⁷⁶ Well planned, high-quality three-dimensional seismic reflection data at strategically chosen locations may hold potential for resolving both the continuity and sense of motion along the offshore Newport-Inglewood Rose Canyon Fault zone. Such information would help constrain the current wide range of faulting models that are needed to fairly assess the ground motion hazard at the site.¹⁷⁷

Another area that warrants further study is the tsunami hazard at the site. SCE has not reassessed the tsunami hazard at SONGS since the plant was designed. Since then scientists have learned that submarine landslides can generate significant local tsunamis. Tsunami run-up maps that are being prepared by the University of Southern California will incorporate expected hazards from such near-to-shore landslides. It is not possible at present to determine whether these new maps will result in significantly revised estimates of the tsunami hazard at the plant. An increase in the estimated maximum tsunami run-up of a few feet could raise significant concerns about the adequacy of the site's seawall.

¹⁷⁵ Grant, L.B. and K.J. Mueller, et al. "Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California." 1999; Grant, L.B. L.J. Ballenger and E.E. Runnerstrom. "Coastal Uplift of the San Joaquin Hills, Southern Los Angeles Basin, California, by a Large Earthquake Since A.D. 1635." 2002; Grant, L.B. and P.M. Shearer. "Activity of the Offshore Newport-Inglewood Rose Canyon Fault Zone, Coastal Southern California, from Relocated Microseismicity." 2004; Rivero, C. J.H. Shaw and K Mueller. "Oceanside and Thirty-mile Bank Blind Thrusts: Implications for Earthquake Hazards in Coastal Southern California." 2000.

¹⁷⁶ Geomatrix Consultants and GeoPentech. 2001; Geomatrix Consultants. "Appendix A (to Title 43) - Seismic Source Characterization." 1995.

¹⁷⁷ Geomatrix Consultants and GeoPentech. 2001; Geomatrix Consultants. "Appendix A (to Title 43) - Seismic Source Characterization." 1995.

Technical Note 1: Earthquake Occurrence Frequency Assessment

There are two fundamental approaches for assessing earthquake recurrence frequency: historical frequency assessments and geological frequency assessments. Historical frequency assessments are based on statistical analyses of the historical catalog of earthquakes that have occurred within a region. Geological earthquake frequency assessments are generally based either on a prehistoric record of earthquake occurrence on faults (termed paleoseismicity) or on physical estimates of seismic moment on individual faults or throughout broad regions.

Historical frequency assessments apply the common Gutenberg-Richter relationship of occurrence frequencies:

$$\text{Log } N(m) = a - bm \quad (1)$$

where $N(m)$ is the number of earthquake events equal to or greater than magnitude m occurring on a seismic source per unit time, and a and b are regional constants (10^a is the total number of earthquakes with magnitude >0 , and b is the rate of seismicity; b is typically 1 ± 0.3). In quantitative ground motion assessments that employ earthquake recurrence frequency, the truncated exponential form of this relationship is more commonly preferred

$$N(m) = N(m^0) \frac{\exp(-\beta(m - m^0)) - \exp(-\beta(m'' - m^0))}{1 - \exp(-\beta(m'' - m^0))} \text{ for } m \leq m'' \quad (2)$$

where m^0 is an arbitrary reference magnitude, m'' is an upper-bound magnitude where $n(m) = 0$ for $m > m''$, and $\beta = b \cdot \ln 10$. In this form, earthquake frequency approaches zero for some chosen maximum earthquake of a region.

Paleoseismic geological earthquake frequency assessments apply data compiled through detailed field geologic investigations. Moment-based recurrence frequency estimates require some knowledge of the average long-term rate at which faults are slipping or the regional rate at which tectonic deformation is occurring over a region.

Fault slip-rate can be related to earthquake occurrence frequency through the use of seismic moment.¹⁷⁸ Seismic moment, M_o , is the most physically meaningful way available to describe the size of an earthquake in terms of static fault parameters. It is defined as

$$M_o = \mu A_f D \quad (3)$$

where μ is the rigidity or shear modulus of the fault, usually taken to be $3 \times 10^{11} \text{ dyne} / \text{cm}^2$, A_f is the rupture area on the fault plane undergoing slip during the earthquake, and D is the average displacement over the slip surface. The seismic moment is translated to earthquake magnitude according to an expression of the form,

¹⁷⁸ Anderson, J. G. "Estimating the Seismicity from Geological Structure for Seismic Risk Studies," *Bull. Seism. Soc. Am.* vol. 69, 1979, pages 135-158.

$$M_o(M) = c M + d \quad (4)$$

Based on both theoretical considerations and empirical observations, c and d are rationalized as 1.5 and 16.1, respectively.¹⁷⁹ However, to be consistent with the definition of moment magnitude, d should be set equal to 16.05.¹⁸⁰

The total seismic moment rate, M_o^T , is the rate of seismic energy release along a fault. According to Brune, the slip rate of a fault can be related to the seismic moment rate, M_o^T , as follows,

$$M_o^T = \mu A_f S \quad (5)$$

where S is the average slip rate (per unit time) along the fault. The seismic moment rate, therefore, provides an important link between geologic data and seismicity data.¹⁸¹

While the Gutenberg-Richter relationship describes the regional occurrence frequency of earthquakes, it has been found to be nonrepresentative of large earthquake occurrence on individual faults.^{182, 183} Physically, this can be attributed to the breakdown of the power law of the Gutenberg-Richter relationship between large and small earthquakes because they are not self-similar processes.¹⁸⁴ Geologic investigations of faults of the San Andreas system of western California and of the Wasatch fault in central Utah have indicated that surface-rupturing earthquakes tend to occur within a relatively narrow range of magnitudes at an increased frequency over that which would be estimated from the Gutenberg-Richter relationship. These have been termed characteristic earthquakes. The characteristic recurrence frequency distribution reconciles the exponential rate of small- and moderate-magnitude earthquakes with the larger characteristic earthquakes on individual faults (Figure 12). The summed rate of earthquakes over many faults in a region reverts to the truncated exponential distribution and is therefore consistent with the regional empirical Gutenberg-Richter relationship.¹⁸⁵

The characteristic recurrence frequency distribution can be separated into a non-characteristic Gutenberg-Richter relationship for small and moderate earthquakes and a characteristic

¹⁷⁹ Molnar, P. "Earthquake Recurrence Intervals and Plate Tectonics," *Bull. Seism. Soc. Am.* Vol. 69, 1979, pages 115-134.

¹⁸⁰ Kanamori, H. Quantification of Earthquakes. *Nature* 271, 1978, pages 411-414.

¹⁸¹ Brune, J. N. "Seismic Moment, Seismicity and Rate of Slip Along Major Fault Zones," *J. Geophys. Res.* vol. 73, 1968, pages 777-784.

¹⁸² Schwartz, D. P. and K. J. Coppersmith. "Fault Behavior and Characteristic Earthquakes: Examples From the Wasatch and San Andreas Fault Zones," *J. Geophys. Res.* Vol. 89, 1984, pages 5681-5698.

¹⁸³ Wesnousky, S.G. "The Gutenberg-Richter or Characteristic Earthquake Distribution, Which is it?" *Bull. Seism. Soc. Am.* Vol. 84, 1994, pages 1940-1959.

¹⁸⁴ Scholz, D. H. *The Mechanics of Earthquake Faulting*, Cambridge University Press. 1990.

¹⁸⁵ Youngs, R. R. and K. J. Coppersmith. "Implications of Fault Slip Rates and Earthquake Recurrence Models to Probabilistic Seismic Hazard Estimates," *Bull. Seism. Soc. Am.* Vol. 75, 1985, pages 939-964.

frequency part for large earthquakes. The cumulative rate of non-characteristic, exponentially distributed earthquakes, N_e , is estimated from the seismic moment and seismic moment rate as follows,

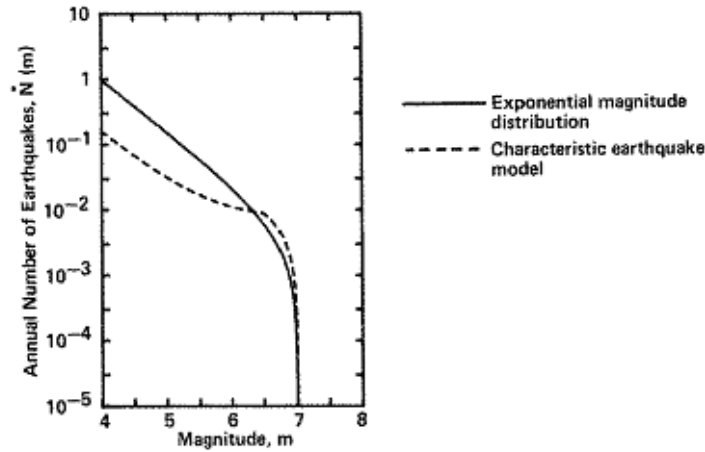
$$N_e = M_o^T \frac{1 - e^{-\beta(m_u - 0.25)}}{M_o e^{-\beta(m_u - 0.25)} \left(\frac{b10^{-c/2}}{c-b} + \frac{b10^b(1-10^{-c/2})}{c} \right)} \quad (6)$$

The cumulative rate of characteristic earthquakes, N_c , is related to the cumulative rate of non-characteristic earthquakes by the expression,

$$N_c = \frac{\beta N_e e^{-\beta(m_u - m_0 - 1.5)}}{2(1 - e^{-\beta(m_u - m_0 - 0.5)})} \quad (7)$$

Similar to the truncated exponential recurrence model, frequency estimates from the characteristic recurrence model approach zero at the defined maximum magnitude for the source.

Figure 12: Comparison of Exponential and Characteristic Recurrence Frequency Distributions



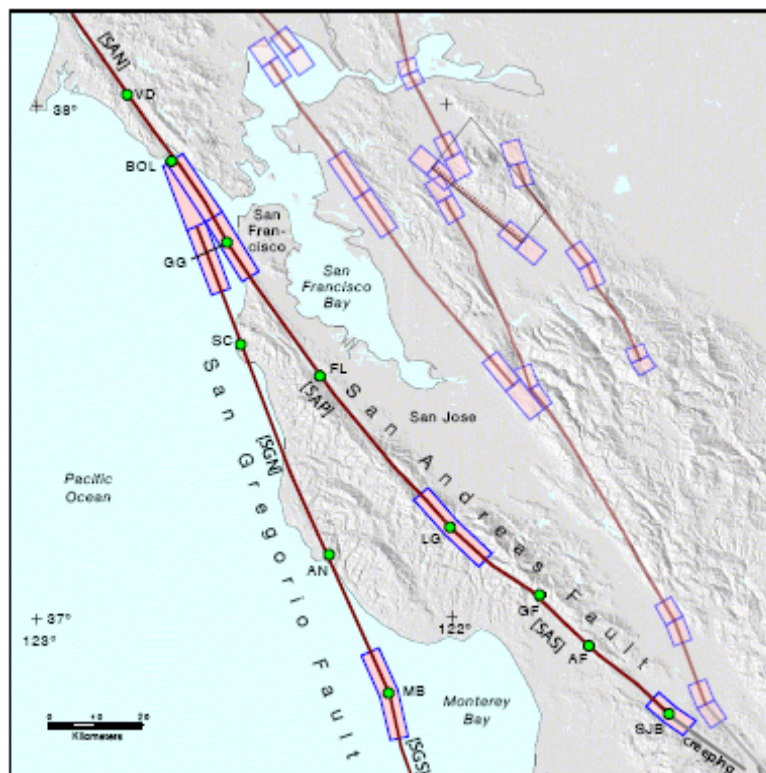
Source: Youngs and Coppersmith¹⁸⁶

¹⁸⁶ Youngs, R. R. and K. J. Coppersmith. 1985.

Technical Note 2: Fault Segmentation

Faults seldom rupture their entire lengths in single earthquakes and commonly rupture in less than half of their entire length.¹⁸⁷ It can thus be useful in the context of seismic hazard analysis to consider individual segments of a fault (Figure 13). A working tenet of fault segmentation is that, in a relative sense, smaller earthquakes tend to be confined to single segment ruptures whereas larger earthquakes tend to be characterized by multi-segment ruptures. Specific lengths of segment ruptures depend on the tectonic environment of the region and the style of faulting that is present.

Figure 13: Segmentation Model of the San Andreas and San Gregorio Faults in the San Francisco Bay Region



Fault segmentation model for the San Andreas Fault System in the San Francisco Bay region defined by the Working Group on California Earthquake Probabilities (2003).¹⁸⁸ Rectangles indicate segment rupture boundaries. The length of each rectangle indicates uncertainty in the location of rupture endpoints. The San Andreas Fault segments are labeled as follows: SAN, North Coast; SAP, Peninsula; SAS, Santa Cruz Mountains. San Gregorio Fault segments are labeled as follows: SGN, North; SGS, South. Localities (circles) are: AF, Arano Flat; AN, Ano Nuevo; BOL, Bolinas; FL, Filoli; GF, Frizzly Flat; GG, Golden Gate stepover zone; LG, Los Gatos bend; SC, Seal Cover; SJB, San Juan Bautista; VD, Vedanta.

¹⁸⁷ Albee, A.L. and J.L. Smith. "Earthquake Characteristics and Fault Activity in Southern California" in *Engineering Geology in Southern California*, R. Lung and T. Proctor, Eds. Association of Engineering Geologists, Sudbury, MA, 1966, pages 9-34.

¹⁸⁸ Working Group on California Earthquake Probabilities. "Earthquake Probabilities in the San Francisco Bay Region: 2002-2031." U.S. Geological Survey Open-File Report 03-214. 2003.

Faults are geometrically and mechanically segmented on a variety of scales.¹⁸⁹ Repeated faulting over geologic time will produce recognizable geologic structure at segment boundaries due to the slip deficit that accumulates at these boundaries. Over some period of time, all segment boundaries within a fault zone must eventually rupture in some manner in order to absorb strains placed on it from ruptures on either side. If a segment boundary did not ever rupture, infinite strains would accumulate at these boundaries.¹⁹⁰ Accordingly, the usefulness of the segmentation concept is not universal to all fault zones. It is useful only to the degree that it serves to explain the geometrical and behavioral characteristics of faulting indicated by detailed fault-rupture investigations.¹⁹¹

Slip rate typically varies among the segments of a fault as the result of any number of physical changes along the fault. A difficulty in seismic hazard assessment is accounting for the varying slip-rate values between different segments of individual faults. The Working Group on California Earthquake Probabilities developed a "cascade" model of earthquake occurrence frequency to account for varying slip rates on well-studied fault zones in western California.^{192,}

193

The cascade model assumes that large earthquakes break multiple, contiguous segments of a fault at a frequency that is governed by the lowest-slipping segment. Once the moment rate of the slowest-slipping segment is depleted in the production of these large earthquakes, it drops from any further considerations regarding multi-segment ruptures, and the remaining segments' slip rates are reduced by the rate of the slowest-slipping segment. A new set of multi-segment ruptures are thereby defined, and the procedure repeats until only single-segment ruptures of the highest-slipping segments are left to rupture in single earthquakes at a rate that is determined from the residual slip when all multi-segment ruptures have been exhausted. This modeling approach maintains the slip-rate and seismic-moment budget on each defined fault segment.

¹⁸⁹ Schwartz, D.P. and R.H. Sibson. "Introduction" in Fault Segmentation and Controls of Rupture Initiation and Termination, D.P. Schwartz and R.H. Sibson, eds. U.S. Geological Survey Open File Report 89-315, 1989, pages i-iv.

¹⁹⁰ Scholz, D. H. *The Mechanics of Earthquake Faulting*, Cambridge University Press. 1990.

¹⁹¹ McCalpin, J.P. *Paleoseismology*, Volume 62, International Geophysics Series, R. Dmowska and J.R. Holton, eds. Academic Press, San Diego, 1996.

¹⁹² Working Group on California Earthquake Probabilities. *Seismic Hazards in Southern California: Probable Earthquakes, 1994 to 2024*, Working Group on California Earthquake Probabilities, *Bull. Seism. Soc. Am.* Vol. 85, 1995, pages 379-439.

¹⁹³ Working Group on California Earthquake Probabilities. *Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030—A Summary of Findings*. Working Group on California Earthquake Probabilities, USGS Open-File Report 99-517, 1999.

Technical Note 3: Ground Motion Attenuation Relationships

A ground motion attenuation relationship is a mathematical model that relates a strong ground motion parameter, such as peak ground acceleration, peak ground velocity, or other peak spectral accelerations, to earthquake characteristics, such as magnitude, source-to-site distance, faulting mechanism, and local site conditions.¹⁹⁴ A wide variety of empirical ground motion attenuation relationships are available for application in seismic hazard analysis, and research has shown ground motion attenuation to be regionally dependent.¹⁹⁵ In large part, the choice of an appropriate relationship is governed by the regional tectonic setting of the site of interest, such as whether it is located within a stable continental region or an active tectonic region, and whether it is located near a subduction zone tectonic environment.

In their simple form, ground motion attenuation relationships typically follow a form of $Y = ae^{bM}R^{-n}e^{-\gamma R}$, where Y is the strong motion parameter of interest, M is magnitude, and R is distance from the earthquake source to the site. The functional form of this equation is based on fundamental seismologic principles. The exponential form of magnitude derives from the definition of magnitude as the logarithm of an instrumental measure of displacement. The degree to which the ground motion (Y) scales with this measure is described by b . R^{-n} is the attenuation of Y due to geometrical spreading as the wave front travels from the earthquake source to the site, and n is the coefficient of geometrical attenuation. The exponential form of R comes from the attenuation of Y due to material damping and wave scattering as the waves propagate from the source; γ is the coefficient of anelastic attenuation.

Considerable research into ground motion attenuation has resulted in quite complicated modern forms of attenuation relationships that incorporate a number of variables having an influence on ground motion amplitudes.^{196, 197} Modern attenuation relationships incorporate coefficients that allow for the determination of a wide range of ground motion accelerations and velocities across a range of vibration frequencies, or so-called spectral attenuation relationships.

Examples of attenuation plots of peak ground acceleration (PGA) and 10-second period spectral acceleration (SA) are shown below (Figure 14). Both are for events located in the western U.S. of magnitudes 5 through 8, a shear-wave velocity of 760 m/sec, and basin depth of 2 km.

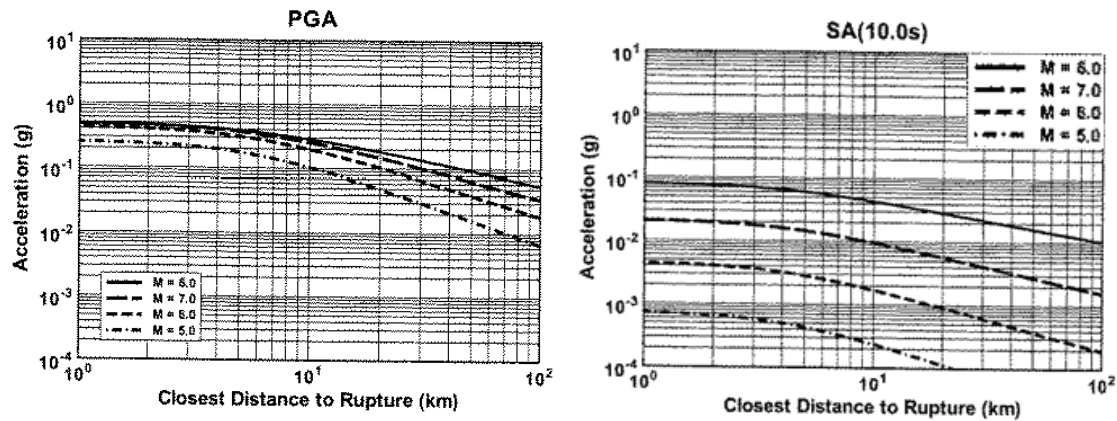
¹⁹⁴ Campbell, K.W. *Engineering Seismology*, Encyclopedia of Physical Science and Technology, Vol. 5, Academic Press, Inc. 1987.

¹⁹⁵ Campbell, K.W. "Strong Motion Attenuation Relations: A Ten-Year Perspective," *Earthquake Spectra*, vol. 1, 1985, pages 759-804.

¹⁹⁶ Stewart, J.P. S-J Chiou, J.D. Bray, R.W. Graves, P.G. Somerville, N.A. Abrahamson. Ground Motion Evaluation Procedures for Performance-Based Design, Pacific Earthquake Engineering Research Center, PEER 2001/09, 225, 2001.

¹⁹⁷ Stewart, J.P. R.J. Archuleta, M.S. Power, eds. "Special Issue on the Next Generation Attenuation Project" *Earthquake Spectra*, Vol. 24, 2008, 341 pages.

Figure 14: Peak Ground Acceleration and Spectral Acceleration Attenuation Plots



Source: Campbell and Bozorgnia, 2008¹⁹⁸

¹⁹⁸ Campbell, K.W. and Y. Bozorgnia. "NGA Ground Motion Model for Geometric Mean Horizontal Component of PGA, PGV, PGD and 5% Damped Linear Elastic Response Spectra for Periods Ranging from 0.01 to 10 s," Earthquake Spectra, Vol. 24, 2008, pages 139-172.

Technical Note 4: Earthquake Response Spectra

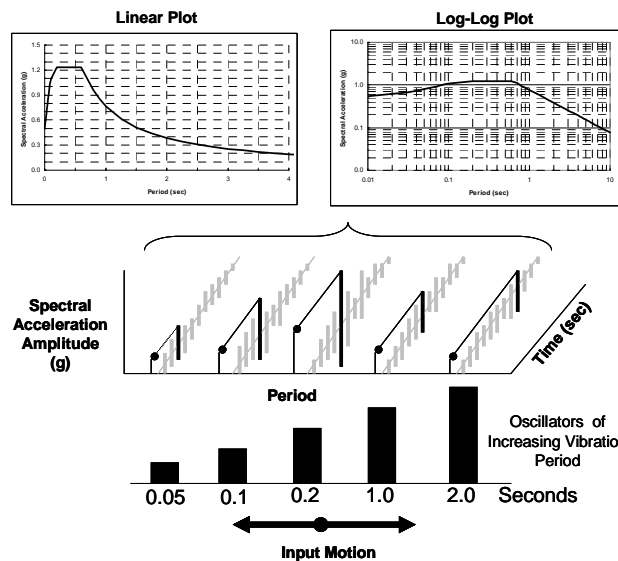
An earthquake response spectrum is a plot of the peak response of a series of oscillators of differing natural frequencies that are put into motion by the same earthquake shock. The plot shows the response of a linear system, given the system's natural period of oscillation.¹⁹⁹

Damping must be applied or else the response will be infinite. Free-field response spectra from earthquakes are typically developed for damping levels 5 percent of critical. However, other damping values can be applied for various types of structures and responses that are critical to engineering design. For transient seismic ground motions, the peak response for each oscillator period is typically reported.

Response spectra can also be used in assessing the response of linear systems with multiple modes of oscillation, although they are only accurate for low levels of damping. Modal analysis is performed to identify the modes, and the response in that mode can be picked from the response spectrum. This peak response is then combined to estimate a total response. A typical combination method is the square root of the sum of the squares (SRSS) if the modal frequencies are not close. The result is typically different from that which would be calculated directly from an input, since phase information is lost in the process of generating the response spectrum.

The figure below graphically shows the development of earthquake response spectra (as portrayed in both linear and log-log plots) from the peak responses of oscillators of increasing vibration period from the same base input motion (earthquake shock).

Figure 15: Development of Earthquake Response Spectra



Bottom half of the figure is redrawn and modified from Kramer²⁰⁰

¹⁹⁹ Chopra, A.K. *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, Second Edition, Prentice Hall, Englewood Cliffs, N.J. 2001.

²⁰⁰ Kramer, S.L. *Geotechnical Earthquake Engineering*, Prentice Hall International Series in Civil Engineering and Engineering Mechanics, W. J. Hall, ed. Prentice Hall, N.J. 653 pages. 1996.

Technical Note 5: Capable (Active) Faults

The Code of Federal Regulations, which governs seismic siting criteria for nuclear power plants, defines *capable faults* as follows:

- (g) A capable fault is a fault which has exhibited one or more of the following characteristics:
- (1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
 - (2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with a fault.
 - (3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could reasonably be expected to be accompanied by movement on the other.²⁰¹

In some cases, the geologic evidence of past activity at or near the ground surface along a particular fault may be obscured at a particular site. This might occur, for example, at a site having deep overburden. For these cases, evidence may exist elsewhere along the fault from which an evaluation of its characteristics in the vicinity of the site can be reasonably based. Such evidence shall be used in determining whether the fault is a capable fault within this definition.

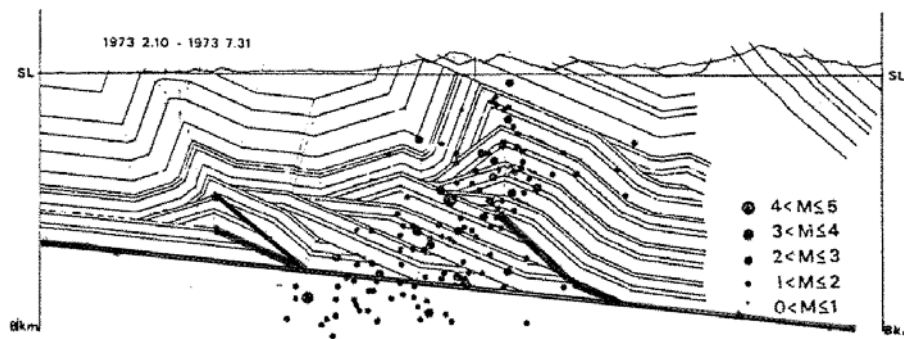
Notwithstanding the foregoing paragraphs III(g) (1), (2) and (3), structural association of a fault with geologic structural features which are geologically old (at least pre-Quaternary) such as many of those found in the Eastern region of the United States shall, in the absence of conflicting evidence, demonstrate that the fault is not a capable fault within this definition.

²⁰¹ Code of Federal Regulations. 10 CFR Chapter 1, Appendix A to Part 100, Section III. Office of the Federal Register, National Archives and Records Administration. Revised 1998.

Technical Note 6: Thin-Skinned vs. Thick-Skinned Tectonic Models

“Thin-skinned” tectonic models refer to deformational models in which folding and faulting are confined to a shallow layer of the Earth’s crust above a zone of detachment, as shown in Figure 16.²⁰² The detachment zone is referred to as a sole thrust fault along which the shallow deformation is detached from undeformed rocks below. “Blind” thrust faults (thrust faults that do not reach to the surface) rise out of sole thrust faults as ramps along which the transported rocks rise to shallower levels. Typically, sole thrust faults occur in very weak sedimentary layers such as shale, gypsum, or salt.

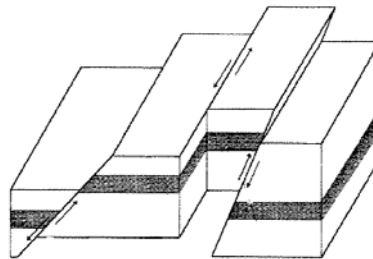
Figure 16: Thin-Skinned Tectonic Model



Thin-skinned style deformation above a shallow-dipping sole thrust fault as indicated in a balanced cross-section. Several blind thrust faults rising from the sole thrust are shown by the heavy black lines. Black dots show the locations of earthquake hypocenters that are keyed to magnitude by size in the legend of the figure.²⁰³

“Thick-skinned” tectonic models refer to block deformational models in which the deformational elements penetrate the entire brittle crust at steep angles, including deep crystalline rocks (Figure 17).²⁰⁴

Figure 17: Thick-Skinned Deformation (Block Faulting)²⁰⁵



²⁰² Nemcok, M., S. Schamel, and R. Gayer. *Thrustbelts*, Cambridge University Press, 2005, 554 pages.

²⁰³ Suppe, J. “Imbricated Structure of Western Foothill, Belt, Southcentral Taiwan.” *Petroleum Geology of Taiwan*, No. 17. 1980, pages 1-16.

²⁰⁴ Nemcok, M., S. Schamel, and R. Gayer. 2005.

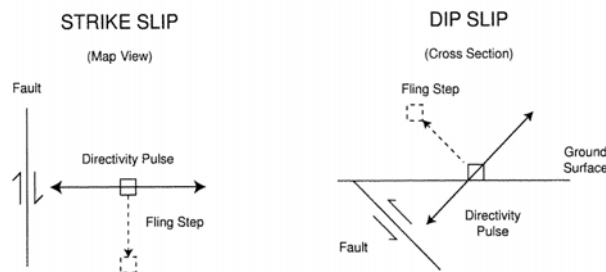
²⁰⁵ Suppe, J. 1980.

Technical Note 7: Rupture Directivity and Fling Effects

Strong ground motion recordings within about 20 km of earthquake fault ruptures exhibit magnitude-dependent long period motion pulses on the horizontal component perpendicular to the strike of the fault. These long-period pulses are a rupture directivity effect in which the rupture propagation velocity on the fault towards a site approaches that of the shear wave velocity. The seismic energy accumulates near the rupture front and arrives at the site in a single large pulse of motion, typically as a large amplitude of motion at intermediate to long periods with a short duration. The radiation pattern from the fault shear dislocation causes the motion pulse to be oriented perpendicular to the fault plane. Forward directivity occurs when the rupture front propagates towards the site and the slip direction is aligned with the site. This is the most severe case. Backwards directivity occurs when the rupture propagates away from the site producing long duration, low-amplitude motions at long periods at the site. These effects occur in both dip-slip and strike-slip earthquake ruptures.

A second near-source effect that is not strongly coupled with the dynamic rupture-directivity effect is referred to as fault “fling” and is due to the static deformation field of the earthquake displacement in the direction of the rupture. In strike-slip faulting, the fling effect occurs on the strike-parallel component to the faulting whereas in dip-slip faulting the fling effect occurs on the strike-normal component. Directions of both the directivity pulse and fling-step effect relative to dip-slip and strike-slip faulting styles are shown in the figure below.

Figure 18: Directivity Pulse and Fling-Step Effect



Source: Stewart, et al. 2001²⁰⁶

²⁰⁶ Stewart, J.P. S-J Chiou, J.D. Bray, R.W. Graves, P.G. Somerville, N.A. Abrahamson. Ground Motion Evaluation Procedures for Performance-Based Design, Pacific Earthquake Engineering Research Center, PEER 2001/09. 2001, page 225.

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Chapter 3: Seismic Vulnerability of the Diablo Canyon and SONGS Plants

A magnitude 6.8 earthquake that struck Japan in 2007 damaged the world's largest nuclear power plant. The earthquake and the plant's performance have drawn attention both to the seismic vulnerabilities of nuclear power plants and to their structural integrity. The seismic integrity of California's two operating nuclear plants, Diablo Canyon and the San Onofre Nuclear Generating Station (SONGS), is a chief concern of both policymakers and the general public in light of the plants' locations in the vicinity of active faults.

Following federal regulations, all aspects of the plants that are important to safety were designed "to withstand the effects of natural phenomena such as earthquakes...without loss of capability to perform their safety functions."²⁰⁷ However, aspects of the plants that are not related to safety may not be designed and built to withstand the maximum earthquake that might occur at the sites. As a result, some of these components could be damaged during earthquakes, causing the plants to be shut down for a period of time. The extent of damage that could occur depends on the magnitude of the earthquake and on the operating condition of the reactors at the time an earthquake occurs. The amount of time that would be needed to bring the plants back into service would also depend in part on which components were damaged.

This chapter describes the seismic design of nuclear plants and identifies the components that are most susceptible to damage during earthquakes. First, key seismic design concepts and their application to Diablo Canyon and SONGS are introduced. Second, the likely response of a nuclear plant to earthquakes and the time to return to service following earthquakes of different magnitudes are discussed. Third, seismic vulnerabilities that could lead to extended outages at Diablo Canyon and SONGS are assessed and an overview of nuclear plant probabilistic risk assessments is provided. Finally, the 2007 earthquake in Japan and the damage that occurred at the Kashiwazaki-Kariwa nuclear power plant are reviewed.

Seismic Design

Federal regulations require that "the design of each nuclear power plant shall take into account the potential effects of vibratory ground motion caused by earthquakes."²⁰⁸ The seismic design process for the current generation of plants that includes Diablo Canyon and SONGS is based on an analysis of the particular seismic hazards at the power plant sites and the largest earthquakes that could occur on nearby faults. (The seismic settings for Diablo Canyon and SONGS were discussed in Chapter 2.) The plant systems, structures, and components (SSCs) were then designed to be able to withstand such earthquakes without compromising safety.

In very broad terms all of the SSCs of a nuclear power plant fall into one of two categories: safety-related and non-safety related. Safety-related SSCs are those that need to remain functional in order to maintain the safety of the reactor and to prevent the release of radioactive material offsite. Non-safety related SSCs are those whose failure would not result in the release

²⁰⁷ U.S. Nuclear Regulatory Commission. 10 CFR Part 100, Appendix A.

²⁰⁸ U.S. Nuclear Regulatory Commission. 10 CFR Appendix A to Part 100, Section V(a).

of significant amounts of radioactive material and would not prevent reactor shutdown or degrade the operation of an engineered safety system.

The primary functions of safety-related SSCs are as follows: 1) to ensure the integrity of the reactor coolant pressure boundary (i.e., to ensure that the reactor remains cooled and isolated), 2) to maintain the capability to safely shutdown the reactor and to maintain it in a safe condition, and 3) to prevent or mitigate the consequences of accidents that could result in offsite exposures approaching the maximum allowable levels.^{209, 210}

Safe Shutdown Earthquake and Operating Basis Earthquake

All safety-related SSCs, including their foundations and supports, are designed to remain functional during an earthquake of a magnitude defined as a “safe shutdown earthquake.” (These SSCs are designated as Seismic Category I under NRC regulations.)²¹¹ Non-safety related SSCs may fail during a safe-shutdown earthquake (SSE), as failure of these components, while disruptive to power generation, does not compromise safety.

The NRC considers two categories of earthquakes in the design and regulation of nuclear plants: the safe-shutdown earthquake and the operating basis earthquake.

1. The SSE is the design basis earthquake. It represents the maximum earthquake potential for a specific site based on the regional and local geology and seismology and the local subsurface material. Nuclear plants are designed to remain safe during an SSE, though they may sustain some damage. Federal regulations require all safety-related SSCs to be designed to remain functional during an SSE.²¹² Non safety-related SSCs are not subject to this requirement.
2. The operating basis earthquake (OBE) is an earthquake that “could reasonably be expected to affect the plant site during the operating life of the plant.”²¹³ Federal regulations require that “those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public will remain functional” during and immediately following an OBE.²¹⁴ In particular, the

²⁰⁹ U.S. Nuclear Regulatory Commission. “Seismic Design Classification.” Regulatory Guide 1.29.

²¹⁰ References to safety in this chapter are to the safety of the public at large, or offsite safety. While recognizing an important purpose for building codes is to protect persons working or residing in a building, a discussion of plant worker safety, except where specifically mentioned in the text, was beyond the scope of this study.

²¹¹ U.S. Nuclear Regulatory Commission, Regulatory Guide 1.29.

²¹² U.S. Nuclear Regulatory Commission. 10 CFR 100, Appendix A, part vi. <<http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-apps.html>>.

²¹³ It is often designated at half the magnitude of an SSE. U.S. Nuclear Regulatory Commission. 10 CFR 100, Appendix A, part iii; U.S. Nuclear Regulatory Commission. “Failure of Welded-Steel Moment-Resisting Frames During the Northridge Earthquake.” Information Notice 97-22. April 25, 1997, page 2. Accessed: July 3, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97022.html>>.

²¹⁴ U.S. Nuclear Regulatory Commission. 10 CFR 100, Appendix A, part iii.

stresses in safety-related plant structures during an OBE may not exceed 40 percent of the structures' stress limits.²¹⁵ Federal regulations require that a plant be shut down during an OBE and inspected prior to being restarted.

By definition, an SSE has a very low probability of occurring during the plant lifetime. This is why the regulations "allow," from a design point of view, a plant to sustain damage to non-safety related SSCs during an SSE, while they require all SSCs necessary for the safe operation of the plant to remain functional during an OBE. After an OBE, a plant is expected to be ready for restart immediately after safety inspections have been conducted.

An OBE is also an unusual event. For example, the largest earthquakes experienced to date by Diablo Canyon and SONGS were just 25 percent and 13 percent of the plants' OBE design conditions, respectively.²¹⁶ On December 22, 2003, a magnitude 6.5 earthquake struck 35 miles north-northwest of Diablo Canyon. The earthquake became known as the San Simeon earthquake. The low intensity did not automatically shut down Diablo Canyon's reactors, and PG&E decided not to shut down the plant while immediate inspections began. No damage or leaks were discovered.

Only one earthquake exceeding the OBE has occurred at a U.S. nuclear plant.^{217, 218} This was a 1975 magnitude 5.5 earthquake centered 15 miles south of the Humboldt Bay nuclear power plant in northern California.²¹⁹ The plant was inspected following the earthquake; the inspection took two days, and, based on information available to the Consultant Team, it appears that the plant was subsequently restarted without incident.²²⁰

The NRC and the industry have not focused upon earthquakes of lower magnitudes that may have a higher probability of occurring and could lead to damage of non-safety related SSCs. More frequent but smaller magnitude earthquakes are important from a reliability standpoint.

²¹⁵ U.S. Nuclear Regulatory Commission. Information Notice 97-22.

²¹⁶ Pacific Gas & Electric. Presentation to NRC at Diablo Canyon - San Simeon Earthquake Meeting, May 27, 2004; Southern California Edison. "Comments to the Draft Consultant Report: AB 1632 Assessment of California's Operating Nuclear Plants." October 2, 2008, page 3.

²¹⁷ U.S. Nuclear Regulatory Commission. "Item B-50." NUREG-0933. <<http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec2/b50r1.html>>.

²¹⁸ The Perry (in Ohio) and Summer nuclear plants both experienced earthquakes that caused ground motions that exceeded their SSE design spectra but only in the high frequency range. The plants were not damaged. Electric Power Research Institute. "Program on Technology Innovations: The Effects of High-Frequency Ground Motion on Structures, Components, and Equipment in Nuclear Power Plants." Technical Update, June 2007, page 2-2.

²¹⁹ Brookhaven National Laboratory. "Assessment of Seismic Analysis Methodologies for Deeply Embedded Nuclear Power Plant Structures." Prepared for the U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research. NUREG/CR-6896. February 2006, page 23. (In comments submitted on the draft report, PG&E contradicted the Brookhaven report, stating that this earthquake was a 5.3 magnitude.)

²²⁰ U.S. Nuclear Regulatory Commission. "Item B-50: Post-Operating Basis Earthquake Inspection (Rev. 1)." NUREG-0933. <www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec2/b50r1.html>.

Diablo Canyon Design Earthquakes

Diablo Canyon was initially designed for an earthquake with peak ground acceleration of 0.40 g.²²¹ (All peak ground acceleration references in this chapter are to peak *horizontal* ground acceleration. The concepts of ground motion, peak ground acceleration, and ground motion attenuation are discussed in Chapter 2.) This design basis was associated with a magnitude 7.25 earthquake on the Nacimiento Fault located approximately 20 miles from the site and a magnitude 6.75 earthquake that was considered possible directly at the site as a possible aftershock to a large San Andreas earthquake.²²² The design value of the peak horizontal ground acceleration for the lower magnitude earthquake is 0.20 g.²²³

Diablo Canyon Design Earthquakes

Hosgri Earthquake	.75 g
Safe-Shutdown Earthquake	.40 g
Operating Basis Earthquake	.20 g

In 1972, scientists discovered the offshore Hosgri Fault, which lies approximately 4.5 km west of Diablo Canyon. Upon this discovery, scientists inferred that the 1927 offshore Lompoc earthquake was associated with the southern end of this fault and conservatively estimated that the fault was capable of a magnitude 7.5 earthquake. They assessed the peak ground acceleration at the site from such an earthquake at 0.75 g.

PG&E commissioned a series of seismic hazard analyses to assess the likelihood of the plant site exceeding the original design basis ground motion²²⁴ and to probabilistically assess the ground motions from a magnitude 7.5 earthquake on the Hosgri Fault and throughout area sources

²²¹ Peak ground acceleration is measured in proportion to the force of gravity (g).

²²² The response spectra for SSE and OBE horizontal and vertical ground motion are developed by using U.S. NRC Regulatory Guide 1.60, Design Response Spectra for Seismic Design of NPP.

²²³ PG&E refers to the operating basis earthquake as the design earthquake (DE) and the SSE as the double design earthquake (DDE).

²²⁴ Ang, A. H-S. and N.M. Newmark. "A Probabilistic Seismic Safety Assessment of the Diablo Canyon Nuclear Power Plant." Report to the Nuclear Regulatory Commission. 1977.

around the plant.²²⁵ PG&E subsequently upgraded the plant to the 0.75 g design level; this design basis is referred to by PG&E as the Hosgri Earthquake basis.²²⁶

Later, as part of the Long-Term Seismic Program, PG&E reevaluated the location and magnitude of the November 4, 1927, Lompoc earthquake²²⁷ and determined that it was further seaward than previously thought.²²⁸ This new location precluded the earthquake as being associated with the Hosgri fault zone. PG&E then reevaluated the maximum capable earthquake on the Hosgri fault zone as 7.2.²²⁹

SONGS Design Earthquakes

SONGS' SSE seismic design is based on an estimated peak horizontal ground acceleration of 0.67 g. This value is associated with a magnitude 7.0 earthquake on the South Coast Offshore Fault Zone. The ground motion estimate for an OBE is estimated to be 0.335 g.²³⁰

SCE initially developed an SSE for SONGS Units 2 and 3 based on a magnitude 6.5 earthquake on the South Coast Offshore Fault Zone. SCE based this calculation on a number of considerations including activity in the near-offshore area of the South Coast Offshore Fault Zone and fault rupture/displacement-magnitude relationships. However, given uncertainties

²²⁵ Blume, J.A. "DC NPP: Probabilities of Peak Site Accelerations and Spectral Response Accelerations from Assumed Magnitudes up to and Including 7.5 in All Local Fault Zones." *Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site*. PG&E, Volume V, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 11. 1977, pages D11-1 to D11.29; Blume, J.A. "Probabilities of Peak Site Accelerations Based on the Geologic Record of Fault Dislocations." *Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site*. PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 41. 1977, pages 41-1 to D41.28; Blume, J.A. "Diablo Canyon Plant: Plat-Boundary and Diffused Areal Probabilistic Considerations." *Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site*. PG&E, Volume VII, USNRC Docket No. 50-275 and 50-323, Appendix D, D-LL 45. 1977, pages 45-1 to D45.11.

²²⁶ For the SSE, OBE, and Hosgri Earthquakes, the vertical ground motion is assumed to be two-thirds the horizontal ground motion. Pacific Gas & Electric. "Diablo Canyon Power Plant Units 1 and 2 - Final Safety Analysis Report Updated, Revision #17." Docket # 50-275 and 50-323, Section 3.7.3, *Seismic Subsystem Analysis*, Section 5.2.1.5, *Design Transients* and Table 5.2-4, *Summary of Reactor Coolant System Design Transients*. November 2006.

²²⁷ Hanks, T.C. "The Lompoc, California, Earthquake (November 4, 1927; M = 7.3) and its Aftershocks." *Bulletin of the Seismological Society of America*, Vol. 69. 1979, Figure 4.

²²⁸ Gawthrop, W.H. "Seismicity and Tectonics of the Central California Coastal Region." California Division of Mines and Geology Special Report 137, *The San Gregorio - Hosgri Fault Zone, California*. 1978, pages 45 - 56.

²²⁹ Pacific Gas & Electric. "PG&E Final Report of the Diablo Canyon Long Term Seismic Program." PG&E Diablo Canyon Power Plant Docket No. 50-275 and 50-323. 1988.

²³⁰ Because of certain site-specific characteristics, the site tends to amplify long-period motions and to attenuate short-period motions. The vertical ground motion is assumed to be two-thirds of the horizontal ground motion. Southern California Edison. "San Onofre Nuclear Generating Station Units 2 and 3 - Updated Final Safety Analysis Report." Docket # 50-361 and 50-362. Table 3.9-8, *Loading Combinations ASME Code Class 1 NSSS Components*, and Table 3.9-10, *Design Loading Combinations for ASME Code Class 1, 2, and 3 Non-NSSS Components*. June 2005.

regarding the degree of activity of the fault zone, SCE ultimately used a more conservative SSE of magnitude 7.0. SCE determined that an earthquake with a magnitude greater than 7.0 is “inconsistent with the geologic and seismologic features of the hypothesized [South Coast Offshore Fault Zone] and is therefore not credible.”²³¹

SONGS Design Earthquakes	
Safe-Shutdown Earthquake	0.67 g
Operating Basis Earthquake	0.335 g

Probabilistic Seismic Hazard Analysis for Diablo Canyon and SONGS

Probabilistic seismic hazard analysis is used to calculate the probability that design basis earthquakes may occur and to predict how effectively a plant will respond (see Technical Note). In analyzing the response of SSCs to earthquakes, numerous design conditions of graduated severity are considered. For example, five design conditions are evaluated for the reactor coolant systems at Diablo Canyon and SONGS: normal, upset, emergency, faulted, and testing. This information is used to determine what frequency of inspections, tests, and examinations is required in order to be confident that each safety system can fully operate during a design basis earthquake, even after enduring the worst single failure to the system or to supporting systems.

In the early 1990s, PG&E conducted a probabilistic seismic hazard analysis and calculated the probabilities that earthquakes with a range of ground motion acceleration levels would occur at Diablo Canyon. The results of that analysis are integrated into the risk assessments performed for the facility.

For SONGS, the estimated probability of exceeding the estimated ground motions are roughly .0002 per year for an SSE and .002 per year for the OBE, corresponding to return rates of 5,000 years and 500 years, respectively (Figure 19).

Subsidence

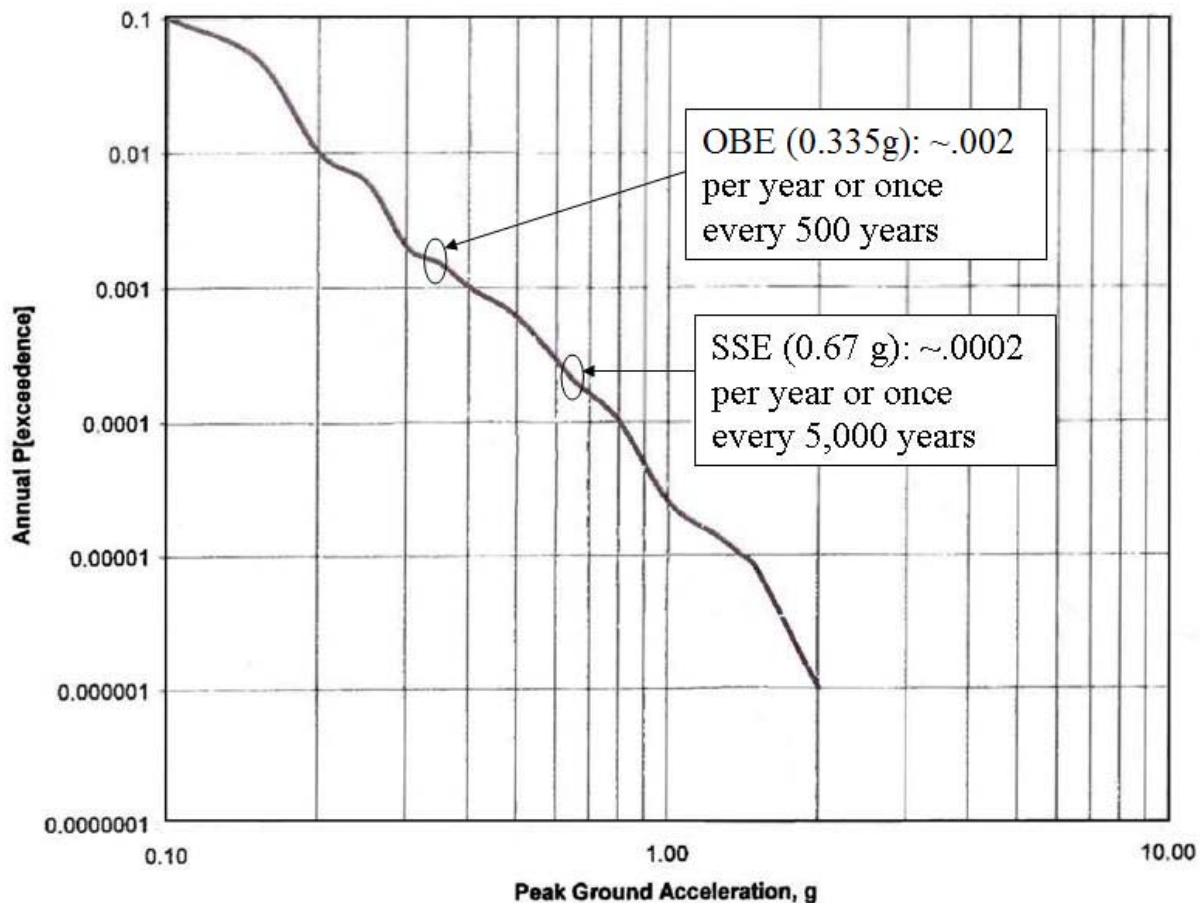
Significant subsidence at a plant site has the potential to weaken SSCs and could impact safety. Significant subsidence also would result in a plant being out of service as the condition is assessed and possible mitigative strategies are identified and implemented. For these reasons, subsidence potential is carefully evaluated as part of the plant design process.

Because Diablo Canyon is situated on a rock site, no subsidence is expected. Any measurable subsidence would likely require an assessment of the situation and therefore an extended plant shut down period.

²³¹ Southern California Edison. “San Onofre Nuclear Generating Station Units 2 and 3 - Updated Final Safety Analysis Report.” June 2005.

SONGS is located on a soft soil site. Investigations have concluded that subsidence in the vicinity of the plant is expected to be less than one inch over the life of the facility.²³²

Figure 19: Seismic Probability Assessment for SONGS²³³



Cumulative Stress of Multiple Seismic Events

In determining the design criteria for Diablo Canyon, PG&E assumed that one SSE and 20 OBEs would occur during the 40-year license period and that 20 maximum stress cycles would occur during each OBE. Thus, the systems are designed to withstand 400 stress cycles before components need to be replaced.²³⁴ As mentioned above, to date no OBEs have occurred at the plant so the SSCs have been only minimally stressed from earthquakes.

²³² San Onofre 2&3 Updated FSAR, section 2.5.1.2.5.3

²³³ ABS Consulting. "A Comparison Study of Earthquake Hazard Curves." Prepared for Swiss Nuclear, Report No. 1330831-R-001. December 2004.

²³⁴ Pacific Gas & Electric. "Diablo Canyon Power Plant Units 1 and 2 - Final Safety Analysis Report Updated, Revision #17." November 2006.

In determining the design criteria for the plant, SCE assumed that one SSE and two OBEs would occur during the 40-year operating license. Consequently, if more than one SSE and two OBE-magnitude earthquakes occur at SONGS, the seismic capacity of SONGS' SSCs would need to be reanalyzed and some or all of SSCs could need to be replaced. No OBEs or SSEs have yet occurred at SONGS.

Seismic Design Process

As is evident from the previous discussion, a major focus of the seismic design process is an analysis of the ground motion that could be expected to occur as a result of earthquakes. The acceleration of the ground in the north-south, east-west, and vertical directions is analyzed for a range of earthquake magnitudes. This information is used to evaluate the expected ground motion that would impact each SSC during an OBE and an SSE.²³⁵ Design standards are then calculated for each SSC based on the maximum ground motion that may be encountered and based on the classification of each SSC as safety- or non-safety related. These standards are intended to ensure that safety-related SSCs remain functional during an SSE and non safety-related SSCs remain functional during an OBE.

Diablo Canyon's nuclear reactors are pressurized water reactors designed and manufactured by Westinghouse Electric Corporation. PG&E received construction permits in 1968 and 1970 for Units 1 and 2, respectively. The two units were designed to comply with the NRC's General Design Criteria as published in 1967 and 1971.²³⁶ In 1981 design errors associated with the containment structure were discovered. Redesign and construction activities took an additional two years and commercial operations began in 1985 for Unit 1 and 1986 for Unit 2.

The SONGS Units 2 and 3 nuclear steam supply system (NSSS), including pressurized water reactors, was designed by Combustion Engineering, Inc. The remainder of these units, including the prestressed concrete reactor containment buildings in which each NSSS is located, was designed by the Los Angeles Power Division of the Bechtel Power Corporation. SONGS Units 2 and 3 were granted operating construction permits in 1973. Unit 2 began commercial operation in 1983 and Unit 3 began commercial operation in 1984. SONGS Units 2 and 3 were also designed to meet the NRC's General Design Criteria.

For both plants, buildings considered to be "non-safety related" were designed to conform with the Uniform Building Code in place at the time of design. These codes have evolved significantly since the original design of Diablo Canyon and SONGS. The implication is that, unless these non-safety related buildings have been strengthened since their original design,

²³⁵ Mathematical modeling is used to assess the response of an SSC to an earthquake. For example, each building is represented by a two- or three-dimensional matrix that corresponds to the shape and size of the structure. Within the building, the elevation and grid floor location of each nuclear plant component or system is geometrically located by its center of gravity. The size of each component is generally represented by its single mass weight (or mass array for a complex component) and how it is connected to the building. The seismic computer model calculates each structure's displacements, accelerations, shears, and moments during a seismic event. This information is used to determine the design criteria for building the supporting structural members, components, and piping assemblies.

²³⁶ The General Design Criteria are contained in Appendix A to 10 CFR Part 50.

such buildings built to meet the older standard could more readily fail during an earthquake (i.e., they would be damaged during more frequent, smaller earthquakes when compared to buildings built to conform with more recent updates to the Uniform Building Code). A probabilistic availability analysis could objectively provide insights as to the influence of the Uniform Building Code vintage on plant recovery time. The Consultant Team was not able to identify any such probabilistic availability analysis for the nuclear industry.

A nuclear power plant is designed to ensure that the failure of a non safety-related component during an SSE does not damage a safety-related component. To this end, whenever practical, safety-related components are separated from non-safety related components. When adequate separation of safety- and non-safety related components is not possible, non-safety related components are provided with seismic supports or barriers are placed between the safety-related and non-safety related components. Safety-related pumps, valves, motors, and other components are also protected against damage from impact with objects that may be dislodged during earthquakes.

Testing and surveillance throughout a plant's lifetime is designed to ensure that all safety systems and components continue to operate within the limits of their technical specifications.²³⁷ Depending upon the nature of the function being verified, surveillance is performed as often as two or three times a day or as infrequently as every 18 months during refueling outages. Additional surveillance is required when a safety system is out of service to ensure that the replacement system remains available and fully functional.²³⁸

Balance of Plant Seismic Design

Diablo Canyon and SONGS are both dual-cycle plants, meaning that the plants are divided into a nuclear (or primary) side and a non-nuclear side, referred to as the balance of plant. Radioactive water remains in a closed loop on the nuclear side of the plant and is separated completely from the non-nuclear side. This prevents the spread of radioactive material from the reactor to other areas of the plant (Figure 20).

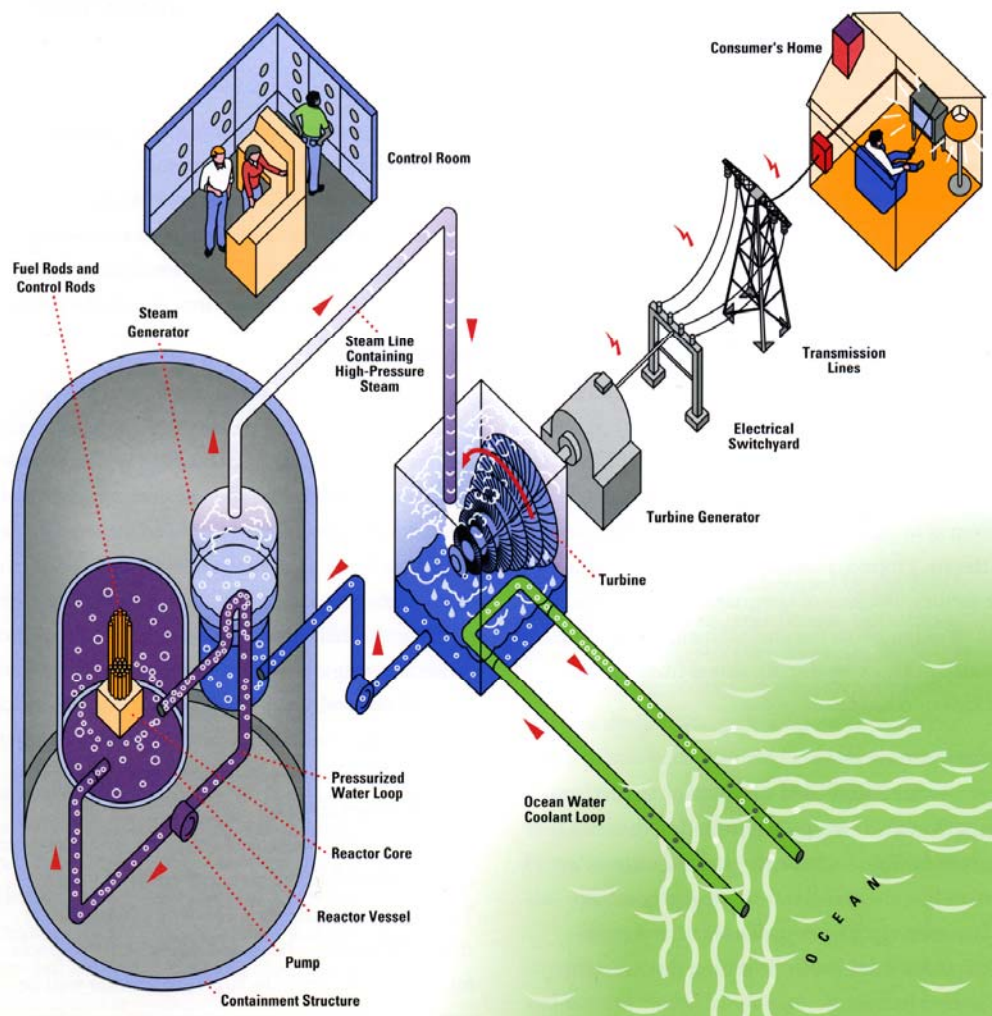
In the design, construction, operation, and management of a nuclear power plant, most resources are applied to the nuclear side of the plant, rather than to the balance of plant, for two reasons. First, standards are higher in the nuclear side because the safety consequences of equipment failure are much higher. The consequences of equipment failure in the balance of plant are limited to potential harm to personnel and a likely interruption in power generation, whereas the consequences of equipment failure in the nuclear side include the risk of release of radioactive material that could cause harm to the public and the environment. Second, it is more expensive to procure equipment and to do maintenance on the nuclear side because specialized equipment, radiation-protection procedures, and specially trained labor are

²³⁷ Surveillance schedules are specified as part of a plant's operating license. Pacific Gas & Electric. "Diablo Canyon Power Plant Units 1 and 2 - Final Safety Analysis Report Updated, Revision #17." November 2006.

²³⁸ These surveillances follow in-service testing and inspection codes and methods that have been prescribed by the American Society for Mechanical Engineering (ASME), Institute of Electrical and Electronic Engineers (IEEE), American Society for Testing of Materials (ASTM), and the American Welding Society (AWS).

required. The Consultant Team estimates that recovering from a problem in the nuclear side takes roughly 10 to 30 times as much money and time as recovering from a problem in the balance of plant.

Figure 20: Nuclear Plant Layout²³⁹



For these reasons, plant owners build systems to a more robust standard in the nuclear side than in the balance of plant. As a result, systems and components in the balance of plant side are, in a relative sense, more vulnerable to seismic events. This was evidenced by the damage to the Kashiwazaki-Kariwa nuclear power plant during the 2007 Niigata Chuetsu-Oki earthquake in Japan (see “Observations from Niigata Chuetsu-Oki Earthquake”).

It is possible to apply the same “robust” design standards to every component within a plant; however, the eventual costs would make it economically infeasible for the owner-operator of the plant and ultimately for ratepayers. There would be little benefit with respect to safety for

²³⁹ Southern California Edison. <http://www.sce.com/NR/rdonlyres/A050B788-F86C-448A-9A66-8FABD9F302B4/0/NuclearEnergy_process.jpg>.

such investments. In general, the balance of plant uses commercially available equipment when possible and where appropriate. For example, in other California (non-nuclear) power plants, the use of seismically designed or qualified equipment is very common. This equipment can be used for most balance of plant systems. On the nuclear side, specialized equipment that meets more demanding seismic criteria is required. Accordingly, the balance of plant is likely to experience the most damage from a major seismic event.

Table 3 identifies the major plant buildings, structures, and components for both Diablo Canyon and SONGS.²⁴⁰ As shown, there are both safety- and non safety-related components on the nuclear side of the plant and in the balance of plant. However, most of the major structures and components housed on the nuclear side of the plant are safety-related.

Table 3: Major Plant Buildings and Structures²⁴¹

Building or Structure	Function	Characterization
Containment Building	Houses nuclear steam supply system, which consists of the reactor, reactor coolant system, steam generators, pressurizer, reactor coolant pumps, and associated auxiliary systems.	Nuclear side, safety-related ²⁴²
Auxiliary Building	Houses most auxiliary and safety systems, including instrumentation and control systems and emergency cooling water systems	Nuclear side, safety-related
Fuel Building	For receiving fuel, handling and storing spent fuel (in pools)	Nuclear side, partially safety-related
Tank Areas	Holds reserve water for plant	Balance of plant, safety-related
Service water intake structure and ultimate heat sink	Provides water for cooling system and other purposes	Balance of plant, partially safety-related
Diesel Generator Building ²⁴³	Back-up power source	Balance of plant, safety-related
Turbine Building	Electricity generation	Balance of plant, partially safety-related
Switchyards	Transformers and electricity transmission lines	Balance of plant, not safety-related

²⁴⁰ Although the types of plant buildings and structures are the same for both Diablo Canyon and SONGS, the general arrangement is different based upon many factors, including site size and location, water sources, reactor type, the number of units in operation, and efficiencies of combined-use facilities. For example, the composition and number of nuclear components inside a plant is based upon the design of the reactor vendor. In addition, the names of some buildings vary from reactor to reactor.

²⁴¹ NUREG-0800; Barrie, D., T.S. Tatnall and E. Gath. "Neotectonic Uplift and Ages of Pleistocene Marine Terraces, San Joaquin Hills, Orange County, California." 1992.

²⁴² Most systems in the containment building are safety-related, but not all. For example, the reactor coolant pump is not considered a safety-related component since other components would take over the pump's function in the case of pump failure.

²⁴³ There is no diesel generator building at Diablo Canyon. Instead, diesel generators are housed in diesel generator rooms that are integral parts of the turbine-generator building.

Further Analysis of Seismic Design Standards for Non-Safety Related SSCs

Seismic design standards have evolved significantly since Diablo Canyon and SONGS were designed and licensed. Indeed, the Uniform Building Code has been updated to reflect new understandings of how buildings and structures respond to seismic events roughly 10 times since the 1970s. As was discussed above, non-safety related SSCs at Diablo Canyon and SONGS were built to industry standards that were in effect at the time the plants were designed and constructed. Given the evolution of seismic design standards, non-safety related SSCs at the plants may be less seismically robust than if those same SSCs were built to current standards.

To assess the reliability of the plants, a full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of seismic design changes that have occurred since these plants were designed and built. The analysis should consider how newer seismic design criteria compare to the seismic design criteria employed when the plants were originally designed and constructed. The analysis should also consider whether components were built to higher standards than the formal design criteria and whether replacement components have been built to more recent standards. In evaluating non-safety related components of the nuclear plants, their design standards should be compared to California's current seismic standards for non-nuclear power plants. In cases where plant components were built to standards that are less stringent than current seismic standards, the analysis should evaluate the reliability implications of potential damage to these components.

Response to Earthquakes

Nuclear power plants are designed to automatically shut down in the event of earthquakes. To protect the plant, the reactor protection system of the instrumentation and control system automatically trips when it detects an earthquake that exceeds a minimum magnitude, which is always less than the OBE. There is no need for operator action for at least 15 minutes. The plant is inspected after the earthquake to determine whether it sustained any damage.

There are many factors that would affect the extent of damage to a nuclear plant caused by an earthquake, including the magnitude of the earthquake, the amount of ground motion in different parts of the plants, and the operating condition of the plant. In addition, equipment that had been weakened by earlier earthquakes may be more susceptible to damage. Identifying the cumulative damage that might occur as a result of a series of earthquakes is complex because it depends on the damage that has already occurred. This is an area that would require further study.

As discussed below, the estimated times to repair or to replace components within a nuclear power plant may range from as little as one week to as much as several years. One determining factor would be the location of the damage, i.e., whether the repair is on the nuclear side or the non-nuclear side of the power plant. Another would be the specific component or system that had been damaged. Equipment on the non-nuclear side of the plant is generally standard power plant equipment, such as switches and utility poles, whereas equipment on the nuclear side of the plant is often specialized. Repairs on the nuclear side tend to take longer and cost more since there are fewer sources of experienced workers and appropriate equipment.

This section presents scenarios to illustrate possible damage that earthquakes of various magnitudes would cause and the amount of time it would take to recover from these earthquakes. These scenarios are *purely illustrative* of the types of damage that could occur. Actual damage would depend on where the earthquake struck and specific conditions at the plant. It is unlikely that each of the illustrative damages would occur in a single earthquake. Moreover, as was stated above, very large earthquakes are rare events; thus, the likelihood of a large magnitude earthquake causing severe damage to a nuclear plant is similarly small.

The estimates of time to repair presented in this section (and throughout this chapter) are based solely on the experience and judgment of the Consultant Team members. A thorough review and analysis of times to repair for specific SSCs in a nuclear plant was not feasible within the time and resource constraints of this study. The Consultant Team attempted to support its estimates with publicly available research and information, but ultimately was unable to do so. This is an area that could benefit from a collaborative study effort involving the utilities, manufacturers, and researchers with the appropriate expertise.

Plant vulnerabilities are discussed more generally in the subsequent section called “Nuclear Plant Vulnerabilities.”

Impact of an OBE

An OBE is not expected to cause any damage within the buildings housing the reactor components, the nuclear steam supply system, safety-related SSCs, and balance of plant support systems. All of a plant’s safety systems are designed to accommodate the increased external forces on the respective systems and to continue to operate unimpeded.

Minor damage could occur in some non-nuclear areas of the plant. Following are examples of the types of damage that could be expected:

- Temporary work platforms could fall.
- Swaying electrical lines could cause cracking of insulators.
- Electrical equipment surges would likely trip 4.1-kV busses.
- Balance of plant support systems could become inoperable if off-site power is lost.
- Loads stripped from busses may not reactivate if 480v switch gear has been damaged or motor controller units fail to start due to tripped breakers.
- Office filing cabinets could topple particularly if the top drawer is open.
- Plant personnel could suffer falling injuries from moving over an unstable surface.
- Unsecured objects could fall to the ground, perhaps with consequences to persons in the vicinity.

This damage is relatively minor. The NRC assumes that inspections following an OBE will take two weeks.²⁴⁴ However, a reactor could only return to service after balance of plant equipment has been repaired.

Impact of an SSE

An SSE is not expected to cause any damage within the buildings housing the reactor components and the nuclear steam supply system.²⁴⁵ Non-safety related SSCs that exist within a safety-related building or structure could be damaged, and balance of plant support systems may be damaged. An SSE would cause more severe damage to the non-nuclear areas of the power plant than an OBE, and plant personnel would face increased risk. Following are examples of the types of damage that could occur, in addition to the damages previously described for an OBE. This list is illustrative; each of the following may or may not occur.

- The switchyard could be severely damaged.
- Hydrogen stored prior to use in cooling the main generator rotors or oil stored for use in cooling and lubricating the turbine shaft could be released. It is possible that a fire could result complicating plant recovery.
- There could be scuff marks on the inside of the turbine housings and contact marks on the turbine blades. Turbine blades could need replacement, which would be a significant repair.
- Fallen electrical lines could pose hazards to personnel if any power is still available from off-site sources.
- Spent fuel pool water could slosh onto the floor, creating a potential radiation hazard to personnel. (See Chapter 4 for a discussion of sloshing from spent fuel pools.)
- Water leaks may appear around valve gaskets or flanged pipe joints over time as seepage progresses. A number of leaking pipes may appear in fire protection system lines. Threaded joints may separate.
- Ceilings could fall inside of administrative office buildings and simulator training centers, and there could be damage to building decorative facades.
- On-site roads could settle, and pavement cracks and ruts could appear. This could make it difficult for emergency personnel to reach the site or for plant employees to evacuate.
- Equipment that had been disassembled for maintenance could be damaged if left unsupported.

²⁴⁴ Inspections following the Humboldt Bay OBE took just two days since an emergency operating procedure that covered inspection procedures was already in place and the inspection team already had detailed knowledge of the plant. U.S. Nuclear Regulatory Commission. "Item B-50: Post-Operating Basis Earthquake Inspection (Rev. 1)." <<http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec2/b50r1.html>>.

²⁴⁵ As noted above, the Diablo Canyon Final Safety Analysis Report refers to an SSE as the double-design earthquake. For Diablo Canyon, the expected peak ground acceleration of an SSE is 0.40 g.

- Lighting in portions of buildings may be lost, and battery backup lights may not function.
- Some safety systems could lose power, which would slow the shutdown of the reactor. (This would not present a safety hazard.)
- The water supply system could lose power and be unable to pump water to the fuel pool. Other systems would remain available to keep water in the pool.
- A fuel bundle that is being relocated in the spent fuel pool storage racks could be dropped. This would result in extensive NRC review and could pose a hazard to personnel.

Following such an event, the nuclear plant could be ready to return to full power in roughly 60 to 90 days with repairs continuing in areas that are separate from those supporting nuclear power generation.²⁴⁶ The majority of this time would be spent in repair of the turbine and restoration of the switch yard equipment.

Impact of an Earthquake Twice as Intense as an SSE

An earthquake of double the intensity of an SSE could cause some or all of the damage caused by an SSE but with more severity. No major damage would occur within the buildings housing the reactor components, the nuclear steam supply system, safety-related SSCs, and balance of plant support systems *as long as the systems were designed with large safety margins*, as many engineers in the nuclear industry expect them to be. Following are examples of the types of damage that could be expected, in addition to the damages previously described for an OBE and an SSE:

- The turbine building roof could deform.
- The turbine housing could have major damage from multiple turbine blades' impacts. This alone could require an extended outage to repair.
- The generator could have a rotor noise that will require major disassembly, testing and possible refurbishment or repair.
- There could be spills and broken drum seals in the radioactive waste and spent fuel handling portions of the plant. Release of radioactive material from the gaseous waste systems is also possible.
- Safety-related systems could experience piping deformations, as the buildings experience greater movements. Pipe supports may yield and snubbers may break.
- Cracks may appear in some circular floor areas that act as internal diaphragms within the building.
- Localized failures could result in falling equipment and additional strain on other components.

²⁴⁶ Political opposition could delay the restart of the power plant for an additional period of time.

- There could be a small line rupture on the auxiliary feedwater system but there would be no leak in the reactor coolant system, and the steam generator would be isolated automatically on a low water level signal.
- Heat removal from the steam generators could be available only through the steam-driven auxiliary feed pump train even after on-site power is restored to one emergency bus.
- Other lines could be broken within the plant buildings, such as fire protection lines and potable water systems.
- The balance of plant circulating water system could have a line breakage and excessive water damage in the adjacent areas.
- Transmission towers could topple near the site boundary.

The minimum amount of time to prepare the reactor to return to full power after such an earthquake is estimated to be two to three years. Ultimately, the time needed to prepare the plant for restart could be significantly greater than three years. Although repairs in the non-nuclear side of the plant could potentially be completed in less than six months, a significant amount of time would most likely be needed to reanalyze the plant for a more stringent design basis earthquake. Other factors that would affect the duration of a shut down include the amount of time needed to investigate the full plant for damage and the need for design and backfitting efforts. Repair of the turbine and generator would be completed within the same time frame as the overall plant is restored to service. Public opposition also could delay the restart of the power plant.

Nuclear Plant Vulnerabilities

Nuclear plants are designed to withstand an OBE without any damage that would require downtime for repairs due to damage to safety-related SSCs. Damage to non-safety related SSCs could result in downtime for evaluation, analysis, review and repair. In this section the Consultant Team considers whether there may be other plant or component vulnerabilities or regulatory conditions that could keep a nuclear plant offline for an extended period of time.

For this assessment, the Consultant Team reviewed numerous documents, including licensee event reports at various nuclear power plants in the U.S., recent Diablo Canyon and SONGS inspection reports, and events at overseas reactors.^{247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265}

²⁴⁷ U.S. Nuclear Regulatory Commission. "Diablo Canyon Unit 1, 4th Quarter of 2007 Performance Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB1/diab1_chart.html>.

²⁴⁸ U.S. Nuclear Regulatory Commission. "Diablo Canyon Unit 2, 4th Quarter of 2007 Performance Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB2/diab2_chart.html>.

²⁴⁹ U.S. Nuclear Regulatory Commission. "SONGS Unit 2, 4th Quarter of 2007 Performance Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO2/sano2_chart.html>.

²⁵⁰ U.S. Nuclear Regulatory Commission. "SONGS Unit 3, 4th Quarter of 2007 Performance Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO3/sano3_chart.html>.

²⁵¹ U.S. Nuclear Regulatory Commission. "Assessment of Debris Accumulation on PWR Sump." Generic Issue #191. <<http://www.nrc.gov/reading-rm/doc-collections/generic-issues/gis-in-implementation>>.

²⁵² U.S. Nuclear Regulatory Commission. "Reactor Operational Experience and Reactor Safety Focus Areas." <<http://www.nrc.gov/reactors/operating/ops-experience.html>>; U.S. Nuclear Regulatory Commission. "Generic Issues Program." <<http://www.nrc.gov/about-nrc/regulatory/gen-issues.html>>.

²⁵³ U.S. Nuclear Regulatory Commission. "Human factors Information system (HIFS) IR/LER category Analysis by Docket Report, 2005 for DCP#1." Docket 050-275. <<http://www.nrc.gov/reading-rm/doc-collections/human-factors/2005/diablo-canyon-1.pdf>>.

²⁵⁴ U.S. Nuclear Regulatory Commission. "4th Quarter 2007, ROP Action Matrix Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/actionmatrix_summary.html>.

²⁵⁵ U.S. Nuclear Regulatory Commission. "4th Quarter 2007 Performance Summary for San Onofre 2 and 3." NRC letter dated March 3, 2008 to SCE, *Annual Assessment Letter for SONGS*. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/LETTERS/sano_2007q4.pdf>.

²⁵⁶ Pacific Gas & Electric. "Diablo Canyon - San Simeon Earthquake Meeting." May 27, 2004 slide presentation to NRC.

²⁵⁷ Shukla, Girija S., NRC DCP# Project Manager. "Summary of meeting held on May 27, 2004 to discuss PG&E response to the San Simeon earthquake and related licensing basis issues." June 9, 2004.

²⁵⁸ U.S. Nuclear Regulatory Commission. "Vogtle 1 and 2 Electric Generating Station." LER 01-90-006 and LER 02-90-002. March 20, 1990.

²⁵⁹ U.S. Nuclear Regulatory Commission. "Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 – 1996." NUREG/CR-5496, ADAMS #ML-003769668. November 1998.

²⁶⁰ U.S. Nuclear Regulatory Commission. "SONGS Unit 3, 4th Quarter of 2007 Performance Summary." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO3/sano3_chart.html>.

²⁶¹ Stevenson, John D. "Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake." American Society of Mechanical Engineers (ASME), *The Evaluation Methods for Seismic Design of ASME Mechanical Distribution Systems and Components*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

²⁶² Yamashita, Kazuhiko. "Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake." TEPCO, *Inspection and Analysis of Kashiwazaki-Kariwa Nuclear Power Station*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

²⁶³ Hardy, George. "Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake." Electric Power Research Institute (EPRI), *EPRI Independent Peer Review of TEPCO Seismic Walkdown and Evaluation of the Kashiwazaki-Kariwa Nuclear Plants*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

²⁶⁴ Nomoto, Toshiharu. "Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake." SANE, *Interim report of the Structural Integrity Assessment Committee for Nuclear Components damaged by Earthquake (SANE)*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

²⁶⁵ Labb, Pierre. "Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake." EDF, *Source Margins in the Seismic Design of Piping*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

The Consultant Team applied experience and judgment to estimate the impact of defined sets of seismic events for safety-related SSCs, balance of plant SSCs, and other plant structures and to identify conditions that could result in extended outages. The results are *broad estimates* rather than precise predictions based on calculations. Accordingly, any design condition postulated and the consequences derived are open to further conjecture and should be treated as such by decision makers.^{266,267}

Nuclear Side of Plant

As discussed above, the nuclear side of the plant is built to very high seismic standards. In particular, the containment building and the other Seismic Class I buildings that house the safety-related SSCs that support nuclear operations are the most hardened parts of the nuclear plant, and they appear to be built with large margins of safety even beyond their design requirements. Consequently, the nuclear side of the plant is less vulnerable to damage during a large earthquake of an SSE magnitude. The seismic vulnerability of the nuclear side of the plant is discussed below under “Overview of Probabilistic Risk Assessments for Nuclear Power Plants.”

Balance of Plant

The balance of plant is vulnerable to damage during earthquakes, including earthquakes of less magnitude than an SSE. The switchyard, in particular, is likely to be damaged during earthquakes. Another plant system vulnerable to damage is the fire protection system, which is typically not designed to the same standards as safety-related systems. A degraded fire protection system could contribute to delays in extinguishing fires resulting from earthquake damage to other SSCs. In an earthquake greater than an SSE (i.e., a beyond design basis earthquake), there could also be damage to the turbine building and the tank area. A beyond design basis tsunami could also cause damage to components in the balance of plant.

The following discussion highlights certain balance of plant areas that are vulnerable to damage during earthquakes.

Switchyards

In a report prepared for the Energy Commission, PG&E noted that the “vulnerability of high-voltage substation equipment, including transformers and their components, circuit breakers, and switches has been the primary reason that power grids have failed in past earthquakes.”²⁶⁸ This equipment, located in the switchyards, is not safety-related and is part of the balance of

²⁶⁶ The Consultant Team recognizes that many factors would affect the safety margin above design standards. As one example, the aging of components (which is discussed in Chapter 5) may have reduced safety margins.

²⁶⁷ SCE reported that there are no studies that assess the seismic vulnerability of non-safety related SSCs at SONGS. Southern California Edison Company’s Comments to the Draft Consultant Report, October 2, 2008.

²⁶⁸ Pacific Gas & Electric. “Electric System Seismic Safety and Reliability.” Report for the California Energy Commission CEC-500-2005-007. January 2005, page 58. Accessed: July 4, 2008. <http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-007.html>.

plant, so there are no radiological concerns associated with a potential failure. However, it is needed to deliver the power generated at the nuclear plants onto the transmission grid and into customers' homes and businesses. Failure of this equipment would result in a loss of power from the plant, even if both reactors were in operable condition. (Loss of power to a nuclear plant is discussed separately below.)

Electrical equipment in the switchyard is vulnerable to damage in large part because the configuration of some of the equipment amplifies the ground motion. In addition, the areas where electrical equipment is located consist of many unsupported electrical cables that are strung between fixed-end supports with connectors often cantilevered from building, transformers, bushings, and towers. The differential movements during an earthquake strain these cables and connectors and can damage them. Since this equipment is outside, it does not have benefit of the support given to cables inside the plant by the electrical raceways for routing of power and instrumentation lines throughout the plant.²⁶⁹

The October 1989 Loma Prieta earthquake severely damaged the switchyard associated with the Moss Landing gas-fired power plant (Figure 21). The nearest recorded peak horizontal ground acceleration to the switchyard was 0.39 g with a duration of strong shaking of 10 seconds.^{270,271} Four live-tank circuit breakers were severely damaged, and transformers and disconnect switches were also damaged.²⁷² There was also some damage at the plant itself including deformed or broken pipe restraints and pipe hangers, minor leaks in tubes within the boiler, and the failure of an unanchored freshwater storage tank.²⁷³ In all, it took several weeks to restore operations at Moss Landing.²⁷⁴

Switchyards at nuclear plants are built of standard components that are also used at other power facilities. Thus, the process of repairing a switchyard at a nuclear plant should be comparable to the process of repairing a switchyard at a fossil fuel plant. Depending on the

²⁶⁹ The Institute of Electrical and Electronics Engineers (IEEE)-344 standards (IEEE, 1987) to which most of the electrical equipment comply has been updated and is constantly being improved or replaced with new standards, as more information is learned about the seismic response of normally installed electrical components. Institute of Electrical and Electronics Engineers. *IEEE Standard Recommended Practice For Seismic Qualification Of Class 1E Equipment For Nuclear Power Generating Stations*. IEEE 344-1987 (R1993). January 1987.

²⁷⁰ U.S. Geological Survey, in cooperation with the National Science Foundation. "The Loma Prieta, California, Earthquake of October 17, 1989—Lifelines." 1998: A7.

²⁷¹ The Consultant Team was not able to ascertain how the recorded ground motion data compared to the design values for the switchyard; thus, it is not possible to draw any conclusions as to the extent of damage vis-à-vis the design standards.

²⁷² An analysis of the overall damage to the switchyard found that the failure of the live-tank circuit breakers most likely contributed to the damage of other equipment. U.S. Geological Survey, in cooperation with the National Science Foundation. "The Loma Prieta, California, Earthquake of October 17, 1989—Lifelines." United States Government Printing Office, Washington. 1998, page A14.

²⁷³ U.S. Geological Survey, in cooperation with the National Science Foundation. "The Loma Prieta, California, Earthquake of October 17, 1989—Lifelines." 1998: A7.

²⁷⁴ Disaster Recovery Journal. "The Loma Prieta Earthquake: Impact on Lifeline Systems." Accessed: July 4, 2008. <http://www.drj.com/index.php?option=com_content&task=view&id=394&Itemid=450>.

extent of the damage, it would likely take on the order of several weeks to complete the repairs. Factors that could extend the down time at a switchyard include special analytical or administrative activities due to the switchyard's relation to a nuclear power plant.

The vulnerability of a particular plant's switchyard depends on the specific equipment installed and the location of the switchyard. Older equipment is much more susceptible to failure as a result of an earthquake than equipment designed to the newest Institute of Electrical and Electronics Engineers (IEEE) seismic design standards. For older equipment, a primary source of vulnerability arises from the potential to overturn during seismic events if peak ground accelerations exceed the capability of high-strength restrainers. This is a particular concern in soft soil sites such as at SONGS where ground motion can be amplified. Diablo Canyon's 500 kV switchyard is built on deep fill making it particularly vulnerable to subsidence and ground motion amplification. Additional sources of vulnerability are the transformer porcelain bushings, which have performed well in shake table tests but have often failed in the field when earthquakes have occurred.²⁷⁵ The use of certain types of rigid bus connectors and other flexible connectors without load restraints also may cause electrical failures. However, equipment that complies with the most recent IEEE standards is not as susceptible to these vulnerabilities. The status of switchyard upgrades at Diablo Canyon and SONGS to newer industry standards is not known at this time.²⁷⁶

²⁷⁵ Bushings are generally tested on a rigid frame instead of on a transformer body since it is expensive to place the full-scale transformer-bushing system on a shake table for testing. However, the supporting structure of the bushing has some flexibility, which amplifies the ground acceleration. This is not incorporated into the rigid frame tests and may be the source of the unexpected failures that have been observed during earthquakes; Matt, H. and A. Filiatrault. "Seismic Qualification Requirements for Transformer Bushings." April 2004. Final Project Summary found in Energy Systems Research, Electric System Seismic Safety and Reliability. 2004, page 234.

²⁷⁶ In 2005, PG&E reported that system-wide the utility had replaced 40 percent of the utility's porcelain bushings, as these are susceptible to failure during an earthquake. PG&E did not report specifically on upgrades to Diablo Canyon. Energy Systems Research. Electric System Seismic Safety and Reliability. 2004: 72.

Figure 21: Moss Landing Switchyard after the Loma Prieta Earthquake, 1989²⁷⁷



Turbine Building

The turbine building at Diablo Canyon is extremely large with an expansive open space inside.²⁷⁸ According to PG&E, the concrete shear walls are the weak links for the turbine building. In a beyond design basis earthquake, the turbine building could sustain damage that would take substantial time to repair.

Tsunami Damage

During a large tsunami, water rushes away from the shoreline and in a tsunami larger than the design basis tsunami, there could be insufficient water for the plant's intake system. If this were to occur, the heat exchangers would intake air instead of water and moving parts could be damaged. Loss of all water in the intake structure would have a serious safety impact. Without

²⁷⁷ Pacific Gas & Electric. "Countermeasures for Earthquake Induced Ground Deformation at Power Plants," February 27, 2008: 12. <http://www.jaif.or.jp/pdf/2008_12_NAbrahamson_en.pdf>.

²⁷⁸ Pacific Gas & Electric. "Diablo Canyon Power Plant Units 1 and 2 - Final Safety Analysis Report Updated, Revision #17." November 2006.

a connection to the ultimate heat sink, the operators of the nuclear power plant would have only a limited quantity of water in the on-site storage tanks to maintain core coverage, but no ability to remove heat. Unless the ultimate heat sink was restored, core damage would ultimately occur. This is a greater concern at Diablo Canyon than at SONGS because the SONGS intake pipes are further offshore. One way to reduce damage in this event is to shut down one of the two heat exchangers in order to reduce flow. PG&E's procedures are not described in any public technical specifications, so the Consultant Team was unable to evaluate them.

Operational Conditions

Power plants are less susceptible to damage from earthquakes if the reactors are in normal operating conditions. During a refueling or maintenance outage, disassembled equipment is more vulnerable to damage. Loss of offsite power, which can accompany an earthquake, also increases the vulnerability of the plant, as does the potential for human error.

Disassembled Equipment

Internal components of Japan's Kashiwazaki-Kariwa nuclear power plant were disassembled when the Niigata Chuetsu-Oki earthquake struck in July 2007. These components suffered damage during the earthquake (see "Observations from the Niigata Chuetsu-Oki Earthquake"). The most significant damage was to a component that matches alignment parts for re-assembly. The component was sitting at its station in the refueling pond when the earthquake occurred. The component's support legs and mating guide pins were damaged as the earthquake motion apparently lifted and shifted the position of the component in the pool. The time to repair and restore component functionality has not yet been determined.

If the reactor had been operating during the earthquake, the reactor components would have been securely situated and would not have been vulnerable to damage. The components were only vulnerable since they were situated in the refueling pond and were not tied down. Therefore, operational procedures that involved tying down or otherwise shielding components could significantly reduce this vulnerability.

Loss of Electrical Power

Major earthquakes, grid instability, or accidents can trigger the loss of offsite power. If a plant's emergency diesel generators lose function while offsite power is unavailable, a black out will ensue at the plant.

Although not precipitated by an earthquake, a black out occurred at a nuclear power plant that illustrates the type of situation that could ensue if offsite power is lost. In March 1990 a truck at the Vogtle Electric Generating Station hit a support pole for one of the auxiliary transformer incoming lines.^{279, 280} At the time, the second auxiliary transformer and a diesel generator were both in preventative maintenance servicing. A second generator automatically started but it

²⁷⁹ U.S. Nuclear Regulatory Commission. "Vogtle Unit #1 - Licensee Event Report (LER)." Docket #50-424, LER 1-90-006. March 20, 1990.

²⁸⁰ U.S. Nuclear Regulatory Commission. "Vogtle Unit #2 - Licensee Event Report (LER)." Docket #50-425, LER 2-90-002. March 20, 1990.

tripped two successive times, and a station black out ensued. The instability in the grid resulted in successive trips of the generator, turbine, and reactor. A site emergency was declared, and critical safety-related shutdown systems were left without any electric, steam, or diesel power to maintain shutdown cooling system heat loads. In this case, the short duration of the event did not lead to excessive boiling in fuel pools or in the open reactor vessel cavity.

Black outs at nuclear plants are serious events that significantly increase the likelihood that fuel in the reactor could be damaged.²⁸¹ During a black out, reactors at full power must achieve a shutdown by relying on components that do not require alternating current power, such as the auxiliary feedwater steam-driven pump or other system diesel-driven pumps. The ability of these systems and their associated instrumentation to remain powered is limited by their components' batteries. The time to recover any electrical alternating current source to power the emergency busses is thus critical to maintaining safe-shutdown capabilities. Most plant black outs last for a couple of hours at most.²⁸² However, there have been three cases since 1968 of extreme weather events causing a loss of offsite power for more than 24 hours.²⁸³

Operator Error

During an earthquake, the likelihood of human error increases due to the unusualness of the event, and possible confusion. One example of an operator error that could cause plant damage would be the inadvertent activation of the containment spray system. This would release water inside the containment building and could damage components and clog the sump screens.²⁸⁴

²⁸⁵ If this were to occur and any components became submerged as a result, these components would need to be evaluated before returning to service. It could take more than six months to evaluate and repair or replace damaged components.

The vulnerability of sump screens to clogging is being addressed by nuclear plant owners. In September 2004 the NRC directed nuclear plant owners to evaluate the possibility of sump screen clogging and to take actions to ensure system function.²⁸⁶ PG&E and SCE addressed this issue by replacing the screens with much larger screens as well as undertaking other modifications to reduce debris. SCE completed physical modifications to the SONGS units in

²⁸¹ Current risk analyses indicate that station blackouts can contribute more than 70 percent of the overall risk at some plants (NUREG/CR-6890).

²⁸² Idaho National Laboratory. "Reevaluation of Station Blackout Risk at Nuclear Power Plants: Analysis of Loss of Offsite Power Events: 1986-2004." Prepared for the U.S. Nuclear Regulatory Commission. NUREG/CR 6890. December 2005, page xv.

²⁸³ Idaho National Laboratory. December 2005: 5.

²⁸⁴ The containment spray system is typically activated following a loss of coolant accident, when it is required to keep the reactor cool; or other conditions when it is desired to cool water in the sump and normal cooling means are not available. Under non-emergency circumstances, the containment building should remain dry.

²⁸⁵ See, for example, NRC Generic Safety Issue 191 from the document titled Assessment of Debris Accumulation on PWR Sump.

²⁸⁶ U.S. Nuclear Regulatory Commission. "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors." Generic Letter 2004-02. September 13, 2004.

January 2008.²⁸⁷ PG&E additionally implemented other physical and operational improvements, including installing debris interceptors and initiating a more aggressive containment clean-up program. PG&E will perform final mitigation measures when the new steam generators are installed in early 2008 and 2009.²⁸⁸

Regulatory Conditions

Another potential cause of an extended outage at Diablo Canyon or SONGS would be the discovery of new seismic information that predicts a different type of earthquake than previously assumed in the seismic design analyses. The NRC would require an analysis of the seismic hazard if the new information suggested potential earthquakes of a longer duration, higher vertical or horizontal acceleration, or a wider range of excitation frequencies. Depending on the outcome of the analysis, the NRC might require a plant owner to retrofit the plant.

Overview of Probabilistic Risk Assessments for Nuclear Power Plants

The seismic design process and seismic safety evaluation process have evolved in the decades since Diablo Canyon and SONGS were designed and constructed. The NRC summarized this evolution as follows:

The licensing basis for existing NPPs [nuclear power plants] used historical data at each site to analyze design basis loads from the area's maximum credible earthquake. This process [assumed] an earthquake could happen at any time. While the initial licensing process did not include a probabilistic assessment of earthquake hazards or their potential impact, the NRC later required all NPPs to assess their potential vulnerability to earthquake events, including those that might exceed the design basis... This process considered the available safety margins of the existing NPPs for various earthquakes and ensured these margins, together with the plant's accident management programs, continues to protect public health and safety.²⁸⁹

Probabilistic risk assessments are being increasingly used by the nuclear power industry with regulators allowing insights from risk assessments to be used as the basis for license amendments in specific areas such as maintenance. Below is a summary of the evolution of PRAs in the United States and their use in the nuclear industry today.²⁹⁰

²⁸⁷ Southern California Edison. "Letter to the NRC Regarding Generic Letter 2004-02." Docket No. 50-361 and 50-362. February 27, 2008. Attachment 1, pages 2-3.

²⁸⁸ Pacific Gas & Electric. "Supplemental Response to Generic Letter 2004-02." Docket No. 50-275 and 50-323, Letter to the NRC. February 1, 2008, pages 10-11.

²⁸⁹ US Nuclear Regulatory Commission, "Seismic Issues for Existing Nuclear Power Plants," Fact Sheet, Office of Public Affairs, June 2008.

²⁹⁰ This summary draws heavily from "Probabilistic Risk Assessment Practices in the USA for Nuclear Power Plants," by B. John Garrick and Robert F. Christie, published in *Safety Sciences*, 40 (2002) 177-201.

The first major study to use a risk-based approach to analyzing the safety of nuclear power plants was the Reactor Safety Study (RSS), also known as the WASH-1400 study, published in 1975. The authors of the RSS concluded that “the dominant contributor to risk [was] not the large loss of coolant accident previously emphasized as the design basis accident, [but rather] transients and small loss of coolant accidents.” PRAs for specific nuclear power plants followed in the late 1970s and early 1980s.

In 1988 the NRC published Generic Letter 88-20 requiring an Individual Plant Examination (IPE) to assess the public health risk associated with nuclear power plants. Nuclear power plants in the U.S. performed PRAs for either core damage frequency (considered a Level 1 analysis) or containment (a Level 2 analysis). The initial IPEs were eventually supplemented with additional analyses of external events; these studies became known as IPEEEs. The NRC encouraged a policy of using PRAs for nuclear regulatory activities in 1995, and many nuclear power plants continue to develop and refine their PRAs.

While there are no specific requirements for a plant to update its IPE, plants have found their plant-specific PRAs to be valuable tools contributing to more effective training, procedures and maintenance. Other incentives also have evolved to encourage utilities to keep their PRA models up-to-date and to expand the scope of these models. The two nuclear plants in California maintain their plant-specific PRAs as “living” documents, periodically updating them as operational experience is gained and models are improved.²⁹¹

Ever since WASH 1400 and the early plant-specific PRAs that followed, the quality of the underlying analyses has been a concern. To address this concern, the NRC and the nuclear industry have developed standards for different portions of a plant-specific PRA. These standards continue to be developed under the auspices of the ASME and the ANS.²⁹² Standards for “at-power” PRAs and for “external events” PRAs (including seismic PRAs) have been published by the ASME and ANS, respectively. Processes for an independent peer review of specific PRAs are available to “certify” compliance with these standards. These standards also include requirements for “maintenance and update” of the underlying models.

The NRC currently has an effort underway to adopt “risk-informed” regulations that would be based on PRAs. NRC policy specifies that a utility seeking to use information from their PRA in a regulatory submittal must meet the appropriate standards that have been formally in place for more than one year.

A compendium of the lessons learned from the IPEEE program was published by the NRC in 2002.²⁹³ To meet the requirements of the IPEEE program, plants in a ‘non-seismic’ location could choose to perform a simplified vulnerability analysis (a seismic margin analysis) that does not yield insights as detailed as a seismic probabilistic risk assessment. Some 27 plants, including

²⁹¹ The plant-specific PRAs are no longer publicly available documents in light of heightened security concerns in the wake of the 9-11 terrorist attacks.

²⁹² See for example, American Nuclear Society, *American National Standard External-Events PRA Methodology*, ANSI/ANS-58.21-2007, March 2007.

²⁹³ Nuclear Regulatory Commission, “Perspectives Gained From the Individual Plant Examination of External Events (IPEEE) Program,” Final Report, NUREG-1742, volumes 1 and 2, April 2002.

Diablo Canyon and SONGS, performed seismic PRAs. The NRC's review of those studies resulted in the following observations:

1. Results from the seismic PRAs indicated that the frequency of events that are precursors to impacting the public health and safety of newer plants are similar to those of older plants built before some of the later design criteria were in place. These data suggest that the seismic backfit programs for older plants have successfully brought them in line with those of newer plants.²⁹⁴
2. Additionally, the seismic margins of plants built before some of the later design criteria were in place were found to be similar to the seismic margins of the newer plants.²⁹⁵
3. Scenarios identified by these plants that lead to core damage typically involved loss of offsite power, loss of other electrical power sources and non-seismic failures.

One goal of the IPEEE program was to systematically search for plant-specific vulnerabilities and to identify plant improvements to overcome these vulnerabilities. The SONGS IPEEE identified actions such as improving the reliability of cross-connecting emergency diesel generators giving more flexibility to respond to a loss of power, improving supports of selected equipment and strengthening electrical cabinets.²⁹⁶ Diablo Canyon did not identify any vulnerabilities or improvement actions specifically as a result of the IPEEE. The NRC attributed this to actions taken in response to earlier programs including the Long Term Seismic Program and active use of their plant-specific PRA.²⁹⁷ Diablo Canyon's and SONGS' estimated frequency of core damage results were within the range of numerical results for the 27 plants performing seismic PRAs. Neither Diablo Canyon nor SONGS were found to be outliers among the plants from a seismic safety point of view.²⁹⁸

Observations from the Niigata Chuetsu-Oki Earthquake

On July 16, 2007, a magnitude 6.8 earthquake, referred to as the Niigata Chuetsu-Oki (NCO) earthquake, struck Japan.^{299, 300, 301, 302} The epicenter of the earthquake was 16 km from the

²⁹⁴ NUREG -1742, volume 1: xxi.

²⁹⁵ NUREG -1742, volume 1: xxi.

²⁹⁶ NUREG-1742, volume 2, table 2.4: 2-16.

²⁹⁷ NUREG-1742, volume 2, table 2.4: 2-13.

²⁹⁸ NUREG-1742, volume 2, table 2.2: 2-5.

²⁹⁹ Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigata Chuetsu-oki Earthquake, presentation by John Stevenson, ASME, *The Evaluation Methods for Seismic Design of ASME Mechanical Distribution Systems and Components*. February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpodoc.html>.

³⁰⁰ Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigata Chuetsu-oki Earthquake, presentation by Kazuhiko Yamashita, TEPCO, *Inspection and Analysis of Kashiwazaki-Kariwa Nuclear Power Station*. February 26, 2008.

Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP). The earthquake resulted in ground motions that were in excess of the maximum predicted for the nuclear power plant site. However, the plant shut down safely without significant damage to safety-related components.³⁰³

Over a year after this event, the KK NPP remains shut down. Investigations into its ability to operate safely were only recently completed.³⁰⁴ Tokyo Electric Power Company (TEPCO), the plant owner, will be forced to buy 50-60 TWh of electricity annually until the KK NPP resumes operations. TEPCO does not expect to restart any of the plant's reactors in 2008.

Layout of the Kashiwazaki-Kariwa Nuclear Power Plant

The KK NPP is the world's largest nuclear power plant, consisting of seven operating reactors with a combined capacity of 7,965 MW. Of the seven reactors, five are boiling water reactors and two are advanced boiling water reactors.³⁰⁵ The seven reactors entered into commercial operation between 1985 (Unit 1) and 1997 (Unit 7). (The reactor type and commercial operating date for each reactor are provided in Table 4.) Reactor Units 1-4 are grouped together in one location with Units 5-7 located together a short distance from the other group (Figure 22).

Damage Sustained Due to the NCO Earthquake

At the time the earthquake struck, three reactors were operating, one unit was in start-up condition, and three units were shut down for planned outages. According to the International Atomic Energy Agency (IAEA), the "earthquake caused automatic shutdown of the operating reactors, a fire in the in-house electrical transformer of Unit 3, release of a very limited amount of radioactive material to the sea and the air and damage to non-nuclear structures, systems and components of the plant as well as to outdoor facilities."³⁰⁶ (The release of radioactive material to the sea is discussed in Chapter 4 under "Spent Fuel Pools.")

Even though the earthquake exceeded the design basis, initial examinations revealed no damage to any safety-related SSC. In other words, all seismic Class A SSCs, Class I pipe vessels,

³⁰¹ Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake, presentation by George Hardy, EPRI, *EPRI Independent Peer Review of TEPCO Seismic Walkdown and Evaluation of the Kashiwazaki-Kariwa Nuclear Plants*. February 26, 2008.

³⁰² Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake, presentation by Toshiharu Nomoto, SANE, *Interim report of the structural Integrity Assessment Committee for Nuclear Components damaged by Earthquake* (SANE). February 26, 2008.

³⁰³ International Atomic Energy Agency. "Preliminary Findings and Lessons Learned From The 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP." August 6-10, 2007, page 1. Accessed: July 4, 2008. <http://www.iaea.org/NewsCenter/News/PDF/kashiwazaki060807_vol1.pdf>.

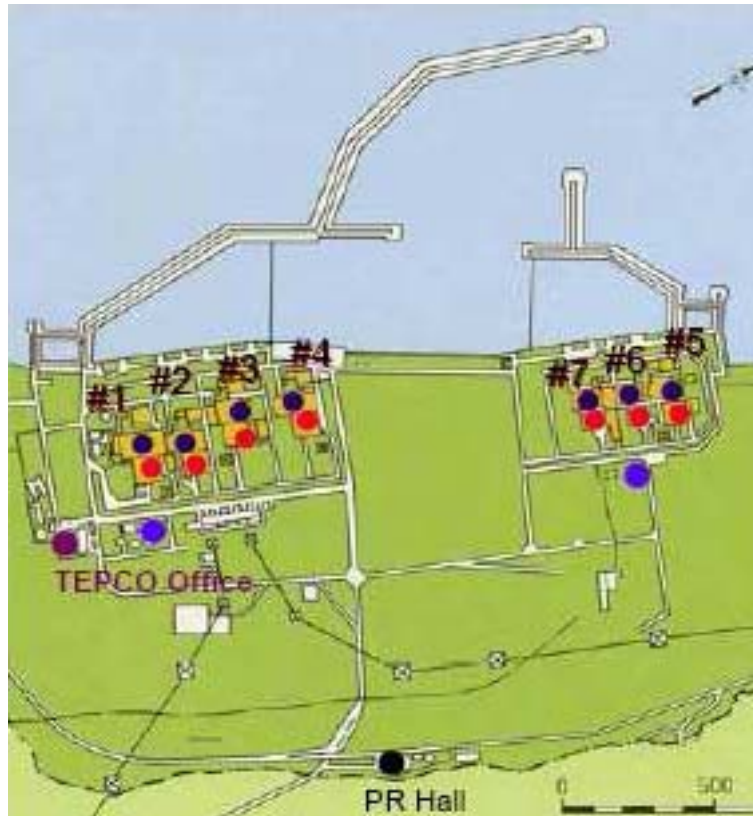
³⁰⁴ Japan Atomic Industrial Forum, Inc. "External Inspections of All Kashiwazaki Kariwa NPS Units Soon to Finish: Seismic Reinforcement Work Commencing Successively." July 22, 2008.

³⁰⁵ The two advanced BWR units are GE-designed. The Kashiwazaki-Kariwa plant was the first nuclear plant in the world to employ the GE Gen III designed reactor for commercial operation.

³⁰⁶ International Atomic Energy Agency. August 6-10, 2007: 1

supports, and anchors remained fully operational. Upon initial examination, the International Atomic Energy Agency (IAEA) reported that “safety related structures, systems and components of the plant seem to be in a much better general condition than might be expected for such a strong earthquake.”³⁰⁷ (Figure 23 displays an image of damage discovered adjacent to the plant.)

Figure 22: Site Layout of Kashiwazaki-Kariwa Nuclear Power Plant³⁰⁸



The fire in the in-house electrical transformer of Unit 3 was the result of multiple failures. The main cause of the various failures was primarily ground subsidence that led to ruptured underground piping of the outside fire protection system for Units 1-4. Japan’s fire code did not require the plant’s fire protection system to be seismically qualified. Although fire walls provided adequate protection, the fire was not suppressed completely for approximately 2 hours. The practice at the plant was to rely on offsite fire fighting services. Damage to the access roadways significantly delayed the arrival of this vital service.

Because the fire was isolated to the non-nuclear side of the plant it had no impact upon radiological safety and the safety of the public. Nevertheless, the public announcement of the fire caused concern and the fire itself is significant in terms of the broader safety of a nuclear

³⁰⁷ International Atomic Energy Agency. August 6-10, 2007: 1

³⁰⁸ International Atomic Energy Agency. August 6-10, 2007: Volume II, page 53.

power plant from seismically induced events. TEPCO and Japanese regulators have studied the root causes of the fire and the component failures and developed a number of responses based on their findings. TEPCO intends to seismically retrofit the fire protection system and will increase the fire-fighting capacity of the plant's fire protection system to permit firefighting of 1-2 hours without outside (i.e., the local municipality's fire fighters') assistance. TEPCO will also form and train an in-house fire-fighting brigade.

Figure 23: Coastal damage adjacent to the Kashiwazaki-Kariwa Nuclear Power Station³⁰⁹



Internal reactor components that had been removed from the reactor for refueling and servicing operations were particularly impacted by the earthquake. For example, one peripheral fuel bundle was unseated from its support on the core support plate for Unit 5, and the wedge that is unscrewed to remove the jet pump was found to be loose and mispositioned. One of the supporting legs for the Unit 1 separator core structure (which is used only when the core structure is not installed in the reactor) was bent. Additionally, one of the two vertical guide pins by which the core structure internals are positioned into place was bent. The deformed parts can all be repaired within a relatively short time frame as long as any necessary raw materials are available.

³⁰⁹ U.S. Geological Survey. "USGS Researchers Lead International Team Investigating Damage Caused by Offshore Earthquake Near World's Largest Nuclear Power Plant in Japan," *Sound Waves* Jan./Feb. 2008. <<http://soundwaves.usgs.gov/2008/01/index.html>>.

Recorded Ground Motion Data

The maximum horizontal accelerations for the NCO earthquake observed at the lowest level of the reactor building (“basemat”) were 0.694g versus the seismic design value of 0.279g. The highest vertical accelerations in the same building were 0.416g versus the seismic design value of 0.240g.^{310, 311} In other words, at the reactor building the earthquake exceeded the design basis in the horizontal direction by 150 percent and in the vertical direction by 75 percent. Based on the initial reports from the plant owner and limited visual inspections by an IAEA team, the IAEA concluded that damage to the plant had been less than might have been expected.³¹²

...safety related structures, systems and components of the plant seem to be in a much better general condition than might be expected for such a strong earthquake, and there is no visible significant damage. This is probably due to the conservatism introduced at different stages of the design process. The combined effects of these conservatisms were apparently sufficient to compensate for uncertainties in the data and methods available at the time of the design of the plant, which led to the underestimation of the original seismic input.

The sheer size of the KK NPP plant and its seven separate units that incorporate different seismic design bases allows for an interesting comparison of damage and design bases. Looking exclusively at east-west ground motion – the dominant axis in the case of the NCO earthquake – it is clear that the observed accelerations at the bases of all seven reactor buildings exceeded their respective design bases, in some cases greatly, by up to a factor of 3.6 (Unit 2). However, there was little correlation between the magnitudes by which the design bases were surpassed and the damage experienced by the units. Table 4 below provides a brief description of the damage incurred at each unit with the ground motion recorded at each unit.

Design Basis for KK NPP

In 2006 Japan’s Nuclear Safety Commission released a revised regulatory guide for reviewing the seismic design of Japan’s nuclear power plants to reflect new knowledge gained from a 1995 earthquake. Japan’s utilities were required to re-evaluate the seismic design of existing nuclear power plants as a result. A re-evaluation of geologic data for the vicinity of KK NPP was underway at the time the earthquake struck in 2007. Following the NCO earthquake, TEPCO undertook a geological investigation to reassess the active faults in the vicinity of the KK NPP. TEPCO submitted an interim report to Japanese regulators in May 2008.

TEPCO’s analysis determined that “the scale of assumed earthquakes becomes larger by postulating that active faults are longer [than initially estimated] and that multiple active faults

³¹⁰ Yamashita, Kazuhiko. “Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake.” February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpo_doc.html>.

³¹¹ Hardy, George. “Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken Chuetsu-oki Earthquake.” February 26, 2008. <http://www.jaif.or.jp/english/news/2008/2008_simpo_doc.html>.

³¹² International Atomic Energy Agency. August 6-10, 2007: 1.

would move simultaneously.”³¹³ TEPCO concluded that a number of faults both offshore and inland were longer than had previously been estimated and that although the offshore faults are independent faults, there could be concurrent activity on the three faults, which in total stretch for about 90 km.

Another key finding of TEPCO’s assessment is that certain characteristics of the area around the KK NPP intensify seismic motions. First, TEPCO found that the hypocenter of the NCO earthquake was capable of generating an earthquake 1.5 times larger than normal. Second, because of the characteristics of the deep ground, seismic motion propagated at a slow speed, thereby allowing subsequent motions to catch up with the first motions. Finally, an old bended structure in the ground beneath the reactors amplified seismic motions. The magnitude of amplification to Units 1-4 was greater than that for Units 5-7 due to this bended structure. TEPCO believes that the manner in which the reactor buildings are embedded in the ground weakens the seismic motion, but not equally for each building.

Reflecting these new analyses, TEPCO recently announced that it will adopt a new ground acceleration standard for the KK NPP. Under the new standard, the maximum acceleration for Units 1-4 will be set to 2,280 Gal; this standard is approximately 5 times the previous ground acceleration standard.³¹⁴ The maximum acceleration for Units 5-7 will be 1,156 Gal. TEPCO will need to undertake retrofit projects to bring the reactor units in line with these new design bases.

Implications for Diablo Canyon and SONGS

The earthquake and the plant’s performance have drawn attention both to the seismic vulnerabilities of nuclear power plants and to their structural integrity. Although the earthquake resulted in ground motions that were in excess of the plant’s design bases, the plant shut down safely without significant damage to safety-related components. Nevertheless, more than a year after the earthquake, the plant remains shut down while investigations into the characteristics of the earthquake and the resulting damage to the plant continue.

There are limitations to making direct comparison between the KK NPP’s performance and how Diablo Canyon or SONGS might respond to an earthquake of a similar magnitude. First, U.S. and Japanese seismic regulatory standards are not identical. Second, the KK NPP’s reactors are of a different type and different vintages to the reactors at Diablo Canyon and SONGS. Nevertheless, the experience at KK NPP does illustrate the vulnerability of the non-nuclear (the non safety-related) portions of a nuclear power plant and that even minor damage can result in an extended outage under certain circumstances. The event also demonstrated the importance of having on-site emergency services for fire fighting. Finally, the event demonstrated the dependence on dependable plant access to support plant recovery.

³¹³ Tokyo Electric Power Company. “Actions We Have Taken Regarding the Kashiwazaki-Kariwa Nuclear Power Station and the Establishment of the Design-basis Seismic Motion,” <<http://www.tepco.co.jp/en/images/seismic.pdf>>.

³¹⁴ JAIF, “Seismic Retrofitting at Kashiwazaki-Kariwa to Withstand 1,000-Gal Acceleration,” June 3, 2008.

Table 4: Damage at Kashiwazaki-Kariwa Nuclear Plant from NCO Earthquake³¹⁵

Unit #	Status Before Earthquake	Reactor Type	Year Began Operations	East-West Acceleration At Reactor Building Base (gal: cm/s/s)		Significant Damage Events
				<i>Observed</i>	<i>Design Basis</i>	
All	Various			Various	Various	Hundreds of solid waste drums tipped over and dozens were found with lids open. All units had water puddles on the reactor building refueling floors as well as transformer oil leakages.
1	Shutdown <i>in an outage</i>	BWR	1985	680	273	Damage to fire protection system piping resulted in a 40 cm-deep radioactive puddle of water on the lowest floor of the Reactor Combination Building (leakage up to 2,000 cubic meters). The spent fuel pool temporarily experienced a low-water level. The double door of the reactor building was kept open due to power loss.
2	Starting up	BWR	1990	606	167	The spent fuel pool temporarily experienced a low-water level.
3	Operating	BWR	1993	384	193	The spent fuel pool temporarily experienced a low-water level. A house transformer caught on fire and was extinguished within two hours.
4	Operating	BWR	1994	492	194	24 cubic meters of seawater leaked from a 4.5 meter crack. Service platform in the spent fuel pool fell on the spent fuel storage rack; the spent fuel was not damaged.

³¹⁵ IAEA, August 2007, "Preliminary Findings and Lessons Learned from the 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP," Volume II, 50, 132-134.

Unit #	Status Before Earthquake	Reactor Type	Year Began Operations	East-West Acceleration At Reactor Building Base (gal: cm/s/s)		Significant Damage Events
				<i>Observed</i>	<i>Design Basis</i>	
5	Shutdown <i>in an outage</i>	BWR	1990	442	254	A filtered water tank leaked; the leakage was not radioactive.
6	Shutdown <i>in an outage</i>	ABWR	1996	322	263	A minuscule amount of radioactivity was found on 3 rd floor of the reactor building (0.6 liter) and mezzanine 3 rd floor of the reactor building. Leaked water discharged to the sea (1.2 cubic meters) containing Cobalt-58, Cobalt-60, and Antimony-124.
7	Operating	ABWR	1997	356	263	Iodine and particulate material were detected during a weekly measurement of the main exhaust stack. The water-tight doors of the Reactor Core Isolation Cooling System and Residual Heat Removal System degraded. A service platform in the spent fuel pool fell on the spent fuel storage rack; the spent fuel was not damaged.

Conclusions

The safety-related systems, structures, and components of Diablo Canyon and SONGS are designed to remain safe during earthquakes of magnitudes as large as 7.5 on the Hosgri Fault and 7.0 on the South Coast Offshore Fault Zone, respectively. These earthquakes are expected to be the largest magnitude earthquakes that could impact the plants, given what is currently known about the geology of local faults. Nevertheless, Diablo Canyon and SONGS would incur some damage if earthquakes occurred at or near the plant sites.

Earthquakes with magnitudes equivalent to the safe-shutdown earthquakes would likely cause serious damage to Diablo Canyon or SONGS with the damage centered on the non-nuclear areas of the plants. The safety-related portions of the plants—the reactor, primary steam supply, containment, and associated equipment—are expected to withstand safe-shutdown earthquakes without damage that would impact safety. Notably, the largest earthquakes experienced at SONGS and Diablo Canyon have been significantly less than the plants' safe-shutdown earthquakes.

The non-safety related SSCs of the plants are most vulnerable to damage from earthquakes. Damage to non-safety related SSCs could pose risks of injury and loss of life to plant workers and occupants. Damage would not pose a direct safety hazard to the public; however, it could result in extended outages for repairs lasting weeks or months. The seismic-related reliability risk of non-safety related SSCs is not well understood in part because the nuclear industry and the NRC historically have focused on safety-related SSCs.

The switchyards of the plants could be particularly vulnerable to earthquake damage because the equipment configuration and the dispersed and interconnected nature of the switchyard facilities make them vulnerable to ground motion. Diablo Canyon's 500 kV switchyard, through which the plant's energy is transmitted to the grid, is built on deep fill making it particularly vulnerable to subsidence and ground motion amplification. In part, the degree of damage that could be sustained will depend on the extent to which SCE and PG&E have upgraded their plants' switchyard equipment to meet the newest seismic design standards. Failure of a switchyard could result in a loss of power from the plants even if the reactor units remain safe and undamaged.

Seismic design standards of non-safety related SSCs have evolved significantly since Diablo Canyon and SONGS were designed and licensed. Given the evolution of seismic design standards since these reactors were designed in the 1970s and early 1980s, non-safety related SSCs at Diablo Canyon and SONGS may be less seismically robust than if those same SSCs were built to current standards. A full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of the evolution of seismic design standards since these plants were designed and built. Such an analysis should consider any retrofits to SSCs that PG&E and SCE may have completed.

Diablo Canyon or SONGS could be shut down following an earthquake for as little as one week to as much as several years for repairs or component replacement. Estimates of time to repair or replace nuclear plant components are very uncertain since this information is not readily available. The determining factors most likely would be the extent and location of the damage,

i.e., whether the repair is on the nuclear side or the non-nuclear side of the power plant, and. the availability of replacement parts. Other factors affecting the duration of a shutdown include the amount of time needed to investigate the plant for damage and the need for design and backfitting efforts. Public or regulatory concerns also could delay the restart of the power plant.

There are many lessons to be learned from the experience of the Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP) and the 2007 Niigata Chuetsu-Oki earthquake. The KK NPP experienced ground motions significantly higher than the design basis ground motion and yet suffered no significant damage to safety-related components. Nevertheless, more than a year after the earthquake, the KK NPP remains shut down. Extensive investigations and a re-evaluation of the seismic design standards for the plant appear to be the primary cause of the lengthy shut down, suggesting that repairing or replacing damaged components be just one factor in how long a nuclear power plant is shut down following a major seismic event.

Technical Note: Seismic Hazard Analysis

There are two primary types of seismic hazard analysis: deterministic and probabilistic.

Deterministic seismic hazard analysis (DSHA) specifies the ground motion hazard at a site from a single earthquake (usually a maximum estimated event) on a specified fault or at a specified distance from the site of interest. The estimated ground motion at the site is typically given in the form of a percentile level, such as the 50th-percentile (median) or 84th-percentile motion, which is calculated from the standard deviation of the ground motion attenuation relationship used in the analysis. DSHA is most commonly applied at sites that are close to active faults since it can be expected that earthquakes on these faults dominate the ground motion hazard at the site.

There are two types of uncertainties associated with DSHA. *Aleatory variability* refers to the statistical variability in parameters used in seismic hazard analyses. *Epistemic uncertainty* refers to the uncertainty in which of the available ground motion attenuation models to apply to represent the range of results given by different ground motion models. To account for these uncertainties, judgments are typically made in the application of DSHA results as to reasonably suitable levels of conservatism required for seismic safety.

Probabilistic seismic hazard analysis (PSHA) is a more complex analysis than DSHA and involves a methodology that was first proposed by Cornell.³¹⁶ PSHA can be summarized as the solution of the following expression of the total probability theorem:

$$\lambda[X \geq x] \approx \sum_{\text{Sources } i} \nu_i \int_{M_o}^{M_{\max}} \int_{R|M} P[X \geq x | M, R] f_M(m) f_{R|M}(r|m) dr dm \quad (1)$$

where $\lambda[X \geq x]$ is the annual frequency that ground motion at a site exceeds the chosen level $X=x$; ν_i is the annual rate of occurrence of earthquakes on seismic source i that have magnitudes between M_o and M_{\max} ; M_o is the minimum magnitude of engineering significance; M_{\max} is the maximum magnitude assumed to occur on the source; $P[X \geq x | M, R]$ denotes the conditional probability that the chosen ground motion level is exceeded for a given magnitude and distance; $f_M(m)$ is the probability density function of earthquake magnitude; and $f_{R|M}(r|m)$ is the probability density function of distance from the earthquake source to the site of interest. In application, this expression is solved for each seismic source i of a seismotectonic model.

Once the annual exceedance rate $\lambda[X \geq x]$ is known, the probability that an observed ground-motion parameter X will be greater than or equal to the value x in the next t years (the exposure period) is easily computed from the equation

$$P[X \geq x] = 1 - \exp(-t\lambda[X \geq x]) \quad (2)$$

³¹⁶ Cornell, C.A. Engineering Seismic Risk Analysis, Seismological Society of America Bulletin, Vol. 58, 1968, pages 1583-1537.

and the “return period” of x is

$$R_x(x) = \frac{1}{\lambda[X \geq x]} = \frac{-t}{\ln(1 - P[X \geq x])} \quad (3)$$

Probability values commonly used and cited in PSHA are ground motions that have a 10% probability of being exceeded in a 50-year exposure period of engineering interest. From equation three, this gives a return period of:

$$R_x(x) = \frac{-50}{\ln(1 - 0.1)} = 475 \quad (4)$$

Thus, these specific ground motions, which have a 10% probability of being exceeded during 50 years, are commonly termed to have an average 475-year return period. It is informative to note that setting the exposure period equal to the return period results in a 63% probability that the ground motions will be exceeded in t years under the Poisson assumption used to develop these relationships.

The PSHA process models a range of earthquake magnitudes of engineering interest on all potential seismic sources throughout a region around a site of interest.^{317,318} Specialized computer programs are used due to the large number of calculations that are required for PSHA.

Figure 24 below illustrates a simplified PSHA procedure. Sources of earthquakes are initially identified and the earthquake occurrence frequency is analyzed for each source. These sources can be individual faults or can be specified as areas where earthquakes are not clearly associated with known faults or where active faults are unknown. They can also be composite sources, in which active faults are embedded within area sources with each source perhaps having a different magnitude range of potential earthquakes.

Epistemic uncertainty regarding the parameters of the earthquake sources is input to the PSHA process via a logic-tree, in which alternative values are weighted according to their likelihood of being correct. The generic form of the fault-source logic-tree used by PG&E in the 1988 Diablo Canyon LTSP report is shown in Figure 25. Typically, several or more attenuation relationships are also incorporated into the analysis in order to encompass epistemic uncertainty related to the ground motion models. Aleatory variability for statistically determined input parameters is incorporated into the analysis through mathematical integration.

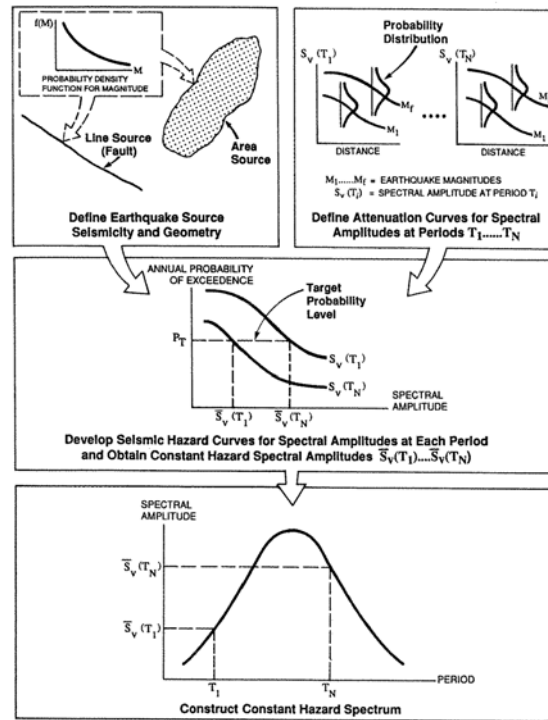
The result of PSHA is a suite of hazard curves for spectral amplitudes at each vibration period of interest. The hazard curves can then be sampled at various annual probabilities of

³¹⁷ McGuire, R.K. Seismic Hazard and Risk Analysis, EERI Monograph Series No. 10, 2004, page 221.

³¹⁸ Thenhaus, P.C., and K.W. Campbell. “Seismic Hazard Analysis”, in W.-F. Chen and C. R. Scawthorn, eds., Earthquake Engineering Handbook, CRC Press, Inc., Boca Raton, Florida, 2002.

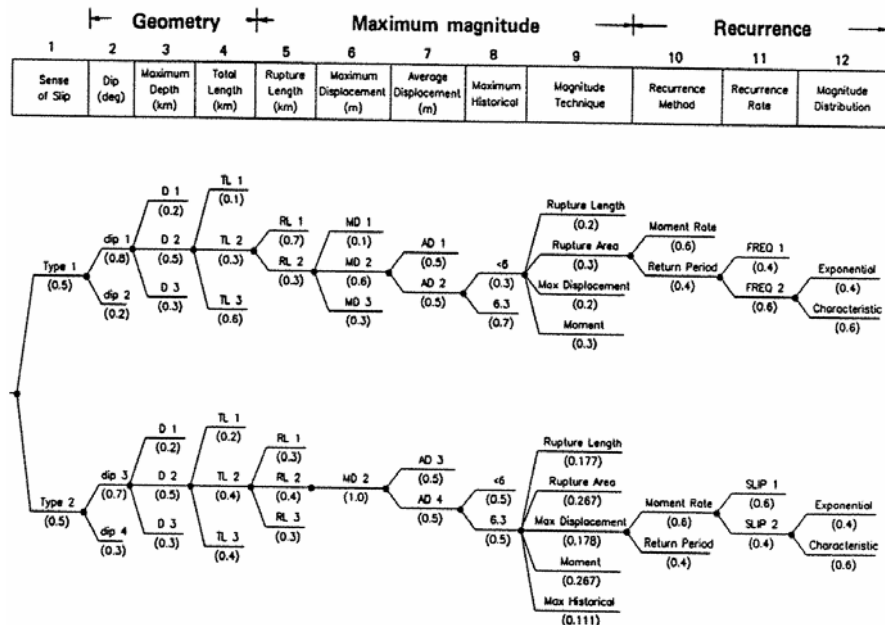
exceedance to obtain constant, or uniform, hazard spectral amplitudes that are plotted together as a constant, or uniform, hazard spectrum.

Figure 24: Probabilistic Seismic Hazard Assessment Procedure³¹⁹



³¹⁹ Earthquake Engineering Research Institute (EERI) Committee on Seismic Risk. The Basics of Seismic Risk Analysis, *Earthquake Spectra*, Vol., 5, 1989, pages 675-702.

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³²⁰ PG&E. Diablo Canyon Long-Term Seismic Program, 1988.

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U.S. Nuclear Regulatory Commission. 10 CFR 100.

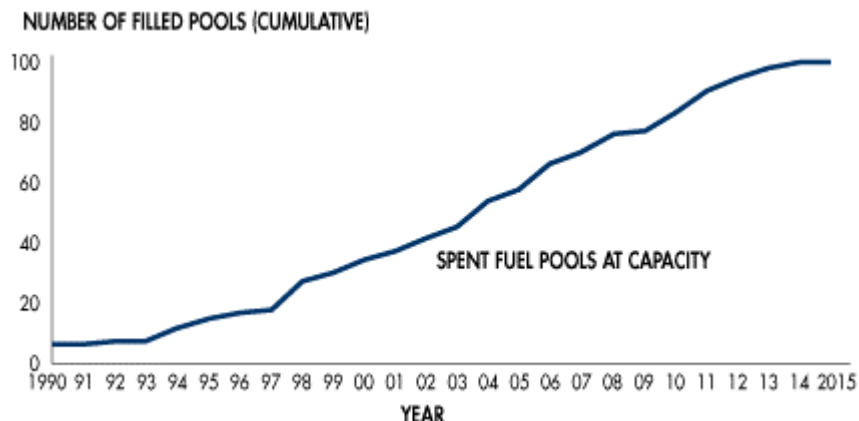
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Chapter 4: Seismic and Other Vulnerabilities of Spent Fuel Storage Facilities, Transmission Systems, and Access Roadways

Periodically, about one-third of the nuclear fuel in an operating reactor needs to be unloaded and replaced with fresh fuel. Designers of nuclear power plants anticipated that the spent fuel would be reprocessed, with usable portions recycled and the rest disposed as waste. They built pools in which to store the spent fuel at the reactor sites until the spent fuel could be shipped to a reprocessing facility or permanent waste repository. However, commercial reprocessing was never successfully developed in the U.S., and a permanent waste repository has not yet been developed. As a result, many of the spent fuel pools at domestic commercial nuclear power plants are nearing capacity and nearly all will reach their full capacity by 2015 if alternative methods of storage are not employed (Figure 26).

Figure 26: Spent Fuel Pool Capacity, U.S. Commercial Nuclear Plants³²¹



Congress is considering options to create additional storage capacity on federal lands to store commercial spent fuel until a repository or advanced reprocessing technologies can be developed. A commercial interim storage facility remains a possibility. However, an interim storage facility, whether operated by the U.S. Department of Energy (DOE) or a private company, would take at least a decade to plan and license.

In the early 1980s, utilities began looking at options for increasing the capacity of spent fuel pools. Current regulations permit re-racking (placing fuel rod assemblies closer together in spent fuel pools) and fuel rod consolidation, subject to U.S. Nuclear Regulatory Commission (NRC) review and approval, to increase the amount of spent fuel that can be stored in the pool. Both of these methods are constrained by the size of the pool. The spent fuel pools at both Diablo Canyon and the San Onofre Nuclear Generation Station (SONGS) have been re-racked to allow for a higher density of stored spent fuel.

³²¹ U.S. Nuclear Regulatory Commission. "Nuclear Fuel Pool Capacity." Accessed: April 2008. <<http://www.nrc.gov/waste/spent-fuel-storage/nuc-fuel-pool.html>>.

Another option is to build an independent spent fuel storage installation (ISFSI) at the reactor site or elsewhere. While an ISFSI technically could be a second spent fuel pool, in practice utilities that have built ISFSIs have used a dry cask design. (In this chapter and throughout the report, the term “ISFSI” refers to a dry cask storage facility.) Under this approach, spent fuel freshly removed from a reactor is stored in a spent fuel pool while older fuel that has cooled for at least five years in the spent fuel pool is transferred to the dry cask ISFSI. The dry cask storage containers are typically placed outside on concrete pads away from plant buildings but within the secured area of the nuclear power plant site.

According to the NRC, there are 49 operating ISFSIs in the U.S.³²² Another 16 nuclear power plants have applied to the NRC for licenses to build and operate an ISFSI. Both the Diablo Canyon and SONGS sites have built or are building ISFSIs.

Under normal operating conditions, spent fuel pools and dry cask storage systems both provide safe means of storing spent fuel. This chapter reviews scientific studies and data to assess whether these storage systems would continue to effectively contain radiation from the spent fuel under extreme seismic or terrorist events. The chapter then considers spent fuel transport risks, local and state emergency preparedness plans, and the vulnerability of transmission systems at the nuclear plants to damage from seismic or terrorist events.

Spent Fuel Pools

Spent fuel pools are large structures constructed of thick, reinforced concrete walls and slabs. Pool walls are about 5 feet thick; pool floor slabs are around 4 feet thick and are lined with at least 1/8-inch of stainless steel. Overall pool dimensions are typically about 50 feet long by 40 feet wide and 55 to 60 feet deep.

Both Diablo Canyon and SONGS’ spent fuel pools share the same seismic design basis as their respective plants (see Chapter 3). In Diablo Canyon and SONGS, the spent fuel pool structures are located outside the containment structure and supported on the ground or partially embedded in the ground. The location and supporting arrangement of the pool structures affect their capacity to withstand seismic ground motion beyond their design basis. The design and dimensions of the pool structure are generally derived from radiation shielding considerations rather than seismic demand needs. Because the radiation shielding criteria are more stringent than the seismic criteria, spent fuel structures at nuclear power plants are able to withstand seismic loads substantially beyond those for which they were designed.³²³

Vulnerability to Seismic or Terrorist Events

The greatest risk to any nuclear spent fuel pool is the loss of water or the loss of active cooling. A loss-of-coolant event could be precipitated by earthquakes or a terrorist attack. Such an event would likely not lead to radiation release in a spent fuel pool that used open frame racks (i.e.

³²² Nuclear Regulatory Commission. “Thoughts on Spent Fuel Storage.” Prepared Remarks of Commissioner Gregory Jaczko at the Nuclear Energy Institute’s Dry Storage Information Forum. May 13, 2008.

³²³ U.S. Nuclear Regulatory Commission. “Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants.” October 2000.

that had not been re-racked). In this configuration, spent fuel that had cooled for more than five days after shut down before transfer to the spent fuel pool could survive a complete loss of pool water without cladding failure. However, a loss-of-coolant event in a re-racked spent fuel pool, if not mitigated, could result in overheating of the stored spent fuel, melting of the fuel cladding, and the subsequent release of radioactive material.

In order to protect against loss-of-coolant events, the NRC requires spent fuel storage facilities and all structures and equipment necessary to maintain minimum water levels necessary for radiation shielding to be designed to Seismic Category I requirements, the highest NRC standard.^{324, 325, 326} The Diablo Canyon and SONGS spent fuel pools are designed to these requirements and are also supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis. They are therefore not expected to suffer a catastrophic loss of cooling as the result of earthquakes.

In 2003 Robert Alvarez, a Senior Scholar of Nuclear Policy at the Institute for Policy Studies, evaluated the repercussions of a loss-of-coolant event in a spent fuel pool that had been re-racked and was densely packed.³²⁷ Alvarez concluded that such an event would lead to the rapid heat-up of the newer spent fuel to temperatures at which the zirconium alloy cladding would catch fire and release many of the fuel's fission products, particularly cesium-137. He suggested that the fire could spread to the older spent fuel in the pool, resulting in long-term contamination consequences that would be worse than those from the Chernobyl accident. He did not consider the likelihood of these scenarios.

Alvarez and his co-authors recommended that spent fuel be transferred to dry storage within five years of discharge from the reactor. They noted that this would reduce the cesium-137 inventory of a typical spent fuel pool by a factor of four, allow the remaining fuel to be returned to open-rack storage to allow for more effective coolant circulation, and eliminate cladding ignition in the case of a total loss of pool water. The authors also discussed other compensatory measures, such as the installation of emergency ventilation and emergency water sprays, that could be taken to reduce the consequences of a loss-of-coolant event.

The Alvarez analysis received extensive attention and comments, including a comment from NRC staff.³²⁸ None of the commentators challenged the main conclusion of the study that a severe loss-of-coolant accident might lead to a spent fuel fire in a densely packed pool. Rather, the commentators challenged the likelihood that such an event could occur through accident or

³²⁴ U.S. Nuclear Regulatory Commission. "Spent Fuel Storage Facility Design Basis." Regulatory Guide 1.13, March 2007.

³²⁵ U.S. Nuclear Regulatory Commission. "Seismic Design Classification." Regulatory Guide 1.29.

³²⁶ U.S. Nuclear Regulatory Commission. "Spent Nuclear Fuel Project Seismic Design Criteria." NRC Equivalent Evaluation Report. WHC-SD-spent fuel-DB-004, Rev. 1. 1996.

³²⁷ Alvarez, Robert, and Jan Beyea, et al. "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States." *Science & Global Security*, 11:1. (2003), pages 1 - 51.

³²⁸ U.S. Nuclear Regulatory Commission. "Fact Sheet on NRC Review of Paper on Reducing Hazards from Stored Spent Nuclear Fuel." Accessed: April 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/reducing-hazards-spent-fuel.html>>.

sabotage. They also challenged the assumptions used to calculate the offsite consequences of such an event and the cost-effectiveness of the authors' proposal to move spent fuel into dry cask storage. NRC staff concluded that the analysis relied on "studies that made overly conservative assumptions or were based on simplified and very conservative models. The use of these previous studies, most of them NRC or NRC contractor studies, provides overly conservative and misleading results when assessing potential spent fuel pool vulnerabilities to terrorist events."¹⁴⁰

Even without a complete loss of coolant, an earthquake or other impact to a spent fuel pool could result in the spread of radioactivity if contaminated water spills from the pool. This occurred during the July 2007 Niigata Chuetsu-Oki (NCO) earthquake in Japan. The earthquake's ground motion caused water to slosh in the spent fuel pool at the KK NPP and to spill in the Unit 6 reactor building. The contaminated water then leaked out of conduits in the reactor building floor into the Sea of Japan.³²⁹

The IAEA noted in its follow-up report on the NCO earthquake that the "phenomenon of water spilling over from the spent fuel pool is now well known and had already been observed during previous earthquakes."³³⁰ Both SONGS' and Diablo Canyon's spent fuel pools are designed to curb the effects of sloshing. At Diablo Canyon, waves of less than 2 feet would be contained by the freeboard of the spent fuel pool's walls.³³¹ A 12-inch high curb around the perimeter of the pool would contain water spilled due to sloshing over the freeboard area. This is what occurred during the San Simeon earthquake, which had a magnitude of 6.5. Both SONGS and Diablo Canyon have drainage systems in the floor around the pool that are designed to collect water and route it to a sump system that handles liquid radiation wastes.

As noted above, the manner in which water from the Japanese plant's spent fuel pool leaked into the sea was through floor penetrations that were not sufficiently leakproof. PG&E stated in response to a data request that it is currently investigating the water-tightness of conduits in its auxiliary building.³³² SONGS responded that the power plant does not have "pathways in the Fuel Handling Building that will allow contaminated water to flow to a "clean" sump which in turn would automatically pump water to the ocean as occurred in Japan. Therefore, no significant safety or environmental impacts are anticipated due to spent fuel pool water spillage that might result from an earthquake."³³³

³²⁹ IAEA, Volume I, page 53. The manner by which the contaminated water ultimately leaked into the Sea of Japan was described by the IAEA as follows: "The water spilled over from the spent fuel pool to the reactor building refuelling [sic] floor, where it filled up a cable chase. It then leaked into an uncontrolled area on the lower floor through a cable penetration that had a defective sealing. The water dripped down one additional floor along cables and a penetration. It finally collected one floor down in a pit of discharged water. The contaminated water was then sent to the sea by the discharge pump through the discharge outlet."

³³⁰ IAEA, Volume I, page 53.

³³¹ PG&E Data Request Responses, 2008.

³³² PG&E Data Request Responses, 2008.

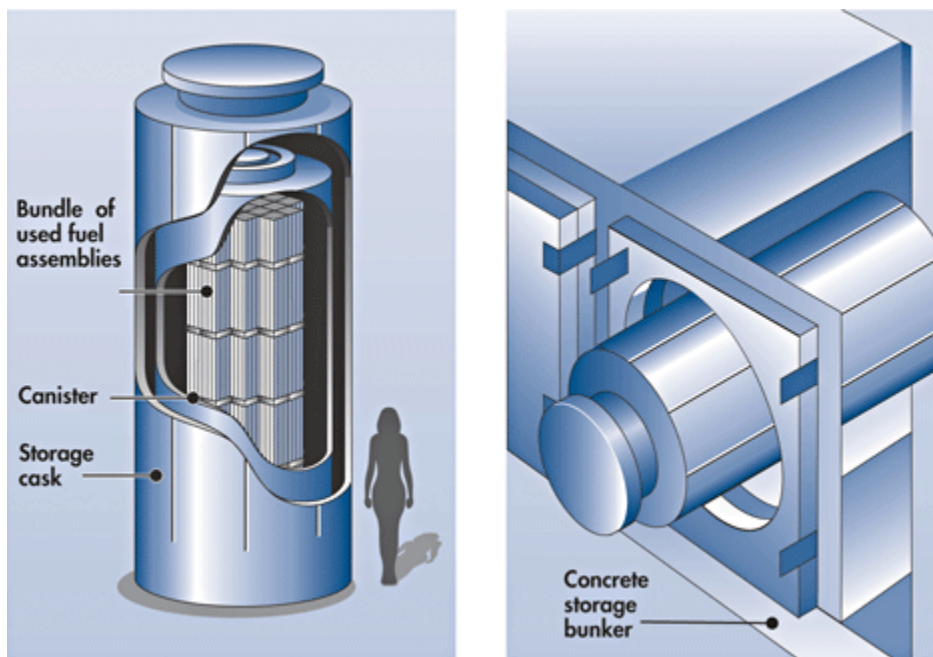
³³³ SONGS Data Request Responses, 2008.

Another potential concern at a spent fuel pool is heat build-up following the loss of active cooling (i.e. circulation pumps in the spent fuel pools). However, this scenario is much less likely to lead to a fire. As long as water does not spill out of the pool, operators would have about 100 hours (more than four days) to act before enough cooling water boiled away to expose the spent fuel.³³⁴

Dry Cask Storage

Dry cask ISFSIs are designed to resist floods, tornadoes, projectiles, temperature extremes, and other unusual scenarios. Dry casks typically consist of metal or concrete outer shells with inner sealed metal cylinders that contain the spent fuel (Figure 27). The NRC requires that spent fuel be cooled in a spent fuel pool for at least five years before being transferred to dry casks. During this period, significant cooling of the spent fuel rods occurs (see Chapter 9).

Figure 27: Dry Cask Storage³³⁵



There are two ways a dry cask ISFSI may be licensed. A “site-specific license” authorizes operation of a storage facility at a nuclear power plant or elsewhere, subject to the NRC’s standard licensing requirements. The license specifies the type of storage system to be used. Alternatively, nuclear power plant operators may operate an ISFSI under a “general license” using NRC-approved dry storage casks. The general license option allows plants to avoid

³³⁴ National Research Council, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, Board on Radioactive Waste Management. “Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report.” National Academies Press. 2005.

³³⁵ U.S. Nuclear Regulatory Commission. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fig43.gif>>.

repeating certain evaluations (such as environmental impact or seismic reviews) that were already conducted for the plant's operating license. SONGS' ISFSI is operated under a general license, and PG&E has applied for a site-specific license for the Diablo Canyon ISFSI.

Dry cask ISFSIs are considered by many experts to be safe and environmentally sound. Over the last 20 years, there have been no radiation releases which have affected the public, no radioactive contamination, and no known or suspected attempts to sabotage ISFSIs.

Risk Assessments of Dry Cask Storage Facilities

Two comprehensive probabilistic risk analyses, performed in parallel but independently by NRC and Electric Power Research Institute (EPRI), have been conducted for dry cask storage systems.³³⁶ The NRC study considered the HI-Storm 100 system as implemented at an unnamed East Coast boiling water reactor plant. The EPRI study considered a "generic" dry cask containing spent pressurized water reactor (PWR fuel). These studies considered both internal and external initiators. Internal initiators are those events that result from operational failures or malfunctions (e.g. the drop of a cask) that could potentially threaten the integrity of the cask or cause the release of radioactive material. External initiators are those events whose origin is outside of normal operational control (such as an earthquake or aircraft crash) that has the potential for an undesirable outcome. Neither study explicitly considered terrorist-initiated scenarios.

The risk metric used in both studies was the frequency of early fatality of a member of the public. Both studies specifically considered the risk of prompt early fatality of a member of the public (located within one mile of the facility in the NRC study and at the site boundary in the EPRI study) and latent cancer deaths in the surrounding population. Both studies predicted zero prompt fatalities and very low values of latent cancer deaths for the scenarios considered. Both studies predicted a higher risk for a cask in its first year of use as compared to subsequent years. This is because additional operations such as cask loading and transportation occur during the first year. The NRC study predicted that the frequency of latent cancers per year per cask for the first year is on the order of 2×10^{-12} ; the corresponding value from the EPRI study is on the order of 6×10^{-13} per year per cask. For subsequent years, the NRC and EPRI studies predict risks on the order of 3×10^{-14} and 2×10^{-13} , respectively.

General Vulnerability

Dry cask storage of spent fuel is among the safest of all the phases of the nuclear fuel cycle. The basic safety goals that must be met are to ensure that (a) sufficient shielding is provided so that workers at the facility are not exposed to hazardous levels of radiation, and (b) the fuel is contained so that any release of radioactive material from the casks to the surrounding environment is reliably prevented. These goals are not difficult to achieve.

³³⁶ U.S. Nuclear Regulatory Commission. "A Pilot Probabilistic Risk Assessment Of a Dry Cask Storage System At a Nuclear Power Plant." NUREG-1864, March 2007; Electric Power Research Institute. "Probabilistic Risk Assessment of Bolted Storage Casks: Updated Quantification and Analysis Report." 1009691, December 2004.

In dry cask storage there are few scenarios that could provide the energy needed to break the cask and spread radioactive material into the surrounding environment. This is quite different from the situation in a reactor core, where extreme care is taken to contain the intense heat and pressure generated by the nuclear reaction, or in a fuel processing plant, where a variety of strong chemical reactions are likely to be used that could potentially result in explosive energy releases. With dry cask storage, a solid material (the spent fuel assemblies) remains completely still inside a strong, thick container. In such a system, there is very little that could precipitate a significant release of radioactivity. Moreover, dry storage casks are massive structures that are subjected to extensive mechanical testing before NRC approval to ensure that they will withstand very significant physical abuse before failure and any possible release of their radioactive content. Dry casks are also less vulnerable than spent fuel pools because they contain much smaller inventories of spent fuel, less cesium-137 activity, and are not vulnerable to a loss-of-coolant accident.

To ensure that dry cask storage systems provide adequate shielding and containment, the systems are designed to meet the following requirements: (1) fuel cladding must maintain its integrity while in storage; (2) high temperatures that could cause fuel degradation must be avoided; (3) accidental chain reactions (“criticality”) must be prevented; (4) effective radiation shielding must be provided; (5) radiation releases must be avoided; and (6) fuel retrievability must be ensured in case any problem arises.

Under normal conditions, the main vulnerability associated with dry cask storage is the loading of spent fuel from the pool into the casks. During this process, the fuel is not as fully protected as it is when it is in the casks or the pool, and it is in motion, which increases the possibility for accidents. The NRC’s PRA study (discussed above) found that the largest contributor to risk was the transfer of the spent fuel from the pool to the dry cask storage containers.³³⁷ In some cases, welding torches or other sources of energy that could precipitate a chemical reaction may also be present. An additional potential concern is that spent fuel cladding could degrade from exposure to high temperatures inside the casks for many years. If too much degradation were allowed to occur, the cladding could rupture and pieces of fuel could fall out into the canister. Such an occurrence would create a potential contamination risk when the fuel was eventually unloaded. For this reason, the NRC places strict limits on the maximum temperature for dry storage (effectively a limit of 380 degrees C).³³⁸ Inspections of spent fuel that had been stored in dry casks for nearly 15 years revealed no increase in the cladding creep of its fuel rods.

Vulnerability to Seismic and Terrorist Events

The dry casks at SONGS and Diablo Canyon have been designed to withstand the design basis seismic events at the respective sites. The vulnerability of dry cask storage to a terrorist attack is still being studied. A terrorist attack that breached a dry cask could potentially result in the release of radioactive material from the spent fuel into the environment through one or both of the following processes: mechanical dispersion of fuel particles or fragments and dispersion of

³³⁷ U.S. Nuclear Regulatory Commission. “A Pilot Probabilistic Risk Assessment Of a Dry Cask Storage System At a Nuclear Power Plant.” March 2007.

³³⁸ Kazimi, Mujid S. and Neil E. Todreas. “Nuclear Power Economic Performance: Challenges and Opportunities.” Annual Review of Energy and the Environment. 1999.

radioactive aerosols (e.g. cesium-137). The latter process would have greater offsite radiological consequences. Sandia National Laboratories is currently analyzing the response of several dry cask systems to a number of potential terrorist attack scenarios at the request of the NRC.

In his 2003 study, Alvarez concluded that terrorists could cause releases from dry-cask modules, although it is difficult to imagine how they could release a large fraction of the total stored inventory, short of detonation of a nuclear weapon. Alvarez identified shape-charged missiles, aircraft turbine spindles, and fire as possible threats. To release radioactive material, Alvarez observed that either the wall of the container must be penetrated from the outside or a fire must cause failure of the container.

Setting and Design of the Diablo Canyon ISFSI

PG&E plans to use the HI-Storm 100 dry cask storage system (see “Diablo Canyon ISFSI System” below).³³⁹ This system is comprised of multipurpose canisters, storage overpacks, and HI-TRAC transfer casks located above ground.³⁴⁰ A photo of loaded HI-Storm casks is shown in Figure 28.

Loaded overpacks are stored on a series of concrete pads within a protected area separate from the reactors. Each storage pad is designed to accommodate up to 20 loaded overpacks in a 4-by-5 array. Ultimately, seven such pads may be built to accommodate a full offload of Units 1 and 2 reactor cores and their spent fuel pools at the end of their existing operating licenses. The series of seven storage pads will cover an area approximately 500 feet by 105 feet. The protected area has applicable barrier, access, and surveillance controls meeting NRC requirements for an ISFSI co-located with a nuclear power plant.

Construction of the ISFSI is still in process, and regulatory reviews and approvals are not yet complete.³⁴¹

With respect to seismic issues, in 2004 PG&E updated the Diablo Canyon ground motion analysis to account for the characteristics of the ISFSI. In particular, the new analysis accounts for near-source fault rupture phenomena. These phenomena affect long-period motions to which the ISFSI is more sensitive than power plant facilities. The Coastal Commission staff geologist agreed with PG&E and the NRC that the updated ground motion estimates are to be used in the ISFSI design.

³³⁹ The Hi-Storm 100 system is also slated to be used at several other sites including Bryan, Braidwood, LaSalle, Dresden, Quad Cities and Fermi.

³⁴⁰ Marine Research Specialists (MRS). “Diablo Canyon Independent Spent Fuel Storage Installation (ISFSI) Final Environmental Impact Report.” SCH # 2002031155, January 2004.

³⁴¹ PG&E is awaiting approval for license amendments to allow for the preparation and loading of the canisters in the fuel handling building or auxiliary building. Additionally, there are other licensing amendment requests before the NRC for changes to the Hi-STORM 100 System. PG&E has received all the necessary regulatory approvals to begin dry-runs for fuel loading into the casks.

Figure 28: Photo of Loaded HI-Storm Casks at Plant Hatch³⁴²



Diablo Canyon ISFSI System

Diablo Canyon will utilize the “HI-STORM 100” dry cask storage system. In this system, spent fuel is stored in multi-purpose canisters. These canisters are stainless steel, integrally-welded cylindrical pressure vessels that hold up to 24 or 32 Diablo Canyon spent fuel assemblies in individual fuel baskets. The fuel baskets use a honeycomb configuration and boron carbide neutron absorbers to prevent nuclear chain reactions. Canisters are moved from the spent fuel pool to a storage “overpack” inside a transfer cask made of a carbon steel shell with neutron and gamma shielding provided by water and lead, respectively.

Loaded canisters are anchored and vertically stored in “overpacks.” The overpack is a rugged, heavy-walled cylindrical container that provides gamma and neutron shielding, ventilation passages, and protection from terrorist and natural phenomena. Each loaded overpack is approximately 11 feet in diameter, 20 feet high, and weighs about 360,000 pounds. The overpack is in turn enclosed by cylindrical steel shells, a thick steel baseplate, and a top plate. Additional concrete shielding is attached to the top of the overpack lid. Inlets and outlets allow air to circulate naturally to cool the canister.

A transporter is used to move transfer casks to the transfer facility, which is about 100 feet from the ISFSI storage pads. The transfer facility has a lifting platform to position an overpack below grade to facilitate the transfer of a loaded canister from the transfer cask to the overpack. After the canister is placed in the overpack, the transporter is again used to move the loaded overpack to the storage pads.

(The design and operation of these components are described in detail in the HI-STORM 100 System Final Safety Analysis Report. (FSAR, 2000))

³⁴² Holtec International. “Welcome to Holtec International.” Accessed: June 3, 2008. <<http://www.holtecinternational.com/>>.

A number of seismic safety features are integrated into the ISFSI design to account for the updated ground motion analysis. For example, the cask storage pads are designed to accommodate the weight and necessary anchorage of the HI-STORM 100SA overpack at these high seismicity sites. A seismic restraint also will be mounted in a recess in the floor of the spent fuel pool to support the canister while it is in the pool.

Beyond seismic issues, the accidents evaluated for the ISFSI facility are predominately natural events affecting the ultimate storage position of each cask. Some limited analyses have been performed to address potential terrorist events. There appears to be little apparent credibility to the effect on operations of a concurrent seismic event; the exception would be a transporter moving a loaded cask.

Non-terror and non-seismic risk issues for Diablo Canyon's ISFSI include the following:

- The cask transporter cannot get into the building because the rollup door is too small. This necessitates offloading large loads onto a temporary track to move the cask into position. Potential problems with the temporary track system have not been investigated.
- There are provisions in Diablo Canyon's ISFSI license that require PG&E to have a process for opening sealed spent fuel canisters. Part of reopening a canister entails cutting the canister lid weld. Oxidation of the boron-carbide neutron absorbers and the aluminum components contained in the canister may create hydrogen gas while the canister is filled with water. Appropriate monitoring for combustible gas concentrations must be performed prior to, and during, lid cutting operations. In addition, the space below the canister lid must be exhausted prior to, and during, lid welding operations to provide additional assurance that explosive gas mixture will not develop in this space. The NRC reviews PG&E's procedures for reopening a canister.
- The minimum physical separation distance between the transport route and the ISFSI is 1,200 feet based on the maximum quantities of flammable material having an equivalent weight of TNT of 12,100 lb. The resultant setback distance ensures that the 1 pound per square inch maximum overpressure acceptance criterion is met. PG&E uses administrative controls to ensure that this setback distance is maintained. The NRC has the responsibility to periodically review the administrative controls to ensure their adequacy.

Setting and Design of the SONGS ISFSI

The SONGS ISFSI is a fenced, protected area located within the Unit 1 Industrial Area, which is dedicated to the dry storage of spent fuel from Units 1, 2 and 3. The ISFSI is sized to accommodate the total contents of the Unit 1 spent fuel pool in addition to all fuel to be offloaded during the current licensed lives of Units 2 and 3.

The final ISFSI configuration will consist of multiple rows of Advanced Horizontal Storage Modules located aboveground. Each storage module is a concrete structure 8'-5" across the front, 22'-7" deep, and 20'-7" high. Modules are joined together to form rows. The modules sit above ground atop a three-foot thick concrete pad that provides a minimum 10-foot clearance

around the module array to allow for sliding during a seismic event. A one-foot thick approach road provides access to the modules.

Enclosed within the storage modules are the dry-shielded canisters. A dry-shielded canister is a horizontally positioned, cylindrical vessel capable of holding up to 24 fuel assemblies. Unit 1 canisters are 67" in diameter, 186" long, and are designed for a 14 KW heat load. Unit 2 and 3 canisters are 67" in diameter, 197" long, and are designed for a 24 KW heat load.

The ISFSI is located in an area with secured access. Lightning protection is provided for the modules and the security light towers. Except for periods of facility expansion (i.e. adding additional modules onto a row), routine inspections, and during actual fuel loading operations, the ISFSI will be empty of vehicles, extraneous equipment, and personnel.³⁴³

SONGS maintains that the seismic safety of the site has been assured through review by the NRC, during the licensing review for Unit 2 and 3 in the 1970s. In addition, the SONGS ISFSI was built to higher seismic standards at all frequencies than required by the design. In reviewing these data, the California Coastal Commission concluded that it is reasonable to conclude that even a much larger earthquake, a much lower epicentral distance, or both, will not produce ground shaking that would exceed the design of the ISFSI.³⁴⁴

The Coastal Commission found that there is credible reason to believe that the design basis earthquake approved by NRC at the time of the licensing of SONGS 2 and 3 – a magnitude 7.0 earthquake on the Newport-Inglewood-Rose Canyon Fault system 8 km from the site, resulting in a ground shaking with a high frequency component peaking at 0.67 g – may underestimate the seismic risk at the site. This does not mean that the facility is unsafe – although the design basis earthquake may have been undersized, the plant was engineered with very large margins of safety, and would very likely be able to attain a safe shutdown even given the larger ground accelerations that might occur during a much larger earthquake. ... the seismic design of the proposed project which is under consideration [*sic* ISFSI], so far exceeds the ground accelerations anticipated from the design basis earthquake that it is reasonable to believe that it will be safe from even a much larger earthquake whose focus is even closer than the design basis earthquake.³⁴⁵

However, some opponents of the SONGS ISFSI believe that new information on the geologic environment offshore of the SONGS site indicates that the design basis earthquake may underestimate the seismic risk at the site. (The seismic setting for the SONGS site is reviewed in Chapter 2.)

³⁴³ For the design basis of the dry cask storage system, refer to the Final Safety Analysis Report for the Standardized Advanced NUHOMS Horizontal Modular Storage System for Irradiated Nuclear Fuel. For the licensing basis, refer to Certificate of Compliance No. 72-1029.

³⁴⁴ California Coastal Commission. "Construction of San Onofre Nuclear Generating Station (SONGS) Unit 2 and 3 Temporary Spent Nuclear Fuel Storage Facility." Item Number: Tu5a, CDP Application No. E-00-014.

³⁴⁵ California Coastal Commission. "Construction of San Onofre Nuclear Generating Station (SONGS) Unit 2 and 3 Temporary Spent Nuclear Fuel Storage Facility." Item Number: Tu5a, CDP Application No. E-00-014: 20.

Spent Fuel Transport Risks

Spent fuel canisters are used for on-site transport from a spent fuel pool to an ISFSI and will also be used for off-site transport to an interim or final centralized storage location. These canisters have been developed to prevent containment failure even if the canisters are dropped or subjected to stresses that result in large plastic deformations and high strains. Significant testing of the canisters has demonstrated that the canisters can achieve the intended design goals without failure. Blandford et al. concluded that containment failure can be averted in spent nuclear fuel canisters that are accidentally dropped if the canisters conform to NSNFP specifications.³⁴⁶ The results of the drop testing show that the design of the standardized spent fuel canister is robust and that its containment system will remain intact and functional even if the canister is dropped. Helium leak testing has shown that leak-tight conditions are maintained after an accidental drop. These physical observations are supported by computer analyses that predict the structural responses of the canisters.

The NRC has sponsored a series of studies since the 1970s examining the risk that spent fuel could be released during transportation accidents. The NRC's most recent assessment of spent fuel transportation accident risks was conducted by Sandia National Laboratory and was published in 2000.³⁴⁷ This study, like preceding accident studies, found that an accidental release of spent fuel in transit is very unlikely and that significant human health impacts are even less likely. The study estimated that in over 99.9 percent of all truck and rail accidents, the shipping container would experience no significant damage, and even in the cases where damage to the container occurred, there would be no release of radioactive material.³⁴⁸ A draft of an updated NRC analysis concludes that the risk of radiation release is even lower.³⁴⁹ These assessments are consistent with U.S. experience: of the eight accidents that occurred during 1,300 commercial spent fuel shipments between 1979 and 1995, none damaged the fuel casks, compromised the shielding, or caused any release of radioactive material.³⁵⁰

The National Academies' Committee on Transportation of Radioactive Waste similarly concluded that there are no fundamental technical barriers to the safe shipment of spent nuclear

³⁴⁶ Blandford, R.K. D.K. Morton, T.E. Rahl, and S.D. Snow. "Preventing Failure in Spent Nuclear Fuel Canisters." PFANF8. (2003) pages 4:43-49.

³⁴⁷ U.S. Nuclear Regulatory Commission. "Reexamination of Spent Fuel Shipment Risk Estimates." NUREG/CR-6672, Washington, D.C. March 2000.

³⁴⁸ Government Accountability Office (GAO). "SPENT NUCLEAR FUEL, Options Exist to Further Enhance Security." Report to the Chairman, Subcommittee on Energy and Air Quality, Committee on Energy and Commerce, U.S. House of Representatives. July 2003.

³⁴⁹ U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. "Discussion Draft: An Updated View of Spent Fuel Transportation Risk." A Summary Paper for Public Meetings. 2000. <<http://ttd.sandia.gov/nrc/docs/draft.pdf>>; based on a study prepared for NRC by Sandia National Laboratories: Sprung, J.L. et. al. "Reexamination of Spent Fuel Shipment Risk Estimates." NUREG/CR-6672 Vols. 1-2, SAND2000- 0234. (2000). <<http://ttd.sandia.gov/nrc/docs.htm>>.

³⁵⁰ U.S. Nuclear Regulatory Commission. "Public Meeting on Revision to Spent Fuel Cask Transportation Study." December 1999.

fuel and high-level radioactive waste in the United States.³⁵¹ The Committee found that when conducted in strict adherence to existing regulations, spent fuel transport is a low radiological risk activity with manageable safety, health, and environmental consequences. However, they also noted that there are a number of social and institutional challenges to the successful initial implementation of large-quantity shipping programs. Careful attention to safety, including extensive preplanning and effective and independent regulation, is required in order to ensure that spent fuel shipments pose little risk to the public.

There is less public information available on the potential impacts of terrorist attacks on spent fuel shipments. A variety of studies have concluded that even an attack on a spent fuel transport using shaped-charge explosives on the casks would spread only a minor amount of radioactivity if the scenarios did not involve combustion of the zirconium cladding.³⁵² However, Dr. Ed Lyman, director of the Nuclear Control Institute, has criticized these studies as inadequate. For example, Lyman criticized the design basis threat specified in 1999, indicated that the source term analyzed did not fully consider all relevant radionuclides, and that the impact of respirable particles had not been fully considered.³⁵³ Lyman and others have similarly criticized federal regulations pertaining to spent fuel transport security.³⁵⁴

A specific terrorist scenario has been postulated for the Diablo Canyon ISFSI.³⁵⁵ In this scenario, it is hypothesized that an attack on a canister results in puncture of both the top and bottom of the cask and a zirconium fire. If the cask's anchors were to survive, the passive cooling feature of the cask could result in a "chimney effect" and lead to the release of a significant amount of cesium. The scenario is presented based on its potential severe consequences; the conditional likelihood of the scenario (e.g. the occurrence of the necessary physical damage and onset of cladding fire) given a well-designed terrorist attack were not reviewed by the authors of the current report.

³⁵¹ Transportation Research Board, Nuclear and Radiation Studies Board, Committee on Transportation of Radioactive Waste. "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States." *The National Academies Press*. 2006.

³⁵² Alvarez, Robert and Jan Beyea, et al. "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States." 2003: 1 – 51; Lange, F. G. Pretzsch, E. Hoermann, and W. Koch. "Experiments to quantify potential releases and consequences from sabotage attack on spent fuel casks." 13th International Symposium on the Packaging and Transportation of Radioactive Material. Chicago, September 2001; Hirsch, H. and W. Neumann. "Verwundbarkeit von CASTOR-Behaltern bei Transport und Lagerung." <http://www.bund.net/lab/reddot2/pdf/studie_castorterror.rtf>.

³⁵³ Lyman, Ed. "A Critique of Physical Protection Standards for Transport of Nuclear Materials." Proceedings of the 40th Annual Meeting of the Institute of Nuclear Materials Management. July 1999.

³⁵⁴ Government Printing Office. "Requirements For Physical Protection of Irradiated Reactor Fuel in Transit." 10 Code of Federal Regulations Part 73.37. <<http://www.nrc.gov/NRC/CFR/PART073/>>.

³⁵⁵ Thompson, G. "Assessing Risks of Potential Malicious Actions at Commercial Facilities: The Case of a Proposed Independent Spent Fuel Storage Installation at the Diablo Canyon Site." See also: San Luis Obispo Mothers for Peace "Reply to NRC Staff and GG&E Subpart K." Presentations. June 16, 2008.

Local and State Emergency Preparedness Plans

Under California law, counties have the authority and responsibility to protect the lives and property of their citizens; however, the state supports emergency response activities involved in nuclear power plant planning. In 1979, following the accident at the Three Mile Island nuclear power plant in Pennsylvania, the California Legislature mandated that the Governor's Office of Emergency Services, together with Department of Health Services and affected counties, investigate the consequences of a serious nuclear power plant accident. These agencies conducted site-specific studies and developed Emergency Planning Zones around the state's nuclear plants and integrated emergency plans.³⁵⁶ In addition, in the event of an emergency at one of these plants, the Office of Emergency Services would mobilize state resources in support of the counties to help mitigate the effects of radiation released into the atmosphere.

During an emergency response, the State Office of Emergency Services would have absolute coordination authority over utility, local, state, federal, and volunteer response. The Department of Health Services would be the technical lead for preventing contaminated water, food, and food animals from reaching the consumer and for restoring areas to pre-accident conditions. The state's Nuclear Power Plant Emergency Response Plan identifies the required activities in the Emergency Response Zones.³⁵⁷

In the Emergency Planning Zone, an approximate ten-mile radius around the plants defined for the plume exposure pathway, plans are in place to protect people, property, and the environment in that zone from the effects of radioactive contamination. These plans are reviewed and approved by the NRC and periodic exercises are conducted as described below.

In the Ingestion Pathway Zone, an approximate 50 mile radius around that plant, plans are in place to mitigate the effects on agriculture, and food processing and distribution. These plans are also reviewed and approved by the NRC.

On a regular basis, the utilities distribute educational materials to inform the public within 35 miles from the nuclear plants (in the Public Education Zones) about plant operations, what to expect in the event of an accident, and what plans are in place for public protection. The utilities are required to publish and disseminate this information for both residents and transient populations, including telephone directory guidance.

Planning and preparedness are cooperative efforts by state agencies, local jurisdiction, and the utilities. These efforts aim to develop integrated and refined plans for emergency response and to prepare a cadre of trained emergency responders. The plans and attendant procedures are informed by guidance provided by the Federal Emergency Management Agency in concert with the NRC.

Emergency responders test their plans and their skills through regularly scheduled exercises, based on a federally-mandated six-year cycle. Exercises test organizations' integrated capability

³⁵⁶ California Department of Public Health. "Nuclear Emergency Response Program." Accessed: April 2008. <<http://www.cdph.ca.gov/healthinfo/envirohealth/Documents/NERP/NERP.pdf>>.

³⁵⁷ During an emergency response, best efforts would be made to follow action plan criteria without regard to whether particular areas are inside or outside zones.

and major portions of the plans. State law requires full activation of state level response every two years.

The Diablo Canyon Independent Safety Committee is an independent organization consisting of three members, one each appointed by the Governor, the Attorney General, and the Chairperson of the California Energy Commission, serving staggered three-year terms. The role of the Committee is to review Diablo Canyon operations for the purpose of assessing the safety of operations and suggesting any recommendations for safe operations. The Committee reviewed Diablo Canyon's Emergency Preparedness Program and found that a recently-developed Strategic Plan will bring about needed improvements. In particular, the new plan will improve the communication of radiation release projections and data to the media, the county, and the public. This is an area that had been identified by the Safety Committee as needing improvement.³⁵⁸

Access Roadways

Diablo Canyon is located in a relatively remote area, while SONGS is located along a major interstate highway. From a planning perspective, Diablo Canyon's remoteness is preferable since there is a non-populated zone around the plant that serves as a final protective boundary for the safety of the public. This is also a beneficial feature when keeping the plant secure from external threats. However, remoteness can hinder timely emergency response.

At Diablo Canyon, a two-lane asphalt road is the main route to and from the site. During an emergency, this restricted access could result in traffic congestion and increase the potential for traffic accidents and further road blockages. If an emergency occurred during the winter rainy season, the risk of congestion and traffic accidents would be even greater since the hills through which the road is cut and the coastal plains upon which the road is built are subject to slides and sloughing during and after heavy rains.

In addition to this main access road, there are unpaved emergency access roads through privately held lands north of the plant that connect with a narrow windy road through a state park. To the east, there are unpaved access roads that are used to service transmission lines and towers. These roads are also located on privately held lands and used by the utility only under the grant of local easements.

Access roadways to SONGS have a much larger capacity to bring in emergency supplies, relief personnel, food, fuel, and replacement equipment within a very short period of time. However, if the emergency threatens nearby residents, there could be an unprecedented amount of traffic traveling through this corridor to escape a threatening situation. To avert such a situation, SCE and state and local authorities have developed emergency plans. For example, during the October 2007 wildfires in southern California, state and local authorities coordinated access to the SONGS site for plant personnel.

³⁵⁸ The Diablo Canyon Independent Safety Committee. "Summary of Major DCISC Review Topics." 17th Annual Report. July 1, 2006 thru June 30, 2007. Accessed: April 2008. <<http://www.dcisc.org/annual-report-17-2006-2007/volume1/4-07-emergency-preparedness.html>>.

Both nuclear plants' sites are vulnerable to seismic ground subsidence that can directly affect all roadways arriving to the site and the access roadways within each plant complex. These impacts were reported in the 2007 Japanese earthquake. The resulting uneven or soft surfaces can prevent large equipment vehicles from arriving until the road surfaces can be restored to handle the heavy loads. PG&E maintains roadway repair materials and equipment at the plant site and San Luis Obispo County similarly keeps equipment readily available in case of major damage to access roadways.

Vulnerability of Transmission Systems

Transmission systems have two roles at the nuclear plants: to provide power for on-site loads and to deliver power generated by the nuclear plants to the grid. Under most circumstances a disruption to the transmission system would not damage the nuclear plants since the plants are designed to successfully withstand the loss of offsite power. However, in the very unlikely event that the loss of offsite power coincided with additional independent failures of the on-site emergency generators, the plant could be damaged.

A more likely result of transmission failure would be a disruption in the delivery of power from the nuclear plants to the grid. A 1990 Federal Emergency Management Agency (FEMA) review of records from past earthquakes found that electrical transmission towers, poles, and lines are not very vulnerable to earthquake damage, particularly on the West Coast where transmission systems are generally built to be earthquake resistant.³⁵⁹ Notably, no transmission tower damage was reported from the Loma Prieta earthquake or from four other California earthquakes examined in the FEMA study.³⁶⁰ However, transmission facilities are more vulnerable to terrorist attack. It would be relative easy to dismantle a tower, to cut out structural members, or to knock down a weakened transmission tower during the night without detection. Such acts would disrupt electrical power transmission if any cables were severed or torn.

In August Diablo Canyon's Unit 2 automatically tripped as a result of a fire in a transformer. Unit 2 remained shut down for 20 days following the incident while the transformer was replaced and associated damage repaired. As a result of the transformer fire and reactor trip, electricity from the 230 kV switchyard flowed into the plant through a startup transformer to provide electricity to power plant equipment. Diablo Canyon has been plagued with transformer fires over the years.³⁶¹ For example, an auxiliary transformer for Unit 1 caught fire in 2000 and in 1996 causing the unit to automatically trip. PG&E and the transformer vendor,

³⁵⁹ Federal Emergency Management Agency. "Earthquake Resistant Construction of Electric Transmission and Telecommunication Facilities Serving the Federal Government." 1990. Accessed: July 2008. <<http://www.fema.gov/library/viewRecord.do?id=1635>> pages v, 4-6.

³⁶⁰ The California earthquakes included in this review are the 1952 Kern County earthquake (Magnitude 7.7), the 1971 San Fernando earthquake (M 6.5), the 1986 Palm Springs earthquake (M 5.8), and the 1989 Loma Prieta earthquake (M 7.1). Federal Emergency Management Agency. 1990: page 5.

³⁶¹ Union of Concerned Scientists. "Diablo Canyon Transformer Fire (Again)." Issue Brief. August 20, 2008.

Siemens, are investigating the cause of the most recent transformer fire. The NRC will then review the results of that investigation.

As discussed in Chapter 3, substations are vulnerable to earthquake damage. Particularly prone to damage are ceramic components, including bus-support structures, disconnect switches, columns supporting circuit breakers, and bushings and radiators of transformers.³⁶² High voltage equipment is most vulnerable, and blackouts are often associated with damage to high voltage substations.³⁶³ Such damage need not result in an extended blackout: during the Loma Prieta earthquake, service was restored before repairs were completed by bypassing some of the damaged circuit breakers.^{364, 365}

Conclusion

The greatest risk to any nuclear spent fuel pool is the loss of water or the loss of active cooling. A loss-of-coolant event could be precipitated by earthquakes or a terrorist event. If not mitigated, such an event could lead to overheating of the stored spent fuel, melting of the fuel cladding, and the subsequent release of radioactive material. Loss of spent fuel pool water has occurred at plants outside California, but these events were recovered before the fuel damage occurred. Because of the risk associated with loss-of-coolant events, spent fuel storage pools are designed to reduce the possibility of draining leading to water levels lower than the stored fuel (which is what is necessary for overheating). In the case of Diablo Canyon and SONGS, the spent fuel pools are designed to the highest safety classification, and the pools are supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis. The pools are not expected to suffer a catastrophic loss of coolant as the result of earthquakes. In addition, there are emergency back-up procedures in the event of a loss-of-coolant event to mitigate the potential loss of water from the pools.

As is the case for all operating nuclear plants in the United States, SONGS and Diablo Canyon have had to continue to store spent fuel on site well beyond original expectations. The solution the industry first turned to was to make modifications to the fuel pools to allow more fuel to be stored than was originally planned. The more densely configured (“re-racked”) spent fuel pools are considered to have a higher degree of risk than a spent fuel pool that has a more open racking arrangement. While regulations permit Diablo Canyon and SONGS to use re-racking, a

³⁶² Federal Emergency Management Agency. 1990: page 7.

³⁶³ National Academy of Sciences, Board on Infrastructure and the Constructed Environment. “Preventing Earthquake Disasters: The Grand Challenge in Earthquake Engineering: A Research Agenda for the Network for Earthquake Engineering Simulation.” National Academies Press. 2004. Accessed: July 2008. <http://www.nap.edu/catalog.php?record_id=10799> page 53.

³⁶⁴ Federal Emergency Management Agency. 1990: page 7.

³⁶⁵ The 48-hour outage in downtown San Francisco following the Loma Prieta earthquake was not due to direct damage but rather to the need to check for gas leaks prior to energizing the local grid. National Academy of Sciences, Commission on Engineering and Technical Systems. “Practical Lessons from the Loma Prieta Earthquake.” 1994. Accessed: July 2008. <http://books.nap.edu/catalog.php?record_id=2269> page 151.

loss-of-coolant event in a re-racked spent fuel pool could result in extensive radiation release and contamination.

An earthquake could result in the spread of radioactivity if contaminated water spills from the pool, as occurred during the July 2007 Niigata Chuetsu-Oki earthquake in Japan. Spilled water in one reactor building at the KK NPP leaked into the Sea of Japan from conduit leaks in the reactor building floor. The SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of sloshing. However, in light of the leak at the KK NPP, PG&E is investigating the water-tightness of conduits in the Diablo Canyon auxiliary building where the spent fuel pool is housed.

The spent fuel pools, even after reracking, are nearing their maximum capacity. The solution developed to store additional spent fuel on site is to utilize dry cask storage. Under such a scheme, fuel that has cooled in the spent fuel pool for a number of years is dried and placed in special containers that are stored on site. Risk analyses of such containers, or casks, strongly suggest that they do not pose an undue risk to the public health from normal operations (loading and on-site transport), storage, or natural hazards, and, in general, a dry cask storage facility is considered to have a lower degree of overall risk than a spent fuel pool.³⁶⁶ Over the last 20 years, there have been no radiation releases from a dry cask storage facility that have affected the public, no radioactive contamination, and no known or suspected attempts of sabotage.

Alvarez has suggested that the increased use of dry cask storage has the potential to reduce the overall risk associated with on-site spent fuel storage. If all fuel that has been cooled for several years were moved to dry cask storage, spent fuel pools could be returned to their original configuration and design loading, and mitigation features would be assured for the remaining “wet stored” fuel.

Dry cask storage probabilistic risk analyses performed by the NRC and the Electric Power Research Institute (EPRI) concluded that cask loading and transportation, which occur primarily during the first year of operation, pose a greater risk of radiation release than routine operations.³⁶⁷ During the cask loading process, spent fuel is exposed and in motion, which increases the possibility for accidents. However, the probability of radiation release is low.

The design of Diablo Canyon’s dry cask storage facility incorporated a number of seismic safety features. These features were included after analysis of near-source fault ruptures showed the potential for types of ground motion to which the dry cask storage facility is more sensitive than the power plant. The SONGS dry cask storage facility was built to higher than required seismic standards at all frequencies. In reviewing the facility’s seismic design, the California

³⁶⁶ National Research Council, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, Board on Radioactive Waste Management. “Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report.” National Academies Press. 2006, page 8.

³⁶⁷ Transferring spent fuel to dry cask storage does not necessarily increase the number of cask loading operations since the spent fuel must ultimately be transferred to a cask for storage in a centralized storage facility or disposal in a geologic repository. However, if the casks used in a dry cask storage facility are not suitable for disposal at Yucca Mountain or if a geologic repository is not available at the end of the design life of the casks, the spent fuel may need to be reloaded into new casks.

Coastal Commission concluded that even an earthquake much larger or closer than the design earthquake would not produce ground shaking that would exceed the design of the facility.

Limited information is available on the vulnerability of dry cask storage to sabotage, which is consistent with the National Academies' finding in its 2006 study of spent fuel storage safety and security.³⁶⁸ While terrorist scenarios have been postulated that could release a significant amount of cesium into the environment, an assessment of the likelihood of such scenarios occurring has not been publicly released.

The primary concerns with seismic vulnerability of roadways serving Diablo Canyon and SONGS is reduced ability for emergency personnel to reach the plants and for the local community and plant workers to evacuate. Diablo Canyon is served by a two-lane asphalt road as well as by a separate emergency access road. During an emergency, this restricted access could result in traffic congestion and increase the potential for traffic accidents and further congestion. At SONGS, access roadways have a large capacity to bring in emergency supplies and relief personnel, but, if the emergency impacts nearby residents, there could be an unprecedented amount of traffic traveling through this corridor to escape a threatening situation. To avert such a situation, SCE and state and local authorities have developed emergency plans. For example, during the October 2007 wildfires in southern California, state and local authorities coordinated access to the SONGS site for plant personnel.

The distributed nature of the transmission system makes the transmission system relatively more vulnerable than a nuclear plant to terrorist attack, but such an attack would not result in high human or environmental risk. Transmission towers and poles are not very susceptible to earthquake damage. However, switchyards are likely to be damaged during large earthquakes.

³⁶⁸ National Research Council. 2006: 4-5.

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Chapter 5: Plant Aging Vulnerability Assessment

Diablo Canyon and San Onofre Nuclear Generating Station (SONGS) are reliable sources of power, and continued vigilance is required to ensure that they remain so as the plants age. If plant components are not properly monitored, maintained, repaired, and replaced, as needed, age-related degradation could result in extended plant outages and impaired safety. According to the Nuclear Regulatory Commission (NRC), age-related degradation is “the cumulative degradation occurring within a reactor system, structure, or component, which, if unmitigated, may result in loss of function and impairment of safety.”³⁶⁹

To date, Pacific Gas & Electric (PG&E) and Southern California Edison (SCE) have adequately managed aging at their nuclear plants, as evidenced by the high reliability of the plants. If not managed well, age-related degradation could increase the frequency of events challenging plant safety systems and reduce the likelihood that the safety systems will succeed in effectively mitigating these events. Degradation that impairs the performance of safety-related plant systems, structures, and components (SSC) could increase the frequency of damage to the reactor fuel core and the release of radioactive material to the public. Degradation to safety or non-safety related areas of the plant could cause extended forced outages and necessitate expensive repairs.

This chapter presents a review of the impacts of aging plant SSCs and an aging/retiring plant work force on the reliability of nuclear plants. It also identifies trends at Diablo Canyon and SONGS related to extended, unplanned plant outages and compliance with federal plant maintenance requirements, and it presents an assessment of each plant’s “safety culture.”

This chapter builds on existing scientific studies, NRC reports, and consultations with the utilities and state and federal agencies. In particular, the Consultant Team conducted a literature search and review of technical reports, plant responses to survey questions, articles, and other information associated with the impacts of aging plant SSCs and an aging/retiring plant work force on the reliability of the plants.

Historic Plant Performance

All nuclear plants in the U.S. are essentially baseload plants. This means that transmission system operators, such as the California Independent System Operator (CAISO), routinely accept 100 percent of the electricity that nuclear plants can provide in all hours of the year. Degradation of performance at a plant is reflected in periods of reduced output or reactor outages, meaning less electricity production.

The standard metric of nuclear plant performance is the capacity factor: how much power the plant generates, or conversely, how much of the time the plant is unavailable or forced to operate at less than full capacity. A capacity factor of 100 percent indicates that a plant operated at full power throughout the period. Reductions in capacity factor over time can provide an indication of an impact of degradation at a plant.

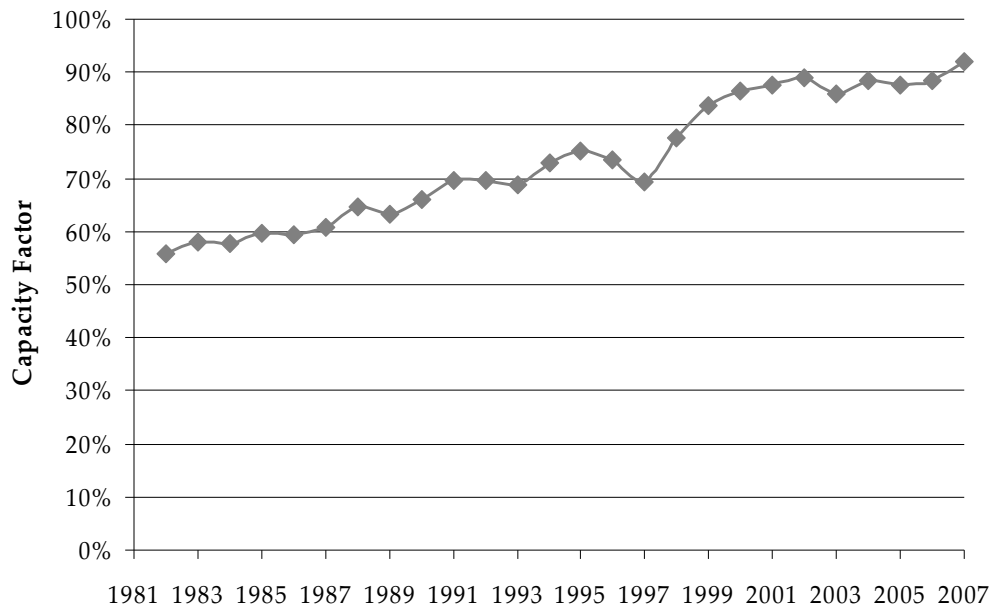
³⁶⁹ U.S. Nuclear Regulatory Commission. “Nuclear Plant Aging Research (NPAR) Program Plan.” NUREG-1144. Revision 2. June 1991.

Historic Performance of U.S. Reactors

Figure 29 presents net capacity factor values for all operating U. S. nuclear plants from 1982 to 2007. These data represent approximately 2,800 unit-years of operating experience. Figure 29 shows an upward trend in capacity factors, from a low of 56 percent in 1982 to a high of 92 percent in 2007.³⁷⁰ This indicates that, up to now, operational improvements and reductions in down time for plant maintenance and refueling have, on average, more than compensated for degradation-related operational losses in most operating U.S. nuclear plants. The experiences of individual plants do not necessarily follow this trend.

These data do not indicate whether plant aging will become an impediment to performance in the future. The performance of reactors after their initial 40-year license period is subject to predictions and speculations since no commercial reactor in the U.S. has yet operated for more than 40 years.³⁷¹

Figure 29: Historical Capacity Factors of U. S. Nuclear Power Plants³⁷²



³⁷⁰ Each plant must be taken out of service for a refueling outage roughly every 18 months for a period of roughly 30 days. Given these planned outages, over an 18-month period the maximum capacity factor for a plant is 95 percent. This also sets an approximate ceiling for an industry-wide capacity factor over a 12-month period.

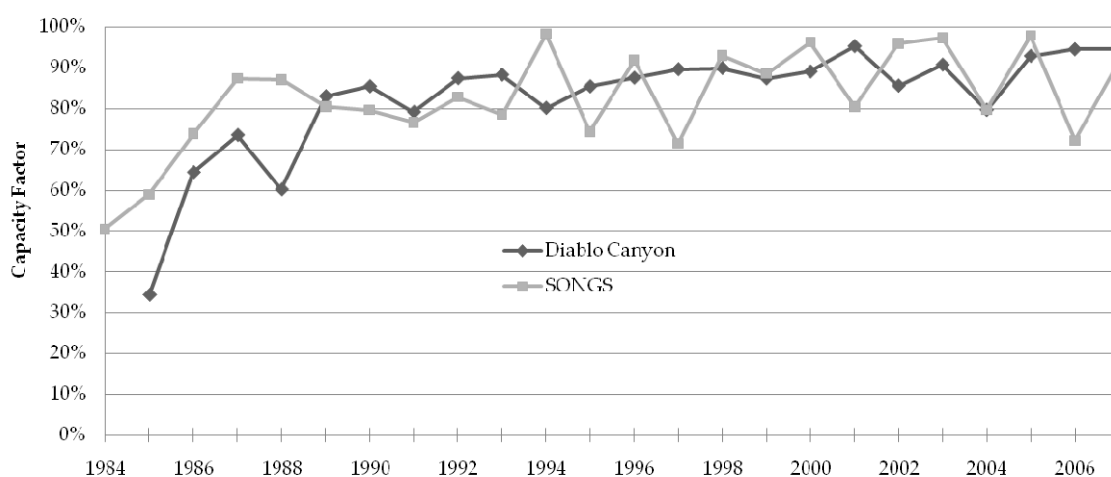
³⁷¹ The oldest operating commercial nuclear plants in the U.S. Oyster Creek and Nine Mile Point, will turn 40 in 2009. U.S. Energy Information Administration. "U.S. Nuclear Reactors." Accessed: May 14, 2008. <http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html>.

³⁷² Nuclear Energy Institute. "NERC-GADS 2007." 2008.

Historic Performance of California Reactors

Figure 30 presents the historical net capacity factors for Diablo Canyon and SONGS. Consistent with the experience of other plants nationwide, the capacity factors at these plants have increased significantly since the early years of plant operation. Although capacity factors continue to vary from year to year, these variations are due in large part to the schedule for refueling outages and other planned maintenance and do not on their own indicate a lapse in performance. Some of the dips in capacity factor may be attributed to outages for replacing or repairing aging equipment,³⁷³ but the 5-year average capacity factors of roughly 90 percent at both plants indicate that the plants are reliable sources of power and that operations in recent years have not been seriously impeded by age-related degradation.

Figure 30: Diablo Canyon and SONGS Capacity Factors³⁷⁴



Degradation of Components

In assessing the impacts that unchecked aging could have on plant components, two types of components are considered: active components and passive components. Active components are those that continuously operate or that change states to perform their functions. These include pumps, turbines, generators, compressors, process sensors, electric breakers, relays, and switches. Passive components are those that generally remain in one state over time to perform their functions, such as pipes, tanks, pressure vessels, certain heat exchangers, electrical conduit and wiring, insulation, structures, and structural supports.

There is general agreement among plant aging researchers that age-related degradation is of greater concern for passive rather than active components. This is because most active

³⁷³ Degradation-related outages at Diablo Canyon and SONGS include outages to replace the steam generators and reactor vessel heads.

³⁷⁴ Nuclear Energy Institute. "CEC-100-2007-005-F." 2008.

components are constantly being monitored or can be easily tested by being turned on and off, whereas it is generally more difficult to monitor or test passive components.

Beginning in the mid-1990s, the NRC undertook an extensive analysis of which passive components were failing in older nuclear plants, how they were failing, and the age at which the failures became pronounced.³⁷⁵ Based on a review of nearly 500 degradation occurrences in U.S. nuclear plants, the NRC found a clear correlation between the age of the plant and the number of degradation occurrences: the occurrence rate of passive system degradation was 0.07 for plants that were 20 years old and 0.18 for plants that were 30 years old.³⁷⁶ Approximately one-third of degradation occurrences were identified during in-house inspections and an additional 15 percent were visually noticed by plant personnel. In 12 percent of occurrences, leaking indicated the presence of degradation.

The NRC also identified the components that were subject to the most degradation and the causes of the degradation:

- Degradation to piping, steam generators, and passive components of the reactor pressure vessel comprised over half of the reported degradation occurrences.³⁷⁷
- For steel passive components, doors accounted for 37 percent of degradation occurrences, followed by spent fuel racks (12 percent) and liners (11 percent). For concrete passive components, walls (including masonry walls) accounted for 49 percent of occurrences, followed by ceilings (15 percent) and cooling water intake structures (10 percent).
- Stress corrosion cracking was the most common aging mechanism, accounting for nearly 25 percent of degradation occurrences. This was followed by simple corrosion (approximately 11 percent) and erosion (approximately 9 percent).

The impact of degradation on performance depends in part on the time to repair or replace the failed component. Table 5 presents the 10 plant components that led to the most forced energy production losses at nuclear plants nationwide between 2002 and 2006.³⁷⁸ The greatest overall contributors to energy production losses were caused by problems with reactor coolant systems and reactor vessels/internals. These two plant components contributed 28 percent to total lost energy production.

One example of degradation leading to plant component failure occurred in August 2007 when a non-safety related portion of the Vermont Yankee cooling tower collapsed.³⁷⁹ Immediately

³⁷⁵ Braverman, J.I. and C.H. Hofmayer, et. al. "Assessment of Age-Related Degradation of Structures and Passive Components for U.S. Nuclear Plants." NUREG/CR-6679. August 2000.

³⁷⁶ The NRC identified only the occurrence of degradation and not the severity of each occurrence.

³⁷⁷ Degradation of the reactor pressure vessel primarily impacted the core shroud (29 percent of occurrences), jet pump assembly (16 percent), and core spray piping (11 percent).

³⁷⁸ The North American Electric Reliability Corporation (NERC) - Generating Availability Data System (GADS). "Cause Code Data." Appendix 5B. 2002-2006.

³⁷⁹ U.S. Nuclear Regulatory Commission. "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report." 05000271/2007004. November 7, 2007.

following the collapse, power output was reduced from 100 percent to 35 percent and remained between 35 percent and 65 percent for approximately 10 days.³⁸⁰ The collapse was caused by structural degradation in the cooling tower from iron-salt and fungus that had weakened two wooden support beams.³⁸¹ The NRC found that proper hands-on inspection of these static components had not taken place.

Table 5: Plant Components Leading to Forced Energy Production Losses (2002-2006)³⁸²

Components Leading to Forced Outages and Derates		
#	Component	GWh/ Unit-Yr
1	Reactor Coolant System	41
2	Reactor Vessel And Internals	39
3	Operating Env. Limitations	15
4	Misc.-Steam Turbine	15
5	Feedwater System	14
6	Electrical	14
7	Steam Generators & System	14
8	Core Cooling/Safety Injection	10
9	Misc.-Reactor	9
10	Condensate System	9
Overall Forced Outages Total		286
<i>Top 10 as percent of total</i>		63%

In another example, plant workers at Vermont Yankee discovered in July 2008 that a pipe joint was leaking approximately 60 gallons per minute of cooling water from one of the cooling towers.³⁸³ The immediate cause of the leak was determined to be the sagging of the supply header, which occurred because an underlying horizontal support beam had detached from the vertical column to which it was bolted. The root cause of the failure has not yet been determined.³⁸⁴

³⁸⁰ U.S. Nuclear Regulatory Commission, "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report," November 7, 2007.

³⁸¹ U.S. Nuclear Regulatory Commission. "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report," November 7, 2007.

³⁸² North American Electric Reliability Corporation-GADS. "Cause Code Data." 2002-2006.

³⁸³ U.S. Nuclear Regulatory Commission. "NRC Sends Specialist to Vermont Yankee to Review Cooling Tower Leak." News Release No. I-08-045. July 13, 2008.

³⁸⁴ U.S. Nuclear Regulatory Commission. "NRC Sends Specialist to Vermont Yankee to Review Cooling Tower Leak." July 13, 2008.

Experiences of Plant Component Degradation

Degradation of nuclear plant components can have economic, reliability, and safety implications. Plant component degradation created a safety hazard and led to an extended outage at the Davis-Besse Nuclear Power Station in Ohio in 2002. Degradation has resulted in large capital projects at many pressurized water reactors to replace degraded steam generators. It has also been raised as a concern in several nuclear relicensing proceedings. This section presents specific cases of plant aging and component degradation at U.S. nuclear power plants and the response of plant owners and the NRC to these issues.

Davis-Besse Experience

The reactor pressure vessel head cavity that was discovered at the Davis-Besse Nuclear Power Station is an example of age-induced degradation. The experience at the plant underscores the importance of oversight in identifying emerging problems and the need for enforcement of safety protocols. In this case, a failure of oversight and enforcement allowed the degradation to continue almost to the point of failure.

In February 2002 the Davis-Besse plant in Oak Harbor, Ohio, began a refueling outage that included inspecting the 69 nozzles that enter the head of the reactor pressure vessel, the container that houses the reactor core and the control rods that regulate the power output of the reactor. The inspections were conducted in response to NRC direction. However, FirstEnergy, the operator of Davis-Besse, with NRC approval had postponed the inspections until the February 2002 refueling outage, which was past the NRC's initial deadline.^{385, 386}

During the inspections, FirstEnergy discovered cracking in three nozzles that are located near the center of the reactor pressure vessel head. Upon further investigation, FirstEnergy found that this cracking had led to corrosion and, ultimately, a large cavity in the reactor pressure vessel head. The cavity was approximately five inches long and, at its widest part, four to five inches wide. In one area, all that remained of the reactor pressure vessel head was the three-eighth of an inch thick stainless steel cladding. If the plant had continued to operate, the cladding would have burst, resulting in an accident that may have been much worse than the one at Three Mile Island.

Following discovery of this degradation, the NRC established a lessons learned task force to evaluate regulatory processes for ensuring reactor pressure vessel head integrity and to recommend improvements for the NRC and the nuclear industry. The task force made 51 recommendations to the NRC, with an emphasis on improving NRC oversight of nuclear plant inspection programs and review of program effectiveness. The task force also concluded that

³⁸⁵ U.S. Nuclear Regulatory Commission. "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles." NRC Bulletin 2001-01. <<http://www.nrc.gov/reading-rm/doc-collections/gen-comm/bulletins/2001/bl01001.html>>.

³⁸⁶ Only FirstEnergy, the Davis-Besse plant operator, and one other plant operator chose not to conduct the nozzle inspections within the timeframe specified by the NRC.

the NRC failed to adequately review, assess, and follow up on relevant operating experience to bring about the necessary industry and plant-specific actions to prevent this event.³⁸⁷

The U.S. Government Accountability Office (GAO) conducted a separate study into the Davis-Besse incident, which it referred to as “the most serious safety issue confronting the nation's commercial nuclear power industry since Three Mile Island in 1979.” GAO noted that since the NRC considered FirstEnergy a good performer, the NRC conducted fewer inspections at the plant and asked fewer questions about plant conditions. This may have contributed to the extent of the degradation that was allowed to occur at the plant. GAO found that the risk assessment that the NRC used in deciding whether the plant should be shut down was flawed and that it underestimated the amount of risk that Davis-Besse posed. Furthermore, GAO found that the level of risk that the NRC estimated, even though underestimated, still exceeded risk levels generally accepted by the agency. GAO expressed concern that the NRC had proposed no actions to help identify early indications of deteriorating safety conditions at plants, decide whether to shut down a plant, and monitor actions taken in response to incidents at plants.³⁸⁸

These concerns were similar to those expressed by the NRC Office of the Inspector General. In an inquiry into the event, the Office of the Inspector General found that the “NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem, versus lack of reasonable assurance of maintaining public health and safety, before it will act to shut down a power plant.”³⁸⁹

The Union of Concerned Scientists also evaluated the NRC's role in the Davis-Besse incident and criticized the NRC's response to the incident. In particular, the Union of Concerned Scientists faulted the NRC for not aggressively pushing FirstEnergy when a safety problem presented itself.³⁹⁰ In fact, Union of Concerned Scientists alleged that the NRC and FirstEnergy agreed that there was a high likelihood that Davis-Besse was violating the conditions of its operating license and that they failed to act upon this potential safety violation.³⁹¹

Tube Degradation in Steam Generators

Steam generators are large heat exchangers that transfer heat from the radioactive primary reactor coolant to the nonradioactive secondary steam piping to provide motive power that turns the turbine-driven main electric generators. A pressurized water reactor (such as SONGS or Diablo Canyon) has at least two steam generators, each weighing up to 800 tons. Although

³⁸⁷ U.S. Nuclear Regulatory Commission. “Davis-Besse Reactor Vessel Head Degradation Lessons-Learned.” Task Force report. May 15, 2002, page viii. <<http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/lessons-learned/lltf-report.html>>.

³⁸⁸ U.S. Government Accountability Office. “Nuclear Regulation: NRC Needs to More Aggressively and Comprehensively Resolve Issues Related to the Davis-Besse Nuclear Power Plant's Shutdown.” Highlights, GAO-04-415. May 17, 2004. <<http://www.gao.gov/docdb/lite/details.php?rptno=GAO-04-415>>.

³⁸⁹ U.S. Nuclear Regulatory Commission, Office of the Inspector General. “NRC's Regulation of Davis-Besse Regarding Damage to the Reactor Vessel Head.” Case No. 02-03S. December 30, 2002, page 22.

³⁹⁰ Union of Concerned Scientists. “Anatomy of a Flawed Decision: NRC Has a Brain, But No Spine.” August 5, 2002, page 8.

³⁹¹ Union of Concerned Scientists. “Davis-Besse: One Year Later.” March 3, 2003, page 5.

originally designed to last the life of a plant, the thousands of tubes in steam generators have degraded more rapidly than expected. Degradation can lead to leaks of radioactive primary coolant and, in extreme cases, ruptured tubes leading to more severe plant problems.

Several methods are used to control steam generator degradation. Improved water chemistry is now widely used to reduce the rate of degradation. When inspections detect unacceptable levels of damage (e.g. cracks greater than 40 percent of a tube's wall thickness), the tube is sleeved, plugged, or treated with heat treatments, chemical cleaning, or other methods.³⁹² Sleeving involves inserting a new tube inside the damaged portion of the original tube. Sleeved tubes remain subject to degradation and may later need plugging. Plugging removes the tube from service. A plant can continue operating with a number of plugged tubes. However when too many tubes are plugged, the steam generator must be replaced in order to keep the plant operating at its rated output. Replacement costs are high, and the work can take several months. Steam generator replacement projects at SONGS and Diablo Canyon are expected to cost \$680 million to \$815 million at each plant.^{393, 394, 395}

As a result of steam generator tube leakage, the NRC developed a Steam Generator Action Plan in the early 1990s.³⁹⁶ In February 2000, a steam generator tube leaked at Indian Point Unit 2. Approximately 146 gallons per minute of radioactive reactor coolant leaked to the nonradioactive steam piping. The plant owner issued an "Alert" declaration, which is the second level of emergency action in the NRC-required emergency response plan. The event resulted in a minor radiological release to the environment that was within regulatory limits. No radioactivity was measured offsite above normal background levels, and the event did not adversely impact the public health and safety. However, the NRC deemed this to be a "risk-significant" event and, in response, significantly upgraded the Steam Generator Action Plan in November 2000.^{397, 398}

³⁹² U.S. Congress, Office of Technology Assessment. "Aging Nuclear Power Plants: Managing Plant Life and Decommissioning." OTA-E-575. September 1993, page 42. Accessed: June 30, 2008. <<http://www.princeton.edu/~ota/disk1/1993/9305/9305.PDF>>.

³⁹³ California Public Utilities Commission. "Decision 05-12-040." Application 04-02-026. December 15, 2005.

³⁹⁴ California Public Utilities Commission. "Decision 05-11-026." Application 04-01-009. November 18, 2005.

³⁹⁵ The steam generator replacement projects at SONGS and Diablo Canyon are described in *Nuclear Power in California: 2007 Status Report*, beginning on page 128.

³⁹⁶ U.S. Nuclear Regulatory Commission. "Steam Generator Action Plan." June 1, 2007. <<http://www.nrc.gov/reactors/operating/ops-experience/steam-generator-tube.html>>.

³⁹⁷ U.S. Nuclear Regulatory Commission. "Steam Generator Tube Failure at Indian Point Unit 2." June 28, 2000. <<http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2000/in00009.html>>.

³⁹⁸ Sheron, Brian W. Associate Director for Project, Licensing and Technical Analysis and Jon Johnson, Associate Director for Inspection and Programs. "NRC Steam Generator Action Plan Memorandum to Samuel J. Collins, Director Office of Nuclear Reactor Regulation." November 16, 2000. <<http://www.nrc.gov/reactors/operating/ops-experience/sgap/sgap-files/ml003770259.pdf>>. See also, <<http://www.nrc.gov/reading-rm/doc-collections/gen-comm/index.html>>.

One challenge in addressing steam generator degradation is the limitation of traditional inspection techniques to identify and precisely measure the size of cracks. The NRC issued Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes" in 1995, alerting plant operators about the importance of performing comprehensive examinations of tubes using appropriate inspection techniques and equipment capable of reliably detecting degradation. During the past decade, the industry has developed better methods of detecting cracks before tube integrity is potentially impaired. However, precisely measuring the size of cracks continues to be a challenge.

Metal Fatigue at Vermont Yankee and Oyster Creek

One potential source of age-related failure at a reactor is metal fatigue—the deterioration of a metal from the repeated cycles of thermal or mechanical loads or strains. Fatigue is one of the primary considerations when conducting a time-limited aging analysis as part of the NRC's General Design Criteria for nuclear power plants. Fatigue of various components in a reactor can result in pipe ruptures, component failures, and the migration of loose pieces of metal through the reactor system, which can interfere with the safe operation of a nuclear plant.

Intervenors in the Vermont Yankee and Oyster Creek relicensing proceedings have suggested that metal fatigue could become a safety hazard for these plants over a 20-year license renewal period.^{399, 400} Questions initially arose when Entergy submitted its relicensing application for the Vermont Yankee nuclear plant, and NRC staff responded that Entergy's calculation of cumulative usage factors of recirculation nozzles was not sufficiently thorough.⁴⁰¹ Dr. Hopenfeld, an expert witness for New England Coalition, Inc. in the Vermont Yankee proceeding, contended that the calculations (specifically the cumulative usage factor calculation for recirculation nozzles) could lead to an overestimation of the expected life of the nozzles by up to 40 percent.⁴⁰² Entergy submitted revised calculations in February 2008,⁴⁰³ but Dr.

³⁹⁹ U.S. Nuclear Regulatory Commission. "Vermont Yankee License Renewal Proceeding, Proceeding." NRC Docket No. 50-271-LR.

⁴⁰⁰ U.S. Nuclear Regulatory Commission. "Oyster Creek Generating Station License Renewal Proceeding." NRC Docket No. 50-219.

⁴⁰¹ A cumulative usage factor is the ratio of the number of cycles experienced by a structure or component divided by the number of allowable cycles for that structure or component (Lahey, November 2007); U.S. Nuclear Regulatory Commission. "Declaration of Dr. Richard T. Lahey, Jr. In the Matter Of Entergy Nuclear Operations, Inc." Docket Nos. 50-247 & 50-286, *Indian Point Nuclear Generating Unit Nos. 2 & 3, Regarding the Renewal of Facility Operating Licenses No. DPR-26 and No. DPR-64 for an Additional 20-year Period*. November 2007.

⁴⁰² Hopenfeld declaration, Joram. "Vermont Yankee License Renewal Proceeding ." Declaration. NRC Docket No. 50-271-LR. April 15, 2008, paragraph 6.

⁴⁰³ U.S. Nuclear Regulatory Commission, Commission. "Transcript of 549th Advisory Committee on Reactor Safeguards." Meeting on February 7, 2008 at 8-10.
<<http://adamswebsearch.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML081200041>)
[ViewDocByAccession.asp?AccessionNumber=ML081200041](http://adamswebsearch.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML081200041)>.

Hopenfeld was not satisfied with the adequacy of these calculations.⁴⁰⁴ The NRC Staff released proposed findings on the matter in August dismissing the New England Coalition's contentions and finding that Entergy's calculations are acceptable.⁴⁰⁵ Further, the NRC Staff found that Entergy demonstrated it can adequately manage the effects of aging for the specific components at issue.

In April 2008 the NRC notified all nuclear plant operators of its concern with the simplified analysis method and in particular asked AmGen, the operator of the Oyster Creek plant, to re-do its analysis.⁴⁰⁶ In response, the Nuclear Information and Resource Service (NIRS), a nuclear watchdog group, and other petitioners requested that the NRC reopen the record in the Oyster Creek relicensing proceeding. NIRS noted that since AmGen determined an initial cumulative usage factor for recirculation nozzles close to the maximum acceptable threshold, even if Oyster Creek's cumulative usage factor would rise by significantly less than 40 percent under the more robust analysis, Oyster Creek's recirculation nozzles would likely not be deemed fit for relicensing.⁴⁰⁷

Intervenors in the Oyster Creek proceeding have also asserted that the proposed metal fatigue monitoring for the recirculation nozzles is "inadequate to ensure that critical components do not exceed their allowable life... This issue is of high safety significance because even NRC's spokesman has conceded that failure of one of the components at issue could cause a severe accident."⁴⁰⁸

Both these relicensing proceedings are ongoing. It is unclear at this point how widespread fatigue problems are for recirculation nozzles and other vital plant components and what the implications of the NRC's more robust analysis requirement will be.

⁴⁰⁴ Seventh Declaration of Dr. Hopenfeld, Joram Hopenfeld. "Vermont Yankee License Renewal Proceeding." Seventh Declaration. NRC Docket No. 50-271-LR. March 17, 2008.

⁴⁰⁵ Nuclear Regulatory Commission. "NRC Staff's Proposed Findings of Fact and Conclusions of Law and Order in the Form of an Initial Decision." NRC Docket Nos. 50-271-LR and ASLB No. 06-849-03-LR. ADAMS Accession Number ML082401825. August 25, 2008.

⁴⁰⁶ On April 11, 2008, the NRC notified licensees to inform them that an analysis methodology used to demonstrate compliance with boiler and pressure vessel fatigue acceptance criteria could be "nonconservative" if not correctly applied; U.S. Nuclear Regulatory Commission. "Fatigue Analysis of Nuclear Power Plant Components." NRC Draft Regulatory Issue Summary. Issued for Public Comment May 1, 2008. <http://www.nirs.org/reactorwatch/licensing/oclr04142008nrcrisfat.pdf>; Federal Register 73 #85, pages 24094-24096.

⁴⁰⁷ Nuclear Information and Resource Service, Inc. et al. "Motion to Reopen the Record and for Leave to File a New Contention, and Petition to Add a New Contention." April 18, 2008. <<http://www.nirs.org/reactorwatch/licensing/oclr04172008citmotreopenfat.pdf>>.

⁴⁰⁸ Nuclear Information and Resource Service, Inc. et al. "Motion to Reopen the Record and for Leave to File a New Contention, and Petition to Add a New Contention." April 18, 2008. <<http://www.nirs.org/reactorwatch/licensing/oclr04172008citmotreopenfat.pdf>>.

Radiation-Induced Embrittlement of Reactor Pressure Vessels

Reactor components that are exposed to neutron bombardment are subject to embrittlement, which is a change in the mechanical properties (or structure) of the materials. Embrittled metals are more susceptible to failure from cracking or fracture.

During the Indian Point license extension proceeding, Dr. Richard Lahey of the Rensselaer Polytechnic Institute testified that embrittlement of reactor pressure vessels and associated internals as a result of long-term exposure to radiation is one of the most important age-related phenomena that the NRC must consider in relicensing Indian Point.⁴⁰⁹ One important safety concern is that the embrittlement would degrade the reactor's ability to withstand pressurized thermal shocks, such as might occur from a severe loss-of-cooling accident. This would threaten the integrity of internal structures in the reactor pressure vessel and the vessel itself, posing a potentially significant safety hazard.

The NRC proceeding addressing the relicensing of Indian Point is ongoing.

Tritium Releases

Tritium is a radioactive isotope of hydrogen that is formed as a byproduct of nuclear fission.⁴¹⁰ Similar to hydrogen, tritium can bond with oxygen to form a type of water called tritiated water. When ingested or inhaled in high concentrations, tritiated water can damage cells and increase the risk of cancer.⁴¹¹ At low concentrations (under 10,000 millirem), tritium poses little health risk.

Commercial nuclear plant operators routinely dilute tritiated water for safe release. These releases are planned, and they are regulated by the NRC to ensure that the impact on public health is very low.⁴¹² However, accidental releases of undiluted tritiated water have occurred at over a dozen domestic nuclear power plants, including a 1993 incident at Diablo Canyon and several incidents at SONGS. In addition, in some cases other radioactive elements have been released together with tritium, including cobalt-58, cobalt-60, cesium-134, cesium-137, nickel-63, and strontium-90.⁴¹³ Properly disposing of contaminated soil can be very expensive.

In response to public concern following well-publicized tritium releases, the NRC created a Liquid Radioactive Release Lessons Learned Task Force in 2006. The Task Force identified two

⁴⁰⁹ U.S. Nuclear Regulatory Commission. "Declaration of Dr. Richard T. Lahey, Jr. In the Matter Of Entergy Nuclear Operations, Inc." November 2007: 3, 9.

⁴¹⁰ A large nuclear power plant, such as Diablo Canyon or SONGS, produces roughly two grams of tritium each year with each gram containing 9,800 Curie of radioactivity. Argonne National Laboratory. "Tritium (Hydrogen-3)." Human Health Fact Sheet. August 2005. Accessed: May 12, 2008. <<http://www.ead.anl.gov/pub/doc/tritium.pdf>>.

⁴¹¹ Lifetime cancer mortality risk is estimated at 4×10^{-14} per picoCurie; Argonne National Laboratory. "Tritium (Hydrogen-3)." August 2005.

⁴¹² U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006, page i.

⁴¹³ U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006, page 11.

causes for inadvertent tritium releases: 1) leaking components, most often spent fuel pools, underground piping, and valves on effluent discharge lines; and 2) operator actions.⁴¹⁴ The largest leaks were caused by inadequate preventive maintenance and inadequate design configuration.⁴¹⁵

It is not clear whether there has been an increasing trend in the release of tritium and other radioactive elements in recent years. It can take years for the elements to reach groundwater, so recently discovered leaks may have occurred years ago, and leaks that have already occurred may not have been discovered. Some leaks are caused by operator action and are likely independent of plant aging; other leaks are caused by age-related degradation and may become more common as the nuclear plants age. Nuclear plant owners have an incentive to prevent or mitigate tritium releases from their plants in that the discovery of previously undetected spills can significantly add to cleanup and decommissioning costs.

In January 2008, the Electric Power Research Institute (EPRI) released guidelines for a voluntary groundwater monitoring program at all U.S. nuclear plants.⁴¹⁶ EPRI also recommended that a comprehensive evaluation be conducted of all systems, structures, and components (SSCs) that contain or could contain radioactive liquids, including radwaste systems, sumps and drains, and spent fuel storage pools. EPRI recommended a review of the preventive maintenance and inspection programs of each of these SSCs and an evaluation of work practices that could potentially contribute to groundwater contamination.⁴¹⁷

The main health risk from unintended releases is that the radioactive elements could contaminate groundwater and drinking supplies. The NRC's Task Force determined that the inadvertent releases of tritium and other radioactive liquids have had a negligible impact on public radiation doses, though many of the releases did increase the radioactive contamination within the nuclear plant sites.⁴¹⁸ As there are no sources of potable groundwater at Diablo Canyon or SONGS, risk of drinking supply contamination from these plants is relatively low.⁴¹⁹

Implications for Diablo Canyon and SONGS

The NRC study on degradation of reactor components and the experiences described above indicate that plant component degradation is occurring at nuclear plants and that, if not properly monitored, degradation could impair safety and lead to extended outages. As

⁴¹⁴ U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 3.

⁴¹⁵ U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 24.

⁴¹⁶ Electric Power Research Institute. "Groundwater Protection Guidelines for Nuclear Power Plants." Report 1016099, Public Edition. January 2008, page v.

⁴¹⁷ Electric Power Research Institute. "Groundwater Protection Guidelines for Nuclear Power Plants." January 2008, Chapter 3.

⁴¹⁸ U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 13.

⁴¹⁹ See full discussion in Nuclear Power in California: 2007 Status Report, pages 176-177.

pressurized water reactors, Diablo Canyon and SONGS could be susceptible to the steam generator degradation, metal fatigue, embrittlement, and tritium releases described above. Indeed, the steam generators at the plants will be replaced between 2008 and 2010 and the reactor vessel heads will be replaced between 2009 and 2012.⁴²⁰ Other components are also susceptible to age-related degradation.

The reactor pressure vessel head cavity at Davis-Besse could have posed a significant safety hazard had it not been detected. Questions about the sufficiency of NRC oversight in this case highlight the importance of plant operators' taking maintenance and inspections seriously. This is discussed further below in the section on Mitigating Plant Degradation through Maintenance.

Even if Diablo Canyon and SONGS are well run and well maintained, the plants could be impacted by problems at other nuclear plants. For example, following the Davis-Besse incident the NRC ordered all owners of pressurized water reactors to inspect the reactor pressure vessel heads at their plants. A more serious incident or the identification of a safety hazard at one plant could result in a regulatory requirement for more extensive inspections, repairs, and even outages at similar plants nationwide.⁴²¹

Mitigating Plant Degradation through Maintenance

Maintenance plays a central role in mitigating age-related component degradation and failure. Maintenance can involve repair or replacement of components which, through inspection, are found to be showing signs of stress or failure. Ensuring that maintenance is performed effectively and that aging plant components are repaired or replaced with appropriate components in a timely fashion is best achieved through aggressive maintenance programs.

The NRC "Maintenance Rule"

NRC requirements relating to SSC maintenance, reliability, and availability are primarily regulated via the "Maintenance Rule" (Figure 31).⁴²² The primary objective of the Maintenance Rule is to ensure the following:

- Safety-related and certain non-safety related SSCs are capable of performing their intended functions.
- Failures of non-safety related SSCs do not occur that prevent the fulfillment of safety-related functions.
- Failures resulting in reactor trips and unnecessary activations of safety-related systems are minimized.

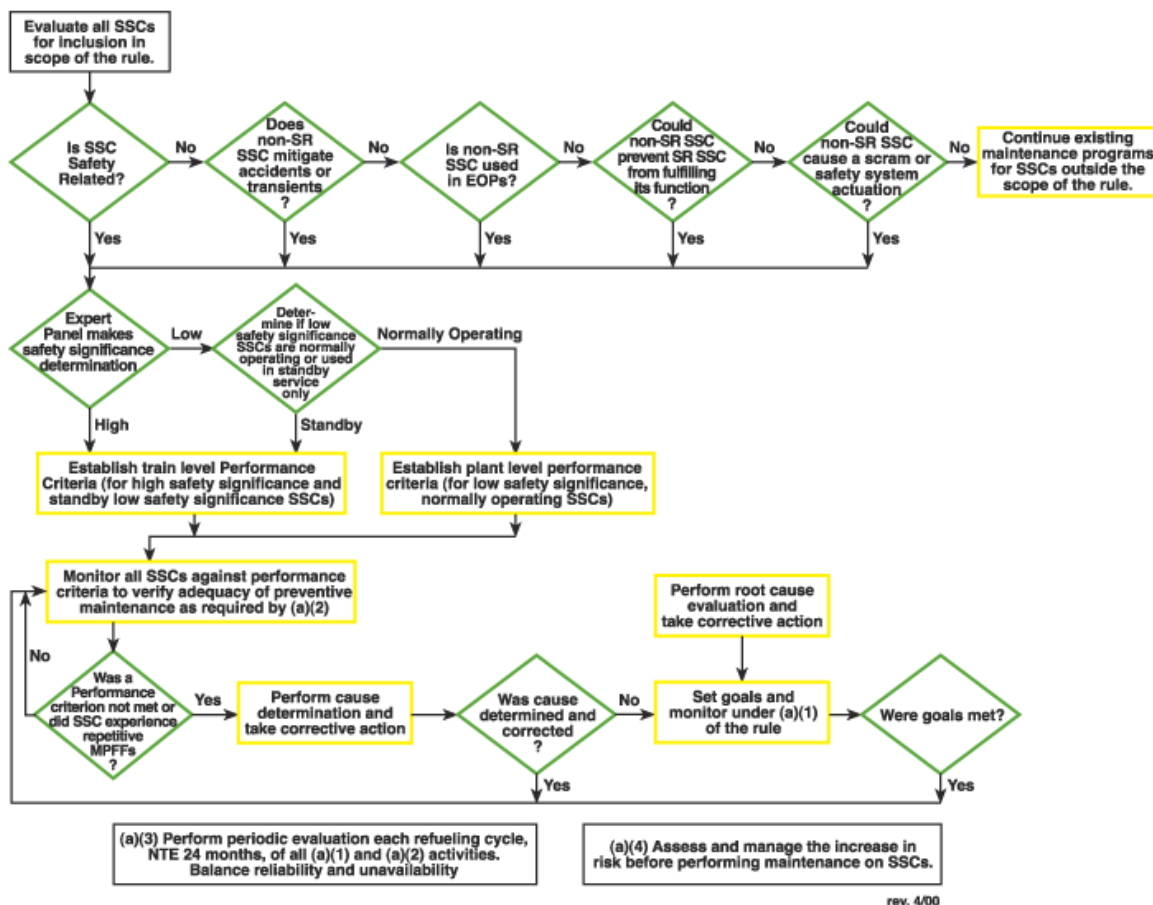
⁴²⁰ PG&E Supplemental Response to Data Request L.4; SCE Data Request Response G1, CEC 2007 IEPR-SCE-02.

⁴²¹ In less serious cases, the NRC simply informs plant owners of events or conditions at one plant that could also be of concern for their plants. This does not impose a specific regulatory requirement, but it does impose pressure on plant owners to investigate and resolve issues of potential concern.

⁴²² 10 CFR 50.65, the "Maintenance Rule."

PG&E and SCE report that both Diablo Canyon and SONGS maintenance programs are in compliance with the Maintenance Rule (see “Diablo Canyon and SONGS Maintenance Programs”).⁴²³ The Consultant Team does not have any information to suggest otherwise.

Figure 31: Simplified Maintenance Rule Flow Chart⁴²⁴



Some nuclear watchdog groups are critical of nuclear plant maintenance programs. In a 2006 report, the Union of Concerned Scientists reviewed the causes of long-term (one year or longer) outages at nuclear plants and concluded that existing quality assurance programs were inadequate.⁴²⁵ (These programs, called Corrective Action Plans, are one element of the Maintenance Rule.) The report further recommended tighter NRC oversight concerning these

⁴²³ Pacific Gas & Electric. “PG&E’s Response to Data Requests AB 1632 Study Report.” March 25, 2008. Request L.2; Southern California Edison. “SCE response to AB 1632 Nuclear Power Plant Assessment: Data Request for San Onofre Nuclear Generating Station (SONGS).” Request L.2.

⁴²⁴ Nuclear Energy Institute. “Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants.” NUMARC 93-01, Revision 2. April 1996.

⁴²⁵ Lochbaum, David. “Walking the Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages.” *Union of Concerned Scientists*. Cambridge, MA. 2006.

programs and that all available reactor data be integrated “so NRC staff around the country can ‘connect the dots’ about potential problems at similar reactors.”⁴²⁶

The Mitigating Systems Performance Index

The Mitigating Systems Performance Index (MSPI) is the NRC’s relatively new risk-informed performance index.⁴²⁷ The MSPI is one component of the broader Reactor Oversight Process framework, which is the current regulatory framework for ensuring reactor performance and safety. Under the Reactor Oversight Process, reactor performance is measured across seven areas: initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection. This process is discussed further in *Nuclear Power in California: 2007 Status Report*.⁴²⁸

Prior to 2006, the NRC relied upon the Safety System Unavailability Performance Indicators to assess nuclear plant safety system performance. By 2002, the NRC and industry found that the indicators had “significant shortcomings.”⁴²⁹ NRC staff and industry members collaboratively developed what became known as the Mitigating Systems Performance Index (MSPI), and the NRC conducted a year-long pilot evaluation of the proposed index at 20 plants. Based on the pilot and comments within the industry and others, the MSPI was refined and fully implemented in September 2006.⁴³⁰

In simple terms, the MSPI reflects the composite average performance of important components and equipment within a monitored system over a 3-year period. In mathematical terms, the MSPI is the sum of two indices: an unavailability index and an unreliability index. The sum of the unavailability index and the unreliability index provide a single value for a monitored system that is expressed in terms of a change in core damage frequency.⁴³¹

Licensees report both an unavailability index and an unreliability index value for each of five monitored systems: emergency alternating current power, high pressure safety injection system, auxiliary feedwater, residual heat removal system, and the cooling water support system.⁴³² The NRC indicates the MSPI value through the use of a color-coded system from green (best) to red

⁴²⁶ Lochbaum, David. “Walking the Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages.” 2006.

⁴²⁷ “Mitigating systems” in a nuclear power plant are those that provide emergency cooling water for the nuclear fuel and their support systems, such as emergency power and support system cooling.

⁴²⁸ MRW & Associates, Inc. *Nuclear Power in California: 2007 Status Report*. Prepared for the 2007 Integrated Energy Policy Report. October 2007.

⁴²⁹ Nuclear Energy Institute. “New Performance Index Provides Closer Look At Nuclear Plant Safety Systems.” Fact Sheet. Washington, DC. 2006.

⁴³⁰ See, for example, the August 23, 2003 letter from the *Union of Concerned Scientists* to John W. Thompson.

⁴³¹ U.S. Nuclear Regulatory Commission. “Regulatory Issue Summary 2006-07: Changes to the Safety System Unavailability Performance Indicators.” RIS 2006-07. June 12, 2006.

⁴³² Data and information used in the MSPI calculation are derived from the at-power, Level 1 plant PRA.

(worst). All units at both Diablo Canyon and SONGS have been given “green” MSPI performance indicators (the highest) since the second quarter of 2006, when MSPI was initiated.^{433, 434}

Diablo Canyon and SONGS Maintenance Programs

PG&E reports that it “undertakes a formal Equipment Reliability Process which integrates a broad range of activities into one process. Using this process, personnel can evaluate important plant equipment, develop and implement long-term equipment health plans, monitor equipment performance and condition, and make adjustments to preventive maintenance tasks and frequencies based on equipment operating experience.”

SCE reports that “SONGS’ maintenance and surveillance programs are designed to provide assurance that plant equipment will fulfill its design functions and perform reliably. To achieve this goal, we rigorously test and evaluate the performance of those systems to ensure they are performing as designed. We also maintain and upgrade our equipment on an on-going basis.”

Sources: Pacific Gas & Electric. “PG&E’s Response to Data Requests AB 1632 Study Report.” March 25, 2008. Request L.2; and Southern California Edison. “SCE response to AB 1632 Nuclear Power Plant Assessment: Data Request for San Onofre Nuclear Generating Station (SONGS).” Request L.2.

Safety Culture

The NRC defines safety culture as “the necessary full attention to safety matters,” and, “the personal dedication and accountability of all individuals engaged in any activity which has a bearing on the safety of nuclear power plants.”⁴³⁵ Important attributes of safety culture include practice of safety-over-production, procedural adherence, conservative decision-making, and willingness of employees to identify safety concerns.⁴³⁶ The final attribute is also known as a safety-conscious work environment.

⁴³³ U.S. Nuclear Regulatory Commission. “Diablo Canyon 2, 1/Q 2008 Performance Indicators.” April 30, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB2/diab2_pi.html#IE01>; U.S. Nuclear Regulatory Commission. “Diablo Canyon 1, 1/Q 2008 Performance Indicators.” April 30, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB1/diab1_pi.html#IE01>; U.S. Nuclear Regulatory Commission. “San Onofre 2, 1/Q 2008 Performance Indicators.” April 30, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO2/sano2_pi.html#PR01>; U.S. Nuclear Regulatory Commission. “San Onofre 3, 1/Q 2008 Performance Indicators.” April 30, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO3/sano3_pi.html#PR01>.

⁴³⁴ Potentially excluding Security Performance Indicators, which are not publicly available.

⁴³⁵ U.S. Nuclear Regulatory Commission. “Recommended Staff Actions Regarding Agency Guidance in the Areas of Safety Conscious Work Environment and Safety Culture.” SECY-04-0111. July 1, 2004, page 2. Accessed: July 1, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2004/secy2004-0111/2004-0111scy.pdf>>.

⁴³⁶ U.S. Nuclear Regulatory Commission. SECY-04-0111. July 1, 2004: 2.

In a safety conscious work environment “employees feel free to raise safety concerns, both to their management and to the NRC, without fear of retaliation.”⁴³⁷ A safety-conscious work environment fosters motivation among workers to identify potential safety issues and to proactively work towards correction. Because correction of safety issues, including the replacement of degraded components, can be expensive to the operating utility, there may be a company-level incentive to ignore safety issues that are not considered urgent. To prevent accidents it is crucial that employees at all levels be rewarded, not punished, for identification of potential safety issues. As the plants age and the likelihood of component degradation increases, a good safety culture and a safety-conscious work environment become all the more important.

Implications of a Weak Safety Culture

Problems with safety culture have been linked to high profile near-misses and operational issues. For example, the NRC determined that weak safety culture was a root cause of the incident at Davis Besse.⁴³⁸ In the wake of the incident, the NRC modified the Reactor Oversight Program to better identify problems with safety culture.⁴³⁹

Palo Verde Nuclear Generating Station (Palo Verde) in Arizona has also experienced a number of operational issues that have been partially attributed to poor safety culture. As discussed in detail in *Nuclear Power in California: 2007 Status Report*, Palo Verde’s performance has degraded significantly since 2002.⁴⁴⁰ The plant has experienced multiple reactor trips and unplanned outages and has operated at a low capacity factor. In 2004 the NRC attributed the cause of an incident at the plant to “a lack of questioning attitude, lack of technical rigor and poor operability determinations by workers.”⁴⁴¹ Since that time, the technical issues have been resolved but the plant operator, Arizona Public Service, has not effectively remedied the safety culture issues.⁴⁴² In late 2006, the NRC cited Palo Verde for further issues and downgraded the plant’s Unit 3 reactor to the “Multiple/Repetitive Degraded Cornerstone” category, the fourth lowest of five regulatory classifications.⁴⁴³ If downgraded further, Palo Verde would be deemed unfit to continue operating.

⁴³⁷ U.S. Nuclear Regulatory Commission. SECY-04-0111. July 1, 2004: 2.

⁴³⁸ U.S. Nuclear Regulatory Commission. SECY-04-0111. July 1, 2004: 3.

⁴³⁹ U.S. Nuclear Regulatory Commission. “Safety Culture Initiative Activities to Enhance the Reactor Oversight Process and Outcomes of the Initiatives.” SECY-06-0122. May 24, 2006, page 1. Accessed: July 1, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2006/secy2006-0122/2006-0122scv.pdf>>.

⁴⁴⁰ MRW & Associates, Inc. “Nuclear Power in California: 2007 Status Report.” October 2007: 219.

⁴⁴¹ U.S. Nuclear Regulatory Commission. “NRC Chairman Dale Klein Discusses Palo Verde Nuclear Plant.” No. 07-026. February 23, 2007.

⁴⁴² U. S. Nuclear Regulatory Commission. “Palo Verde 2: 1Q/2008 Plant Inspection Findings.” June 5, 2008. Accessed: July 7, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/PALO2/palo2_pim.html>.

⁴⁴³ As of the first quarter of 2008, Palo Verde Unit 3 was the lowest rated reactor in the country and the only reactor in its category; U.S. Nuclear Regulatory Commission. “1Q/2008 ROP Action Matrix Summary.” May 7, 2008. Accessed July 7, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/actionmatrix_summary.html>.

In the 2007 annual assessment of Palo Verde, the NRC found persistent issues related to human performance and problem identification and resolution.⁴⁴⁴ The NRC noted that this was the seventh consecutive assessment since March 2005 to identify these issues and that Arizona Public Service's corrective actions had been ineffective. The NRC determined that Palo Verde's self-assessment lacked depth and that Arizona Public Service did not always effectively specify or implement corrective actions. The NRC required Arizona Public Service to undergo a series of inspections, including an independent safety culture analysis which was conducted in October 2007. In response to the findings from the independent safety culture assessment, Arizona Public Service formulated an action plan to address underlying safety culture issues.⁴⁴⁵

It is evident from Palo Verde's experience that safety culture issues can be far-reaching and difficult to address. In this case, self-assessment has been insufficient to correct safety culture issues and problems persist years after original identification in 2004. It is unclear how effective the Arizona Public Service safety culture action plan will be at correcting the problems, and the Arizona Corporation Commission expects Palo Verde to remain in the Multiple/Repetitive Degraded Cornerstone category for roughly two to four years.⁴⁴⁶

Safety Culture at Diablo Canyon

Diablo Canyon has not received any significant enforcement actions from the NRC since 1995, when unescorted access was granted to a contract employee who should have been denied access.⁴⁴⁷ NRC inspections between June 2007 and June 2008 revealed just seven findings, six of which were classified as non-cited violations and determined to be of little safety significance.⁴⁴⁸ The findings included discovery of a degraded fire door, inadequate maintenance procedures, failure to identify a degraded emergency diesel generator, and failure to effectively monitor for radioactive particulate matter. In all cases, the NRC noted underlying safety culture issues in terms of human performance, work practices, decision-making, and problem identification and resolution.⁴⁴⁹

Members of the public and nuclear plant workers are encouraged to submit safety allegations to the NRC. These allegations are generally handled confidentially and may be pursued by NRC

⁴⁴⁴ U.S. Nuclear Regulatory Commission. "Annual Assessment Letter –Palo Verde Nuclear Generating Station." March 3, 2008, page 2.

⁴⁴⁵ Arizona Public Service. "Response to NRC Confirmatory Action Letter (CAL)-4-07-004, Action 5: Submittal of Portions of the Modified Improvement Plan." December 31, 2007, page 19.

⁴⁴⁶ California Energy Commission. "Transcript of CEC June 28, 2007 Workshop on Nuclear Power Issues." June 28, 2007, page 65.

⁴⁴⁷ U.S. Nuclear Regulatory Commission. "EA-96-123 - Diablo Canyon 1 & 2 (Pacific Gas & Electric Company)." June 7, 1996. Accessed: July 8, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/enforcement/actions/reactors/ea96123.html>>.

⁴⁴⁸ U.S. Nuclear Regulatory Commission. "Diablo Canyon 1 - 1Q/2008 Plant Inspection Findings." June 5, 2008. Accessed: July 8, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB1/diab1_pim.html#IE1st>.

⁴⁴⁹ U.S. Nuclear Regulatory Commission. "Diablo Canyon 1 - 1Q/2008 Plant Inspection Findings," June 5, 2008.

investigation and result in enforcement action.⁴⁵⁰ Only two of 13 allegations that were submitted regarding Diablo Canyon between 2004 and 2007 have been substantiated by the NRC and none have resulted in enforcement action.⁴⁵¹ There has been, however, a recent spike in allegations regarding Diablo Canyon—10 allegations were submitted between January and May 2008. At this point it is for the most part unclear whether these allegations will be substantiated and whether they will result in enforcement action.

San Luis Obispo Mothers for Peace (MFP) filed one of the allegations, stating in a letter in April 2008 that it had received information from Diablo Canyon employees reporting that workers perceive a high likelihood of managerial retaliation if they raise safety concerns.⁴⁵² The allegation describes an incident in which a worker received a poor performance evaluation after filing a Difference of Professional Opinion. In addition, MFP alleges that workers have lost trust in the Employee Concerns group and that PG&E has skirted qualifications requirements in hiring new supervisors and managers.⁴⁵³ According to MFP, the NRC investigation found that while a few employees believed that another individual had been subjected to retaliation for raising a Differing Professional Opinion and some individuals lacked confidence in the Employee Concerns Group, these beliefs would not prevent the employees from raising concerns. The NRC thus concluded that the allegation was not substantiated.⁴⁵⁴

In addition to NRC regulation, safety at Diablo Canyon is monitored by the Institute for Nuclear Power Operations (INPO) and the Diablo Canyon Independent Safety Committee (DCISC) (see text box below). Extensive involvement from the local San Luis Obispo community also provides an extra layer of public oversight.

INPO is a private, industry-funded agency that uses peer pressure to encourage enhanced safety and reliability at U.S. nuclear power plants.⁴⁵⁵ As part of this effort, INPO conducts plant inspections and rates each nuclear plant on a quarterly basis. For the first half of 2007, INPO rated Diablo Canyon's overall performance at 96.4 out of 100.⁴⁵⁶ This represents a marked improvement over Diablo Canyon's 1996 rating of 64.9 and 2003 rating of 82.1.⁴⁵⁷

⁴⁵⁰ U.S. Nuclear Regulatory Commission. "Reporting Safety Concerns to the NRC." NUREG/BR-0240, Rev. 3. April 2005.

⁴⁵¹ U.S. Nuclear Regulatory Commission. "Statistics on Allegations." June 17, 2008. Accessed: July 8, 2008. <<http://www.nrc.gov/about-nrc/regulatory/allegations/statistics.html>>.

⁴⁵² Mothers for Peace. "Diablo Canyon Safety Allegations." April 14, 2008. Accessed: July 8, 2008. <<http://mothersforpeace.org/issues/workers/allegations/04142008/>>.

⁴⁵³ Mothers for Peace. "Diablo Canyon Safety Allegations." April 14, 2008.

⁴⁵⁴ Mothers for Peace. "Comments on AB 1632 Assessment of California's Operating Nuclear Plants, Draft Report, September 2008, CEC-100-2008-005-D." September 30, 2008. Accessed: October 7, 2008. <http://www.energy.ca.gov/2008_energypolicy/documents/2008-09-25_workshop/comments/>.

⁴⁵⁵ For a more comprehensive discussion of the INPO and NRC regulatory frameworks, see "Nuclear Power in California: 2007 Status Report," pages 207-216.

⁴⁵⁶ Pacific Gas & Electric. Letter to the Energy Commission Re: 2007 Integrated Energy Policy Report. August 30, 2007.

⁴⁵⁷ Pacific Gas & Electric. Letter to the Energy Commission. August 30, 2007.

The DCISC, in its most recent annual report covering the year ending June 30, 2007, also concluded that Diablo Canyon had operated safely. DCISC found that Diablo Canyon had increased its emphasis on safety culture in part by formalizing Safety Culture and Safety Conscious Work Environment programs that conduct quarterly surveys to assess organization-wide safety culture. DCISC also identified several concerns. Among these concerns, the DCISC noted that the emergency preparedness program and fire protection scheme need improvement and that recent NRC licensed operator exams showed a high failure rate. The DCISC will continue to investigate these concerns.⁴⁵⁸

Diablo Canyon Independent Safety Committee (DCISC)

In 1988 the CPUC established the Diablo Canyon Independent Safety Committee (DCISC) as part of a PG&E rate proceeding. The committee is tasked with “reviewing and assessing the safety of operations” of Diablo Canyon. Three members are appointed by the Energy Commission, the Attorney General and the Governor’s Office and serve staggered three-year terms on the committee. Committee members conduct public meetings twice each year, visit the plant, and are given extended access to Diablo Canyon reports and records. Each year the committee issues an annual report on its findings.

Source: Diablo Canyon Independent Safety Committee. “DCISC 17th Annual Report.” July 1, 2006 – June 30, 2007. <<http://www.dcisc.org/annual-report-17-2006-2007/preface.html>>.

Safety Culture at SONGS

The NRC has issued several enforcement actions and notices of violations to SCE over the past decade. In the late 1990s SCE received three separate enforcement actions regarding failure to comply with technical specifications and the loss of the safeguards contingency plan.⁴⁵⁹ In 2006 SONGS incurred another violation when workers failed to properly secure a canister of low-level waste before transport, and a small amount of low-activity radioactive material leaked from the tanker onto the ground.⁴⁶⁰ Because workers discovered the leak and removed the material shortly after the release occurred and SCE initiated remedial action, the NRC determined that the incident had low safety consequences.⁴⁶¹

Between November 2006 and January 2008, SONGS received enforcement action for five willful violations.⁴⁶² Among the violations, SONGS workers failed to follow a Radiation Work Permit

⁴⁵⁸ Diablo Canyon Independent Safety Committee. “DCISC 17th Annual Report.” July 1, 2006 – June 30, 2007. <<http://www.dcisc.org/annual-report-17-2006-2007/preface.html>>.

⁴⁵⁹ U.S. Nuclear Regulatory Commission. “Escalated Enforcement Actions Issued to Reactor Licensees.” January 14, 2008. Accessed: July 9, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/enforcement/actions/reactors/s.html#SanOnofre>>.

⁴⁶⁰ U.S. Nuclear Regulatory Commission. “Notice of Violation (NRC Inspection Report No. 050-00206/06-011).” EA-06-149. September 13, 2006.

⁴⁶¹ U.S. Nuclear Regulatory Commission. “Notice of Violation (NRC Inspection Report No. 050-00206/06-011).” September 13, 2006.

⁴⁶² U.S. Nuclear Regulatory Commission. “Confirmatory Order.” EA-07-232. January 11, 2008, page 2.

and failed to control work of unqualified technicians operating on safety-related equipment.⁴⁶³ In 2007 SONGS notified the NRC that a midnight shift employee had, over a period of five and one-half years, deliberately falsified fire watch records to indicate that hourly fire watch rounds had been completed when they had not been.⁴⁶⁴ NRC inspections between June 2007 and June 2008 yielded 19 separate findings. Of these findings, 14 were classified as non-cited violations and one was classified as a violation.⁴⁶⁵ All of the findings were found to have low safety significance. Among the findings, the NRC identified crosscutting aspects of human performance, problem identification and resolution, and work practices as potential safety culture issues.

As a result of these incidents and violations, the Energy Commission and the NRC have become concerned that there may be an underlying problem with the safety culture at SONGS. In January 2008, Energy Commissioner James Boyd, State Liaison Officer to the U.S. Nuclear Regulatory Commission, expressed concern to SCE regarding these reports of lapses in the safety culture at SONGS.⁴⁶⁶ That same month, the NRC ordered SCE to undertake a series of tasks to improve SONGS' safety culture.⁴⁶⁷ Among these tasks, SCE was required to develop a Corrective Action Plan, to conduct multi-day interventions with plant employees to reinforce safety culture values, and to undergo an independent safety culture assessment.⁴⁶⁸

SCE recently discovered additional falsified work records at the plant. SCE is currently investigating an incident in which a supervisor appears to have falsely reported that monitoring of painting tasks at the plant had taken place.⁴⁶⁹ At this time it is unclear whether the NRC will seek enforcement action related to this incident.

In a September 2008 inspection report, the NRC noted new instances of employees not being provided with adequate procedures or work instructions and of corrective action programs failing to address the root causes of problems.⁴⁷⁰ Concerned with the persistence of these

⁴⁶³ U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 2.

⁴⁶⁴ U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 2.

⁴⁶⁵ U.S. Nuclear Regulatory Commission. "San Onofre 2 - 1Q/2008 Plant Inspection Findings." June 5, 2008. Accessed: July 8, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/SANO2/sano2_pim.html#IE1st>.

⁴⁶⁶ California Energy Commission. Letter from Commissioner James Boyd, Energy Commission, to Richard Rosenblum, Senior Vice President and Chief Nuclear Officer at Southern California Edison Company. January 22, 2008.

⁴⁶⁷ U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 4.

⁴⁶⁸ U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 4.

⁴⁶⁹ Sisson, Paul. "More falsified documents investigated at San Onofre." *North County Times*. June 28, 2008. Accessed: July 9, 2008. <<http://www.nctimes.com/articles/2008/06/28/news/coastal/oceanside/z479b66a2869a9481882574750060d7e3.txt>>.

⁴⁷⁰ U.S. Nuclear Regulatory Commission. "Midcycle Performance Review and Inspection Plan – San Onofre Nuclear Generating Station." September 2, 2008.

problems, the NRC has requested that SCE address these issues at a public meeting with the NRC.⁴⁷¹

INPO has also reportedly identified deficiencies at SONGS. According to a report by the Los Angeles Times based on an internal SONGS newsletter, SONGS ranks among the bottom 25 percent of all U.S. nuclear plants in overall performance. The report noted that employee injury rates at SONGS are several times higher than the industry average and are the highest among all the plants and that SONGS “lags far behind in areas such as power production and the readiness of backup safety systems.”⁴⁷² According to the report, INPO rated SONGS as a three on a five-point scale.⁴⁷³

There is no independent safety committee at SONGS similar to the DCISC. However, SCE does monitor the safety culture at SONGS via employee surveys. Survey results reveal an employee perception that safety culture at the plant improved from good (about 3.5 on a five-point scale) in 1996 to very good (about 4.0) in 2000 and 2003. Survey results declined slightly (to about 3.9) in 2005.⁴⁷⁴ SONGS’ management concluded that the results of these surveys are unsatisfactory and that improvement is needed.⁴⁷⁵

As with Palo Verde, it may prove difficult for SCE to remedy underlying safety culture issues at SONGS. In fact, SONGS maintenance employees recently discovered a loose electrical connection on an emergency battery that left it inoperable and that similar issues had occurred for over three years.⁴⁷⁶ In response the NRC conducted a special inspection beginning on August 4, 2008. A report on the findings is expected in mid-September 2008.⁴⁷⁷

Plant Staffing and Training

In order for nuclear plants to maintain a strong safety culture and a safety-conscious work environment, they must be fully staffed with well-trained employees. This could become more difficult in coming years since the nuclear energy industry is faced with a potential workforce shortage. According to the NRC, tens of thousands of professionals and skilled craft workers will be needed in coming years to replace retiring workers and to assist in the construction of

⁴⁷¹ U.S. Nuclear Regulatory Commission. September 2, 2008.

⁴⁷² Los Angeles Times. “San Onofre Nuclear Power Plant Feeling Regulatory Pressure.” Reported by Elizabeth Douglas. August 19, 2008.

⁴⁷³ INPO has two ratings systems, one based on a five-point scale and one based on a 100-point scale. Both ratings are confidential. The INPO ratings for SONGS and Diablo Canyon are based on information publicly released by the utilities. One uses the five-point scale and the other uses the 100-point scale. Additional information on the plants’ ratings are not publicly available.

⁴⁷⁴ Southern California Edison. “SONGS’ Safety Conscious Work Environment and Nuclear Safety Culture.” Presentation to the NRC. May 2006, pages 8, 11.

⁴⁷⁵ Southern California Edison. “SONGS’ Safety Conscious Work Environment and Nuclear Safety Culture.” May 2006: 20.

⁴⁷⁶ U.S. Nuclear Regulatory Commission. “NRC Conducting Special Inspection at San Onofre Nuclear Plant.” News Release No. IV-08-033, July 30, 2008.

⁴⁷⁷ U.S. Nuclear Regulatory Commission. July 30, 2008.

new plants.⁴⁷⁸ The NRC forecasts that 90,000 new workers will be needed by 2011 to continue operating current plants.⁴⁷⁹ A 2001 study by NEI estimated that demand for nuclear engineering graduates would be about 150 percent of supply by 2010.⁴⁸⁰ Great need similarly exists in other employment categories such as qualified radiation protection professionals. According to NEI, demand for these workers is currently 130 percent of supply and is expected to reach 160 percent in the next five years.⁴⁸¹ These projected shortages are driven by the demographics of an aging workforce: NEI estimates that only 8 percent of nuclear industry employees are younger than 32 and that one-third to one-half of industry workers will be eligible to retire by 2015.^{482, 483}

The workforce demographics at Diablo Canyon and SONGS roughly match the national trend. In 2006 the average age of Diablo Canyon employees was 47.6, and 42 percent of employees were within five years of being eligible for retirement with full benefits.⁴⁸⁴ Similarly, the median age of SONGS employees was around 45 in 2005, and roughly 30 percent of the SONGS workforce was 53 or older (Figure 32).⁴⁸⁵ In anticipation of skilled worker retirements, PG&E and SCE have intensified their recruiting and training efforts in recent years at an annual cost of roughly \$1 million to \$3 million per year.⁴⁸⁶

In addition to short-term increases in recruiting and training expenses, utilities could face operational challenges as experienced workers are replaced by new hires. A recent study by the American Public Power Association found that loss of critical knowledge would be the biggest challenge facing public power utilities as a result of upcoming retirements.⁴⁸⁷ In its 2005 survey, 62 percent of respondents reported that the inability to find replacements with utility-specific

⁴⁷⁸ U.S. Nuclear Regulatory Commission. "Testimony by Dale E. Klein, Chairman." March 28, 2007.

⁴⁷⁹ U.S. Nuclear Regulatory Commission. "Maintaining a Competent and Dedicated Workforce." Speech by Peter B. Lyons, NRC Commissioner. May 1, 2008, page 3.

⁴⁸⁰ Nuclear Energy Institute (NEI). "Nuclear Energy Industry Initiatives Target Looming Shortage of Skilled Workers." January 2007. Accessed: May 6, 2008. <http://www.nei.org/filefolder/nuclear_energy_industry_initiatives_target_looming_shortage_of_workers_0107.pdf>.

⁴⁸¹ Nuclear Energy Institute, January 2007.

⁴⁸² Stiles-Shell, Lisa, Nuclear Energy Institute. "2015: Do You Know Where Your Work Force Is?" Speech. May 19, 2006. Accessed: May 6, 2008. <<http://www.nei.org/newsandevents/speechesandtestimony/2006/assemblystilesshellextended/>>.

⁴⁸³ Nuclear Energy Institute, January 2007.

⁴⁸⁴ Pacific Gas & Electric. "Testimony in 2007 General Rate Case." A.05-12-002. Exhibit 3, pages 4-14.

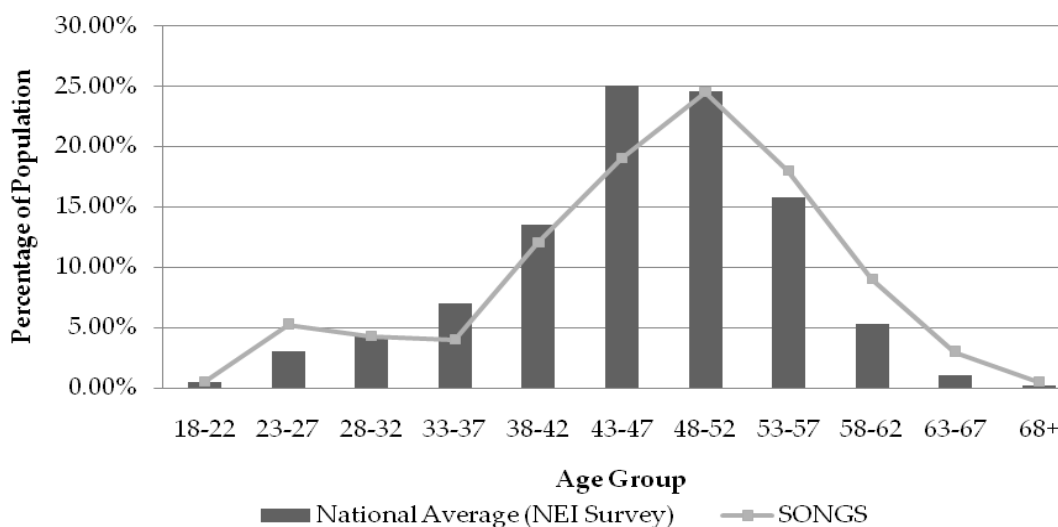
⁴⁸⁵ Southern California Edison. "2009 GRC Testimony Part 2." Volume 2. A.07-11-011, page 13.

⁴⁸⁶ SCE increased SONGS recruiting expenses from roughly \$300,000 in 2005 to over \$1.3 million in 2008, and SCE requested \$1.8 million for 2009. (All figures in 2006 dollars.) PG&E requested \$3 million in Diablo Canyon hiring and training costs for 2007, primarily due to additional labor costs. PG&E anticipated these costs to decrease to \$1 million in 2009. (Costs are in constant 2006 dollars.) Southern California Edison. "2009 GRC Testimony Part 2." Pages 36-37 and workpapers, page 261; Pacific Gas & Electric. "Testimony in 2007 General Rate Case." Pages 4-15.

⁴⁸⁷ American Public Power Association. "Workforce Planning for Public Power Utilities: Ensuring Resources to Meet Projected Needs." 2005, page 6.

skills was also a challenge.⁴⁸⁸ Successful recruiting and effective training and knowledge transfer are critical for ensuring that the plants continue to operate safely and reliably.

Figure 32: SONGS Workforce Demographics⁴⁸⁹



In response to potential labor availability issues, PG&E and SONGS are implementing new recruitment tactics. PG&E is currently seeking to hire 50-75 engineers, but anticipates that it will be difficult to recruit them.⁴⁹⁰ PG&E has also launched a new program to collaborate with community colleges, community-based organizations, workforce investment boards and labor unions in order to recruit new employees.⁴⁹¹ SCE has supplemented its recruitment processes by offering sign-on bonuses, relocation benefits, enhanced housing allowances, and loan repayment plans.⁴⁹² In addition, SCE has increased partnerships with high schools, community colleges, and technical schools to bolster future recruitment efforts.

Conclusions

The primary concern with plant aging is how aging, if not properly managed, could degrade plant structures, systems, and components, which, in turn, could impair safety and result in extended outages. There is a clear correlation between the age of a plant and the number of degradation occurrences experienced at that plant. A plant that is 30 years old experiences passive system degradation occurrences at a rate twice that of a 20-year old plant.

⁴⁸⁸ American Public Power Association, 2005: 6.

⁴⁸⁹ Southern California Edison 2009 GRC Testimony Part 2 Volume 2, page 13.

⁴⁹⁰ Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Supplemental Data Requests." Docket No. 07-AB-1632. April 28, 2008, H1.

⁴⁹¹ Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Supplemental Data Requests." April 28, 2008, H1.

⁴⁹² Southern California Edison. "2009 GRC Testimony Part 2." Page 14.

Significant plant degradation should be reflected in a decline in the plant's capacity factor. The capacity factors at Diablo Canyon and SONGS have averaged approximately 90 percent for the past five years, suggesting that, up to now, operational improvements and reductions in down time for plant maintenance and refueling have more than compensated for degradation-related operational losses.

Age-related degradation is of greater concern for passive rather than active components. The NRC found that piping, steam generators, and the passive components of reactor pressure vessels experience the greatest number of degradation occurrences. This is consistent with the experience at Diablo Canyon and SONGS, both of which are replacing their steam generators and reactor vessel heads prematurely. Problems with reactor coolant systems and reactor vessels/internals have contributed to the greatest losses in energy production at nuclear plants nationwide.

Effective maintenance and oversight can forestall outages and prevent the safety hazards that could arise as a result of age-related degradation. PG&E and SCE both have maintenance programs in place at their plants to detect and remedy component degradation. A key element of an effective maintenance program is the plant's safety culture. Problems with safety culture have been linked to high profile near-misses and operational issues, such as the incident at Davis-Besse.

The NRC has rated both Diablo Canyon and SONGS with the highest performance ratings in recent years; however, as a result of continuing violations, the NRC has become concerned that there may be an underlying problem with the safety culture at SONGS. In January 2008 the NRC ordered SCE to undergo a series of tasks to improve the SONGS safety culture. Diablo Canyon appears to have an excellent safety culture, having no NRC violations since 1995. In this regard, Diablo Canyon may benefit from the oversight of the DCISC, which investigates concerns that do arise, and from the participation of the local community. There is no similar independent safety committee that oversees SONGS, and historically there has been less active participation from the local community near this plant.

Effective maintenance programs and safety cultures require well-trained workforces at the plant with strong "safety-first" dedication and accountability. As with virtually all nuclear plants, the staffs at Diablo Canyon and SONGS are getting older—the average age of workers at the two plants is over 45. Both PG&E and SCE have instituted programs for the retiring staff to pass on their institutional knowledge to newer staff. It is critical to the ongoing reliability and safety of the plant that programs to transfer knowledge from retiring workers to new workers are successful and that strong safety cultures are maintained throughout this shift in the plants' workforce.

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CHAPTER 6: Impacts of a Major Disruption at Diablo Canyon and SONGS

Diablo Canyon and SONGS are large power plants that provide 12 percent of California's electric power supply.⁴⁹³ As discussed in Chapters 3 and 5, while the plants have been very reliable in recent years, they could be vulnerable to long-term disruptions as a result of major earthquakes or age-related plant degradation. Other unexpected events, such as a major accident or a terrorist attack at any U.S. nuclear plant, could also result in extended shutdowns.

Short-term power outages at nuclear power plants are not uncommon, whether from planned refueling outages that last approximately one month to shorter-term outages and output reductions due to loss of offsite power or weather conditions ranging from winter storms to wildfires. These sorts of reductions in power production are built into expectations about nuclear power plant performance, and under normal circumstances they do not significantly impair system reliability. An extended disruption at Diablo Canyon and SONGS, however, could have more significant impacts, especially if the disruption extended through a period of high demand or low system resource availability. The disruption would reduce the state's power supply and could also impair transmission system reliability.⁴⁹⁴ In the short term, the lost power from the nuclear plants would be replaced mostly by fossil-fueled power. This would increase the cost of power and overall greenhouse gas emissions from power generation.

This chapter presents a literature review and analysis of the impacts of a major outage at Diablo Canyon or SONGS. The first section summarizes existing literature on the impacts to the transmission system from a prolonged outage at either of the plants. The second section presents an analysis of the availability of replacement power following the loss of one or both of the plants. The third section presents an evaluation of historic nuclear outages, which is used to develop modeling scenarios for a replacement power (production cost modeling) analysis. The fourth section presents the modeling results along with a discussion of the reliability, economic, environmental, and public safety impacts of relying on replacement power during a nuclear plant outage. In the final section, the implications of the extended outage at the Kashiwazaki-Kariwa nuclear power plant in Japan are considered.

Existing Studies on Diablo Canyon and SONGS and Grid Reliability

In general, a disruption of operations at a large power plant could cause transmission reliability issues as a result of 1) an inability to respond immediately to a loss of supply due to a lack of spinning reserve capacity⁴⁹⁵ or other operational issue, 2) a shortage of replacement generation

⁴⁹³ California Energy Commission. "2007 Net System Power Report." CEC-200-2008-002-CMF. April 2008, page 4. Accessed: May 14, 2008. <<http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>>.

⁴⁹⁴ Diablo Canyon is interconnected with the PG&E service area, and SONGS is interconnected to both the SCE and SDG&E service areas.

⁴⁹⁵ Spinning reserve is capacity that can be ramped up within 10 minutes to meet increasing demand for electricity as needed (CAISO Ancillary Services Requirements Protocol)

needed to meet peak loads, or 3) a reduction in grid support. This section describes plant reliability studies of Diablo Canyon and SONGS. In particular, this review focuses on studies of long-term outages and any associated local and system reliability issues. These studies indicate that a prolonged shutdown of Diablo Canyon would not pose reliability concerns under typical conditions, whereas a prolonged shutdown of SONGS could result in serious grid reliability shortfalls unless transmission infrastructure improvements are completed. In addition, while replacement power would be available under most circumstances, the outage of either plant would exacerbate electricity supply-demand imbalances during peak demand and adverse supply conditions.

Diablo Canyon Operational Study

PG&E prepared the *Diablo Canyon Power Plant Operational Study* in 2000 in response to the California Independent System Operator's (CAISO) concerns regarding the potential transmission reliability impacts of generation plant shutdowns in the 2000-2007 time period.⁴⁹⁶ The study focused on the impact of a full shutdown of Diablo Canyon on the CAISO transmission system.⁴⁹⁷

As shown in Figure 33 below, the Diablo Canyon substation is interconnected to the Gates substation to the northeast and to the Midway substation to the southeast. There are two constrained transmission paths that are affected by Diablo Canyon's operations, Path 15 and Path 26. The PG&E study analyzed transmission transfer capability and potential violations of reliability criteria with and without Diablo Canyon under a variety of load and resource scenarios. When constructing the load and resource scenarios, PG&E assumed that the resources would be available in the regions from which makeup generation was assigned and did not analyze the availability of resources in those areas.

The study found that some generation replacement scenarios would result in violations of reliability criteria in the event of a Diablo Canyon shutdown, but that these criteria violations could be mitigated without the construction of additional transmission lines, voltage support equipment, or generation. In the case of reliability impacts, the two scenarios in which Diablo Canyon generation is replaced entirely with generation either north of Path 15 or south of Path 26 would result in violations of the reliability criteria. However, the study showed that these violations could be mitigated in one of two ways:⁴⁹⁸

1. Limit Path 15 and Path 26 transfers to a level that is supported by the presently available post-contingency remedial actions. This can be accomplished by reducing generation makeup in the sending zone to approximately one-third of Diablo Canyon capacity and providing the rest of make-up generation in the receiving zone. Allowing make up in both the sending and middle zones provides greater transfers to the receiving zone.

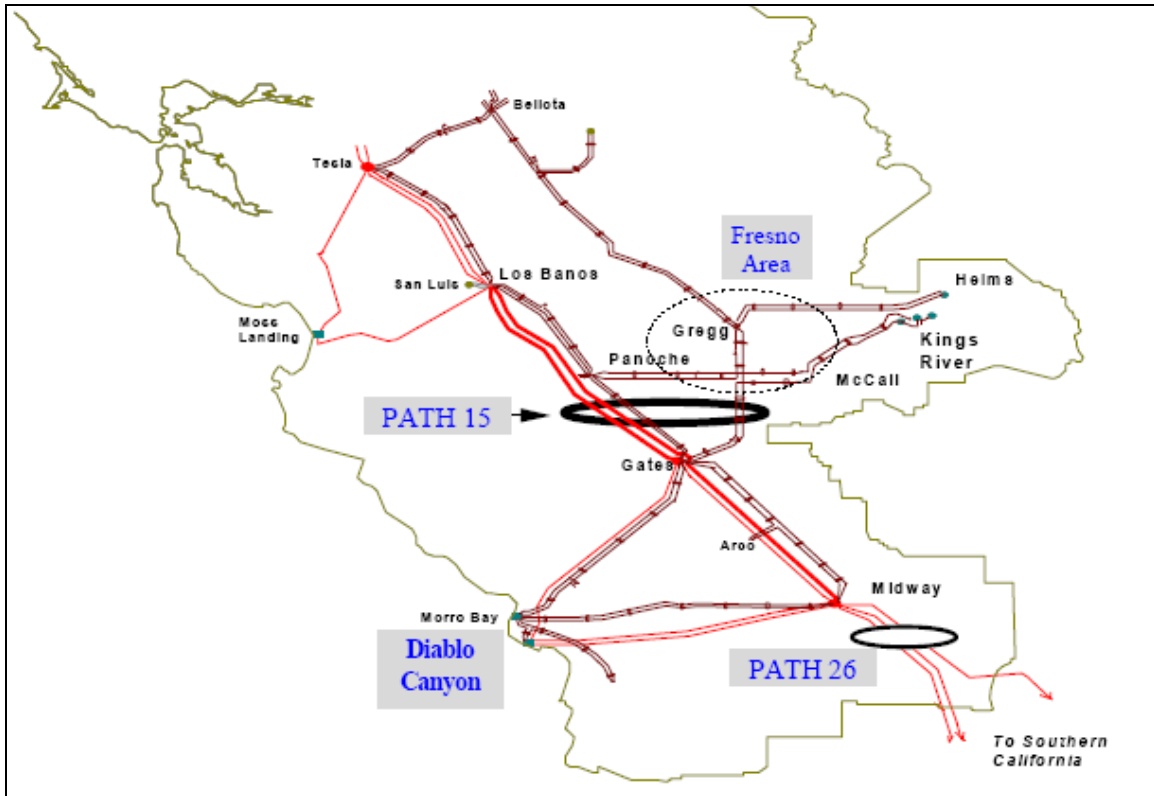
⁴⁹⁶ Fluckiger, Kellan and Armando Perez. "CAISO Memorandum to CGRO Committee." April 19, 1999.

⁴⁹⁷ Note that the study pre-dates the Path 15 upgrade, which was placed in service in December 2004.

⁴⁹⁸ Pacific Gas & Electric. "Diablo Canyon Power Plant Operational Study." 2000, page 4.

2. Increase remedial actions following outages of two transmission lines and two generating units. For up to 3,300 MW of north-to-south Path 15 transfers, the presently available remedial actions should be supplemented by 1,300 MW of load dropping in northern California and about 1,500 MW of load dropping in southern California. For up to 4,000 MW of south-to-north Path 26 transfers, the presently available remedial actions should be supplemented by 1,350 MW of load dropping in southern California.

Figure 33: Diablo Canyon Interconnections to CAISO Transmission System⁴⁹⁹



PG&E's *Diablo Canyon Power Plant Operational Study* demonstrates that while it is possible to conceive generation replacement scenarios that lead to reliability criteria violations, there are viable mitigation options available to prevent these violations. As such, operation of Diablo Canyon is not necessary to meet the transmission reliability criteria.

SONGS Transmission Assessment for CAISO

SCE also prepared an assessment for the CAISO on the potential transmission reliability impacts of a SONGS shutdown. The SONGS transmission assessment found that a significant number of mitigation measures would be required if SONGS were permanently shut down. Mitigations would include construction of a 500 kV line, re-wiring and upgrading existing 230 kV lines, installing shunt capacitors and reactive power compensation devices, reducing area

⁴⁹⁹ Pacific Gas & Electric, 2000: 5.

import capabilities, or dropping load.⁵⁰⁰ The CAISO report noted that installation of new generation reduces the need for some of these transmission upgrades but does not eliminate them.

The assessment identified two transmission-only mitigation scenarios and two mitigation scenarios involving both new generation and transmission resources. In addition to specific transmission or generation resources, each scenario assumed a common set of required transmission upgrades:

- Upgrade the conductors on SCE's Del Amo-Ellis and Barre-Ellis 230 kV lines, and form a second Barre-Ellis 230 kV line.
- Install 750 MVAR of shunt capacitors on the SCE system.
- Bypass the Southwest Power Link series compensation.
- Install series compensation (75 percent) on the four 230 kV lines north of SONGS or construct a new 15 mile Ellis-Santiago 230 kV line.

The first transmission-only mitigation scenario, which focused primarily on upgrades to the 230 kV system, assumed the installation of 4,460 MVAR power support, mostly dynamic, in both SCE's and SDG&E's systems. The second transmission-only mitigation scenario, which focused primarily on 500 kV transmission system facilities, assumed the installation of the Valley-Rainbow 500 kV line including a 230 kV connection to SDG&E's system and installation of 3,300 MVAR reactive power support in both SCE's and SDG&E's systems. Approval to build the Valley-Rainbow line was denied by the California Public Utilities Commission (CPUC) in 2002.⁵⁰¹

The first generation/transmission mitigation scenario assumed construction of up to 3,000 MW of new generation in the Orange County area. SCE assumed that this generation consisted of repowering existing power plants at Alamitos, Huntington Beach, and San Bernardino. In addition, this scenario assumed installation of 2,100 MVAR reactive power support in both SCE and SDG&E systems. The second generation/transmission mitigation scenario assumed construction of the (then) proposed Otay Mesa Power Plant near Miguel Substation and installation of shunt capacitors. It should be noted that this scenario also assumed a significant reduction in import capability by SDG&E.⁵⁰²

⁵⁰⁰ A shunt capacitor is a low-resistance connection between two points on an electric circuit that forms an alternative path for a portion of the current.

⁵⁰¹ California Public Utilities Commission. "Application of San Diego Gas & Electric Company (U 902-E) for a Certificate of Public Convenience and Necessity Valley Rainbow 500 kV Interconnect Project." Decision (D.) 02-12-066. December 19, 2002.

⁵⁰² Unlike the other scenarios, this mitigation option does not require the bypassing of the Southwest Power Link series capacitors.

2004 SCE Testimony on SONGS

SCE testified in the SONGS steam generator replacement proceeding at the CPUC that if SONGS were shut down, significant transmission mitigation would likely be required in addition to the development of new generation resources.⁵⁰³ SCE proposed three different transmission mitigation scenarios. One of these scenarios involved upgrades to the 230 kV system; the other two scenarios involved development of alternative 500 kV transmission lines. The upgrades to the 230 kV system would involve upgrading the Barre-Ellis line and adding 2,520 MVAR of static VAR compensator devices.⁵⁰⁴ SCE estimated that this upgrade would cost \$287 million (in 2004 dollars) and could be completed in five years.⁵⁰⁵ The first 500 kV upgrade scenario involved constructing a transmission line from the Imperial Valley substation in SDG&E's service territory to the Ramona substation, which corresponds to a major element of SDG&E's currently proposed Sunrise Powerlink transmission project. This scenario would also involve upgrades to Path 49 and the addition of 1,374 MVAR of series static VAR compensator devices. SCE estimated that the upgrade would cost \$673 million (2004 dollars) and could be completed in five years. The second 500 kV scenario involved construction of the Valley-Rainbow line (with a small addition to the proposed scope of this project) and 924 MVAR of series SVC dynamic reactive devices. SCE estimated that this upgrade would cost \$491 million (2004 dollars) and could be completed in five years.⁵⁰⁶ For each of these scenarios, SCE assumed that the Devers-Palo Verde No. 2 line and upgrades to the Southwest Power Link are implemented (with a cost of approximately \$700 million).⁵⁰⁷

SDG&E and other parties pointed out that SDG&E would likely add a 500 kV interconnection to its system regardless of whether SONGS was shut down and that with the addition of such a line only a modest amount of voltage support equipment would be needed. The CPUC in Decision 05-12-040 agreed that it was reasonable to assume the addition of a 500 kV line, and in fact SDG&E has since applied for regulatory approval to build the Sunrise Powerlink.⁵⁰⁸ Consequently, while a shutdown of SONGS today would result in grid reliability shortfalls, SONGS will be less important for grid reliability if proposed transmission lines are constructed.

⁵⁰³ O'Donnell, Jeffrey P. "Administrative Law Judge's Ruling Regarding Motion for Protective Order." Application of Southern California Edison: Prepared for the California Public Utilities Commission. A.04-02-026 SCE-4. February 27, 2004, page 4.

⁵⁰⁴ Static VAR Compensators provide reactive power compensation on high-voltage electricity transmission networks in order to regulate voltage.

⁵⁰⁵ The 2004 application stated that the upgrade could be completed by 2009.

⁵⁰⁶ SCE assumed that the Valley-Rainbow transmission line was unlikely to be built since this project has been rejected twice by the CPUC.

⁵⁰⁷ The California portion of the Devers-Palo Verde No.2 line was approved by the CPUC in January 2007. The Arizona Corporation Commission did not give SCE approval to construct the Arizona portion of the project. SCE is pursuing an application at FERC for the Arizona portion of the line.

⁵⁰⁸ California Public Utilities Commission. "Interim Opinion Adopting Methodology for 2005 Market Price Referent." D. 05-12-040. December 15, 2005, pages 26-27.

West-Wide Power Supply Assessment

The Western Electricity Coordinating Council (WECC) released in September 2008 a draft forecast of electricity supply and demand across the western interchange through 2017.⁵⁰⁹ The purpose of this assessment is to reveal the extent to which peak planning needs are not satisfied by existing resources and committed additions. It is thus, by design, a conservative assessment. For example, the base cases exclude power plant proposals that are not already undergoing regulatory review or construction as well as those that have projected in-service dates after 2013. In addition, all cases assume adverse hydro conditions, restricted transfer capabilities, and the simultaneous peaking of demand in all WECC regions.⁵¹⁰

The WECC draft forecast results indicate that, given these adverse conditions, there would be sufficient capacity to replace the power from Diablo Canyon and SONGS during winters through at least 2013.⁵¹¹ The forecast additionally shows that an outage at either plant during July under these same conditions could reduce reserve margins below five percent in 2013 (southern California) or 2014 (northern California) if additional plants are not constructed, and reserve margins would continue to decline through 2017 (see Table 6). This result is a consequence of the exclusion in the supply forecast of all new power plants with in-service dates after 2013. It should be expected that new power plants will continue to be built, in part because the CPUC requires PG&E and SCE to maintain 15 percent reserve margins.

Table 6: Projected Reserve Margins during Outages at Diablo Canyon and SONGS

Northern California				
	2009	2012	2015	2017
Winter	38%	23%	18%	13%
Summer	7%	7%	4%	2%
Southern California				
	2009	2012	2015	2017
Winter	14%	14%	10%	3%
Summer	10%	6%	(1%)	(4%)

Reliability Studies Related to Aging Plants and Once-Through Cooling

Diablo Canyon, SONGS, and 17 other coastal power plants in California use ocean water in a process called once-through cooling. Due to its harmful effects on marine organisms, the use of

⁵⁰⁹ Western Electricity Coordinating Council. "2008 Power Supply Assessment (Draft)." September 29, 2008.

⁵¹⁰ Western Electricity Coordinating Council. September 29, 2008: 11, 19, 59.

⁵¹¹ The WECC forecast results are shown in terms of available reserves above a set reserve margin. For northern and southern California, these reserve margins are approximately 11 percent in the winter and 15 percent in the summer. To calculate the impact of the loss of Diablo Canyon or SONGS on the power supply, the Consultant Team calculated the total available capacity by adding back these reserve margins and then subtracting out the capacity of the nuclear plants.

once-through cooling may be restricted in the future. A full discussion of the environmental impacts of once-through cooling and potential policy implications is included in Chapter 9. The State Water Resources Control Board commissioned a preliminary analysis of the reliability impacts of retrofitting, repowering, or retiring the power plants using once-through cooling.⁵¹² (The study did not specifically address the reliability benefits of Diablo Canyon and SONGS.) The study concluded that excess capacity provided by sufficient investment in transmission could potentially compensate for any once-through cooling plant retirements.⁵¹³ However, if sufficient lead time is not provided, and all once-through cooling plants including the nuclear plants were retired, new generation capacity and transmission could cost ratepayers as much as \$11 billion.⁵¹⁴

A similar study is being conducted by the CAISO which will examine reliability implications of removing older thermal generating units and units with once-through cooling.⁵¹⁵ The goal of the study is to formulate plans to mitigate reliability problems including transmission, new generation, distributed local area generation, and load management programs.⁵¹⁶ The CAISO study will provide a more comprehensive reliability analysis than the State Water Resources Control Board study and will include potential retirement impacts from each plant.⁵¹⁷ The full report is expected in the fourth quarter of 2008.⁵¹⁸

Characterization of Major Disruptions

The remainder of this chapter presents a more detailed analysis of the reliability, economic, and environmental implications of a major disruption at Diablo Canyon or SONGS. The first step in this assessment was to identify an appropriate outage scenario. For this step, the Consultant Team reviewed historical outages at reactors in the U.S. and in Japan.

Typical Outages at Nuclear Plants

Between 2002 and 2006, pressurized water reactors with net power ratings over 1,000 megawatts electric (MWe), such as Diablo Canyon and SONGS, were unavailable just 10 percent of the time. At each plant, there was an average of 3.25 forced outages lasting a total of

⁵¹² California Ocean Protection Council. "Electric Grid Reliability Impacts from Regulation of Once-Through Cooling in California." California State Water Resources Control Board, prepared by ICF Jones & Stokes, Global Energy Decisions and Matt Trask. April 2008. <http://www.swrcb.ca.gov/water_issues/programs/tmdl/docs/power_plant_cooling/reliability_study.pdf>.

⁵¹³ California Ocean Protection Council, 2008: 56.

⁵¹⁴ California Ocean Protection Council, 2008: 3.

⁵¹⁵ California Independent System Operator. "Mitigation of Reliance on Old Thermal Generation Including Those Using Once-Through Cooling Systems." September 21, 2007. <<http://www.caiso.com/1c5e/1c5edff632c50.pdf>>.

⁵¹⁶ California Independent System Operator. September 21, 2007.

⁵¹⁷ California Ocean Protection Council, 2008: 53.

⁵¹⁸ California Independent System Operator. "Old Thermal Generation – Phase 1 Report." February 29, 2008. <<http://www.caiso.com/1f80/1f80a4a5568f0.pdf>>.

7.7 days per year, suggesting an average of 2.4 days per forced outage. Maintenance and planned outages were longer, averaging 10 days and 27.6 days per outage, respectively (Table 7).⁵¹⁹

Table 7: Outage Durations at Pressurized Water Reactors (> 1,000 MWe), days⁵²⁰

	2002	2003	2004	2005	2006	5-yr average
Average Duration of Forced Outage	3.2	6.5	3.9	0.6	4.9	2.4
% of Year in Forced Outage	1.7%	3.7%	1.9%	1.4%	1.9%	2.1%
Average Duration of Maintenance Outage	23.3	4.2	3.2	5.1	33.2	10.0
% of Year in Maintenance Outage	1.2%	0.3%	0.2%	0.5%	1.1%	0.7%
Average Duration of Planned Outage	21.3	32.0	33.8	26.5	27.3	27.6
% of Year in Planned Outage	6.5%	7.1%	6.6%	7.6%	7.8%	7.1%
Total Unavailability Percent	9.4%	11.1%	8.7%	9.5%	10.8%	9.9%

These data indicate that on average unplanned and maintenance outages at large pressurized water reactors do not last very long. However, the data do not indicate the longest outages experienced by each plant, which, for reliability planning, is more important than the average durations. In addition, major disruptions could be longer than any disruption that occurred at these 33 reactors over the past five years. It is thus important to consider also the major disruptions that have occurred at these or other nuclear plants.

Major Disruptions at Nuclear Plants

Many commercial nuclear reactors in the United States have experienced significant operational disruptions. David Lochbaum of the Union of Concerned Scientists chronicled 51 incidences of reactor outages lasting more than a year.⁵²¹ The majority of these year-plus outages were attributed to components that had degraded to the point that shutdown and system-wide maintenance were needed in order to ensure safe operation.⁵²² Half of the year-plus outages lasted between one and two years. The longest outage to date occurred at Browns Ferry Unit 1, which was offline for over 20 years.

The most recent year-plus outage at a U.S. nuclear plant occurred at Davis-Besse in 2002 when the reactor was taken offline for a routine refueling and maintenance outage, and a large cavity was found in the reactor vessel head (see Chapter 5).⁵²³ As a result, what was originally

⁵¹⁹ North American Electric Reliability Corporation. "GADS Services." <<http://www.nerc.com/~gads/>>.

⁵²⁰ North American Electric Reliability Corporation. "GADS Services." <<http://www.nerc.com/~gads/>>.

⁵²¹ Lochbaum, David. "Walking a Nuclear Tightrope." *Union of Concerned Scientists*. September 2006.

⁵²² Lochbaum, David. "Walking a Nuclear Tightrope." September 2006: 1.

⁵²³ Lochbaum, David. "Davis Besse." *Union of Concerned Scientists*. September 2006. Accessed: July 16, 2008. <http://www.ucsusa.org/assets/documents/clean_energy/Davis-Besse-II.pdf>.

intended as a standard maintenance and refueling outage kept the plant offline for nearly two and a half years.⁵²⁴

In addition, the Kashiwazaki-Kariwa nuclear plant in Japan has been shut down since the Niigataken Chuetsu-oki earthquake on July 16, 2007. Although the safety protection system worked as designed to secure safety for the reactors, various instruments were broken and some radioactive leaks occurred. As discussed in Chapter 3, repairs on the plants are largely completed but regulatory requirements are delaying the restart of the operations.

Definition of a Major Disruption

The experiences of nuclear plants presented above indicate that most unplanned outages last just a few days, but outages lasting a year or longer do occur. The replacement power analysis presented in the remainder of this chapter is based on a hypothetical year-long outage at either plant.

The results of this analysis are not applicable for permanent outages. In the case of a permanent outage, the utilities would construct new renewable or conventional power plants to replace the nuclear unit, and the cost and environmental impacts of this scenario would depend on the replacement power that the utilities chose to develop. The implications of potential replacement power options are discussed in Chapter 9.

Replacement Power Analysis

When any of California's nuclear reactors are not operating, the power from these reactors must be replaced with power from other sources. PG&E and SCE generally schedule refueling outages and other maintenance so as to avoid periods of peak power demand and reduce the cost of replacement power. However, unplanned outages can occur at any time. This section evaluates what replacement power options would be used in the event of a hypothetical year-long unplanned outage at one or both of the nuclear plants in 2012.

Production Simulation Model

For the replacement power analysis, the Consultant Team simulated the operations of the electricity market with and without one of the nuclear plants utilizing a proprietary hourly chronological production simulation model (MARKETSYM™). MARKETSYM™ dispatches generating resources to match hourly electricity demand and minimize the total system cost, including costs of fuel, operations and maintenance, emissions, and start-up.

Underlying this model is a detailed database of expected retail power demand and of the operating characteristics of generation and transmission facilities within the Western Electricity Coordinating Council (WECC). The data in this database are based on (a) utilities' regulatory filings to the U.S. Energy Information Administration and the Federal Energy Regulatory Commission regarding projected demand and operating characteristics of existing generating and transmission facilities, (b) public announcements of generation and transmission developments and upgrades, and (c) forecasts of fuel prices, emission allowance costs, and

⁵²⁴ Lochbaum, David. "Walking a Nuclear Tightrope." September 2006: 10.

other technical and economic parameters. This database was recently used by the Energy Commission in its 2007 Integrated Energy Policy Report (IEPR) Scenario Analysis of California's Electric System and by the Ocean Protection Council and the Water Resources Control Board in a study of the impact of regulating once-through-cooling technology in California.

Methodology and Assumptions for Simulations

Using MARKETSYSTM, the Consultant Team simulated the operation of individual generators, utilities, and control areas to meet fluctuating loads within a region each hour. The simulation minimizes the cost of serving load within the modeled electric system subject to a number of operational constraints and assuming strategic bidding by market participants.⁵²⁵ The result is a price forecast that allows existing and new generators to recover all short- and long-term costs (including financing costs) from the market.

Three fundamental principles guided the forecast development:

- Maintain sufficient reliability in all market areas. Each market area is delineated by critical transmission constraints. Within a market area, it is assumed that there are no transmission limits.
- In the short term, benchmark the model against observed historical market prices and market heat rates.
- In the long term, allow new base-load capacity to recover all costs, including fixed and financing costs from the energy market.

The base case for this analysis is the same as the aging plants retirement scenario from the 2007 IEPR. The Consultant Team developed this scenario by starting with current resources and adding and subtracting resources according to the following rules:

- Plants are added that are under construction or under contract and are reasonably assured to be on line by 2012.
- Baseload resources (mainly combined cycle gas turbines): Beyond plants under construction or contract, baseload resources are added only if the costs of these resources would be fully recovered from the energy market. To project the economic entry of baseload capacity, the Consultant Team started at current market conditions and gradually added capacity.⁵²⁶
- Renewable resources are added based on filings from utilities and other load serving entities to the Energy Commission, and other likely resource additions estimated by Energy Commission staff.

⁵²⁵ The simulation methodology is not based on an economic general equilibrium concept wherein market participants maximize profits subject to demand and behavior of competitors. Rather, the authors simulated the price formation in competitive markets using a least cost approach with an explicitly defined scarcity bidding behavior.

⁵²⁶ Capacity was added so as to achieve a long-term market equilibrium where new capacity just meets long-term revenue requirements.

- Beyond plants under construction or contract, peaking resources are added as needed to fulfill system reliability and reserve margin requirements. The costs of these capacities may not be fully recovered from the energy market since profitability of peaking capacity is determined not only by the simulated deterministic prices but also by the cost of supporting necessary reliability and the likelihood of failure of other generation and transmission facilities.
- Units are removed first based on publicly announced retirement or repowering dates. For example, the Humboldt Bay steam turbines will be replaced by 10 diesel generators (16.3 MW each) during the fall of 2008 and the Potrero gas turbines will be replaced by the San Francisco Electric Reliability Project. Units that are recommended by the Energy Commission for retirement prior to or in 2012 are removed. These include Alamitos Unit 3, Etiwanda Units 3 & 4, and Ormond Beach Unit 1. For units whose retirement dates are unknown, the Consultant Team used a rule-of-thumb of 55 years lifetime for gas and coal units and 60 years for nuclear units.
- Forced outages are based on Monte Carlo analysis.

In addition to the base case, the Consultant Team simulated two outage scenarios in which one of the nuclear plants does not operate throughout the year 2012 as the result of unanticipated repairs or maintenance. These scenarios follow the same rules as the base case. No capacity was specifically added to replace the nuclear units since the units in these scenarios have been unexpectedly shut down for a limited time. Instead, power from the nuclear units is replaced by power from existing generating facilities that otherwise would not operate as much. Since the model determines which facilities generate power by ordering the facilities based on operating costs, operating costs of the replacement power are higher than operating costs of the nuclear units.

Results

The simulations find that for a year-long outage in 2012 at Diablo Canyon, 62 percent of the replacement generation would come from California gas-fired power plants, mostly combined cycle plants. Another 35 percent would come from gas-fired plants in neighboring states, and just under two percent from out-of-state coal plants (Table 8). For a year-long outage in 2012 at SONGS, 55 percent of the replacement generation in the outage scenarios would come from gas-fired power plants in California, 42 percent from gas-fired plants in neighboring states, and less than two percent from out-of-state coal plants.

Table 8: California 2012 Power Supply, GWh

	Base Case	Diablo Canyon Outage		SONGS Outage	
	Total Generation	Total Generation	Change from Base Case	Total Generation	Change from Base Case
In-State Nuclear Generation	31,000	16,000	(15,000)	15,000	(16,000)
Other In-State Generation	200,000	211,000	10,000	210,000	9,000
Imported Power	81,000	86,000	5,000	87,000	7,000
<i>Total California Load</i>	<i>312,000</i>	<i>312,000</i>	-	<i>312,000</i>	-

Reserve Margin Implications

Reserve margins reflect the amount of capacity available to the system in excess of anticipated need. Positive reserve margins are required to maintain system stability and prevent blackouts in the event of plant outages or higher than anticipated demand.

An outage at Diablo Canyon or SONGS would reduce system capacity by about 2,200 MW. According to the simulations, this would reduce the statewide planning reserve margin from 26 percent to 23 percent (Table 9).⁵²⁷ As noted earlier, a 23 percent planning reserve margin is greater than the 15 percent reserve margin currently required by the CPUC. Therefore, the simulations suggest that no supply shortages would occur as the result of either Diablo Canyon or SONGS being unexpectedly off-line for an extended period, nor would remedial action, such as additional demand response, energy efficiency, or additional capacity be needed for reliability purposes. Depending upon the exact nature of the replacement power, such programs might be justified on economic grounds.

Table 9: California 2012 Planning Reserve Margin

	Base Scenario	Diablo Canyon Outage	SONGS Outage
Peak Load (MW)	60,780	60,780	60,780
Total Capacity⁵²⁸	76,841	74,593	74,609
Reserve Margin	26%	23%	23%

⁵²⁷ Actual reserve margins may be lower if currently planned projects are not developed or if imports into southern California are reduced on account of an outage at SONGS. SCE estimates that a SONGS outage could reduce import capabilities by up to 1,500 MW. Southern California Edison. October 2, 2008: 5.

⁵²⁸ The nameplate capacity of wind and solar power generators has been adjusted in this calculation to account for the intermittent availability of these resources. Wind resources were counted at 22 percent of nameplate capacity; photovoltaic at 42 percent of nameplate capacity; and centralized solar at 75 percent of nameplate capacity.

Economic Implications

The primary costs of an extended outage are the costs to purchase replacement power and the costs to repair the plant so that it can resume operating.

Replacement power costs would include the operating costs of the units providing the replacement power (for units controlled by PG&E or SCE) and the costs to acquire power from out-of-state at market rates.⁵²⁹ For a year-long loss of either nuclear plant, the simulations find that these costs would be \$470 million higher than the cost to obtain the power from the nuclear plant. This would increase average rates for customers of either PG&E or SCE/SDG&E by approximately 0.5¢ per kilowatt-hour (kWh) for one year.

Replacement power costs are roughly the same for either plant's outage due to the fact that the two plants are of similar size and the replacement power is dominated by gas-fired combined cycles. Replacement power costs are somewhat lower during the spring, when gas prices tend to be lower and the large hydro runoff prevents the need for less efficient (i.e. more expensive) units and peaking units to run. This allows the more efficient generators to set the marginal market price. Replacement power costs are higher from the early fall through winter, when demand is higher (pushing less efficient generators to set the marginal market price) and gas prices peak.

These results should be interpreted only as indicative because of the uncertainties in future fuel prices, technology improvements, and regulatory requirements. A carbon tax or greenhouse gas cap and trade program, which was not incorporated into this modeling, could alter the unit dispatch in the simulation and would likely increase the cost of the replacement power.⁵³⁰

Plant repair costs would depend on the outage cause and could vary widely. For example, the cost to repair seven reactors that had extended outages between 1982 and 1998 ranged from \$136 million for a 1.3 year outage at Nine Mile Point Unit 1 to \$702 million for a 2.3 year outage at Rancho Seco.⁵³¹ Overall, outage repairs at these plants cost between \$100 million and \$300 million per year of outage, with an average of \$203 million per year of outage.⁵³² Should capital improvements of this scale be required to repair Diablo Canyon or SONGS, these repair costs

⁵²⁹ The modeling assumes that incremental power from in-state resources can be acquired at the cost of service (i.e. are owned by the utilities or under a tolling contract) while incremental power from out-of-state must be purchased at market rates calculated internally within the MARKETSYS model.

⁵³⁰ The cost of the replacement power portfolio described above would increase by roughly \$55 million if an \$8 per tonne charge were assessed on carbon emissions. Further simulations are required to ascertain whether this charge would change the unit dispatch and result in an alternate replacement power portfolio being used.

⁵³¹ The outages reviewed occurred at SONGS Unit 1, Rancho Seco, Pilgrim Unit 2, Peach Bottom Unit 2, Oyster Creek, Nine Mile Point Unit 1, and Crystal River Unit 3. These outages were selected based on the availability of data concerning the cost of outage-related capital improvements. However, details of these costs are not available, and regulatory costs and other outage costs may in some cases be included in the capital cost estimates. Union of Concerned Scientists. "Unlearned Lessons of Year-Plus Reactor Outages – Case Studies." September 26, 2006. Accessed: June 9, 2008. <http://www.ucsusa.org/clean_energy/nuclear_safety/unlearned-lessons-from.html>.

⁵³² All figures are in 2008 dollars.

would likely be included in the plant's ratebase and recovered from ratepayers over the expected lifetime of the capital improvement.⁵³³ This would reduce the rate impact in any given year. For example, a \$203 million capital improvement recovered over 10 years would cost ratepayers at most \$46 million in one year, which would raise rates by roughly 0.05¢ per kWh.⁵³⁴

Environmental Implications

The environmental implications of an outage arise from replacing nuclear power with replacement power, which would primarily be fueled by natural gas. The simulations found that an outage at either nuclear plant would have notable impacts on greenhouse gas emissions. A year-long outage at SONGS would increase in-state greenhouse gas emissions from power generation by 7 percent (+4.3 million tons CO₂), while the analogous outage at Diablo Canyon would increase in-state greenhouse gas emissions from power generation by 7.6 percent (+4.7 million tons CO₂). Taking into account the out-of-state replacement generation, the total greenhouse gas impact would be the additional emissions of approximately 7 million tons of CO₂.

As shown in Table 10, emissions of NO_x and SO_x would also increase, albeit by a much smaller percentage than seen for CO₂.

Table 10: Emissions Changes from year-Long Plant Outage in 2012

	Base Case Emissions, Thousands of Tons	Change in emissions due to Diablo Canyon Outage		Change in emissions due to SONGS Outage	
		Thousands of Tons	Percent Change	Thousands of Tons	Percent Change
In California					
CO ₂	61,376	4,684	7.6%	4,308	7.0%
NOx	235	1.6	0.7%	0.6	0.3%
SOx	63	0.8	1.3%	0.4	0.6%
Out of State					
CO ₂	379,861	2,179	0.6%	2,849	0.7%
NOx	547	0.7	0.1%	0.9	0.2%
SOx	451	0.6	0.1%	0.7	0.2%

Public Safety Implications

There are several ways in which an extended outage at Diablo Canyon or SONGS could impact public safety: via transmission instability, via power outages, or via the direct safety implications of operating a replacement power plant in place of operating a nuclear reactor.

⁵³³ In some cases, a portion of outage costs could be borne by shareholders.

⁵³⁴ This calculation presumes a 9 percent cost of capital and a 44 percent tax rate.

- **Transmission Instability:** In the unlikely event that an outage at Diablo Canyon or SONGS destabilizes the transmission system, widespread and extended power outages could ensue.
- **Power Outage:** Under most circumstances, a plant outage would not result in the loss of power for customers since there are sufficient system reserves to replace the lost power with other power supplies. However, if the plant outage occurred during a time of unusually high demand and/or coincided with other supply outages or low hydro supplies, the plant outage could contribute to a need for customer outages. These outages would likely be constrained to short durations, such as the 2-hour rolling blackouts that Californians experienced during 2000 and 2001. Hospitals and other essential services would not be impacted. The overall public safety implications of these outages would thus likely be limited.
- **Operations:** During an outage, the power from the nuclear reactor would be replaced by power from a gas-fired plant. On balance, this increases public safety since the public safety risk from reactor operations are greater than public safety risks from gas-fired plant operations. However, given the extensive safety procedures and mechanisms in place for nuclear reactor operations, the public risk from reactor operations is small. The increase in public safety due to the reactor outage is consequently not significant.

Implications of Outage at Kashiwazaki-Kariwa

The simulation modeling described above provides insight into the potential impacts of a hypothetical year-long outage in California. It is also instructive to consider the impacts that have been experienced from an actual outage at a large nuclear plant. The outage at the Kashiwazaki-Kariwa plant in Japan, the largest nuclear plant in the world, provides such a case study.

Since the Niigataken Chuetsu-Oki earthquake shut down the Kashiwazaki-Kariwa nuclear plant in July 2007, Tokyo Electric Power Co. (TEPCO), the plant owner, has been forced to depend on thermal power plants for about 40,000 GWh of electricity in FY 2007 alone and 50,000-60,000 GWh annually until the plant resumes operations.⁵³⁵ This has resulted in the incremental emissions of 24 million tons of CO₂, representing two percent of Japan's emissions in FY 2007 and approximately three percent of Japan's emissions per year of outage going forward.⁵³⁶ PG&E has said that TEPCO suffered about \$9 billion in losses during the first year since the earthquake, in part due to long term contract obligations and high replacement power costs.⁵³⁷

Liquefied natural gas (LNG) and oil power plants have played a central role in making up for the lost nuclear capacity. TEPCO consumed 21 percent more LNG and 38 percent more fuel oil

⁵³⁵ Institute of Energy Economics, Japan. "Impacts on International Energy Market of Unplanned Shutdown of Kashiwazaki-Kariwa Nuclear Power Station." April 2008, page 1.

⁵³⁶ Institute of Energy Economics, April 2008: 23.

⁵³⁷ California Energy Commission. "Transcript of AB 1632 Workshop." September 25, 2008: 93-94.

over the summer of 2007 than over the summer of 2006.⁵³⁸ A recent study from the Institute of Energy Economics, Japan found that the increase in demand did not notably impact the prices for LNG and fuel oil due to fuel inventories and adjustments to refinery product mixes.⁵³⁹ However, the potential impacts of the shutdown could become more severe as fuel inventories are depleted.⁵⁴⁰

Less than a month after the earthquake, on August 22, 2007, a heat wave brought the anticipated electrical demand peak within TEPCO's service area to 61.5 GW—a near record demand level. In order to preserve a reserve margin TEPCO initiated its demand-response program for the first time in 17 years and had 23 large customers reduce demand by a total of 3 GW. TEPCO also purchased about 3 GW of capacity from other utilities.⁵⁴¹ With these measures, TEPCO managed to continue serving customers and even maintain a reserve margin of at least 4.1 percent through the day.

An outage at a California nuclear plant would result in different impacts than experienced in Japan due to the differences in electricity supply options and electricity markets between California and Japan. However, there are a number of lessons that can be learned from this experience that relate directly to California:

- Similar to the situation in Japan, the lost power from a shut-down nuclear plant in California would be replaced by fossil-fueled power, at least in the near-term, resulting in an increase in greenhouse gas emissions.
- Potential market impacts from an increased reliance on fossil fuels depend on overall market conditions. If an outage in California occurs during a time when there is a surplus of natural gas in storage, market implications may be minor. If the outage continues for an extended period, storage reserves could become depleted and market implications may become more significant.
- The loss of the nuclear plant would be most strongly felt during periods of peak electricity demand. Demand response and imported power could be important for maintaining reserve margins during these periods.

Conclusions

Production simulation modeling of electricity market operations and a WECC study of future supply and demand conditions both indicate that adequate replacement power would be available in the event of extended outages at Diablo Canyon and SONGS during winter peak demand conditions in the near term. The studies differ in their assessments of the adequacy of replacement power during summer peak demand conditions: the production simulation modeling indicates that sufficient replacement power would be available to meet California's 15

⁵³⁸ Institute of Energy Economics, April 2008: 14, 18.

⁵³⁹ Institute of Energy Economics, April 2008: 16, 21.

⁵⁴⁰ Institute of Energy Economics, April 2008: 27.

⁵⁴¹ Institute of Energy Economics, April 2008: 12-13.

percent reserve margin requirement, while the WECC study indicates that the loss of the plants would reduce reserve margins to six or seven percent.⁵⁴²

The difference between these results is primarily a consequence of input assumptions about supply conditions. The production simulation modeling assumed that there is currently excess capacity in the system and that new generation capacity will be added to the system as needed in order to maintain a 15 percent reserve margin. In contrast, the WECC study assumed adverse supply conditions and limited new generation projects coming on-line in future years. Together, the studies suggest that while replacement power would be available under most circumstances, the outage of either plant could exacerbate supply-demand imbalances during peak demand and adverse supply conditions. Both studies will need to be revisited in the coming years to reflect updated supply and demand conditions. In addition, more detailed study would be needed to assess the availability of replacement power at the local level given transmission constraints that could restrict the deliverability of replacement power to some areas.

The production simulation modeling indicates that during a year-long disruption at either nuclear plant in 2012, replacement power would be supplied primarily by combined cycle natural gas plants. Over the course of a year, this would increase the cost of power by \$470 million and increase CO₂ emissions from California's electricity generation by about eight percent.

Previous studies have shown that while Diablo Canyon represents a significant generation resource and supports power flows through transmission Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. However, SONGS is a more integral part of the Southern California transmission system, and imported power flows are restricted when it is shut down. Consequently, there would likely need to be modification to the transmission system in the event of a long-term SONGS shutdown. The extent of the transmission system changes would depend on the transmission configuration in place at the time of the shutdown.

⁵⁴² At this level of reserve margin, the CAISO would call a Stage 1 emergency and encourage conservation and voluntary load reduction. If reserve margins were to fall further (to five percent), the CAISO would call a Stage 2 emergency and would require customers on "interruptible" service plans to reduce their electricity usage. California Independent System Operator. "About Today's Outlook." Accessed: October 21, 2008. <<http://www.caiso.com/awe/AboutThisPage.html>>.

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 <http://www.cc.state.ca.us/Divisions/Utilities/Electric/Biennial/2008%20BTA/DPV2%20BTA%20Workshop_May%2022-23%202008.ppt>.

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Chapter 7: Nuclear Waste Accumulation at Diablo Canyon and SONGS

Nuclear reactors produce radioactive waste during the process of electricity generation and plant maintenance. Both spent fuel and low-level waste are stored at Diablo Canyon Power Plant (Diablo Canyon) and at San Onofre Nuclear Generating Station (SONGS).

Spent nuclear fuel is a byproduct of electricity generation. Approximately every 18 to 24 months, a portion of the fuel rods in a reactor are removed and replaced with fresh fuel rods. The spent or “used” fuel is then placed into storage. All commercial nuclear power plants in the U.S. store spent fuel in water-filled pools for at least five years at the power plant site. In the past decade or so, nuclear plant owners have also begun to use dry casks for storing older spent fuel. Because off-site spent fuel storage and disposal options are currently unavailable, the volumes of nuclear waste stored at the plant sites will increase in the years to come. Already, Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) have accumulated over 2,200 metric tons of spent fuel at the plant sites. The federal government is responsible for the ultimate disposal of this spent fuel.

Storing nuclear waste at the plants imposes financial costs and also exposes nearby populations and the environment to risks of radiological contamination. Ratepayers bear some of the costs for storing nuclear waste at the plants, and taxpayers will bear the remaining costs. The taxpayer obligation arises from damage payments that the federal government is making to utilities for failing to take on-time delivery of spent fuel for disposal at a geologic repository. This obligation is increasing with time and with the amount of nuclear waste stored at plant sites throughout the country.

The U.S. Department of Energy (DOE) is pursuing a permanent geologic repository for spent fuel at Yucca Mountain, Nevada. The license application for Yucca Mountain was filed with the NRC on June 3, 2008. If the license is granted, Yucca Mountain will begin operations sometime after 2020.⁵⁴³ The history and current status of Yucca Mountain and other federal spent fuel initiatives are discussed in Appendix A.

If Yucca Mountain or another geologic repository is opened in the future, spent fuel will be shipped from the plant sites to the repository. Similarly, if an off-site spent fuel storage facility is opened, PG&E and SCE could choose to ship the waste from their nuclear plants to this facility. As many as 390 shipments could be needed to move off site all of the spent fuel generated by Diablo Canyon and SONGS during the current operating period. Each shipment creates risks for the state and its residents. The state will also incur costs for training and emergency preparedness that may not be fully reimbursed by the federal government.

This chapter provides an assessment of the growing amounts of spent fuel and low-level waste accumulating at Diablo Canyon and SONGS. First, it presents an overview of the characteristics of radioactive waste. Next, it describes the spent fuel storage options pursued by PG&E and SCE and the storage capacity these options provide. Next, it presents the costs associated with

⁵⁴³ Nuclear Energy Institute. “Key Issues: Yucca Mountain.” Accessed: September 12, 2008. <<http://www.nei.org/keyissues/nuclearwastedisposal/yuccamountain/>>.

storing nuclear waste at the plants and the packaging requirements, transport costs, and emergency preparedness costs associated with the nuclear waste. Finally, it discusses the cost and availability of disposal options for low-level waste from Diablo Canyon and SONGS.

Characteristics of Radioactive Waste

There are two major categories of radioactive waste from commercial nuclear reactors: spent fuel and low-level radioactive waste.⁵⁴⁴ Spent fuel is composed of uranium, plutonium, and fission byproducts that remain after the fuel has been used for electricity generation.⁵⁴⁵ Low-level waste is radioactive waste that does not meet the classifications of spent fuel and other high-level waste categories. It includes items that have been contaminated with radioactive material or have become radioactive through exposure to neutron radiation. These items include everything from protective clothing and cleaning supplies to water treatment residues and discarded reactor parts.⁵⁴⁶

Spent fuel recently removed from a reactor is significantly more hazardous than low-level waste. Spent fuel emits a lethal dose of radiation in a one-meter radius for roughly 50 years, and it can take hundreds of thousands of years for the radioactive materials to decay to a harmless state.⁵⁴⁷ Figure 34 compares the radiation dose that would be received by someone located one, five, or ten meters from spent fuel that has cooled for up to 50 years. Health risks associated with specific radiation levels are also shown.

The risks from exposure to low-level waste depend on the type of radioactive material in the waste and its concentration.⁵⁴⁸ Some forms of low-level waste pose no hazard unless inhaled or consumed; others can increase the risk of cancer or death to unprotected people nearby.⁵⁴⁹ The U.S. Nuclear Regulatory Commission (NRC) has defined four disposal categories of low-level waste that require differing degrees of confinement and monitoring: Class A, B, C, and Greater than Class C (GTCC).⁵⁵⁰ Of these categories, Class A waste generally has the lowest concentration of long and short-lived radioactive material and remains a hazard for the shortest

⁵⁴⁴ 42 USC 10101, pages 1-4.

⁵⁴⁵ Spent fuel can be reprocessed and converted into fresh reactor fuel; however, this is not currently done in the U.S. See Appendix 7A for information about current federal reprocessing initiatives.

⁵⁴⁶ U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." May 2002, page 20. Accessed: February 5, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0216/r2/br0216r2.pdf>>.

⁵⁴⁷ U.S. Nuclear Regulatory Commission. "High-Level Waste". February 13, 2007. Accessed: February 5, 2008. <<http://www.nrc.gov/waste/high-level-waste.html>>.

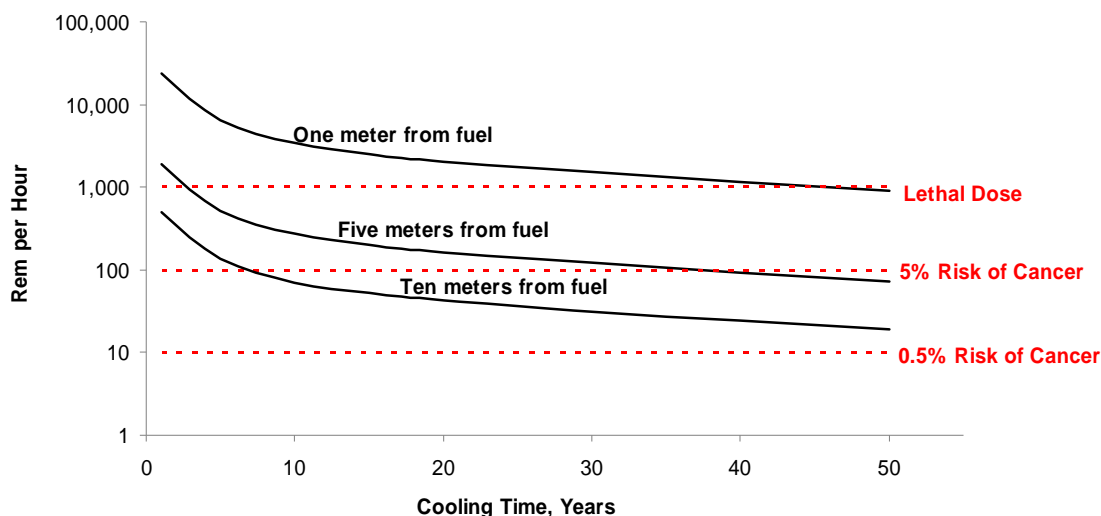
⁵⁴⁸ U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." (NUREG/BR-0216, Rev. 2). May 2002. <<http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0216/r2/br0216r2.pdf>>.

⁵⁴⁹ U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." May 2002.

⁵⁵⁰ U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." May 2002.

period. Class A and Class B wastes are intended to decay to acceptable levels of hazard within 100 years, and Class C waste within 500 years (Table 11).⁵⁵¹

Figure 34: Radiation Dose Rate from a Pressurized Water Reactor Spent Fuel Assembly⁵⁵²



Low-level waste is packaged for storage according to its level of hazard and can require shielding with lead, concrete, or other materials to protect workers and members of the public.⁵⁵³ GTCC low-level waste, including reactor control rods and other activated metal hardware, is the most hazardous of low-level waste and emits dangerous amounts of radiation for more than 500 years.⁵⁵⁴ Unlike Class A-C low-level waste, GTCC low-level waste may not be disposed of in a surface or near-surface level facility and may require disposal in a deep geologic repository.⁵⁵⁵ State governments are responsible for the disposal of Class A, B, and C waste. The federal government is responsible for the disposal of GTCC waste and spent fuel.⁵⁵⁶

⁵⁵¹ U.S. Nuclear Regulatory Commission, 10 CFR 61.7.

⁵⁵² Lloyd, Sheaffer, and Sutcliffe. "Dose Rate Estimates from Irradiated Light-Water-Reactor Fuel Assemblies in Air." Lawrence Livermore National Lab, UCRL-ID-115199. January 31, 1994. Accessed: May 23, 2008. <<http://www.osti.gov/bridge/servlets/purl/10137382-BSfGip/native/10137382.PDF>>; Canadian Centre for Occupational Health and Safety. "Radiation – Quantities and Units of Ionizing Radiation." Accessed: May 23, 2008. <http://www.ccohs.ca/oshanswers/phys_agents/ionizing.html>

⁵⁵³ U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." (NUREG/BR-0216, Rev. 2) February 2007. Accessed: May 23, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0216/>>.

⁵⁵⁴ U.S. Department of Energy. "Greater-Than-Class C Low-Level Radioactive Waste (GTCC LLW) and DOE GTCC-like Waste". Accessed: May 23, 2008. <<http://www.gtccis.anl.gov/guide/gtccllw/index.cfm>>.

⁵⁵⁵ In May 1989, NRC promulgated a rule that requires disposal of GTCC low-level waste in a deep geologic repository unless disposal elsewhere has been approved by the NRC; U.S. Department of Energy. "Integrated Data Base Report." DOE/RW-006, Rev 12. December 1996, page 109.

⁵⁵⁶ 42 USC 2021c.

There are no facilities currently licensed by the NRC for the disposal of GTCC low-level waste or spent fuel.

Table 11: Low-Level Waste Characteristics and Disposal Methods⁵⁵⁷

Category	Description	Disposal Method
Class A	Least hazardous – short and long-lived waste that will not endanger inadvertent human intruder beyond 100 years	Near-Surface
Class B	More hazardous – short-lived wastes that will not endanger inadvertent intruder beyond 100 years	Near-Surface with 300 year waste stability
Class C	More hazardous – short and long-lived wastes that will not endanger inadvertent intruder beyond 500 years	Near-Surface with 300 year waste stability and either greater depth or 500 year intruder barrier
GTCC	Most hazardous of LLW - dangerous to inadvertent intruder beyond 500 years. Current law requires it to be disposed in geologic repository	Geologic repository or alternate approach to be determined

Waste Volumes

Through the end of 2007, Diablo Canyon and SONGS operations had generated 2,300 metric tons of uranium (MTU) in spent fuel, 44,000 ft³ of Class A low-level waste, and 1,700 ft³ of Class B and C low-level waste.⁵⁵⁸ Operations at the facilities will continue to generate spent fuel until the plants cease operating and will continue to generate low-level waste through decommissioning. Table 12 provides a summary of the waste that has been and will be generated at these plants under the current license period, during a possible 20-year license extension, and during decommissioning.

⁵⁵⁷ U.S. Department of Energy. "Greater-Than-Class C Low-Level Radioactive Waste (GTCC LLW) and DOE GTCC-like Waste." <<http://www.gtcceis.anl.gov/guide/gtccllw/index.cfm>>.

⁵⁵⁸ As of December 31, 2007, Diablo Canyon had generated 1,136 MTU of spent fuel and SONGS Units 2 and 3 had generated 1,383 MTU of spent fuel; Pacific Gas & Electric. "PG&E's Response to Data Requests AB 1632 Study Report." Docket No. 07-AB-1632. February 27, 2008, question B1; Southern California Edison. "AB 1632 Nuclear Power Plant Assessment Data Request for San Onofre Nuclear Generating Station." Docket No. 07-AB-1632. March 21, 2008, question B1.

Table 12: Waste Generated at Diablo Canyon and SONGS (Unit 2 and Unit 3 only)

		Spent Fuel		Low-Level Waste			
		(No. of assemblies)	(MTU)	Class A (ft ³)	Class B (ft ³)	Class C (ft ³)	GTCC ⁵⁵⁹ (ft ³)
Diablo Canyon ⁵⁶⁰	Generated through 2007	2,642	1,136	8,130 ('02-'07)	804 ('02-'07)	563 ('02-'07)	Unknown
	2008 through Initial License	1,668	717	22,406 ⁵⁶¹	2,546	1,786	Unknown
	License Extension	2,112	908	17,480	2,680	1,880	Unknown
	Decommissioning	None	None	240,752 ⁵⁶²	23,308	1,148	866
	Total	6,422	2,761	288,768	29,338	5,377	
SONGS ⁵⁶³	Generated through 2007	2,702	1,138	35,914 ('01-'07)	220 ('01-'07)	115 ('01-'07)	Unknown
	2008 through Initial License	2,270	988	SCE declined to provide this information. ⁵⁶⁴			Unknown
	License Extension	3,024	1,326				Unknown
	Decommissioning	None	None				~2,700
	Total	7,996	3,452				

The main component of spent fuel by mass is uranium-238, which is a weakly radioactive naturally occurring element. Spent fuel also contains other uranium isotopes, transuranic elements such as plutonium and neptunium, and fission products. Cesium-137, strontium-90, and other short-lived fission products contribute most of the spent fuel's heat and radiation.⁵⁶⁵ The composition of Diablo Canyon's spent fuel is provided in Table 13.

⁵⁵⁹ Disposal volume of GTCC waste is not determined until the waste shipment is prepared.

⁵⁶⁰ Pacific Gas & Electric. February 27, 2008: B1.

⁵⁶¹ Includes 3,000 ft³ for removal of first set of steam generators and 2,800 ft³ for two reactor heads removed in 2009 and 2010.

⁵⁶² Includes 17,342 ft³ for both sets of steam generators.

⁵⁶³ Southern California Edison. March 21, 2008: B1.

⁵⁶⁴ SCE considers this information confidential. Southern California Edison. "Southern California Edison's 2007 Nuclear Power Plant-Related Data." Letter to California Energy Commission. Docket No. 06-IEP-1N. April 5, 2007.

⁵⁶⁵ After most of the short-lived fission products decay, radiation from the transuranic elements will dominate. This will occur in roughly a thousand years; U.S. Nuclear Regulatory Commission. "Backgrounder on Radioactive Waste." April 12, 2007. Accessed: April 30, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html>>.

Table 13: Composition of Spent Fuel⁵⁶⁶

	Isotope	Diablo Canyon		SONGS	
		All extracted spent fuel (mass percent) ⁵⁶⁷	Most recently extracted (mass percent) ⁵⁶⁸	All extracted spent fuel	Most recently extracted
Uranium	U-238	93.1%	92.2%	SCE declined to provide this information	SCE declined to provide this information
	U-235	0.90%	0.98%		
Transuranic Elements	Pu-239	0.51%	0.55%		
	Pu-240	0.24%	0.26%		
	Pu-241	0.09%	0.15%		
Fission Products and Other Isotopes		5.16%	5.86%		

On-Site Spent Fuel Storage

Spent fuel is transferred directly from the reactor to a spent fuel pool, where it must cool for at least five years. The spent fuel pools at Diablo Canyon and at SONGS Units 2 and 3 have capacities of 2,948 and 3,084 spent fuel assemblies (1,267 and 1,326 MTU), respectively.⁵⁶⁹ This is sufficient to store the spent fuel from roughly 25 years of operations. Since the spent fuel pools are approaching capacity, PG&E and SCE have been constructing on-site dry cask storage facilities, also known as independent spent fuel storage installations (ISFSIs), to provide additional storage space.⁵⁷⁰ SCE has already begun moving spent fuel from its spent fuel pools to its ISFSI (see "ISFSI Construction Schedules"). PG&E is currently awaiting approval for license amendments to allow for the preparation and loading of its spent fuel canisters. PG&E is also awaiting a final decision from the NRC on challenges to the ISFSI license by Mothers for

⁵⁶⁶ Pacific Gas & Electric. February 27, 2008: B2.

⁵⁶⁷ SCE declined to provide information to the Energy Commission on the composition of SONGS spent fuel.

⁵⁶⁸ Over the years of Diablo Canyon operations, the average burnup rate of fuel at the plant has increased, resulting in more of the uranium fuel being converted into fission products. Peterson, Per. "Annotated Draft Consultant's Report." CEC-100-2007-005-D. June 28, 2007 page 47.

⁵⁶⁹ For Diablo Canyon, this figure includes the capacity of two temporary spent fuel racks that each store 154 fuel assemblies. These racks will be removed prior to placing fuel in dry storage; Pacific Gas & Electric. "PG&E's Responses to CEC's Nuclear Power Plant Data Requests." Docket No. 06-IEP-1N. April 5, 2007, questions B1, C12; Southern California Edison. "Data Request Set CEC 2007 IEPR-PV-SCE-01." 2007 IEPR 06-IEP 1I. March 28, 2007, questions B1, C12.

⁵⁷⁰ In addition to spent fuel, both Diablo Canyon and SONGS are storing damaged fuel rods that require special handling and disposal. PG&E reports that 16 fuel rods at Diablo Canyon are damaged and currently reside in the Unit 2 spent fuel pool. SCE has identified 107 assemblies with potentially damaged fuel rods. These assemblies will need to be specially packaged before they can be placed into dry storage; Pacific Gas & Electric. February 27, 2008: B3; Southern California Edison. March 21, 2008: B3.

Peace; nevertheless, the Diablo Canyon ISFSI license remains valid (see “Mothers for Peace Challenge Diablo Canyon ISFSI License”).⁵⁷¹

ISFSI Construction Schedules

PG&E’s ISFSI has been licensed and permitted for a capacity of up to 4,416 spent fuel assemblies (roughly 1,900 MTU). PG&E plans to build the ISFSI with capacity for 1,280 assemblies initially and to expand the facility in the future, though no schedule has been set. PG&E expects to finish the initial phase of construction in late 2008 and to begin transferring spent fuel from the spent fuel pools in June 2009.

The ISFSI at SONGS is being constructed using two concrete storage platforms, or pads. SCE completed Pad 1 of the SONGS ISFSI and began loading spent fuel in 2003. Since that time, SCE has loaded all of the on-site spent fuel from SONGS Unit 1 and 168 assemblies from Unit 2. SCE plans to load 144 spent fuel assemblies from Unit 3 into the ISFSI in June 2008. A second phase of construction will complete Pad 2 in January 2009. Pad 2 will have a capacity of 1,488 assemblies (roughly 640 MTU) housed in 62 storage modules. SCE plans to install these modules over a span of roughly 10 years, with 16 new modules installed every 2-3 years.

Sources: Pacific Gas & Electric. February 27, 2008: C1, C4; Southern California Edison. March 21, 2008: C1, C4; and Southern California Edison Letter to Energy Commission re: AB 1632 Nuclear Power Plant Assessment, (Docket No. 07-AB-1632). Supplemental Data Request for San Onofre Nuclear Generating Station. May 9, 2008.

PG&E and SCE have taken different approaches for the design and use of ISFSIs at Diablo Canyon and SONGS, respectively. PG&E has designed, permitted and is constructing a dry cask storage facility for Diablo Canyon that will allow the utility to transfer most of the spent fuel to be produced during the current operating license.⁵⁷² With the additional storage capacity in the Diablo Canyon spent fuel pool, PG&E will not run out of storage capacity during the current license period. SCE has designed, permitted and is constructing a dry cask storage facility for SONGS with capacity to store 36 percent of the spent fuel generated during the current license period. Even with the additional storage available in the SONGS spent fuel pool, SCE will need to develop additional on-site storage or secure offsite storage to store all the spent fuel to be produced during the plant’s current operating license (Table 14).

⁵⁷¹ Pacific Gas & Electric. February 27, 2008: C2.

⁵⁷² Based on data provided by PG&E (shown in Table 14), it appears that PG&E is planning sufficient ISFSI capacity to store all spent fuel to be generated during the current license period. However, PG&E has indicated that it anticipates not having sufficient ISFSI capacity to store all the spent fuel to be generated during the current license period. Pacific Gas & Electric. February 27, 2008: C4; Pacific Gas & Electric. April 5, 2007: B1, B7, B12; Pacific Gas & Electric. “Comments on the Draft Consultant Report, ‘AB 1632 Assessment of California’s Operating Nuclear Power Plants,’ dated September 2008.” Docket No. 07-AB-1632. October 2, 2008: 2.

Mothers for Peace Challenges Diablo Canyon ISFSI License

In 2005 San Luis Obispo Mothers for Peace (MFP) filed a lawsuit contending that the Environmental Assessment for the Diablo Canyon ISFSI was incomplete because it did not address the environmental impacts of a terrorist attack at the facility, as required by the National Environmental Policy Act. In June 2006 the Ninth Circuit of the U.S. Court of Appeals ruled in favor of MFP. In response, NRC staff produced a brief supplemental Environmental Assessment that concluded that the probability of a successful attack on the Diablo Canyon ISFSI is very low and that, in the event of a successful attack, the radiation dose to members of the public near the facility would be below the dose limit for workers in the nuclear industry. NRC staff therefore issued a Finding of No Significant Impact.

In response, MFP filed five contentions. MFP argued that NRC staff did not disclose supporting documentation, failed to adequately consider land contamination and latent human health effects from a terrorist attack, made improper assumptions, and failed to consider credible threat scenarios. In July 2008 the NRC Commissioners held a hearing on the second contention.

The NRC has not announced a date for its decision. Until a decision is made, the Diablo Canyon ISFSI license remains valid, and PG&E retains full authority to begin operating the facility as planned.

Sources: San Luis Obispo Mothers for Peace; Santa Lucia Chapter of the Sierra Club; Peg Pinard v. Nuclear Regulatory Commission: Opinion by Judge Thomas On Petition for Review of an Order of the Nuclear Regulatory Commission. Page 6096. (U.S. Court of Appeals for the Ninth Circuit No. 03-74628 June 2, 2006). Accessed: October 3, 2006. <[http://www.ca9.uscourts.gov/ca9/newopinions.nsf/2BFBC6088AF13AA98825718000723C79/\\$file/0374628.pdf?openelement](http://www.ca9.uscourts.gov/ca9/newopinions.nsf/2BFBC6088AF13AA98825718000723C79/$file/0374628.pdf?openelement)>; Pacific Gas and Electric Company. Petitioner v. San Luis Obispo Mothers for Peace, et al. Docket 06-466 (U.S. Supreme Court October 3, 2006). Accessed: March 23, 2007. <<http://www.supremecourtus.gov/docket/06-466.htm>>; U.S. Nuclear Regulatory Commission. "NRC Seeks Public Comment on Supplemental Environmental Assessment for Diablo Canyon Spent Fuel Storage Facility." News Release. May 29, 2007; U.S. Nuclear Regulatory Commission. Memorandum and Order. CLI-08-01. January 15, 2008; U.S. Nuclear Regulatory Commission - Atomic Safety and Licensing Board. "Order Granting NRC Staff's Unopposed Motion For Summary Disposition Of San Luis Obispo Mothers For Peace's Contention 1(B)." Docket No. 72-26-ISFSI. May 14, 2008; and U.S. Nuclear Regulatory Commission. "Hearing: Diablo Canyon Subpart K Proceeding, Oral Arguments." July 1, 2008, page 4. Accessed: July 15, 2008.

Table 14: On-Site Spent Fuel Storage Capacity (number of assemblies)⁵⁷³

	Diablo Canyon	SONGS Units 2 & 3
ISFSI Capacity	1,280 ⁵⁷⁴	312 ⁵⁷⁵
Planned Expansions	3,136	1,488
Total Planned ISFSI Capacity	4,416	1,800
Spent Fuel Pool Capacity	2,648	3,084
Total On-site Storage Capacity	7,064	4,884
Assemblies Generated during Current Licensing period	4,310	4,972⁵⁷⁶

Utility dry cask storage is an interim solution for waste disposal. NRC licenses for ISFSIs are valid for 20 years but may be renewed. PG&E's ISFSI has a design life of 50 years, and SCE's ISFSI has a design life of 100 years with canisters rated for 40 years.⁵⁷⁷ If the spent fuel is not transported off-site within the design lives of the ISFSI components, the spent fuel may need to be repackaged on-site and transferred into new storage canisters, or the current canisters or other ISFSI components may need to be bolstered. At this time there are no estimates as to how long the spent fuel will remain in interim dry-cask storage, and no additional off-site or on-site interim fuel storage facilities are being considered by either PG&E or SCE.⁵⁷⁸

Spent Fuel Storage Costs

Based on data provided by PG&E and SCE, constructing and filling the Diablo Canyon and SONGS ISFSIs will cost roughly \$260 million and \$340 million (2007\$), respectively (Table 15).⁵⁷⁹

⁵⁷³ Pacific Gas & Electric. February 27, 2008: C4; Pacific Gas & Electric. April 5, 2007: B1, B7, B12; Southern California Edison. March 21, 2008: C4; Southern California Edison. March 28, 2007: B1.

⁵⁷⁴ PG&E expects the Diablo Canyon ISFSI to be completed in late 2008. Personal communication between PG&E and Barbara Byron, California Energy Commission. August 27, 2008.

⁵⁷⁵ This includes the total current capacity (707 assemblies) less 395 assemblies from Unit 1 that are in the ISFSI.

⁵⁷⁶ SCE additionally has 270 assemblies of spent fuel from Unit 1 stored at a facility in Illinois. Southern California Edison. March 21, 2008: C1.

⁵⁷⁷ Southern California Edison. March 7, 2008: C4; Oatley, David. "IEPR Committee Workshop on Issues Concerning Nuclear Power." Presentation of David Oatley, PG&E, to the California Energy Commission. August 15, 2005, page 6. <http://www.energy.ca.gov/2005_energypolicy/documents/2005-08-15+16_workshop/presentations/panel-2/Oatley_David_PG&E.pdf>; AREVA. "NUHOMS® 24PT1, 2, 4 Dry Shielded Canister." Accessed: April 7, 2008. <<http://www.transuclear.com/nuhoms-24pt124.htm>>.

⁵⁷⁸ Southern California Edison. March 7, 2008: C3; Pacific Gas & Electric. February 27, 2008: C3.

⁵⁷⁹ Pacific Gas & Electric. February 27, 2008: D1; Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

Table 15: ISFSI Construction and Loading Costs⁵⁸⁰

Cost Component	PG&E	SCE⁵⁸¹
Costs through 2007	\$81 million ⁵⁸²	\$139 million ⁵⁸³
Construction and Loading Costs (2007\$)	\$260 million	\$340 million

PG&E additionally provided data on ongoing ISFSI costs (Table 16). Based on these estimates, the present value of PG&E's expenditures to store all of the spent fuel generated by Diablo Canyon in the ISFSI through the end of the plants's current operating license will be \$180 million.⁵⁸⁴ Delays in shipment to offsite storage of up to 25 years might incur \$1.5 million (2008 dollars) per year in operations, maintenance, and security costs.⁵⁸⁵ Additional delays could require that the spent fuel be removed from the ISFSI and repackaged in new canisters.

Table 16: ISFSI Ongoing Costs⁵⁸⁶

Cost Component	PG&E	SCE
Annual Operation and Maintenance Costs	\$600,000	SCE did not provide this information
Annual Security Costs	\$900,000	
Total Cost through Current License (present value)	\$180 million	

Nuclear Waste Fund Litigation

Ratepayers of utilities generating spent nuclear fuel contribute to a Nuclear Waste Fund to finance U.S. Department of Energy (DOE) costs related to the transport, storage, and disposal of nuclear waste. In turn, DOE was obligated to begin receiving spent fuel from the utilities by January 31, 1998.

⁵⁸⁰ This table relies upon data provided by the utilities. However, it is unclear whether PG&E and SCE considered the same factors in their calculations of construction and loading costs. Therefore it may not be appropriate to compare costs between the two utilities.

⁵⁸¹ Figures for SCE include costs for storage of waste from Unit 1.

⁵⁸² Pacific Gas & Electric. "Comments on the Draft Consultant Report, 'AB 1632 Assessment of California's Operating Nuclear Power Plants,' dated September 2008." Docket No. 07-AB-1632. October 2, 2008: 12.

⁵⁸³ Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

⁵⁸⁴ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007, page 46.

⁵⁸⁵ Calculated based on Pacific Gas & Electric. February 27, 2008: D1.

⁵⁸⁶ Pacific Gas & Electric. February 27, 2008: D1; Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

Through 2007, PG&E ratepayers contributed \$332 million (nominal dollars) to this fund, and ratepayers of SCE and other SONGS co-owners contributed \$407 million (nominal dollars).⁵⁸⁷ Including interest, California ratepayers have contributed over \$1 billion to the Nuclear Waste Fund.⁵⁸⁸ If Diablo Canyon and SONGS continue to operate at the same levels as they did from 2001 through 2007 (i.e. roughly 90 percent capacity factors), ratepayers will contribute an additional \$506 million through the end of the current operating license periods. If the Diablo Canyon and SONGS licenses are extended for 20 years and the plants continue to operate at these levels, ratepayers will pay an additional \$636 million (Table 17).⁵⁸⁹

Table 17: Nuclear Waste Fund Payments, millions (nominal dollars)⁵⁹⁰

	Paid through 2007	2008 through end of Current Operating License	Extended Operating License
Diablo Canyon	\$332	\$285	\$331
SONGS	\$407	\$221	\$305

These payments notwithstanding, ten years after the federal statutory and contractual deadline for accepting commercial spent nuclear fuel, DOE has not yet begun to receive spent fuel from the utilities nor has it licensed a federal repository for the waste.⁵⁹¹

PG&E and SCE, along with many other utilities, have sued DOE for breach of contract because DOE did not begin to receive spent fuel at a federal repository by the 1998 statutory and contractual deadline. The utilities' lawsuits are ongoing. The U.S. Court of Appeals ruled in 2005 that utilities suing DOE on this account may claim only damages that have already been incurred unless they are willing to release DOE of all contractual obligations to receive the spent fuel.⁵⁹² Therefore, claim amounts represent only partial damages, and future lawsuits will likely be necessary to supplement damage claims.

PG&E claimed \$36.9 million in damages through 2004 for ISFSI-related costs at Diablo Canyon (Table 18). The court awarded PG&E \$7 million for ISFSI licensing and construction costs at Diablo Canyon but dismissed PG&E's request to recover costs to evaluate on-site and off-site storage and to construct temporary spent fuel racks, reasoning that these costs were not a direct

⁵⁸⁷ Southern California Edison. April 7, 2008: E2; Southern California Edison. March 28, 2007: D5; Pacific Gas & Electric. February 27, 2008: E2; Pacific Gas & Electric. April 5, 2007: D5.

⁵⁸⁸ This figure includes California's share of payments from the Palo Verde Nuclear Generating Station in Arizona; Nuclear Energy Institute. "Nuclear Waste Fund Payment Information by State." Accessed: June 24, 2008. <http://www.nei.org/filefolder/nuclear_waste_fund_payment_information_by_state.xls>.

⁵⁸⁹ Southern California Edison. March 21, 2008: E2; Southern California Edison. March 28, 2007: D5; Pacific Gas & Electric. February 27, 2008: E2; Pacific Gas & Electric. April 5, 2007: D5.

⁵⁹⁰ These figures do not include interest on payments.

⁵⁹¹ The status of a federal repository at Yucca Mountain is discussed in detail in Appendix 7A.

⁵⁹² U.S. Court of Appeals for the Federal Circuit. "Indiana Michigan Power Company v. United States." 04-5122. September 9, 2005.

result of DOE's breach of contract.⁵⁹³ The court did not allow PG&E to recover the full cost of dry cask storage at Diablo Canyon because it found that even if DOE had begun accepting the waste on time, some dry cask storage would have been necessary since Diablo Canyon spent fuel would not have been shipped to the repository by the end of 2007.

PG&E appealed the Court's disallowance of Diablo Canyon dry cask storage costs and requested that its award be increased. The Court of Appeals remanded the basis on which the original court had calculated damages.⁵⁹⁴ The first decision relied on a spent fuel acceptance schedule that was released in 1991. The Court of Appeals determined that by 1991 it had already become clear that DOE would breach the contract and that damages should have instead been based on an earlier acceptance schedule, namely the schedule released in 1987. The Court of Appeals remanded the original court to go back and calculate damages based on this earlier schedule.⁵⁹⁵ The 1991 schedule originally relied upon indicated that by the end of 2007, DOE would have accepted approximately 6,000 MTU of spent fuel from the nation's commercial reactors, but would not yet have accepted any waste from Diablo Canyon. For this reason the original court denied most of PG&E's claims of damage. The 1987 schedule, however, indicated that by the end of 2007, DOE would have accepted roughly 30,000 MTU of spent fuel – roughly five times that estimated in 1991.⁵⁹⁶ It is unclear how much waste was expected to be accepted from Diablo Canyon under the 1987 schedule, but it is possible that this reconsideration will lead to an increase in PG&E's damage award. The original court will be recalculating damages based on this schedule. As the original decision stands, PG&E ratepayers would not be reimbursed for \$29.8 million of costs incurred through 2004.⁵⁹⁷

SCE claimed \$150 million in damages through 2005 (Table 18).⁵⁹⁸ In its claim SCE contended that had DOE not breached its contract, SCE would not have needed to construct an ISFSI at SONGS.⁵⁹⁹ In addition to ISFSI licensing, construction and operation costs, SCE is seeking compensation for payments made to General Electric for storage of Unit 1 spent fuel and

⁵⁹³ PG&E additionally claimed approximately \$55 million for ISFSI costs at Humboldt Bay. The court awarded PG&E \$36 million for costs related to Humboldt Bay. *Pacific Gas & Electric*. April 5, 2007: D9.

⁵⁹⁴ U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

⁵⁹⁵ U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

⁵⁹⁶ U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

⁵⁹⁷ This figure includes damages claimed for the Diablo Canyon ISFSI in excess of the \$7 million awarded, costs associated with the construction of temporary spent fuel racks, and the costs incurred for evaluation of on- and off-site storage options.

⁵⁹⁸ *Southern California Edison*. March 28, 2007: D9.

⁵⁹⁹ *Southern California Edison*. March 28, 2007: Attachment D8, page 3.

investments in the proposed Private Fuel Storage facility in Utah.⁶⁰⁰ The standard discovery phase of the proceeding has ended, though SCE has indicated that additional discovery may be required.⁶⁰¹ No trial date has been set.

Table 18: Nuclear Waste Fund Litigation⁶⁰²

Facility	Damages Claimed through 2004	Status	ISFSI Costs through 2007
Diablo Canyon	\$31.7 million for licensing and construction of ISFSI	\$7 million awarded, remanded by appellate court	\$36.6 million for licensing and construction
	\$2.7 million for licensing and construction of temporary storage racks	Claims denied	
	\$1.5 million for pre-1998 evaluation of on-site storage options		
	\$0.9 million for evaluation of off-site storage options (including Humboldt Bay)		
SONGS	\$122 million for licensing and construction of ISFSI	Trial date TBA	\$138.5 million for licensing and construction
	\$26 million for storage of Unit 1 waste at the Morris Facility		
	\$2 million for investment in Private Fuel Storage		

Spent Fuel Packaging and Transport Issues

Diablo Canyon and SONGS spent fuel will remain at the power plants until a federal repository or offsite interim storage facility is opened. Under DOE's current plan, shipments of commercial

⁶⁰⁰ Private Fuel Storage is a consortium of SCE and seven other utilities that was formed in the early 90's to construct a temporary spent fuel storage facility on the Goshute Indian Reservation in Utah. The proposed facility ran into a number of regulatory obstacles and appears unlikely to go forward. SCE ceased funding of the project in 2001. MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007: 63.

⁶⁰¹ Southern California Edison. March 21, 2008: E1.

⁶⁰² United States Court of Federal Claims. "PG&E v. United States. Case No. 04-75C. Final Decision." October 13, 2006, page 70; Southern California Edison. March 28, 2007: D7; Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

spent fuel would contain one to five casks per train or a single cask per overweight truck.⁶⁰³ Based on the expected volume of waste to be generated at Diablo Canyon and SONGS, it would require between 70 and 340 shipments to transport all of the spent fuel to be generated during the current operating periods and an additional 40 to 190 shipments to transport the spent fuel that would be generated over 20-year license extensions.⁶⁰⁴

Spent fuel must be packaged in special transportation-safe canisters in order to be shipped off-site. These canisters – called “casks” – are designed to remain intact and withstand high-speed crashes, long-lasting fires, and submersion in water even under extreme accident conditions. It remains highly uncertain what would be involved in packaging the spent fuel for shipment and transporting it to an off-site repository, particularly since this will likely not occur for at least another decade.

Packaging Requirements

DOE has proposed designing and developing a Transportation, Aging and Disposal (TAD) canister system for shipments from reactors to the proposed repository at Yucca Mountain. With this system, spent fuel could be moved directly from a spent fuel pool into a TAD canister and then remain in the same canister (with different overpacks) for above-ground dry storage, transportation to Yucca Mountain, and disposal at Yucca Mountain. However, spent fuel that is packaged in canisters that are not TAD-compatible may need to be repackaged either at Yucca Mountain or prior to shipment. Repackaging would likely result in additional costs to the utility, though these costs may be recoverable through the Nuclear Waste Fund (NWF) litigation discussed above.

At a November 2007 public hearing on the draft Environmental Impact Statement (EIS) for Yucca Mountain, Barbara Byron conveyed concerns on behalf of the California Energy Commission regarding the compatibility of proposed TAD regulations with interim storage processes already in place in California. The state claimed that, due to the potential need for repackaging at a reactor site, the “use of the TAD canister system will significantly increase workers' radiological exposure and the risks associated with handling bare spent fuel assemblies, and loading and welding canisters at reactor sites (routine exposures and accidents).”⁶⁰⁵ Byron also recommended that DOE examine how the TAD system will interface with the dry cask storage system at reactor sites and requested clarification on the financial responsibility for developing a repackaging system at reactor sites.

⁶⁰³ U.S. Department of Energy. “Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.” October 2007, pages 2-45.

⁶⁰⁴ Calculated based on Southern California Edison. March 21, 2008: B1; Pacific Gas & Electric. February 27, 2008: B1.

⁶⁰⁵ California Energy Commission. “Barbara Byron Comments on Draft Supplemental Yucca Mountain Repository EIS and Supplemental Rail Corridor and Rail Alignment Environmental Impact Statements.” November 19, 2007, page 6. <http://www.ocrwm.doe.gov/ym_repository/seis/comments/RRR000108.pdf>.

The Nuclear Energy Institute (NEI) anticipates that spent fuel in dry cask storage will not be repackaged into TAD canisters for shipment to Yucca Mountain.⁶⁰⁶ NEI explains that by the time Yucca Mountain is in operation, the amount of spent fuel at utility sites will exceed the current legal capacity of Yucca Mountain. Utilities will have the choice of which spent fuel to ship, and they will choose to ship spent fuel from spent fuel pools, since these have never been packaged into canisters, instead of spent fuel from dry-cask storage, which would need to be repackaged.⁶⁰⁷ NEI anticipates that utilities would only adopt the TAD system for on-site interim storage if DOE offered compensation to cover the increased cost and reduced capacity of the TAD canisters.⁶⁰⁸

To date, DOE has specified only preliminary performance specifications for the proposed TAD system, and no TAD canisters have yet been developed.^{609, 610} In the absence of final regulations, the utilities have adopted their own canister systems. PG&E's spent fuel canister system is not compatible with DOE's proposed TAD system.⁶¹¹ SCE states that at this point it is unclear whether its storage system will comply with DOE's final TAD requirements.⁶¹²

Spent Fuel Transport Costs

DOE will be responsible for paying to transport spent fuel from reactors to a permanent repository. Like repository costs, transportation costs will be paid out of the Nuclear Waste Fund. Spent fuel transportation costs will depend on the quantity of fuel, the distance traveled, and the level of security provided. DOE has estimated that the total cost to transport commercial spent fuel to primary Nevada rail and truck hubs would be \$6.3 billion, or \$75,000 per MTU.⁶¹³ (These estimates do not include the cost to build transportation infrastructure from

⁶⁰⁶ McCullum, Rod, Nuclear Energy Institute. "Transportation, Aging, and Disposal (TAD) Canisters: A Tool for Integrating the Used Fuel Management System." Presentation to WIEB HLW Committee. April 23, 2008, slide 11. <http://www.westgov.org/wieb/meetings/hlwsprg2008/briefing/present/r_mccullum.pdf>.

⁶⁰⁷ McCullum, Rod. "Transportation, Aging, and Disposal (TAD) Canisters." April 2008: 11.

⁶⁰⁸ McCullum, Rod. "Transportation, Aging, and Disposal (TAD) Canisters." April 2008: 9.

⁶⁰⁹ U.S. Department of Energy, Office of Civilian Radioactive Waste Management. "Civilian Radioactive Waste Management System: Preliminary Transportation, Aging and Disposal Canister System Performance Specification, Revision B." *DOC ID: WMO-TADCS-0000001*. November 2006.

⁶¹⁰ In May 2008, DOE awarded contracts to two companies to design, license, and demonstrate the TAD canister system over the next five years; *United Press International*. "Energy Dept. OKs waste storage contracts." May 21, 2008. Accessed: May 23, 2008. <<http://www.upi.com>>.

⁶¹¹ Pacific Gas & Electric. February 27, 2008: E4.

⁶¹² Southern California Edison. March 21, 2008: E4.

⁶¹³ Figures from study escalated to 2007 dollars; U.S. Department of Energy. "Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program." DOE/RW-0533. May 2001, pages 4-19. Accessed: April 28, 2008. <<http://www.ocrwm.doe.gov/about/budget/pdf/tslccr1.pdf>>.

these hubs to the Yucca Mountain facility.) The State of Nevada has estimated that these costs would be \$7.5 billion total or \$90,500 per MTU.⁶¹⁴

If, instead of a permanent repository, DOE or another entity builds an off-site interim storage facility, and PG&E or SCE opt to store spent fuel at the facility, the utility could be responsible for the costs of transporting spent fuel to that site.⁶¹⁵ Since no such facility exists today, it is not known how many shipments, what distances, or what transport methods would be involved. Costs would also vary depending on mode of transport, size of transport vehicles, and security considerations. Using an average of DOE and Nevada's estimates of \$75,000 and \$90,000 per MTU as a ballpark figure for the cost to transport spent fuel, it would cost the utilities roughly \$160 million each to remove the spent fuel generated during the plants' current license terms.⁶¹⁶ It would cost each utility roughly \$100 million more to ship the spent fuel that would be generated during a 20-year license extension.

Accident Prevention and Emergency Preparedness Costs

Emergency preparedness in California is funded in part by taxpayers and in part by the nuclear plant owners. State appropriations fund the Radiological Health Branch of the Department of Public Health and the Governor's Office of Emergency Services for emergency response preparation for nuclear plants in California. PG&E and SCE fund the Nuclear Planning Assessment Special Account, which is administered by the California Office of Emergency Services and used to fund local planning authorities for nuclear power plant-related emergency response planning. Funds are distributed to the counties of San Luis Obispo, San Diego, and Orange and to the cities of Dana Point, San Juan Capistrano, and San Clemente. These cities and counties distribute the funds to local governments within the 10-mile emergency planning zone surrounding the two sites. In FY 2009/2010, the Nuclear Planning Assessment Special Account will provide \$1.7 million for Diablo Canyon-related emergency response and \$1.6 million for SONGS-related emergency response.⁶¹⁷ Legislation passed in October 2007 extended this funding mechanism through 2019.⁶¹⁸

Emergency planning costs reflect the risks of reactor operations and of on-site spent fuel storage. In a study on the Indian Point nuclear power plant in NY, the authors presumed that emergency planning costs would not materially change if the reactors ceased operating as long

⁶¹⁴ Planning Information Corporation, et. al. "An Independent Cost Assessment of the Nation's High-Level Nuclear Waste Program." Prepared for the State of Nevada. February 1998. Accessed: May 22, 2008. <<http://www.state.nv.us/nucwaste/trans/pic2/2piccovr.htm>>.

⁶¹⁵ Neither PG&E nor SCE has any current plans of pursuing interim off-site storage. Pacific Gas & Electric. February 27, 2008: C3; Southern California Edison. March 21, 2008: C3.

⁶¹⁶ Pacific Gas & Electric. February 27, 2008: B1; Southern California Edison. March 21, 2008: B1.

⁶¹⁷ California Emergency Services Act: Nuclear Planning Assessment Special Account. (AB 292, Blakeslee, Signed October 11, 2007).

⁶¹⁸ AB 292, Blakeslee.

as spent fuel remained on site.⁶¹⁹ However, the authors did not provide supporting information for this assumption, and there is some evidence to the contrary. For example, after the Rancho Seco nuclear plant was shut down and its operating license terminated, state and local governments stopped receiving funding because of the reduced hazard.⁶²⁰

Under the Nuclear Waste Policy Act (NWPA) Section 180(c), DOE is required to provide technical and financial assistance for emergency response preparation for repository shipments. DOE has proposed a grant program for safe routine transportation and emergency response training.⁶²¹ DOE proposes to make two grants available to states: 1) a one-time assessment and planning grant of up to \$200,000, and 2) an annual training grant with a base amount of \$100,000 and a state-specific variable amount.⁶²² The assessment and planning grant is to be made available no sooner than four years prior to the first shipment, and the annual training grants are to begin three years prior to the first shipment and to continue for each year of shipments. According to DOE's current schedule, shipments will begin sometime after 2017 and likely after 2020.⁶²³

Many parties submitted comments on DOE's proposed grant program. Among them, the Western Interstate Energy Board (WIEB) noted that DOE has not yet established a national transportation plan for repository shipments.⁶²⁴ WIEB commented that states would require at least three years after shipment routes had been identified and funding dispersed to adequately prepare for the shipments.⁶²⁵

Commissioner James Boyd of the California Energy Commission also submitted comments on DOE's proposed 180(c) funding policy. Commissioner Boyd described California's unique transportation situation. California has multiple waste generator sites and several large metropolitan areas potentially impacted by spent fuel shipments. The State will need significant time and resources to ensure the safe transport of spent nuclear fuel and to prepare for

⁶¹⁹ Levitan & Associates, Inc. "Indian Point Retirement Options, Replacement Generation, Decommissioning / Spent Fuel Issues, and Local Economic / Rate Impacts." Prepared for The County of Westchester and The County of Westchester Public Utility Service Agency. June 9, 2005, page 110. Accessed: June 17, 2008. <<http://www.westchestergov.com/currentnews/2005pr/levitanreport.pdf>>.

⁶²⁰ Personal Communication between Barbara Byron, California Energy Commission, and Ben Tong, California Office of Emergency Services. July 15, 2008.

⁶²¹ Register. Volume 72, No. 140. Monday, July 23, 2007, page 40139. <<http://a257.g.akamaitech.net/7/257/2422/01jan20071800/edocket.access.gpo.gov/2007/pdf/E7-14181.pdf>>.

⁶²² Federal Register. Vol. 72, No. 140. Monday, July 23, 2007: 40139.

⁶²³ U.S. Department of Energy. "Yucca Mountain Repository License Application." December 2007. Accessed: May 23, 2008. <http://www.ocrwm.doe.gov/ym_repository/license/index.shtml#skiptop>.

⁶²⁴ Western Interstate Energy Board. "Comments on Notice of Revised Proposed Policy and Request for Comments on the OCRWM plan for the implementation of section 180 (c) of the Nuclear Waste Policy Act." (Federal Register No 1. 72, No. 1401. Monday, July 23, 2007/Notices). January 17, 2008. <http://www.ocrwm.doe.gov/transport/180c_comments/Overview_dated_01-17-2008_w-Answer_Matrix.pdf>.

⁶²⁵ Western Interstate Energy Board. January 17, 2008.

emergency response along shipment corridors in California.⁶²⁶ Commissioner Boyd stressed that the grant timeline should be flexible to accommodate large, populous states like California. He estimated that California will need a minimum of 4-5 years prior to shipments for grant application, funding, initial needs assessments, plan development, and emergency response training.⁶²⁷ He also characterized DOE's proposed funding levels as "seriously insufficient" for California.⁶²⁸ Commissioner Boyd estimated that it would cost over \$712,000 per year for training and equipment for shipments originating from the four commercial reactor sites in California.⁶²⁹ Additional costs associated with the routing of other states' shipments through California are not included in that figure. Table 19 below summarizes DOE's proposed policy and Commissioner Boyd's recommendations.

DOE has not yet clarified the extent to which state accident prevention and emergency preparation costs related to the shipment of spent fuel will be reimbursable from DOE through the Nuclear Waste Fund. In February 2005, WIEB, the Midwestern Council of State Governments, the Southern States Energy Board, and the Eastern Regional Conference of the Council of State Governments created the "Principles of Agreement among States on Expectations Regarding Preparations for OCRWM Shipments."⁶³⁰ Among these principles, the state governments asked that DOE define transportation-related activities for which funding from the Nuclear Waste Fund will be provided. The parties are still awaiting clarification from DOE.

⁶²⁶ Commissioner James Boyd, California Energy Commission. "Comments on Notice of Revised Proposed Policy and Request for Comments on the OCRWM plan for the implementation of section 180 (c) of the Nuclear Waste Policy Act." (Federal Register No 1. 72, No. 1401. Monday, July 23,2007/Notices). January 22, 2008. <http://www.ocrwm.doe.gov/transport/180c_comments/California_Comments_Final_1-22-08.pdf>.

⁶²⁷ Commissioner James Boyd, California Energy Commission. January 22, 2008.

⁶²⁸ Commissioner James Boyd, California Energy Commission. January 22, 2008: 8.

⁶²⁹ Commissioner James Boyd, California Energy Commission. January 22, 2008: 10.

⁶³⁰ Commissioner James Boyd, California Energy Commission. January 22, 2008: 19.

Table 19: DOE's Proposed Emergency Response Grant Program⁶³¹

	DOE's Proposed Policy	California Estimates
Required time before first shipment for dispersal of assessment and planning grant	4 years	Minimum of 4-5 years
Required time before first shipment for annual dispersals of training grants	3 years	More than 3 years
Amount of assessment and planning grant	\$200,000 maximum	\$200,000 "seriously insufficient"
Amount of annual training grant	\$100,000 plus variable state-related adder	More than \$712,000

Low-Level Waste Disposal

The Low-Level Radioactive Waste Policy Amendments Act of 1985 encourages states to enter into compacts with one another to arrange for disposal of low-level waste at common facilities. Currently there are only three low-level waste disposal facilities operating in the U.S. Until recently, two of those facilities accepted low-level waste from California: the EnergySolutions facility in Clive, Utah, which accepts only Class A waste, and the EnergySolutions facility in Barnwell, South Carolina. The Barnwell facility closed to California and all other states not part of the Atlantic Compact on June 30, 2008.⁶³²

PG&E disposed of all the Class A, B, and C waste generated at Diablo Canyon prior to 2007 except for activated metal in the spent fuel pools, which is being accumulated until a sufficient quantity is available for packaging. Since the Barnwell facility closed to California generators in June 2008, remaining Class B and C waste will be stored in a shielded storage building on site.⁶³³ These on-site facilities have sufficient capacity to store all of the Class B and C waste to be generated through the end of the current operating license and through an extended operating license.⁶³⁴ PG&E reports that it will review other options for the disposal of Class B and C low-level waste if they become available.⁶³⁵ PG&E also plans to store large reactor components on-site until decommissioning in order to minimize low-level waste shipments and costs.⁶³⁶ (This

⁶³¹ Federal Register. Vol. 72, No 140. Monday, July 23, 2007: 40139; Commissioner James Boyd, California Energy Commission. January 22, 2008.

⁶³² The Atlantic Compact includes Connecticut, New Jersey and South Carolina.

⁶³³ Pacific Gas & Electric. April 5, 2007: B9.

⁶³⁴ Pacific Gas & Electric. February 27, 2008: E7.

⁶³⁵ Pacific Gas & Electric. February 27, 2008: E7.

⁶³⁶ Pacific Gas & Electric. February 27, 2008: E6.

includes the soon-to-be replaced steam generators.) A summary of PG&E's low-level waste disposal activities at Diablo Canyon since 2002 is shown in Table 20.

Table 20: Low-Level Waste Disposal Activities 2002-2007⁶³⁷

		Diablo Canyon	SONGS
Time Period	Waste Class	Disposal Volume (ft³)	Disposal Volume (ft³)
2002-2006	Class A	7,178	SCE declined to provide this information
	Class B	706	
	Class C	547	
2007	Class A	952	
	Class B	98	
	Class C	15	

Faced with the Barnwell closure, SCE will also store all Class B and C waste at SONGS pending development of additional disposal options.⁶³⁸ SCE will continue to ship Class A waste to the Clive, Utah facility and will evaluate any treatment and disposal options that become available. SCE also plans to prepare the SONGS steam generators for transportation and disposal off-site once the new steam generators are installed.⁶³⁹

As a result of the Barnwell facility closure, there is no Class B or Class C off-site disposal facility available for over 80 percent of the country's reactors.⁶⁴⁰ In addition, large quantities of low-level waste will be created when the oldest reactors running today begin decommissioning.⁶⁴¹ In October 2007 the NRC issued an assessment of its low-level waste regulatory program in order to address upcoming challenges regarding low-level waste disposal.⁶⁴² The NRC determined that its regulations are outdated and do not address the current large amounts of on-site low-level waste at the nation's reactors. The assessment identified seven high-priority near-term

⁶³⁷ Pacific Gas & Electric. April 5, 2007: B9.

⁶³⁸ Southern California Edison. March 21, 2008, E7.

⁶³⁹ Southern California Edison. March 21, 2008: E6.

⁶⁴⁰ The NRC will continue to have the authority to require the Barnwell facility to accept low-level waste from California and other states for temporary storage for up to 225 days if this is necessary "to eliminate an immediate and serious threat to the public health and safety or the common defense and security." 42 USC 2021f.

⁶⁴¹ U.S. Nuclear Regulatory Commission. "Waste Confidence and Waste Challenges: Managing Radioactive Materials." Speech at the Waste Management Symposium Phoenix, Arizona. S-08-008. February 25, 2008.

⁶⁴² U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." SECY-07-0180. October 17, 2007.

tasks that could improve low-level waste regulation. The first task is to update guidance on extended storage of low-level waste for materials and fuel cycle licensees, to review industry guidance for reactors, and to identify whether there are any gaps in safety or security considerations.⁶⁴³ The NRC expects to complete this task by the end of 2008.⁶⁴⁴

Costs related to the transportation and disposal of low-level waste are the generators' responsibility. Between 2002 and 2006, PG&E spent roughly \$6 million on the storage and disposal of low-level waste.⁶⁴⁵ A summary of PG&E's present and estimated future low-level waste transportation and disposal costs is provided in Table 21.

SCE reports that costs to transport low-level waste vary by the type of material, mode of transportation, and destination. For example, it costs SCE roughly \$5 per cubic foot by rail and \$10 per cubic foot by truck to ship Class A low-level waste from SONGS to the Clive, Utah facility and \$400 per cubic foot to ship Class B and C wastes to Barnwell, South Carolina by truck.⁶⁴⁶ SCE declined to provide the Energy Commission information on SONGS low-level waste disposal costs.

Table 21: Diablo Canyon Low-Level Waste Transportation and Disposal Costs⁶⁴⁷

	Cost through 2006	Through end of Current Operating License	Through Extended Operating License
Class A	\$450/ft ³ - Resin \$50/ft ³ - Trash & Debris	\$500/ft ³ - Resin \$150/ft ³ - Trash & Debris	\$500/ft ³ - Resin \$150/ft ³ - Trash & Debris
Class B	\$2,500/ft ³	Unknown	Unknown
Class C	\$3,200/ft ³	Unknown	Unknown
Total Disposal Cost	\$1 million/year	\$1.1 million/year	\$1.1 million/year

Low-level waste disposal costs have risen significantly in recent years. A 2004 GAO report noted that over the prior 25 years disposal costs had risen from \$1 per cubic foot to over \$400 per cubic foot and that costs were expected to exceed \$1,000 per cubic foot in the future.⁶⁴⁸ These cost increases will have the biggest impact when the plants are decommissioned. For example,

⁶⁴³ U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." October 17, 2007: 5.

⁶⁴⁴ U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." October 17, 2007: 13, C-8.

⁶⁴⁵ Pacific Gas & Electric. February 27, 2008: B1, E3.

⁶⁴⁶ Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

⁶⁴⁷ Pacific Gas & Electric. February 27, 2008: E3.

⁶⁴⁸ U.S. Government Accountability Office (GAO). "Low-Level Radioactive Waste: Disposal Availability Adequate in the Short Term, but Oversight Needed to Identify Any Future Shortfalls." GAO-04-604. 2004, page 20. Accessed: June 12, 2008. <<http://www.gao.gov/new.items/d04604.pdf>>.

PG&E estimated in 2006 that waste disposal costs during Diablo Canyon decommissioning would total \$242 million (2004 dollars).⁶⁴⁹ This estimate was based on a total waste disposal cost of \$248 per cubic foot, which is much less than the blended cost of Class A-C low-level waste disposal today.⁶⁵⁰ An updated estimate of disposal costs would likely be significantly higher. For example, a blended disposal cost of \$450 per cubic foot would increase total waste disposal costs to \$438 million (2004 dollars), and a blended disposal cost of \$1,000 per cubic foot would increase total waste disposal costs to \$974 million (2004 dollars).^{651, 652}

Conclusions

Diablo Canyon and SONGS produce significant quantities of radioactive waste in the form of spent fuel and other radioactively contaminated materials. These wastes must be carefully handled, stored, transported, and disposed of to protect humans and the environment from exposure to radioactive materials. In the case of spent fuel, which remains extremely radioactive for thousands of years, it is necessary to store the fuel assemblies in a water-filled pool for a minimum of five years following removal from the reactor core to shield plant workers against high levels of radiation.

Both Diablo Canyon and SONGS lack sufficient spent-fuel pool capacity to store the quantity of spent fuel to be produced over the period of their operating licenses. The proposed federal repository at Yucca Mountain, which was to accept this spent fuel for disposal, has experienced repeated delays and is not expected to begin accepting waste before 2020, if at all. As a result, both Diablo Canyon and SONGS have been forced to increase their on-site storage capacity for spent fuel through the construction of ISFSIs.

PG&E and SCE have taken different approaches for the design and use of ISFSIs at Diablo Canyon and SONGS, respectively. In the case of Diablo Canyon, PG&E has designed and permitted an ISFSI that will allow the utility to store most of the spent fuel to be produced during the current operating license. With the additional storage capacity in the Diablo Canyon spent fuel pool, PG&E will not run out of storage capacity during the current license period. SCE has designed, permitted, and is constructing an ISFSI with a capacity to store 36 percent of the spent fuel generated during the current license period. Even with the additional storage available in the SONGS spent fuel pool, SCE will need to develop additional on-site storage or

⁶⁴⁹ Pacific Gas & Electric. "2005 Nuclear Decommissioning Cost Triennial Proceeding: Supplemental Workpapers Supporting Chapters 3 and 5." CPUC proceeding A, 05-11-009. March 30, 2006, pages 5-6.

⁶⁵⁰ At \$250 per cubic foot for Class A disposal, \$2,500 per cubic foot for Class B disposal, and \$3,200 per cubic foot for Class C disposal, the blended disposal cost for the volumes of waste disposed of between 2002 and 2007 is \$615 per cubic foot. Calculation based on Pacific Gas & Electric. April 5, 2007: B9.

⁶⁵¹ Calculations based on Pacific Gas & Electric. "2005 Nuclear Decommissioning Cost Triennial Proceeding: Supplemental Workpapers Supporting Chapters 3 and 5." CPUC proceeding A, 05-11-009. March 30, 2006, pages 5-6.

⁶⁵² Disposal costs during decommissioning could be even higher if additional large components are replaced. These components can be costly to transport and dispose of. See *Nuclear Power in California: 2007 Status Report*, page 132.

secure off-site storage to store all the spent fuel to be produced during the plant's current operating license.

Both PG&E and SCE have sued DOE for reimbursement of their ISFSI costs, claiming that DOE has breached the contract requiring the federal government to begin accepting waste for permanent disposal by 1998. PG&E received a favorable judgment that provides for reimbursement of certain ISFSI costs while denying other claims. PG&E is currently appealing the decision. A trial date to hear SCE's claim has not been set.

Utility dry cask storage is an interim solution for waste disposal. PG&E's ISFSI is designed for a lifetime of 50 years, and the canisters used in SCE's ISFSI are designed for a lifetime of 40 years. If the spent fuel is not transported off-site within the design lives of the ISFSI components, the spent fuel may need to be repackaged on site and transferred into new storage canisters, or the current canisters or other ISFSI components may need to be bolstered. The long-term storage, packaging, and transport of this waste add to the expense and the risk of nuclear power in California. At this time there are no estimates as to how long the spent fuel will remain in interim dry-cask storage, and no additional off-site or on-site interim fuel storage facilities are being considered by either PG&E or SCE.

If a federal repository is established, spent fuel will need to be packaged for transport, aging, and disposal (TAD) at a repository. DOE has proposed designing and developing a new TAD canister packaging system, but has not yet established federal TAD packaging requirements, forcing PG&E and SCE to move forward with dry cask storage cask designs that may not be compatible with federal TAD requirements. The costs for transport of spent fuel to off-site storage or disposal facilities will be substantial, including costs for security, accident prevention, and emergency preparedness. Policies are being developed to federally fund state and county emergency response preparation for shipments to the proposed repository; however, California has claimed that the proposed federal program may be insufficient, both in the planned timing of the grant program and the amount of the proposed grants for state planning and for training emergency response personnel to respond to potential accidents involving California's spent fuel shipments.

Low-level radioactive waste also requires care in handling, transport, and disposal. There are only three facilities in the U.S. that accept low-level waste for disposal and, as of June 30, 2008, only the Energy Solutions facility in Clive, Utah, accepts low-level waste from Diablo Canyon and SONGS. This facility accepts only Class A waste. PG&E and SCE expect to continue to ship Class A waste to Clive and to store Class B and C wastes at the reactor sites until a new or existing facility agrees to accept this waste. This does not pose a significant problem at present because the volume of this waste is relatively small, and the waste can be safely stored on site. However, the plants cannot be fully decommissioned until the waste is removed from the plant sites. The NRC is currently reviewing its policies regarding on-site low-level waste storage and expects to complete this task by the end of 2008.

Low-level waste disposal costs are relatively modest during ongoing plant operations. However, a substantial quantity of low-level waste will need to be disposed of when the plants are decommissioned, and the cost to transport and dispose of this waste, presuming a disposal facility is available, is expected to be hundreds of millions of dollars or more. Low-level waste

disposal costs have been rising in recent years, and costs may be substantially higher than estimated during the last CPUC review in 2005.

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CHAPTER 8: Land Use and Economic Implications of On-Site Waste Storage

The considerable uncertainty as to when and if a geologic repository or other interim waste storage facility will allow the removal of spent fuel from the plant sites requires policymakers to consider the land use and local economic implications of extended on-site storage, and even the possibility of nuclear waste remaining at the plant sites after the reactors have been decommissioned. It is widely assumed that long-term storage of spent fuel at the plant sites would have a negative effect on future land uses, local property values, business, and tourism. Underlying this assumption is the perception that spent fuel storage creates health and safety risks that precludes certain land uses or depresses economic conditions.

In this chapter, the Consultant Team explores this presumption by examining the experiences of other communities and by reviewing the available academic research. To provide focus to the discussion, the Consultant Team considers the land use and economic implications of maintaining spent fuel in dry cask storage facilities at the plant sites after the reactors have been shut down. This scenario represents a highly probable long-term outcome if the plants are shut down at the end of their current operating licenses in the 2020s and a possibility even if the plants continue operating throughout a 20-year license extension.

Land Use Implications of On-Site Waste Storage

Diablo Canyon and SONGS are both located near public beaches along the Pacific coast; however, land use in the vicinity of Diablo Canyon is substantially different from land use in the vicinity of SONGS. Diablo Canyon is bordered directly to the northeast by Montaña de Oro State Park and is located on a scenic and habitat-rich coastline about 12 miles southwest of San Luis Obispo. SONGS is located within the boundaries of the U.S. Marine Corps Base Camp Pendleton (Camp Pendleton), approximately four miles south of San Clemente. Diablo Canyon is located in a sparsely-populated region along the central coast; SONGS is located near the border of Orange County and within 60 miles of the San Diego metropolitan area. The Diablo Canyon site is surrounded by about 12,000 acres of Pacific Gas & Electric (PG&E)-owned land, a portion of which is used for farming and ranching.⁶⁵³ SONGS is bordered by a state beach on two sides, the Pacific Ocean to the west, and mostly open land within Camp Pendleton on the other side of Highway 5. The Diablo Canyon site is 760 acres large; the SONGS site is just 84 acres large. As a result of these differences, extended on-site waste storage will have different land use implications for the two plants.

This section describes current land use in the immediate areas surrounding Diablo Canyon and SONGS. It then presents the Consultant Team's assessment of the impacts on future land use in these areas of extended on-site storage of nuclear waste in dry cask facilities.

⁶⁵³ Pacific Gas & Electric. "Steam Generator Replacement Project, Final Environmental Impact Report." August 2005, page ES-7.

Existing Land Uses at Diablo Canyon

The Diablo Canyon power plant is located along the central California coast in an unincorporated area of San Luis Obispo County. According to PG&E, in the year 2000 approximately 424,000 residents lived within 50 miles of the power plant site.⁶⁵⁴ Closest to the site are the communities of Avila Beach, located seven miles southeast of Diablo Canyon, and Los Osos, located eight miles north of Diablo Canyon. Avila Beach and Los Osos had populations of 797 and 14,351, respectively, in 2000. San Luis Obispo, the county hub, lies approximately 12 miles northeast of the plant and has approximately 42,970 residents.⁶⁵⁵

San Luis Obispo County covers over 3,300 square miles and is bordered by a national forest to the south and the Santa Lucia Mountain range to the north (Figure 35). PG&E and its subsidiary, Eureka Energy Company, own 12,000 acres surrounding the plant site, of which about 760 acres are used for the high security zone that includes the power plant.⁶⁵⁶ Land use on PG&E-controlled lands includes farming and ranching. Approximately 200 acres are currently under cultivation, and cattle graze on 2,500 acres.⁶⁵⁷ The agricultural land is considered by the California Department of Conservation to be productive farmland that is subject to protection under the California Environmental Quality Act.⁶⁵⁸

Recreational and scenic opportunities are vital aspects of this part of the California coast. Montaña de Oro State Park to the north of Diablo Canyon features over 8,000 acres of rugged cliffs, secluded sandy beaches, coastal plains, streams, canyons, and hills, including the 1,347-foot Valencia Peak. Avila Beach is a popular beach for residents and tourists. The area offers hiking and biking trails, including the Pecho Coast Trail and the City to the Sea Bikeway, and docent-led tours to the Point San Luis Lighthouse. In addition, the Port San Luis Harbor District, in which Diablo Canyon is located, supports commercial and recreational boating and fishing activities.

⁶⁵⁴ Pacific Gas & Electric. "ISFSI Environmental Report, Amendment 1." October 2002, pages 2.2-4.

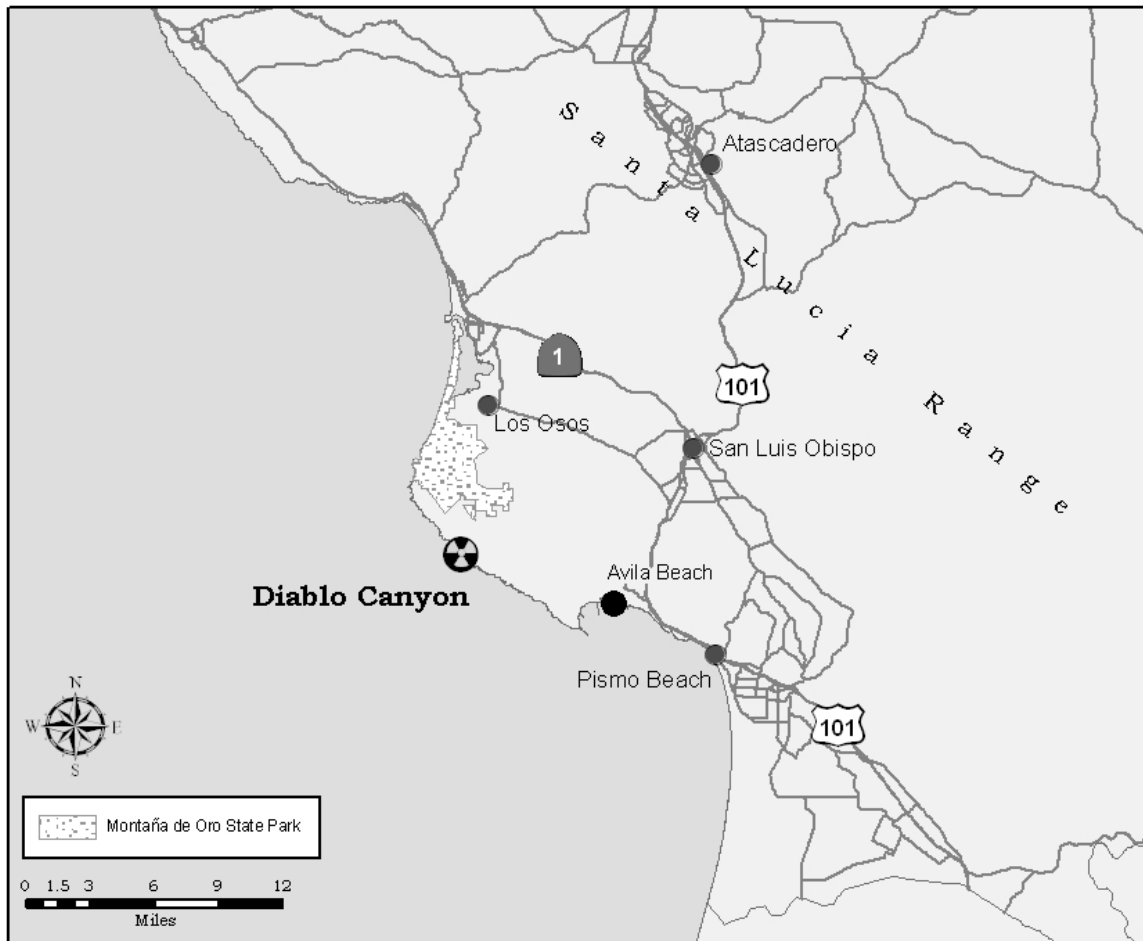
⁶⁵⁵ U.S. Census Bureau. "2006 data." Accessed: March 26, 2008. <<http://www.census.gov>>.

⁶⁵⁶ Pacific Gas & Electric. "Steam Generator Replacement Project, Final Environmental Impact Report." August 2005: ES-7.

⁶⁵⁷ Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008, Section 4.1.

⁶⁵⁸ The Department of Conservation designates farmlands as "prime," "of statewide importance," or "unique" as part of the Federal Mapping and Monitoring Program, and lands surrounding Diablo Canyon fall into each of these three categories. Lands must meet criteria specified by state and federal authorities in order to be assigned these designations. For example, prime farmland is land that is very suitable for growing crops based on the soil quality, growing season, and moisture supply. Farmland of statewide importance is land that does not meet all of the criteria to be considered prime farmland but otherwise is suitable for growing crops. Under California Environmental Quality Act conversion of farmland to other uses can require mitigation.

Figure 35: Diablo Canyon Area Land Use Map



Existing Land Uses at SONGS

SONGS is located on the coast in San Diego County entirely within the boundaries of Camp Pendleton. Camp Pendleton is an active federal military installation dedicated to military training and other military uses. The SONGS site is under a federal easement and lease agreement. Real estate rights are through nine Department of Navy-issued easements and two leases totaling 438 acres.⁶⁵⁹ Current real estate grants authorize SONGS to maintain a presence on Camp Pendleton until approximately 2024.⁶⁶⁰

Figure 36 shows the location of the SONGS site and surrounding land uses. The Camp Pendleton area includes 2,600 buildings and structures and 7,300 housing units.⁶⁶¹ It is

⁶⁵⁹ The Marine Corps is an administrative unit under the Department of the Navy.

⁶⁶⁰ Camp Pendleton. "Draft Integrated Natural Resource Management Plan." August 2005. Accessed: April 30, 2008. <<http://www.pendleton.usmc.mil/base/environmental/inrmp.pdf>>.

⁶⁶¹ Camp Pendleton. "Camp Pendleton: In-Depth." Accessed: April 30, 2008. <<http://www.pendleton.usmc.mil/impact/facilities.asp>>.

surrounded by open space and recreational land uses that are managed by the California State Department of Parks and Recreation and Camp Pendleton. Camp Pendleton maintains a number of recreational facilities at Camp Del Mar near the Camp Pendleton Del Mar Boat Basin, which are used throughout the year by active and retired military personnel and their families. Camp Pendleton extends to the south of SONGS for approximately 18 miles.

SONGS is located within 30 miles of several mid-size Orange County cities, including Costa Mesa, Irvine, and Mission Viejo, and 60 miles from San Diego, which is the seventh largest city in the U.S.⁶⁶² The City of San Clemente, the nearest municipality, is located two miles north of SONGS and has a population of approximately 61,000.⁶⁶³ The City of Oceanside, with a 2006 population of 165,803, lies outside Camp Pendleton approximately 20 miles south of SONGS.⁶⁶⁴ There are also 900 housing units located approximately one mile northwest of SONGS in Camp Pendleton.⁶⁶⁵

San Onofre State Beach borders SONGS to the northwest and southeast. It includes over 3,000 acres of land in four separate subunits and is operated by the State under a 50-year lease with the U.S. Navy.⁶⁶⁶ The beach provides hiking, camping, swimming, surfing, beach access, and scenic viewing. In addition, there is an existing bicycle transit route that begins in San Clemente and traverses Camp Pendleton. Access to the Camp Pendleton section of the bicycle transit route is dependent on military training activities and security concerns and is periodically restricted if military training activities are being conducted.

Future Land Uses

After a nuclear plant is permanently shut down, the plant site is decommissioned. The decommissioning process includes removal and cleanup of all contaminated materials from a site, including spent fuel.⁶⁶⁷ However, if a federal repository is not prepared to accept the spent fuel from the plant at the time of decommissioning, spent fuel could remain in an independent spent fuel storage installation (ISFSIs) at the site after the rest of the site has been decommissioned (see Chapter 7). When this occurs, plant owners can release most of the land for alternate uses; only a parcel containing the ISFSI surrounded by a 100-meter security zone must remain under NRC license.⁶⁶⁸ This has occurred at several decommissioned plants in the U.S. (see “Experiences with Land Use Following Decommissioning”).

⁶⁶² City of San Diego. “Economic Development: Population.” Accessed: June 16, 2008. <<http://www.sandiego.gov/economic-development/glance/population.shtml>>.

⁶⁶³ U.S. Census Bureau. “2006 data.”

⁶⁶⁴ U.S. Census Bureau. “2006 data.”

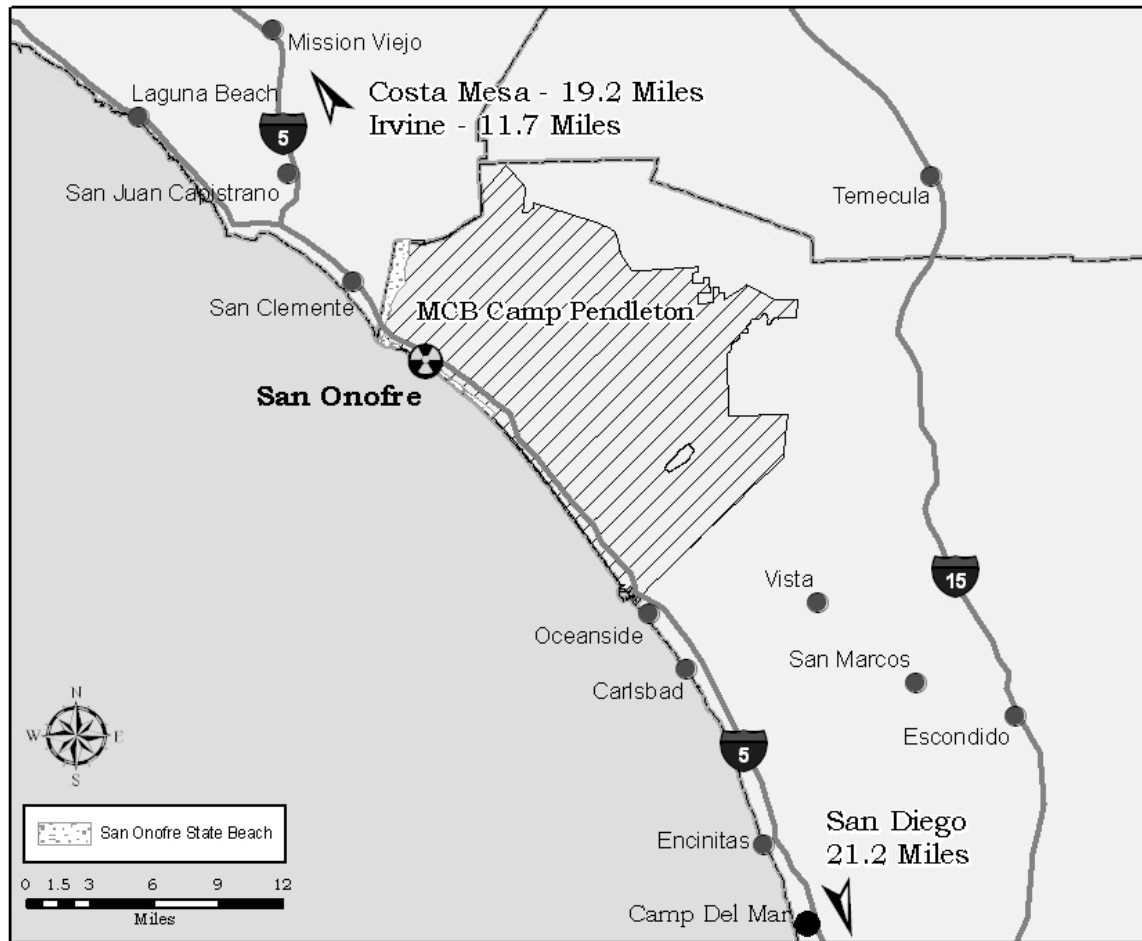
⁶⁶⁵ Camp Pendleton. “San Onofre Housing Community.” Accessed: April 30, 2008. <http://www.cpp.usmc.mil/base/housing/san_onofre.asp>.

⁶⁶⁶ California Department of Parks and Recreation. “San Onofre State Beach Revised General Plan.” June 1984.

⁶⁶⁷ U.S. Nuclear Regulatory Commission. “Frequently Asked Questions About Reactor Decommissioning.” April 17, 2007. Accessed: July 10, 2008. <<http://www.nrc.gov/about-nrc/regulatory/decommissioning/faq.html#1>>.

⁶⁶⁸ U.S. Nuclear Regulatory Commission. “Code of Federal Regulations.” 10 CFR 72.106.

Figure 36: Land Use for San Onofre State Beach Lease on MCB Camp Pendleton



Future land uses of the Diablo Canyon and SONGS sites and surrounding areas will depend on many factors. First, owners of the various land parcels will have to determine their objectives and how to best meet those interests. Second, public perceptions about land formerly used for nuclear power could influence land use decisions. Third, state and local planners and the general public may have specific goals such as public use and enjoyment or habitat preservation that they would want to achieve through land use decisions.

As is discussed below, the citizens of San Luis Obispo County have already expressed a strong preference for reserving the Diablo Canyon lands for public access and public use spaces, habitat preservation, and sustainable agriculture. The SONGS site will remain under the control of the U.S. Navy. The Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use.

Experiences with Land Use Following Decommissioning

The Maine Yankee nuclear plant occupied 820 acres during its years of operation. After the plant was shut down in 1996 and decommissioning activities were completed, the operator of the plant received approval from the NRC to release the majority of the plant site from NRC oversight. Remaining under NRC oversight is the ISFSI, which is located on 8.5 acres with a surrounding security zone of 300 meters in all directions. (The security zone was increased to 300 meters due to design basis threat regulations and conditions specific to Maine Yankee.) The remainder of the land is divided among the former plant owner, which retains between 100 and 150 acres of the original land; a 400 acre mixed-use development that incorporates a clean technology park; and a non-profit organization that will maintain the remaining area as open space with public access.

Another New England power plant, the Connecticut Yankee plant at Haddam Neck, has also completed the decommissioning process. The plant's owner, Connecticut Yankee Atomic Power Company, recently issued a request for Expressions of Interest for development at the old plant site. More than 580 acres once occupied by the nuclear plant may ultimately be made available for development. Within this tract of land, the plant's ISFSI occupies 5 acres with an additional 70 acre security zone to remain under NRC regulation as long as the ISFSI remains.

The Sacramento Municipal Utility District's (SMUD) Rancho Seco nuclear facility was shut down in 1989. Since that time, SMUD has built a 500 MW natural-gas fired power plant less than one mile from the former nuclear plant and a solar photovoltaic plant less than one-half mile from the former nuclear plant. Approximately 1,200 acres were set aside in 2006 for a nature preserve to the east and south of the former plant location. The Rancho Seco Recreational Area located approximately 1.5 miles to the west includes a 160-acre lake and 400-acre park. A separate wildlife refuge adjoins the park on the southwest.

Sources: Electric Power Research Institute. Maine Yankee Decommissioning Experience Report: Detailed Experiences 1997-2004 , pages 1-2, 8-11. Accessed: June 18, 2008. <<http://www.maineyankee.com/public/pdfs/epri/my%20epri%20report-2005.pdf>>; Coastal Enterprises, Inc. "Maine Yankee Power Plant." Accessed: June 10, 2008. <<http://www.ceimaine.org/content/view/12/24>>; Connecticut Yankee. "The Connecticut Yankee Atomic Power Plant." Accessed: May 20, 2008. <http://www.connyankee.com/html/future_use.asp>; Connecticut Yankee, "Haddam Neck Point, Haddam, Connecticut: Property Fact Sheet," page 4 <http://www.connyankee.com/_pdf/CY_Property_factsheet_F.pdf>; and Sacramento Municipal Utility District. "Rancho Seco Nuclear Facility." Accessed: June 4, 2008. <http://www.smud.org>.

Diablo Canyon

A ballot initiative in 2000 asked the citizens of San Luis Obispo County about their land use priorities for the "post-Diablo Canyon" period. Nearly three-quarters of voters responded that the county should "recognize the Diablo Canyon Lands as an exceptionally precious coastal resource by adopting policies that promote habitat preservation, sustainable agricultural activities, and public use and enjoyment consistent with public safety and property rights once

the lands are no longer needed as an emergency buffer for the Diablo Canyon Nuclear Plant after its remaining operating life.”⁶⁶⁹

The experiences of other communities where nuclear plants have been decommissioned while spent fuel has remained on-site, though limited, indicate that extended on-site waste storage need not interfere significantly with plans to maintain the lands surrounding Diablo Canyon for habitat preservation, sustainable agricultural activities, and public use and enjoyment. However, a small portion of the land would need to be set aside for restricted access as long as the ISFSI remained. PG&E estimates that the amount of land needed for the ISFSI itself is between 3 and 10 acres.⁶⁷⁰ In addition, PG&E would be required to create and maintain a security zone around the ISFSI with a minimum distance of 100 meters in all directions,⁶⁷¹ and to the extent that additional spent fuel is generated during an extended license period, the ISFSI could require a larger amount of land. This land is all part of the larger land parcel, known as Parcel P, of 585 acres on which the power plant sits. In response to an information request from the California Energy Commission (Energy Commission), PG&E stated it would likely retain Parcel P even after the power plant is decommissioned.⁶⁷² PG&E stated it is too early to speculate about any other plans for land around this parcel.

SONGS

Future land uses for the SONGS plant site are restricted by the presence of the San Onofre State Beach and Camp Pendleton. The closure of SONGS should not impact land uses at the beach since the San Onofre State Beach Revised General Plan recommends preserving and protecting the significant natural resources, cultural resources, and agricultural preserves within the State Beach.⁶⁷³ The closure of SONGS could lead to other uses of the site at Camp Pendleton. Once the NRC terminates the SONGS operating license, Southern California Edison (SCE) presumably would return the power plant site to the Department of the Navy with the exception, if spent fuel remains on-site, of the land directly surrounding the ISFSI.⁶⁷⁴ Camp Pendleton presumably would then have the option of leasing or selling the land to another party.

⁶⁶⁹ San Luis Obispo County Election. “Advisory vote only on Diablo Canyon Lands -- San Luis Obispo County, Ballot Measure A.” March 7, 2000. Accessed: April 14, 2008 <<http://www.smartvoter.org/2000/03/07/ca/slo/meas/>>.

⁶⁷⁰ Pacific Gas & Electric. “PG&E’s Response to AB 1632 Study Report Supplemental Data Requests.” Docket No. 07-AB-1632. April 28, 2008, Section 4.1.

⁶⁷⁰ Pacific Gas & Electric, April 28, 2008: 4.1.

⁶⁷¹ U.S. Nuclear Regulatory Commission, 10 CFR 72.106.

⁶⁷² Pacific Gas & Electric, April 28, 2008: 4.1.

⁶⁷³ California Department of Parks and Recreation. “San Onofre State Beach Revised General Plan.” June 1984.

⁶⁷⁴ This discussion assumes that SCE would construct additional dry cask storage in order to move all spent fuel from spent fuel pools into the ISFSI if this were required to decommission the remainder of the plant. SCE’s spent fuel management plans are discussed in Chapter 7.

The Camp Pendleton Integrated Natural Resources Management Plan states that future federal lease reviews will require consideration of Camp Pendleton's interest 100 years into the future. Moreover, any proposal would have to conform to the following conditions:⁶⁷⁵

- Cannot adversely affect training;
- Cannot degrade Camp Pendleton quality of life;
- Must be environmentally non-degrading;
- Must ensure safety of operating forces; and
- Must be consistent with Base architecture.

According to these guidelines, many commercial and non-polluting industrial enterprises would be eligible for a land lease. Fossil-fueled power plants would likely not be eligible.

The Coastal Commission may restrict allowable land leases, even though the land is owned by the federal government. In February 2008 the Coastal Commission set precedent by attempting to exert partial jurisdiction over San Onofre State Beach, which is also owned by the federal government.⁶⁷⁶ The Coastal Commission rejected a proposed toll road in the vicinity, citing adverse impacts to public access and to recreation, surfing, visual resources, and endangered species and habitat.⁶⁷⁷ In particular, the Commission considered the impacts to wetlands and listed species at the State Beach and to a campground originally provided as mitigation for impacts from SONGS to constitute coastal zone effects, which fall under the Coastal Commission's jurisdiction.⁶⁷⁸ The Transportation Corridor Agency has appealed the Coastal Commission's ruling to the U.S. Department of Commerce.⁶⁷⁹ If the Coastal Commission prevails, the Coastal Commission could potentially be similarly active in reviewing any proposed land leases for the SONGS site. The Coastal Commission's objectives would be to restrict commercial development, enhance public access, and protect coastal resources.

⁶⁷⁵ Camp Pendleton. "Draft Integrated Natural Resource Management Plan." August 2005. Accessed: April 30, 2008. <<http://www.pendleton.usmc.mil/base/environmental/inrmp.pdf>>.

⁶⁷⁶ The Transportation Corridor Agencies Foothill Toll Road Expansion would have extended Route 241 by an additional 14 miles, providing an alternative route to I-5 for travel from inland Orange County and Riverside County. As proposed, the extension would connect to I-5 at the San Diego/Orange County line near SONGS. The final four miles of the extension would extend through four miles of San Onofre State Park. Transportation Corridor Agencies. "TCA Response to Staff Report and Recommendation on Consistency Certification." Executive Summary. January 2008. Accessed: April 24, 2008. <http://www.ftcsouth.com/home/pdf/Executive_Summary_TCA_Response_to_Coastal_Commission_staff_report.pdf>.

⁶⁷⁷ California Coastal Commission. "Staff Report and Recommendation on Consistency Certification." October 2007. Accessed: April 14, 2008. <<http://documents.coastal.ca.gov/reports/2007/10/Th19a-10-2007.pdf>>.

⁶⁷⁸ California Coastal Commission. October 2007.

⁶⁷⁹ Transportation Corridor Agencies. "The Toll Roads." Accessed: April 24, 2008. <http://www.thetollroads.com/home/news_press_feb08.htm>.

Regardless of whether the SONGS facility is replaced by a commercial or industrial facility or is opened up to the public for recreational use, the area of land containing the ISFSI would not be accessible for public use. However, as discussed above, the amount of land with restricted usage due to the ISFSI would be just a portion of the overall SONGS site. Most of the site, with the exception of the ISFSI and its security zone, could be opened up for development, recreational use, or open space even with the ISFSI remaining on the land.

Economic Implications of On-Site Waste Storage

Communities near nuclear power plants are concerned about living near a long-term nuclear waste storage facility. For residents, their property may be their most important financial asset. For businesses, actual and perceived risk by the public could deter customers and harm the local economy. However, public concerns may overstate the true economic implications of on-site waste storage. This section presents the available research on the effects that dry cask storage facilities have had or are expected to have on property values, business, and tourism.

Property Values

Dry cask storage facilities at Diablo Canyon and SONGS are located within the footprint of the operating nuclear plants. This section examines the potential property value impacts associated only with the addition of dry-cask storage facilities to the plant sites. The impact on property values associated with the operating plants is a complex issue and is discussed in detail in Chapter 10.

There is limited academic research on the impacts of long-term on-site spent fuel storage on property values in part because dry cask storage of spent fuel is a relatively recent development.⁶⁸⁰ The authors of this study were not able to identify any property value research that was conducted for an area surrounding a dry cask storage facility after the facility became operational or research regarding the impacts of long-term spent fuel storage that remained after a plant had been decommissioned. The research that is available and which was reviewed for this present study was completed in the 1990s and evaluated either perceptions about potential nuclear waste storage sites or the impact of announcements of plans to build a dry cask storage facility. Because these studies do not address the same situation as is being considered here, i.e. property value implications of an operating dry cask storage facility, the results of the studies are necessarily limited in their relevance.

In a study published in 1999, David Clark and Tim Allison of Marquette University and Argonne National Lab, respectively, analyzed property sales data for properties within a 15-mile radius of the Rancho Seco nuclear power plant, which was located near Sacramento. At the time of the study, the plant had been recently shut down and the plant owner applied to the NRC for a license to construct a dry cask storage facility.⁶⁸¹ Clark and Allison found that within

⁶⁸⁰ Much more research has been done on property value impacts for properties in the vicinity of an operating nuclear power plant. A discussion of that research is provided in Chapter 10.

⁶⁸¹ Clark, David E. and Tim Allison. "Spent nuclear fuel and residential property values: the influence of proximity, visual cues and public information." *Papers in Regional Science*. Volume 78, (1999): 403-421.

⁶⁸¹ Clark and Allison, 1999: 413.

this 15-mile radius property values increased with greater distance from the plant. However, over the course of the study the extent of this effect declined. The authors attributed this decline to a decreased aversion to the plant. They did not speculate on whether the decreased aversion was related to the plant's not being operational. Notably, they did not observe an increase in aversion (i.e. a decrease in property values) when the plant owner applied for the ISFSI license. The authors concluded that "there is no evidence to support a significant detrimental influence of the announcement of a dry storage facility on [home] sale prices."⁶⁸²

Clark conducted a related study with William Metz of Argonne National Lab in 1997, in which the researchers evaluated property sales data in the vicinities of Rancho Seco and Diablo Canyon. Metz and Clark concluded in this study, as well, that "decisions and announcements about spent nuclear fuel storage activities have not affected the local residential property market to the extent predicted by surveys of attitudes and images...this finding of no property value effect is the case regardless of whether a plant is operating or closed."⁶⁸³

However, the Clark-Allison and Clark-Metz studies may not incorporate the full impacts of on-site waste storage at Diablo Canyon and SONGS. The studies only examine property values within a 15-mile radius of the plants. Within this small sample area, potential negative effects may already be internalized in the property values and may not vary with distance. The studies do not compare property values with comparable areas that do not have on-site fuel storage.⁶⁸⁴

A 1996 study by Gilbert Bassett of the University of Illinois was based on a survey instead of empirical analysis and arrived at different conclusions than these studies. Bassett surveyed over 600 residents living near nuclear power plants in the Midwest about their attitudes and perceptions related to the plants.⁶⁸⁵ When asked to predict what would happen if it became widely known that a nearby nuclear power plant would become a nuclear waste storage site for the foreseeable future, 39 percent of respondents reported that they expected their home values to decrease, and 21 percent reported that the announcement would greatly increase the chance that they would move. Respondents also reported that they perceived spent fuel storage and spent fuel transportation to be roughly equally risky and both to be significantly more risky than nuclear power generation.⁶⁸⁶ In other words, these residents felt comfortable enough about the risk of nuclear power generation to continue to live near a nuclear plant, yet they expected that they would feel substantially less comfortable about the risks of long-term spent fuel storage.

Metz and Clark explained the difference between their results and the Bassett survey results by noting that the studies evaluate different things—the Bassett study evaluated risk perception, while their study evaluated economic impacts. Metz and Clark concluded that perceived risk does not necessarily translate into a change in economic behavior:

⁶⁸² Clark and Allison, 1999: 413.

⁶⁸³ Metz, William C. and David Clark. "The Effect of Decisions About Spent Nuclear Fuel Storage on Residential Property Values." *Risk Analysis*. Volume 17, (1997): 571-582.

⁶⁸⁴ This issue is also discussed in Chapter 10.

⁶⁸⁵ Bassett Jr. Gilbert; Hank Jenkins-Smith, and Carol Silva. "On-Site Storage of High Level Nuclear Waste: Attitudes and Perceptions of Local Residents." *Risk Analysis*. Volume 16, No. 3. 1996.

⁶⁸⁶ Bassett Jr. 1996: 312.

“A major challenge for policy makers in their efforts to site temporary and permanent nuclear waste facilities...is the need to balance survey evidence, that suggests that adverse economic impacts and stigmatization are likely to result, with findings of [statistical] analyses, that suggest that any risk perceptions that exist may not be reflected in local economic behavior.”⁶⁸⁷

This is consistent with the finding of Simons and Saginor based on a comparative analysis of articles and case studies on the effects of contamination on property values: “The most consistent result...is that the use of survey and case study techniques provides larger estimates of property losses regarding contamination than regression studies [of property sales data] do.”⁶⁸⁸ The authors concluded that statistical analysis “provides a more conservative, statistically accurate estimation of property value loss.”⁶⁸⁹ In other words, surveys are likely to overstate potential economic impacts; whereas analyses like the studies done by Clark-Allison and Clark-Metz are more likely to reveal economic effects with greater accuracy.

There could also be other explanations for the difference in results. For example, the studies were performed in different parts of the country. Also, the Bassett survey asked about the expected impacts of a hypothetical situation, whereas the Clark studies evaluated real situations. In a study on homebuyer attitudes near Yucca Mountain, Hoyt, Schwer, and Thompson found that residents who had been aware of the possibility of a high-level waste facility being sited near their homes were less concerned than those who had been unaware.⁶⁹⁰ They concluded that “unawareness breeds concern.” Consequently, asking about a hypothetical situation could evoke greater concern than asking about an actual situation of which the respondents had been informed. This issue is further illustrated by survey results from a decade long University of New Mexico study examining public perception of risks associated with the Waste Isolation Pilot Plant, as reported in a study by the National Academies.⁶⁹¹ Researchers found that over time following the announcement of the plant, support gradually increased and appeared to increase significantly once the first transuranic waste shipments had been completed.⁶⁹²

In conclusion, analytical studies that have measured the property value impacts of waste storage facilities have not identified a negative impact. However, there are only a few relevant analytical studies, their results disagree with survey results, and none assess property value impacts in an area in which a dry cask storage facility had already been constructed and

⁶⁸⁷ Metz and Clark, 1997: 508-509.

⁶⁸⁸ Simons, Roberta and Jesse Saginor. “A Meta-Analysis of the Effect of Environmental Contamination and Positive Amenities on Residential Real Estate Value.” *Journal of Real Estate Research*. Volume 28, Number 1. 2006, page 95.

⁶⁸⁹ Simons and Saginor, 2006: 97.

⁶⁹⁰ Hoyt, Richard, R. Keith Schwer, and William Thompson. “A Note on Homebuyer Attitudes Toward a Nuclear Repository.” *The Journal of Real Estate Research*. Volume 7, Number 2. Spring 1992, pages 227-232.

⁶⁹¹ National Academies. “Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States.” Committee on Transportation of Radioactive Waste, National Research Council. 2006, page 157.

⁶⁹² National Academies. “Going the Distance?” 2006: 157.

operational. Also, the analytical studies and the surveys are all approximately ten years old and may no longer be relevant now that there is an 18-year history of accident-free operations of dry cask storage facilities nationwide.⁶⁹³ More study is required to determine with certainty the impacts of dry cask storage remaining at Diablo Canyon or SONGS after the rest of the plant is decommissioned.

To fully explore the property value impacts of spent fuel storage, a study would also need to consider whether property owners would be better or worse off if, instead of remaining on-site, the spent fuel was shipped off-site to a spent fuel disposal facility such as Yucca Mountain. The Bassett study found that spent fuel transport was perceived as equally risky as spent fuel storage.⁶⁹⁴ Several surveys, including those discussed by the National Academies, have also shown that spent nuclear fuel transport is associated with negative public perception and an anticipated decrease in property values.⁶⁹⁵ As surveys, these studies may overestimate the actual economic impacts of spent fuel transport, as discussed above; however, they suggest that there may be negative property value impacts associated with spent fuel transport that should be weighed against the property value implications of spent fuel storage.

A study on property value impacts of spent fuel storage might also consider how property values could be impacted by a major accident or incident at a dry cask storage facility at the plant site or elsewhere. However, as discussed in Chapter 4, the likelihood of such an event is very small.

Business and Tourism

Business and tourism are vital to the local economies in the areas surrounding Diablo Canyon and SONGS. Local businesses generate jobs and tax revenues, and visitor spending generates revenue for local businesses and tax revenue for local governments (see insert on “Tourism Revenues” below). Business and tourism could be directly affected if on-site waste storage is perceived by the public as posing health and safety risks.

There is limited research on this topic and much of it is focused on how tourism in Nevada would be affected by the opening of a geological repository for nuclear waste at Yucca Mountain. According to the Nevada Agency for Nuclear Projects, this research generally has found that the repository could cause visitors to avoid southern Nevada by a) increasing the perceived risk associated with visiting the area, b) giving rise to “noxious imagery that becomes associated with Nevada,” or c) conferring a stigma on the area.⁶⁹⁶ In other words, the impact of the repository on tourism would depend on whether the repository would lead the public to perceive Nevada as a riskier place.⁶⁹⁷ This would likely be the case if a transportation accident

⁶⁹³ U.S. Nuclear Regulatory Commission. “2007-2008 Information Digest.” August 2007, page 121.

⁶⁹⁴ Bassett Jr. 1996: 312.

⁶⁹⁵ Nevada Agency for Nuclear Project. “A Mountain of Trouble: A Nation At Risk – Report on Impacts of the Proposed Yucca Mountain High-Level Nuclear Waste Program.” February 2002; National Academies. “Going the Distance?” 2006.

⁶⁹⁶ Nevada Agency for Nuclear Project, 2002: 52.

⁶⁹⁷ Nevada Agency for Nuclear Project, 2002: 58.

resulted in a release of radioactive materials in the state, especially if this release resulted in death or illness. Media reports focused on the risks of the repository could also lead to a reduction in tourism.⁶⁹⁸

In the unlikely event of an accident at an on-site waste storage facility, adverse impacts on business and tourism would be expected in the area. In a review of literature concerning tourism impacts related to the 1979 incident at Three Mile Island, Himmelberger, et. al. found that these effects are short-lived and distance dependent.⁶⁹⁹ The researchers found that businesses within 30 miles of the accident suffered mild adverse impacts for four to six months and businesses further than 60 miles from the accident were not adversely affected.⁷⁰⁰

In conclusion, the local economies in the areas surrounding Diablo Canyon and SONGS could be impacted if these areas were stigmatized or seen as riskier due to the waste storage. Some businesses could also be temporarily impacted in the unlikely event of an accident at one of the storage facilities. Most residents surveyed in the Bassett study thought that long-term waste storage would “result in about the same or fewer tourists in to the area,” with similar impacts on new business formation and overall employment.⁷⁰¹ As discussed in the section on property values, the perceptions reported in surveys do not always correlate well with actual economic actions. Since there currently is on-site spent fuel storage at both power plants, local business and tourism are unlikely to be further impacted unless increased media attention on waste storage or an accident at a waste storage facility increases the perception of the risk of on-site storage.

⁶⁹⁸ Nevada Agency for Nuclear Project, 2002: 62.

⁶⁹⁹ Himmelberger, Jeffery, et. al. “Tourism Impacts of Three Mile Island and Other Adverse Events: Implications for Lincoln County and Other Rural Counties Bisected by Radioactive Waste Intended for Yucca Mountain.” *Journal of Environmental Management*, Vol. 19, No. 6. Page 918.

⁷⁰⁰ Himmelberger, Jeffery, et. al. “Tourism Impacts of Three Mile Island and Other Adverse Events: Implications...” *Journal of Environmental Management*, Vol. 19, No. 6. Page 918.

⁷⁰¹ Bassett, Jr. 1996: 316-317.

Tourism Revenues

Tourism revenues in San Luis Obispo County, where Diablo Canyon is situated, result primarily from visitor spending on recreation, hotels, restaurants, shops, and other entertainment venues. In 2006, the tourism industry accounted for 11 percent of county employment and 12 percent of sales tax receipts. In addition, travel spending in San Luis Obispo County accounted for 4 percent of total spending and exceeded \$1 billion.

Economic Impacts of Tourism and Visitor Spending, 2006

County	Employment (jobs) <i>(percent of total)</i>	Travel Spending (\$ Million) <i>(percent of total)</i>	Sales Tax Receipts (\$ Million) <i>(percent of total)</i>
San Luis Obispo	16,610 <i>(10.6%)</i>	1,085 <i>(4%)</i>	29.7 <i>(11.8%)</i>
Orange	86,430 <i>(2.3%)</i>	8,307 <i>(4.7%)</i>	210.2 <i>(6.2%)</i>
San Diego	114,230 <i>(3.4%)</i>	10,556 <i>(5.2%)</i>	281.3 <i>(9.9%)</i>

San Diego and Orange Counties, which are both adjacent to SONGS, also receive economic benefits from tourism. As shown in Table 1, the percentage of workers employed in the tourism industry and percent of the county's sales tax receipts that come from tourism are lower than in San Luis Obispo County, but travel spending as a percent of total spending is slightly higher. Tourism revenue results in part from beach-going visitors. San Onofre State Beach is considered a major tourist attraction, and the area is particularly known for its surfing. Trestles Beach, to the north of SONGS, is considered one of the premier surfing locations in California due to the ideal sedimentary outflow of the San Mateo and Christianos Creek drainages. Visitor spending by surfers at San Clemente and Trestles Beach contributes significantly to Southern Orange County's and Northern San Diego County's local economies. A 2007 socioeconomic survey estimated that surfers visiting Trestles provide an economic impact of from \$8 million per year to \$13 million per year to the City of San Clemente. Looking beyond just Trestles Beach, another study estimated the overall economic value of San Clemente's beaches at about \$37 million per year. Total travel spending in Orange and San Diego counties exceeded \$18 billion in 2006.

Sources: California Division of Tourism. "California Travel Impacts by County 1992-2006." Prepared by Dean Runyan Associates. March 2008. Accessed: June 18, 2008. <http://www.deanrunyan.com/pdf/ca07p.pdf>; McKee, B. "The Future of Trestles." *Surfer Magazine*. Accessed: April 24, 2008. <http://surfermag.com/features.oneworld/trestles/index.html>; Nelsen, C. L. Pendleton, and R. Vaughn. "A Socioeconomic Study of Surfers at Trestles Beach." Accessed: April 30, 2008. <http://www.surfrider.org/surfecon/Trestles2007-WP1.pdf>; and King, P. "Economic Analysis of Beach Spending and the Recreational Benefits of Beaches in the City of San Clemente." <<http://userwww.sfsu.edu/~pgking/sanclemente%20final%20report.pdf>>.

Conclusions

A federal spent fuel repository will likely not be ready to accept spent fuel from Diablo Canyon and SONGS at the end of the plants' current operating licenses, and spent fuel may remain at the plant sites for an indeterminate period of time. NRC regulations allow the majority of a plant site to be decommissioned and redeveloped for other uses while spent fuel remains at the former plant site surrounded by a 100-meter security zone. In fact, local communities near the Rancho Seco and Maine Yankee nuclear power plants successfully converted the land once used for the power plant and immediately around it into areas that provide recreational or economically-productive mixed uses. The Connecticut Yankee nuclear plant site may also soon be developed. Accordingly, the presence of dry cask storage facilities at Diablo Canyon and SONGS after the plants are decommissioned should not prevent alternate uses from being established.

Voters in San Luis Obispo County have expressed a strong preference to convert the Diablo Canyon site to primarily recreational use; however, PG&E has not indicated publicly how it would use the decommissioned plant site. In the case of SONGS, the plant site, which is located on military land, will remain under the control of the U.S. Navy. The Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use. As long as spent fuel remains stored at their respective plant sites, PG&E and SCE will need an NRC license.

Even with a plant site converted to alternate uses, the question remains as to whether the continued presence of the spent fuel has a negative impact on property values, business, and tourism in the area. Literature on economic implications of long-term spent fuel storage is extremely limited. Survey-based literature shows the potential for substantial negative effects on property values, business, and tourism. However, surveys potentially overstate actual economic effects and can be unreliable economic predictors. Statistical studies have not found the announcement of an on-site waste storage facility to clearly impact nearby property values. In addition, there have not been any studies completed that examine the long-term property value impact of on-site dry cask storage, that evaluate whether removal of the waste would result in economic benefit for the surrounding community, or that consider the relative impacts on property values of spent fuel storage and spent fuel transportation. An analysis of property sales data and other economic indicators in areas where a dry cask storage facility is operating would provide a useful starting point to assess potential impacts of extended spent fuel storage at California's nuclear plants.

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CHAPTER 9: Power Generation Options

The California legislature, through Assembly Bill 32 (AB 32, Nunez, 2006), mandated statewide greenhouse gas reductions. The California Air Resources Board, the California Public Utilities Commission, and the California Energy Commission (Energy Commission) are integrating this mandate into the highest levels of the state's energy policies. As the Energy Commission stated in the 2007 *Integrated Energy Policy Report*, "AB 32 requires California to determine how to meet its electricity needs in a way that leaves an ever-shrinking *greenhouse gas* footprint."⁷⁰²

State policy sets a "loading order" for meeting California's growing energy demand while lowering greenhouse gas emissions. Energy efficiency, renewable resources, and distributed generation are at the top of the order.⁷⁰³ According to the Energy Commission, new nuclear plants and "clean" coal plants are "not expected to contribute significantly to the state's near-term AB 32 goals given the economic, environmental, and regulatory barriers these technologies face."⁷⁰⁴

It will be a challenge to meet the growing demands for electricity in California while reducing greenhouse gas emissions, keeping costs down, and avoiding other environmental damage or hazards. At least some aspects of this challenge will be made more difficult if California's current nuclear power plants, which have very low greenhouse gas emissions, are shut down. Shutting down the plants would also pose a financial burden on the local communities near the plants until jobs and a tax base are provided by new industry. However, shutting down the plants would also benefit the public by reducing waste generation, radioactivity, and the potential spread of nuclear materials. The net benefit or cost of keeping the plants operating would depend on the economic and environmental characteristics of the replacement power portfolio.

This chapter provides an overview of available studies on life cycle impacts of nuclear power and alternative generating sources. It reviews information on the availability of each resource and associated costs, environmental impacts, land use impacts, and local economic impacts. It also presents the results of a preliminary analysis of the cost to replace the power from the nuclear plants with power from other sources.

Nuclear Power and Alternative Power Sources

California has several policies in place to guide the selection of power resources for the state. Since 2003, California's energy policy has relied on a loading order to meet growing energy needs—first with energy efficiency and demand response; second, with renewable energy and

⁷⁰² California Energy Commission. "2007 Integrated Energy Policy Report." CEC-100-2007-008-CMF. 2007, page 35.

⁷⁰³ California law (Public Resources Code 25524) prohibits the permitting of land-use for a new commercial nuclear power plant until a federally approved means for the permanent disposal or commercial reprocessing of spent fuel is available. This effectively excludes nuclear power as a means to meet California's growing energy demand.

⁷⁰⁴ California Energy Commission. "2007 Integrated Energy Policy Report." 2007, page 6.

distributed generation energy resources, including combined heat and power;⁷⁰⁵ and third, with clean fossil-fueled generation resources and infrastructure improvement.⁷⁰⁶ A 2006 state law restricts the development of baseload power plants by prohibiting utilities from making long-term commitments for electricity generated by plants that emit any more carbon dioxide (CO₂) than clean-burning natural gas plants emit.⁷⁰⁷ In addition, AB 32, which sets a target for a reduction in statewide emissions to 1990 levels by 2020, pushes greenhouse gas emissions levels to the forefront of any resource decision.

In the past, power plant comparisons have focused on the costs and impacts of specific facilities. This study attempts to go beyond specific facility impacts to examine the full life cycle environmental impacts of power supply options that are consistent with California's electricity procurement policies and laws. The study should be considered a first step of a larger potential study that would be required to identify a specific mix of resources that could be used to replace the power from Diablo Canyon or SONGS. Such an analysis would need to consider local transmission constraints and the characteristics of each resource, such as whether it is a baseload plant or a peaking unit and whether it provides firming or shaping support to the grid. The information in this chapter can be used to identify resources that should be considered for such an analysis and to provide economic and environmental input data that could be used in the analysis. The chapter first considers the technical potential of energy efficiency, demand response, and renewable generation to supply California's energy needs. It then considers the costs, environmental impacts, and local economic impacts of nuclear, gas-fired, and renewable generation options.

Technical and Economic Potential

Broadly speaking, the technical potential of a given resource refers to the amount of the resource that is theoretically attainable after accounting for basic physical, environmental, regulatory, and geographic constraints. The economic potential is that portion of the technical potential that is cost-effective to develop in the near term. However, some economic constraints are also implicitly included in assessments of technical potential. For example, in assessing the technical potential of wind power, locations with wind speeds below 14.3 miles per hour at 50 meters are not generally considered for development because these locations are not currently economically viable for utility-scale generation.⁷⁰⁸ The distinction between technical potential

⁷⁰⁵ Renewable energy is energy from resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and biomass. A distributed generation system involves small amounts of generation located on a utility's distribution system for the purpose of meeting local (substation level) peak loads and/or displacing the need to build or upgrade local distribution lines. Combined heat and power, also called cogeneration, is the simultaneous production of electricity and heat from a single fuel source.

⁷⁰⁶ California Energy Commission. "2007 Integrated Energy Policy Report." Page 20.

⁷⁰⁷ California Senate Bill 1368. A "clean coal" plant with carbon sequestration could be allowed under this law. However, this technology has not yet been demonstrated.

⁷⁰⁸ Black & Veatch Corporation. "RETI Phase 1A Report." April 12, 2008, pages 6-57. Accessed: May 16, 2008. <<http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-D.PDF>>.

and economic potential often depends on the perspective of the assessment and the resource being considered.

The technical and economic potential for improved energy efficiency options for California has been studied for several years, most recently in the 2006 and 2008 ITRON studies conducted under CPUC and Energy Commission program development initiatives. Estimating these potentials is extremely complicated, as analysts must consider an energy efficiency measure's performance within the complex of actual buildings, the costs of the measure, and the cost to deliver the measure to industrial, commercial, agricultural, and residential customers. Estimates of the technical and economic potentials for energy efficiency and demand response are shown in Table 22 and discussed further in Appendix B.

Technical and economic potential studies of renewable power options may address attributes such as energy capacity, intermittency, dispatchability, and environmental impacts. Available studies tend to be general and are used to establish which options deserve further study for specific resource procurement. For example, the studies identify the abundant high quality wind, solar, and geothermal resource potential in the Tehachapi Mountains, Mojave Desert, and Imperial Valley of southern California. They do not evaluate the suitability of a resource for a specific purpose.

The technical and economic potentials of a given resource can vary with technology and market developments. For renewable resources, technological improvements could increase the technical potential, and reductions in the cost to develop renewable resources and increases in the cost of non-renewable power would both increase the economic potential. Appendix B discusses current estimates of the technical and near-term economic potential for selected renewable energy technologies and demand-side resources in California.⁷⁰⁹ A summary of these assessments is shown in Table 22.

It is evident from Table 22 that potential cost-effective renewable energy resources are abundant in California. Statewide power consumption from all sources was 300,000 gigawatt-hours (GWh) in 2007.⁷¹⁰ As shown in Table 22, there appears to be sufficient potential to meet statewide energy demand with renewable power sources. However, solar plants, which supply the bulk of the economic and technical potential, do not generate power at night, and output is reduced on cloudy days. Wind resources are intermittent, and geothermal options are available only at select sites. These reliability and operational limitations of current renewable power technologies, along with economic considerations and transmission constraints, limit the widespread replacement of fossil-fueled and nuclear plants with renewable power alternatives at this time.⁷¹¹

⁷⁰⁹ Demand-side resources are incentives, policies, and programs that reduce electricity demand.

⁷¹⁰ California Energy Commission. "Net System Power Report." CEC-200-2008-002-CMF. April 2008, page 5. Accessed: May 15, 2008. <<http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>>.

⁷¹¹ On the other hand, the increased "peakiness" of California's load combined with an increase in intermittent renewables may also create challenges because the operating nuclear plants and some recently built gas-fired baseload plants cannot ramp up and down as rapidly as needed to meet reliability needs. California Energy Commission. "2007 Integrated Energy Policy Report." Page 115.

Table 22: Summary of California Renewable and Demand Side Resource Technical Potential⁷¹²

Resource	Technical Potential		Near-Term Economic Potential	
	MW	GWh	MW	GWh
Wind⁷¹³	21,000-23,000 ⁷¹⁴	61,000-66,000	5,000	16,000
Solar Thermal⁷¹⁵	1,000,000	2,700,000	450,000-800,000	1,000,000-2,000,000
Solar PV⁷¹⁶	17,000,000	24,000,000	75,000	100,000
Geothermal⁷¹⁷	3,000	17,000	1,500-2,500	10,000-15,000
Biomass⁷¹⁸	2,000-5,000	15,000-35,000	N/A	N/A
Demand Side Resources – Energy Efficiency⁷¹⁹	12,000-15,000	50,000-60,000	7,000-11,000	40,000-50,000
Demand Side Resources – Demand Response⁷²⁰	15,000	N/A	7,000	N/A
Demand Side Resources – Combined Heat and Power⁷²¹	30,000	N/A	2,000-7,000	N/A

⁷¹² Also see Appendix 9A for a full discussion of the technical and economic potential of each resource.

⁷¹³ California Energy Commission. “Strategic Value Analysis: Economics of Wind Energy in California.” June 2005; Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008.

⁷¹⁴ The lower bound includes winds of class 4 or higher across 13 different regions within the state, as calculated by the National Renewable Energy Laboratory (NREL). The upper bound is from the Energy Commission’s Intermittency Analysis Project.

⁷¹⁵ California Energy Commission. “California Solar Resources.” April 2005; Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008

⁷¹⁶ California Energy Commission. “California Solar Resources.” April 2005.

⁷¹⁷ GeothermEx, Inc. “New Geothermal Site Identification and Qualification.” Prepared for Public Interest Energy Research (PIER) Program, California Energy Commission. April 2004; Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008.

⁷¹⁸ Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008; California Biomass Collaborative. “California Biomass and Biofuels Production Potential.” Prepared for the California Energy Commission. December 2007.

⁷¹⁹ Itron, Inc. “California Energy Efficiency Potential Study, Volume 1.” Submitted to Pacific Gas & Electric. May 2006; California Energy Commission. “2007 Integrated Energy Policy Report.” Pages 84-85.

⁷²⁰ California Energy Commission. “2007 Integrated Energy Policy Report.” Pages 84-85.

Cost of Electricity Resource Options

The cost of power from new power plants of all kinds is highly uncertain. Appendix B presents a range of cost estimates for replacement power technologies that could be built in California in the near-term and discusses how these costs could change over time. (Under California law, new nuclear plant cannot be sited in the state at this time.⁷²²) Table 23 summarizes the near-term cost estimates, and the remainder of this section provides a brief overview of the major drivers of these costs. For comparison, with the construction costs of the plant largely depreciated or passed on to shareholders, PG&E ratepayers paid just \$34 per MWh for power from Diablo Canyon in 2007.^{723, 724}

The numbers presented below derive from several studies, including a comprehensive 2007 study of power generation costs conducted by the Energy Commission and studies by Weisser and by Gagnon, et al, which present values from the national and international literature.^{725, 726, 727} These values generally do not include the costs of facility integration, transmission expansions that could be required to connect the plants to the transmission grid, or backup power and ancillary services that would be required to accommodate intermittent resources on the transmission grid. In addition, there is implicitly a large uncertainty in the cost estimates presented. Please see Appendix B for more information on the assumptions and sources behind the data in the table.

⁷²¹ Electric Power Research Institute. "Assessment of California CHP Market and Policy Options for Increased Penetration." Cosponsored by the California Energy Commission Public Interest Energy Research Program (PIER). July 2005, page ix.

⁷²² California law (Public Resources Code 25524) prohibits the permitting of land-use for a new commercial nuclear power plant until a federally approved means for the permanent disposal or commercial reprocessing of spent fuel is available.

⁷²³ Pacific Gas & Electric. "PG&E Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008, question F1.

⁷²⁴ Diablo Canyon and SONGS are currently among the least-cost generation resources in the state since the significant costs to construct the plants (roughly five billion dollars for each plant) have been depreciated or passed on to shareholders, and the cost of nuclear fuel is much lower than the cost of fuel for fossil-fueled plants. More information on the historic and current costs of Diablo Canyon and SONGS can be found in Chapter 6 of *Nuclear Power in California: 2007 Status Report*, available at <<http://www.energy.ca.gov/2007publications/CEC-100-2007-005/CEC-100-2007-005-F.PDF>>. Please also see *Comparative Costs of California Central Station Electricity Generation Technologies, Final Staff Report*, California Energy Commission, Dec. 2007, CEC-200-2007-011-SF.

⁷²⁵ California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007.

⁷²⁶ Weisser, Daniel. "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies." *Energy* 32. (2007), pages 1543–1559.

⁷²⁷ Gagnon, Luc, Camille Belanger, and Yohji Uchiyama. "Life-cycle assessment of electricity generation options: The status of research in year 2001." *Energy Policy* 30. (2000), pages 1267-1278.

Electric generation technologies can be differentiated between capital intensive and fuel intensive resources.⁷²⁸ As shown in Table 23, most of the renewable power options are capital intensive technologies with high construction costs; natural gas plants are less capital intensive and more fuel intensive.

The cost of power from capital-intensive power sources, such as solar, wind, and geothermal, is particularly dependent on materials, labor, and financing costs at the time of plant construction. The weakening dollar and increasing global demand for commodities such as steel have driven up capital costs in recent years. This has significantly increased construction costs for natural gas and coal-fired plants, as well as the estimated construction and levelized costs for new nuclear power plants. Similarly, after decades of cost declines, wind power prices increased in 2006 as a result of rising materials costs and a supply-demand imbalance.⁷²⁹

Costs for solar photovoltaics (PV) and solar thermal plants will also be exposed to upward pressure from materials costs in the coming years. However, costs for these emerging technologies are widely expected to continue to fall as economies-of-scale and technological improvements counterbalance the upward pressures of rising demand and supply cost increases.⁷³⁰

The levelized cost of power from combined cycle natural gas plants is more sensitive to the price of natural gas than to construction costs. Natural gas prices have risen sharply in recent months and years, and the future cost of natural gas is highly uncertain. In addition, the extent of the impact of greenhouse gas emissions regulations on the effective cost of power from natural gas plants is unknown at this time since federal legislative proposals for greenhouse gas emissions reduction and state regulations are under development. However, it is expected that these regulations will increase the effective cost of power from natural gas relative to the cost of power from nuclear and renewable technologies.

Other policy and legislative changes could also impact the costs of these technologies. For instance, renewable technologies are currently subsidized via a federal production tax credit. The elimination of this credit would increase the cost of renewable power. Federal or state renewable portfolio standards could also temporarily increase the cost of renewable power if the available supply is insufficient to meet a sudden increase in demand. New nuclear power plants may also be able to take advantage of a number of financial incentives that may or may not continue in the future.⁷³¹

⁷²⁸ The greatest contributor to the levelized cost of a capital-intensive technology is the plant's large up-front construction cost. In contrast, the greatest contributor to the levelized cost of a fuel-intensive technology is the fuel cost throughout the plant's lifetime.

⁷²⁹ Wiser, Ryan and Mark Bolinger. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007: 15.

⁷³⁰ Denholm, et al. January 2007: 96.

⁷³¹ These incentives, part of the Energy Policy Act of 2005, include loan guarantees for reactor construction, risk insurance to cover regulatory or construction delays, and a production tax credit for generation from new reactors. *Nuclear Power in California: 2007 Status Report* provides a more detailed discussion of the potential costs for new nuclear power plants and the incentives available to new nuclear power plants. See Chapter 7 beginning on page 134.

Table 23: Summary of New Power Costs by Technology (2007 dollars)

Resource	Construction Cost, \$/kW⁷³²	Levelized Cost, \$/MWh⁷³³
Biomass (cofired) ⁷³⁴	\$300 - \$500	-\$1 - \$22
Natural Gas (Combined Cycle) ⁷³⁵	\$763 - \$834	\$36 - \$97
Biomass (not cofired) ⁷³⁶	\$2,263 - \$5,925	\$51 - \$150
Geothermal ⁷³⁷	\$2,988 - \$5,000	\$54 - \$107
Wind (Class 5, onshore) ⁷³⁸	\$1,600 - \$2,400	\$49 - \$128
Solar Thermal (several technologies) ⁷³⁹	\$3,600 - \$6,446	\$110 - \$519
Solar PV ⁷⁴⁰	\$6,500 - \$9,672	\$201 - \$705
Natural Gas (Small Simple Cycle) ⁷⁴¹	\$846 - \$1,053	\$352 - \$647

⁷³² Construction cost estimates represent all-in costs, which include financing and interest costs.

⁷³³ Levelized cost is the constant inflation-adjusted price at which the discounted revenue from electricity sales at this price recovers the discounted cost of building and operating the plant over the plant lifetime.

⁷³⁴ Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 5-9.

⁷³⁵ Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13. Accessed: June 14, 2008; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 10, 18.

⁷³⁶ Energy Information Administration. "Biomass for Electricity Generation: Projections of Biomass Resource Availability at Different Price Levels, 2020." July 2002; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 18; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 5-5.

⁷³⁷ Western Governors' Association. "Clean and Diversified Energy Initiative: Geothermal Task Force Report." January 2006, page 9; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 5-36; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

⁷³⁸ Wiser, Ryan and Mark Bolinger. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007, pages 10, 15, 16; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 5-34; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 18; Milligan, Michael. National Renewable Energy Laboratory. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Wind by 2030." Chapter from "Tackling Climate Change in the U.S." American Solar Energy Society. January 2007, page 107.

⁷³⁹ Western Governors' Association. "Clean and Diversified Energy Initiative: Solar Task Force Report." January 2006, page 16; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 1-7; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

⁷⁴⁰ Borenstein, Severin. "The Market Value and Cost of Solar Photovoltaic Electricity." UC Energy Institute. January 2008, Table 4; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008: 1-7; Denholm, Paul and Robert M. Margolis, National Renewable Energy Laboratory and Ken Zweibel, PrimeStar Solar, Inc. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Solar Photovoltaics by 2030." Chapter from "Tackling Climate Change in the U.S." American Solar Energy Society. January 2007, page 93.

The great uncertainty in future fuel and construction costs, as well as potential regulatory changes, makes comparing the overall levelized costs of various technologies particularly difficult. A recent Congressional Budget Office (CBO) report compares the costs of nuclear, natural gas, and coal electricity under multiple scenarios and finds that a number of factors will contribute to determining the relative costs of electricity generating sources. The CBO report does not include renewable power; however, resource scenarios in which nuclear power appears competitive would also tend to show renewable power as competitive because these technologies share large up-front capital costs and relatively low operations and fuel costs. The CBO reports that coal and natural gas plants appear most competitive in an environment characterized by high construction costs along with declining fuel costs and an absence of greenhouse gas regulations. Nuclear power and other capital-intensive technologies such as renewable energy would be most competitive under a regime of low capital costs, high fuel costs, continued federal subsidies, and the presence of a greenhouse gas emissions cap.⁷⁴²

Comparison of Life Cycle Environmental Impacts

Environmental impacts can occur throughout the power production “life cycle.” The life cycle begins with mining or processing raw materials and includes construction, operations, waste management and disposal, and decommissioning. These activities emit greenhouse gases (GHG) and other pollutants, impact land use and water use, and in some cases can have significant impacts on wildlife and marine environments. In the case of nuclear energy, radioactive waste management, health, safety and security issues are also concerns. The major life cycles impacts of nuclear power and alternate power sources are discussed in Appendix B and summarized in Table 24.

Comparing life cycle analyses of different technologies is limited by analytical and information constraints: data availability varies considerably for different energy sources, and investigators define life cycle impacts differently, making the consideration of environmental impacts more or less comprehensive. These constraints make it difficult to ascertain the total environmental impact of any one technology. Review of the literature suggests that there is adequate information to compare across technologies some specific impacts, such as GHG emissions, while comprehensive comparisons of other impacts, such as impacts from land use, are still under development.

This section continues with a comparison of life cycle GHG emissions and land use impacts of various technologies. While each technology is considered separately, in practice, intermittent renewable facilities generally require fossil-fueled generation for backup power. The environmental impacts of the backup generation must also be considered. Finally, the section ends with a discussion of marine impacts from the use of once-through cooling at coastal power plants. Environmental impacts that are particular to just one or a few of the technologies are discussed in Appendix B.

⁷⁴¹ California Energy Commission. “Comparative Costs of California Central Station Electric Generation Technologies.” December 2007: 7, 10, 18.

⁷⁴² Congressional Budget Office. May 2008: 13.

Table 24: Summary of Life Cycles and Environmental Impacts of Generation Technologies

	Raw Materials/ Processing	Construction and Operations	Decommissioning
Nuclear	Ore mining: radioactivity from waste piles and mine tailings In-situ leaching: potential for groundwater contamination Enrichment: GHG emissions	Typical construction impacts Once-through cooling impacts On-site accumulation of spent fuel Potential for radiation release and tritium leaks Radioactive waste storage, transport and disposal	Radioactive residue; waste removal; transport, storage and disposal; land restoration
Gas	Drilling: Surface disruption; coastal industrialization; gas or oil leaks; waste LNG liquefaction and regasification: habitat disruption; air quality impacts; impingement; waste discharge; thermal pollution; entrainment LNG transport: marine impacts; GHG emissions	Typical construction impacts Combustion: GHG emissions; nitrogen deposition Once-through cooling impacts at coastal plants Potential contamination from wastewater, discharge, spills, and effluent	Waste removal; land restoration
Wind	Turbine tower: Steel mining and fabrication	Typical construction impacts Bird and bat mortality; visual pollution; noise pollution Acreage requirements; habitat fragmentation	Waste removal; recycling costs; land restoration
Solar Thermal	Limited data available	Typical construction impacts Habitat fragmentation and barriers Coolant leakages: Risk of soil/water contamination Dish/ Stirling engines: Potential for hydrogen gas leakage	Waste removal; land restoration
Solar PV	Silicon: Open pit mining and high-temperature processing; hydrofluoric acid burns; silane gas flammability/explosions CdTe: Cadmium toxicity and carcinogenicity CIS: Hydrogen selenide toxicity	Typical construction impacts Habitat fragmentation and barriers; acreage requirements with potentially high compensation ratios	Disposal/recycling of toxic materials in panels; waste removal; land restoration
Geo-thermal	Limited data available; expected impacts from development of drill and well components, infrastructure	Potential impacts on surface features and visual resources Hydrogen sulfide emissions from geothermal extraction; potential water pollution from boron and arsenic; potential land subsidence, lowered water table, and induced seismicity	Waste removal; land restoration
Biomass	GHG emissions from collection and transport of biomass Land and water use for crop growth (if not using crop residues); habitat conversion	Typical construction impacts Combustion/ gasification: Air emissions; ash generation; high cooling water needs (80 m ³ /hour for 1 MW gasifier); liquid waste generation	Waste removal; land restoration

Greenhouse Gas Emissions

The majority of GHG emissions from non-fossil fuel technologies come from fuel and/or raw materials transportation; materials processing; facility construction, operations, and maintenance; and facility dismantling and clean-up. It is relatively straightforward to identify these impacts qualitatively, but there is no standard methodology for quantifying them.

Existing studies of life cycle GHG emissions use different methodologies and assumptions and consider plants of different scales and locations. This makes it difficult to compare results across studies and to apply them to new situations. For example, a study of a single solar PV panel may not translate into results for an industrial scale solar PV plant, and results for a plant in Europe may not be representative for a plant in California. Finally, with ongoing improvements in technology, the results are not static.

While specific values for GHG emissions are under debate, there is general agreement about the relative emissions of various energy technologies. For examples, most studies find that nuclear power and renewable technologies have comparable life cycle GHG emissions and that these emissions are significantly less than the life cycle GHG emissions of gas-fired power.

Appendix B discusses the assumptions that enter into the estimates for each technology and the results of various studies. Nearly all the studies reviewed were completed between 2002 and 2008, and most were published in peer-reviewed journals or by government agencies. Some of the studies are themselves reviews of other studies. Together, these studies have provided a wide range of technically feasible results for GHG emissions of the various technologies. The emissions from a particular project would depend on site-specific factors, such as the technology used, the amount of transportation required for fuel and materials, and the quality of the fuel used (where applicable). The results of these studies are presented in Appendix B are summarized in Table 25.⁷⁴³

⁷⁴³ Solar thermal emissions are not listed due to lack of life cycle data.

Table 25: Summary of CO₂ Emissions from Alternative Generation Technologies⁷⁴⁴

Generation Technology	Life cycle GHG Emissions (g CO₂-eq/kWh)	Major life cycle contributor of CO₂ emissions
Gas-fired ⁷⁴⁵	400-600	Direct fuel combustion during operations (81% of total emissions)
Nuclear ⁷⁴⁶	5-140 Likely range: 25-55	Uranium enrichment, plant construction, plant maintenance, and decommissioning
Wind ⁷⁴⁷	10-150 Nationwide median: ~45 California median: ~65	Turbine production
Solar PV ⁷⁴⁸	20-50	Panel production
Biomass ⁷⁴⁹ (non-cofiring)	45-120	Feedstock production and transportation, biomass burning
Geothermal ⁷⁵⁰	0-40	Similar emissions throughout life cycle

⁷⁴⁴ Also see Appendix 9A for a full discussion of the carbon emission associated with each resource.

⁷⁴⁵ Meier, Paul. "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis." Fusion Technology Institute, University of Wisconsin, Madison. August 2002. Accessed: March 27, 2008. <<http://fti.neep.wisc.edu/pdf/fdm1181.pdf>>; National Renewable Energy Lab. "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System". NREL/TP-57027715. September 2000, page 29. Accessed: December 6, 2006. <<http://www.nrel.gov/docs/fy00osti/27715.pdf>>.

⁷⁴⁶ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007.

⁷⁴⁷ Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." Energy Policy 30 (2002) page 1271; Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." Defense Technical Information Center, March 2003. Accessed: March 24, 2008. <<http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA415268&Location=U2&doc=GetTRDoc.pdf>>.

⁷⁴⁸ Alsema, E.A and M.J. de Wild-Scholten. "Environmental Impacts of Crystalline Silicon Photovoltaic Module Production." 13th CIRP International Conference on Life Cycle Engineering. May 31-June 2, 2006. Accessed: February 28, 2008. <http://www.nrel.gov/pv/thin_film/docs/lce2006.pdf>; Fthenakis, V.M. and H.C. Kim. "Greenhouse-gas Emissions from Solar Electric and Nuclear Power: A Life-cycle Study." Accepted for publication in Energy Policy. 2006.

⁷⁴⁹ Biomass plants using crop residues would not have a direct impact from feedstock production. Gagnon, et al, 2002: 1271; Mann, M. and P. Spath. "Life Cycle Assessment of a Biomass Gasification Combined-Cycle System." NREL. December 1997, pages 46-50. Accessed: July 13, 2008. <http://www.nrel.gov/biomass/process_analysis.html>.

Land Use

The land use requirements of a generating technology provide another indication of its biological impacts.⁷⁵¹ Land use effects from generating technologies occur both directly through the actual plant footprint, and indirectly through mining, fuel processing, and waste storage and disposal. Table 26 provides a summary of direct land use impacts of the different technologies.⁷⁵²

Table 26: Direct Land Use Requirements for Alternative Generation Technologies⁷⁵³

Generation Technology	Operational Land Use (acres/MW)
Nuclear	0.75 (see discussion in text on total land usage)
Natural gas	1.65
Geothermal	1.7
Wind	5.4
Solar thermal (non-hybrid)	5-8.5
Solar PV ⁷⁵⁴	2.5-13.3 (effectively 0 for rooftop PV)
Hydroelectric	20.45
Biomass	Depends on source of biomass

Based on plant footprint alone, less land is required for a nuclear power plant than for each of the alternative generation technologies. However, these values do not include indirect land use requirements. In addition, the direct and indirect land impacts of a given technology depend not only on used acreage, but also on intensity of the land usage and the land use duration. For example, indirect land use of nuclear power includes land required for mining and enrichment of nuclear fuel and land that will be dedicated for the disposal of nuclear waste for tens of thousands of years. Incorporating this indirect land usage would increase the land use impact

⁷⁵⁰ Kagel, A. Bates, D. and Gawell, K. "A Guide to Geothermal Energy and the Environment." Geothermal Energy Association, Washington, D.C. April 2007. Accessed: February 13, 2008. <www.geo-energy.org/publications/reports/Environmental%20Guide.pdf>.

⁷⁵¹ California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008, page 69. <<http://energy.ca.gov/2007publications/CEC-700-2007-016/CEC-700-2007-016-SF.PDF>>.

⁷⁵² California Energy Commission. "2007 Environmental Performance Report." January 2008: 69.

⁷⁵³ California Energy Commission. "2007 Environmental Performance Report." January 2008.

⁷⁵⁴ U.S. Department of Energy- Energy Efficiency and Renewable Energy. "PV FAQs: How much land will PV need to supply our electricity?" February 2004. Accessed: February 27, 2008. <<http://www.nrel.gov/docs/fy04osti/35097.pdf>>.

of nuclear energy up to 200 times that shown in Table 26.⁷⁵⁵ On the other hand, lands used by some alternative generating technologies have complementary uses. For example, the land surrounding wind turbines may be used for agriculture, and solar PV can be developed on rooftops of new or existing buildings. These factors reduce the land use impacts of wind and solar below that implied by the simple acreage comparison in Table 26.

Once-Through Cooling

California's two operating nuclear power plants and 17 operating coastal gas-fired plants use ocean water for cooling their electricity generation systems.⁷⁵⁶ Plant operators pipe water from the ocean to the power plants and then discharge warmer water back to the ocean. This can impact the marine environment in three ways: 1) by taking in small organisms such as eggs, larvae, and fish, and in some cases larger marine animals, such as seals, sea lions, and sea turtles (entrainment); 2) by trapping fish and other marine organisms against the cooling water intake screens (impingement); and 3) by discharging heated water into the ocean and raising the temperature of the receiving water.⁷⁵⁷

For any particular plant, the impacts of the cooling system depend on the volume of water used, the marine environment near the system's intake and outflow pipes, and the technologies utilized. Collectively, the coastal power plants are allowed to cycle or take in around 16.3 billion gallons of water per day. With the exception of Diablo Canyon and SONGS, most of the coastal fleet operates well below the design capacity and permitted levels.⁷⁵⁸ The State Water Resources Control Board (SWRCB) reports that collectively and on an annual basis the coastal fleet's cooling systems impinge around nine million biological specimens having a mass of about 97,000 pounds and entrain about 80 billion biological specimens. In addition around 55 to 60 larger animals, such as seals, sea lions, or sea turtles, are entrained each year.⁷⁵⁹

The SWRCB compiled estimates from biological sampling and statistical studies of once-through cooling impacts from Diablo Canyon and SONGS.⁷⁶⁰ PG&E and SCE believe that the SWRCB data overestimate the number of marine animals that are impinged and entrained as

⁷⁵⁵ Gagnon, et al. 2000: 1267-1278.

⁷⁵⁶ In all, the plants are permitted to use 17 billion gallons of water per day. Of this, the nuclear plants are permitted to use 5.2 billion gallons per day. State Water Resources Control Board (SWRCB), California Environmental Protection Agency. "Water Quality Control Policy on the Use of Coastal and Estuarine Waters For Power Plant Cooling." SWRCB-1000-2008-001. March 2008, pages 2-3.

⁷⁵⁷ SWRCB, 3/2008; Tetra Tech, 2/2008; CEC-700-2005-013.

⁷⁵⁸ CEC-700-2007-016SF.

⁷⁵⁹ SWRCB, March 2008.

⁷⁶⁰ SWRCB, March 2008.

well as the impacts of impingement and entrainment on marine populations.⁷⁶¹ In lieu of other independent, comprehensive studies, the SWRCB results are presented here. According to these results, while Diablo Canyon and SONGS can each withdraw up to 4.8 billion gallons of water per day, the impacts from the plants are quite different (Table 27). The differences arise from the plants' local marine environments, respective designs, and intake and discharge technologies.

The SWRCB estimates that Diablo Canyon annually entrains over 1.8 billion fish and fish larvae but impinges relatively few biological specimens (around 400, plus one large marine animal).⁷⁶² The SWRCB also estimates that thermal impacts from Diablo Canyon, which discharges into a natural rocky cove, have resulted in significant changes to 150 species of marine algae and invertebrates and have greatly altered over a mile of shoreline intertidal and shallow subtidal communities.⁷⁶³ PG&E reports that fewer than one large marine animal is impinged each year and that none have been killed in the once-through cooling system. PG&E also reports that fish eggs and larvae are entrained, but not fish, and notes that the impacted shoreline is contained within Diablo Cove.⁷⁶⁴

The SWRCB estimates that SONGS annually entrains over 5.6 billion fish and impinges over 3.5 million fish (nearly 48,000 pounds) and 47 large marine animals.⁷⁶⁵ According to SCE, an EPRI study found that SONGS annually entrains 2.2 to 2.8 billion fish larvae and 26 to 28 billion eggs and impinges 1.4 million fish (29,000 pounds).⁷⁶⁶ In addition, SCE reports that fewer than 47 large marine animals are impinged each year and that many of the animals that are impinged are released unharmed.⁷⁶⁷

According to the SWRCB report, the SONGS once-through cooling system is responsible for 70 percent of California's total fish impingement and 82 percent of tetrapod impingement.⁷⁶⁸

⁷⁶¹ Pacific Gas & Electric. "Comments on the Draft Consultant Report, 'AB 1632 Assessment of California's Operating Nuclear Power Plants,' dated September 2008." Docket No. 07-AB-1632. October 2, 2008; Pacific Gas & Electric. "Response to Scoping Document on Once-Through Cooling." May 20, 2008. Accessed: June 2, 2008. <http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316_may08/comments/mark_krause.pdf>; Southern California Edison. "2008 Integrated Energy Policy Update (08-IEP-1F) SCE Comments on the Draft Consultant Report: AB 1632 Assessment of California's Operating Nuclear Plants (07-AB-1632)." October 2, 2008.

⁷⁶² SWRCB, March 2008.

⁷⁶³ California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling at California's Coastal Power Plants." CEC-700-2005-013. June 2005, page 25.

⁷⁶⁴ Pacific Gas & Electric. October 2, 2008: 16.

⁷⁶⁵ SWRCB, March 2008.

⁷⁶⁶ Electric Power Research Institute. "Comprehensive Demonstration Study for Southern California Edison's San Onofre Nuclear Generating Station." Prepared by D. Bailey, EPRI, for Southern California Edison. January 2008, cited in Southern California Edison. "2008 Integrated Energy Policy Update (08-IEP-1F) SCE Comments on the Draft Consultant Report: AB 1632 Assessment of California's Operating Nuclear Plants (07-AB-1632)." October 2, 2008.

⁷⁶⁷ Southern California Edison. October 2, 2008: 15.

⁷⁶⁸ SWRCB, March 2008: 16.

Scientists believe that the disproportionate impact from the SONGS cooling system is linked to the system's long intake pipe, which may be attractive to marine animals as a place of refuge.⁷⁶⁹ Thermal impacts at SONGS are reportedly minor; however, turbidity (haziness caused by suspended solids) caused by the discharge may have resulted in the loss of 179 acres of kelp forest.⁷⁷⁰

Thermal impacts at the natural gas-fired plants are site specific and depend on the location and volume of the discharge. For example, thermal discharge from the Morro Bay Power Plant alters 600 feet of rocky intertidal and shallow subtidal habitat, while impacts of discharges from the Moss Landing and Huntington Beach power plants into subtidal zones appear to be minimal.⁷⁷¹

Currently, entrainment impacts from the state's coastal plants are dominated by the impacts of the Encina and Pittsburg gas-fired plants: the Encina cooling system is responsible for 54 percent of fish entrainment (26 billion per year), and the Pittsburg cooling system is responsible for 75 percent of invertebrate entrainment (12 billion per year).⁷⁷² The SONGS cooling system is responsible for an additional 12 percent of fish entrainment (6 billion per year). The Diablo Canyon cooling system is responsible for less than one percent of statewide impingement and roughly four percent of statewide entrainment.⁷⁷³ However, these impacts result in the loss of 10-30 percent of larva for five near-shore species.⁷⁷⁴ These impacts are discussed further in Appendix B and are summarized in Table 27.

The impact of a cooling system on a marine population depends only in part on the number of organisms impacted – the habitat can moderate or exacerbate the impact. For example, according to an October 2007 study by the Electric Power Research Institute (EPRI), entrainment losses in a coastal environment have a less significant impact than entrainment losses in a coastal lagoon or embayment since species along the open coast have larger geographic distributions, and coastal larvae that are lost are replaced by other larvae.⁷⁷⁵ Similarly, the Energy Commission noted in a 2005 report that intakes located in estuaries or bays are more likely to have significant entrainment impacts than intakes located in deeper waters since

⁷⁶⁹ California Energy Commission. "Understanding Entrainment at Coastal Power Plants: Informing a Program to Study Impacts and Their Reduction." CEC-500-2007-120. Prepared by Moss Landing Marine Laboratories. March 2008, page 28. Accessed: June 13, 2008. <<http://www.energy.ca.gov/2007publications/CEC-500-2007-120/CEC-500-2007-120.PDF>>.

⁷⁷⁰ The cooling system discharge creates a turbid plume that moves over the kelp forest, reducing light and increasing sedimentation. This has adversely impacted the the giant kelp and other organisms living in the kelp forest; CEC-700-2005-013, page 25.

⁷⁷¹ California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling." June 2005: 25.

⁷⁷² Figures for fish entrainment do not include fish eggs and larvae. The Encina Power Station once-through cooling system will be eliminated when the plant is repowered. SWRCB, March 2008: 78.

⁷⁷³ SWRCB, March 2008: 15.

⁷⁷⁴ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." CEC-700-2005-016. June 2005, page 94. Accessed: June 11, 2008. <<http://energy.ca.gov/2005publications/CEC-700-2005-016/CEC-700-2005-016.PDF>>.

⁷⁷⁵ EPRI, December 2007: 62.

species use the protected estuary and bay environments as sites to reproduce in great numbers. However, the report noted that intakes in deep waters that are located near rock outcrops or near kelp forest (like SONGS) could also have significant impingement and entrainment impacts.⁷⁷⁶

Table 27: Water Intake and Once-through Cooling Impacts for California Coastal Power Plants

Power Plant	Seawater Intake⁷⁷⁷	SWRCB Estimates of Impingement/ Entrainment⁷⁷⁸	Habitat Impacts⁷⁷⁹
Diablo Canyon (2,200 MW)	~2.7 billion gallons (1.2 million gallons per MW)	Impingement of roughly 400 fish per year; Entrainment of 1.8 billion fish ⁷⁸⁰	Alteration of rocky intertidal and shallow subtidal communities over more than one mile of shoreline, due to warm water discharge
SONGS (2,254 MW)	~2.6 billion gallons (1.2 million gallons per MW)	Impingement losses average 3.5 million fish per year; Entrainment of 5.6 billion fish per year resulting in 13% loss of standing stock of certain fish ⁷⁸¹	Discharge near San Onofre kelp bed; loss of 179 acres of kelp forest due to turbidity
17 coastal natural gas plants (~18,500 MW combined)	~11.9 billion gallons total (0.6 million gallons per MW)	Total impingement losses average 1.5 million fish; Total entrainment averages 40 billion fish per year	Site specific alteration of intertidal and shallow subtidal habitat; Impacts from some plants not yet assessed

⁷⁷⁶ California Energy Commission. "2005 Environmental Performance Report." June 2005, page 94.

⁷⁷⁷ SWRCB, March 2008: 2-3.

⁷⁷⁸ SWRCB, March 2008: 16.

⁷⁷⁹ California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling and California's Coastal Power Plants." June 2005, page 25.

⁷⁸⁰ PG&E objects to these figures. According to PG&E, only fish eggs and larvae are entrained in the Diablo Canyon once-through cooling system, not fish. PG&E estimates that 800 pounds of fish per year are impinged. Pacific Gas & Electric. "Comments on the Draft Consultant Report, 'AB 1632 Assessment of California's Operating Nuclear Power Plants,' dated September 2008." Docket No. 07-AB-1632. October 2, 2008, page 16.

⁷⁸¹ SCE objects to these figures. According to SCE, an EPRI study found that annual impingement losses average 1.4 million fish per year and entrainment losses average 2.2-2.8 billion fish larvae and 26-28 billion eggs at SONGS. Electric Power Research Institute. January 2008,

In some cases, the nuclear plants and other plants have been required to mitigate impacts to coastal habitats.⁷⁸² For example, in response to requirements imposed by the California Coastal Commission, Southern California Edison (SCE) has implemented several programs to mitigate the impact of the SONGS cooling system on the nearby marine environment. These measures include restoration of the San Dieguito River mouth and coastal lagoon, construction of a kelp reef, and support for a California sea bass hatchery. Under the program, SCE must restore and maintain over 160 acres of wetland as well as 280 acres that will become a protected park.⁷⁸³ SCE considers these actions to have fully mitigated marine impacts from the SONGS once-through cooling system.⁷⁸⁴

In some cases, entrainment losses can be partially mitigated by placing mesh screens over the intakes. Impingement losses can sometimes be mitigated by use of technologies that keep water intake velocities low enough for most fish to swim against the intake current.⁷⁸⁵ Thermal impacts are site specific and appear to have less of an environmental effect if volumes are small or if the point of discharge is offshore along the open coast where dilution is rapid. Although these measures reduce impacts, major environmental effects continue to be reported by the SWRCB and other agencies. In addition, many scientists, fishermen, and environmental groups have expressed concern about the harmful effects of seawater-based cooling systems on marine life.

Local Economic Impacts of Alternative Power Sources

Power plants and renewable generating facilities contribute to the economies in the localities in which they are located through jobs, property taxes, and sales taxes. If the nuclear plants were to shut down, the state and the local communities in San Luis Obispo, Orange, and San Diego counties would lose these benefits. However, these communities or other communities could benefit from the development of replacement power sources.

⁷⁸² California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling." June 2005: 25.

⁷⁸³ Southern California Edison. "Response to Scoping Document on Once-Through Cooling." May 20, 2008.

⁷⁸⁴ Southern California Edison. "2008 Integrated Energy Policy Update (08-IEP-1F) SCE Comments on the Draft Consultant Report: AB 1632 Assessment of California's Operating Nuclear Plants (07-AB-1632)." October 2, 2008: 2.

⁷⁸⁵ Electric Power Research Institute (EPRI). "Assessment of Once-Through Cooling System Impacts to California Coastal Fish and Fisheries." December 2007.

Table 28: Contribution of California Power Sources to their Local Economies^{786, 787}

Generation Technology		Nuclear ⁷⁸⁸	Oil/Gas	Wind	Solar Thermal	Geo-thermal	Biomass
<i>Percent of Projects Surveyed</i>		100%	66%	11%	48%	40%	47%
Tax Payments, per MW							
Property Tax	Installed Cap.	\$5,800	\$2,800	\$7,400	\$2,100	\$13,200	\$4,700
	Effective Cap.	\$6,500	\$4,800	\$22,700	\$8,000	\$19,100	\$5,400
Sales Tax	Installed Cap.	\$30	\$200	\$10	\$420	n/a	\$590
	Effective Cap.	\$30	\$350	\$20	\$1,620	n/a	\$680
Payroll, per MW ⁷⁸⁹							
Permanent Employees	Installed Cap.	\$70,436	\$10,248	\$7,968	\$31,991	\$48,809	\$61,057
	Effective Cap.	\$78,777	\$17,874	\$24,435	\$122,317	\$70,617	\$70,450
Contract Employees	Installed Cap.	\$980	\$820	n/a	\$2,329	\$388	\$2,657
	Effective Cap.	\$1,096	\$1,430	n/a	\$8,907	\$561	\$3,065

⁷⁸⁶ The figures for employment in this table reflect only the operations of the power plants. Employment for initial construction is not included. With the exception of some of the nuclear figures, all data are from the 2005 Environmental Performance Report socioeconomic survey; California Energy Commission. "2005 Environmental Performance Report." June 2005: 174.

⁷⁸⁷ The values presented here are generally comparable to but lower than the property tax and employment benefits of renewable technologies presented in the November 2001 EPRI/Energy Commission report, *California Renewable Technology Market and Benefits Assessment*. (See Footnote 787.)

⁷⁸⁸ Property taxes and permanent employee information obtained from PG&E and SCE data requests. Property tax and permanent employee figures are from 2007; contract employee figures and sales tax figures are from 2005 and only reflect survey responses from Diablo Canyon.

⁷⁸⁹ More detail on employment is provided below:

Generation Technology		Nuclear	Oil/Gas	Wind	Solar Thermal	Geothermal	Biomass
Number of Employees, per MW							
Permanent Employees	Installed Cap.	0.75	0.08	0.15	0.39	0.46	0.86
	Effective Cap.	0.84	0.14	0.47	1.48	0.67	1.00
Contract Employees	Installed Cap.	0.01	0.01	n/a	0.12	0.01	0.05
	Effective Cap.	0.01	0.01	n/a	0.45	0.01	0.06
Average Salary, per Employee							
Permanent Employees		\$93,900	\$129,000	\$51,500	\$82,400	\$105,900	\$70,800
Contract Employees		\$92,000	\$132,400	n/a	\$19,800	\$46,300	\$51,100

Source: California Energy Commission. "Socioeconomic survey of power plants in support of the Environmental Performance Report." 2005.

Table 28 compares the economic benefits per unit capacity of power plants located in California to evaluate the socioeconomic benefits from different technologies.⁷⁹⁰ The data in this table are based on responses to a 2005 Energy Commission survey from the owners of 27 percent of California's operational plants (as of 2005). The table compares socioeconomic impacts per unit capacity in terms of both installed and effective capacity.⁷⁹¹ In some cases, effective capacity is similar to installed capacity. However, the effective capacities of wind and solar plants are significantly less than their installed capacities since the capacity factors of these plants are low.⁷⁹²

Diablo Canyon and SONGS each provide California with about 2,000 MW of effective capacity. If either of these plants were to shut down, 2,000 MW of effective capacity would need to be installed to replace them.⁷⁹³ Table 29 shows the total property tax, sales tax, and payroll payments that would be generated were this entire amount of effective capacity replaced by a natural gas plant or a renewable resource.

Table 29 suggests that nuclear power plants provide roughly the same state and local economic benefits as geothermal and biomass plants, less than solar thermal plants, and more than wind and gas-fired plants. However, actual economic impacts could differ depending on whether benefits are concentrated in one location (as with a large power plant) or dispersed, whether the plant is located in a densely or sparsely populated area, and whether the plant is located in an area with other economic opportunities.

⁷⁹⁰ The information provided in Table 28 does not identify how much of the observed differences are due to intrinsic differences in technology costs and how much are due to differences in local sales tax rates, property tax rates, and costs of living across the localities where these plants are sited.

⁷⁹¹ The capacity of a power plant can be defined as either "installed capacity" or "effective capacity." Installed capacity is the technical capacity of the plant based on technical design and is sometimes called the nameplate capacity. Effective capacity, on the other hand, is a measure of how much capacity a plant will contribute to the grid over a certain amount of time. It takes into account the fact that plants do not generally run non-stop at full capacity.

⁷⁹² For example, 6,000 MW of wind capacity would need to be installed in order to obtain 2,000 MW of effective capacity. Natural gas plants would also be required in order to provide backup power.

⁷⁹³ From a reliability standpoint, 2,000 MW of dependable capacity would be needed. (Dependable capacity is the amount of capacity that can be relied on by the system operator.) For intermittent resources, dependable capacity can be much smaller than effective capacity. For example, if a nuclear plant were to be replaced solely by wind plants, around 20,000 MW of wind capacity would be needed. (This is roughly equal to 2,000 MW of dependable capacity for wind power.) However, 20,000 MW of wind capacity provides 6,000 MW of effective capacity. This amount of capacity would produce three times as much energy as the nuclear plant being replaced. As a result, in order to avoid overbuilding capacity, wind plants would not generally be used on their own. Instead, natural gas plants would be used for backup power. With the natural gas plants available for reliability support, 2,000 MW effective wind capacity would be sufficient to replace the 2,000 MW effective nuclear capacity.

Table 29: Total Payments for 2,000 MW Effective Capacity (thousands of dollars)^{794, 795}

	Nuclear	Oil/Gas	Wind	Solar Thermal	Geothermal	Biomass
Property Tax	\$15,000	\$10,000	\$45,000	\$15,000	\$40,000	\$10,000
Sales Tax	\$60	\$700	\$40	\$3,000	-	\$1,500
Payroll	\$160,000	\$40,000	\$50,000	\$260,000	\$140,000	\$150,000
Total Payments	\$175,000	\$50,000	\$95,000	\$280,000	\$180,000	\$160,000

The payments shown in the table are based on current technologies. An increase in capacity factors for renewable technologies would mean that more capacity would be realized with the same costs. This may mean that less capacity would need to be installed, and local and state economic benefits would decrease. Similarly, if efficiency improvements allowed the plants to be built less expensively or to be operated with fewer employees, property taxes or payroll taxes would decrease. In any of these scenarios, the state would benefit from a lower cost of power.

State or local incentives could also reduce tax payments for particular projects. For example, legislation (AB 1451 - Leno) recently passed by the California Senate and Assembly would exempt certain solar energy systems from property tax assessments through 2016.⁷⁹⁶

The construction of new plants adds additional jobs not shown in the tables. A study prepared by the California Public Interest Research Group in 2002 used Energy Commission data to assess the impacts of an aggressive wind scenario in California. The California Public Interest Research Group estimated that 3,700 MW of incremental wind generation in California would create 43,774 total jobs or 11.8 jobs per MW over a period of 30 years. The vast majority of the jobs created for this scenario would be associated with plant construction. According to the data in Table 28, only 0.15 permanent jobs are created per megawatt of wind capacity.

Due to data limitations, Table 28 and Table 29 do not consider the economic impacts of solar PV plants or demand-side resources. As of May 2008, California has no operational utility-scale solar PV plants. However, two firms, OptiSolar and SunPower, have announced plans to build

⁷⁹⁴ California Energy Commission. "Socioeconomic survey of power plants in support of the Environmental Performance Report." 2005.

⁷⁹⁵ Data in this table are based on Energy Commission survey results. Using instead economic data from a 2001 EPRI/Energy Commission report, 2,000 MW of effective capacity would yield payments of \$146 million from wind plants, \$240 million from solar thermal facilities, \$290 million from geothermal plants, and \$218 million from biomass plants. Electric Power Research Institute and California Energy Commission. *California Renewable Technology Market and Benefits Assessment*. November 2001.

⁷⁹⁶ California Assembly Bill 1451. Introduced February 23, 2007. <http://www.leginfo.ca.gov/cgi-bin/postquery?bill_number=ab_1451&sess=CUR&house=B&author=leno>.

large-scale PV farms in San Luis Obispo County with a combined capacity of 800 MW.⁷⁹⁷ The Renewable Energy Policy Project (REPP) estimated the local economic impacts of manufacturing, producing, and installing 9,260 MW of incremental solar PV at a price of \$3.68 per watt by 2015. For California, REPP estimated a total investment of \$8.54 billion and the creation of more than 10,000 jobs as a result of this aggressive scenario.

Demand-side resources do not provide substantial tax and employment benefits to the local communities in which the efficiencies occur in the same way that a power plant or other industrial facility does. However, demand-side resources do provide local employment for engineers, implementation contractors, and utility personnel. These benefits vary depending on the technologies used; the number of employees used to develop, advertise, and manage the programs; and whether the equipment used for the program is manufactured in California. Additional benefits arise from not having to build or dispatch other generation resources. According to a study prepared for PJM Interconnection, a 3 percent reduction in peak demand for a block of several Mid-Atlantic States would reduce energy market prices by \$8-\$25 per megawatt-hour (MWh). If all customers were exposed to the spot market, this would generate annual economic benefits to the Mid-Atlantic states of \$60 million - \$180 million.⁷⁹⁸

Potential Replacement Power Portfolio

If California's nuclear plants were shut down at the end of their current operating licenses, the state would require new generation to replace the capacity and energy that had been provided by the plants.⁷⁹⁹ To begin to explore the possible economic and environmental impacts of this situation, the Consultant Team performed some preliminary production cost model simulations of the western electricity system in 2020, both with and without SONGS and Diablo Canyon.⁸⁰⁰ For the simulations, the Consultant Team used a proprietary hourly chronological production simulation model (MARKETSYM™) in conjunction with a detailed database of expected retail power demand and operating characteristics of generation and transmission facilities within the Western Electricity Coordinating Council (WECC). This model and database were also used by the Energy Commission in the 2007 *Integrated Energy Policy Report* (IEPR) Scenario Analysis of California's Electric System and by the Ocean Protection Council and the Water Resources

⁷⁹⁷ OptiSolar's 550 MW Topaz Solar Farm and SunPower's 250 MW California Valley Solar Ranch are expected to become fully operational in 2012. Pacific Gas & Electric. "PG&E Signs Historic 800 MW Photovoltaic Solar Power Agreements With OptiSolar and SunPower." August 14, 2008. Accessed: September 4, 2008. <http://www.pge.com/about/news/mediarelations/newsreleases/q3_2008/080814.shtml>.

⁷⁹⁸ The Brattle Group. "Quantifying Demand Response Benefits in PJM." Report for PJM Interconnection, LLC and the Mid-Atlantic Distributed Resources Initiative. January 29, 2007, page 2. Accessed: May 16, 2008. <<http://www.energetics.com/madri/pdfs/BrattleGroupReport.pdf>>.

⁷⁹⁹ This exercise simulates the impact of a state policy wherein for whatever reasons the nuclear plants are not relicensed; it does not consider the impact of one or the other, but not both, plants permanently shutting down.

⁸⁰⁰ The year 2020 was chosen as it is the latest year for which data that had been vetted by the Energy Commission are available. Although the plant's licenses extend beyond 2020, any detail added by extrapolating from this data set to subsequent years would be of very questionable value due to the large uncertainties in supply and demand this far into the future.

Control Board in a study of the impact of regulating Once-Through-Cooling technology in California.^{801, 802} See Chapter 6 for a more detailed description of the model algorithms and database.

The base case assumed that both nuclear plants are operating and that current renewable portfolio standards are met.⁸⁰³ For the case where the plants are removed, the lost nuclear capacity is replaced with renewable generation (with natural gas plants providing backup power, as needed).⁸⁰⁴ Replacing nuclear capacity with renewable capacity is consistent with the state's adopted loading order and GHG reduction goals (i.e. the replacement scenario was set to be effectively carbon neutral).

The preliminary results suggest that replacing the nuclear plants with the selection of renewable technologies modeled would come at a non-trivial cost to California – on the order of hundreds of millions or billions of dollars. The National Research Council, which assessed the cost to replace the power from the Indian Point nuclear plant, found that replacing this power with power from efficient natural gas power plants would also significantly raise costs (see insert on Indian Point replacement power study below). For the Diablo Canyon and SONGS replacement power analysis, replacing the nuclear capacity with natural gas resources was not modeled since doing so would increase carbon emissions. The cost implications of such a scenario would be strongly dependent upon future natural gas prices. With high gas prices, the annual cost of a gas replacement scenario could exceed that of the renewable replacement scenario. Additional model runs would be required to understand at what gas price the gas replacement scenario annual cost exceeds that of the renewables replacement scenario modeled here.

Additional detailed modeling is needed to (a) better reflect the evolving cost and performance of renewable technologies; (b) optimize the renewables replacement portfolio, (c) update the underlying gas price; (d) understand the tradeoffs between replacing the nuclear plants with gas generation versus renewable generation; and (e) integrate a transmission load-flow model so as to fully incorporate the cost of incremental transmission investment needed to connect the new renewable power sources to the grid.⁸⁰⁵

⁸⁰¹ California Energy Commission. "Scenario Analyses Of California's Electricity System: Preliminary Results For The 2007 Integrated Energy Policy Report." CEC-200-2007-010-SD. June 2007. Accessed: June 14, 2008. <http://energy.ca.gov/2007_energypolicy/documents/index.html#06252807>.

⁸⁰² ICF-Jones & Stokes, Global Energy Decisions, and Matt Trask. "Electric Grid Reliability Impacts from Regulation of Once-Through Cooling in California." Prepared for California Ocean Protection Council and State Water Resources Control Board, April 2008. Accessed: June 14, 2008. <http://www.swrcb.ca.gov/water_issues/programs/tmdl/docs/power_plant_cooling/reliability_study.pdf> .

⁸⁰³ California Energy Commission. "Scenario Analyses Of California's Electricity System." June 2007: Case 1b aging plants retirement scenario for 2020.

⁸⁰⁴ California Energy Commission. "Scenario Analyses Of California's Electricity System." June 2007: Case 4a.

⁸⁰⁵ Other considerations may also be important in designing a replacement power portfolio. For example, SONGS provides grid support to the Los Angeles basin. A replacement power portfolio would need to provide this same support.

Indian Point Replacement Power Study

In 2006 the National Research Council published a review of options available for replacing the power produced by the 2,000 MW Indian Point nuclear plant. The report identified no insurmountable technical barriers to the replacement of Indian Point power; however, significant financial, institutional, regulatory, and political barriers would have to be overcome.

For the report, the National Research Council assumed that new generating capacity would come primarily from high-efficiency natural gas combined-cycle units. Accordingly, they found that the expected economic impact of replacing the Indian Point units would be heavily dependent on the cost of natural gas. They also emphasized that there would be an overall increase in carbon dioxide emissions from this substitution of fossil fuel for nuclear fuel.

The report points out that it is reasonable to expect that replacing the nuclear plant, which has low operating costs and depreciated fixed costs, would raise the ultimate cost of electricity to consumers. The report estimated that the net change in the wholesale electricity price solely due to shutting down Indian Point might be an increase of \$7 per MWh for the New York Control Area and \$13 per MWh in New York City, by 2015. The analysis underlying these values accounted for load growth and scheduled retirements and utilized the “higher” fuel price forecast. (Note that even the gas prices in the report’s “higher” fuel price scenario are lower than current prices.)

In order to shed some light on how similar the results of such an analysis would be for the replacement of a nuclear plant in California, one must be mindful of the enormous uncertainty present in the report’s numbers. The price of natural gas has risen significantly since the report’s issuance, California’s wholesale and retail electricity markets are different from New York’s, and the state is more dependent on natural gas than New York is. Nonetheless, the replacement of nuclear capacity with natural gas capacity would also likely raise the price of wholesale power in California, as the report expected in New York. Furthermore, California’s greenhouse gas regulations would likely limit the utility’s ability to replace the carbon-free nuclear power with gas generation.

Source: National Research Council, Committee on Alternatives to Indian Point for Meeting Energy Needs. “Alternatives to the Indian Point Energy Center for Meeting New York Electric Power Needs.” ISBN: 0-309-66231-1. 2006, pages 1, 70-74.

Conclusions

California has substantial potential for renewable energy resources. In the long term, renewable resources could be suitable replacement power options if either Diablo Canyon or SONGS were to be shut down, assuming the resolution of key operational and cost issues. However, most

current renewable energy technologies cannot replace the operational characteristics of baseload nuclear plants. If either nuclear plant is shut down, natural gas plants would likely be required to provide backup power and ancillary services. Operational and local transmission issues must be studied more carefully to identify which attributes of these plants would need to be replaced if the plants shut down, and sufficient planning, siting, and construction time would be needed to develop these resources and any necessary transmission infrastructure.

No power generation technology is free of environmental impacts. A comparison of the life cycle GHG emissions for nuclear power, wind, solar PV, geothermal, and biomass shows that these technologies have comparable levels of life cycle GHG emissions. In addition, each of these technologies has some impact on the environment, affecting land, water, or wildlife. Moreover, the fossil fuel power plants needed to support many renewable units emit greenhouse gases and cause additional environmental impacts. Nuclear energy generation also imposes adverse impacts, including impacts from nuclear waste storage, transport, and disposal and impacts from a potential major plant accident, major earthquake, or terrorist attack.

Life cycle analyses can provide decision-makers a clearer and more complete understanding of the health and environmental impacts of different generating technologies. However, the usefulness of these analyses in comparing technologies is constrained by widely varying methodologies and assumptions and, in many cases, limited data. Extreme care must be taken to interpret the results of such analyses in light of these limitations.

Local economic impacts of generating facilities can be important factors in policy decisions about resource options. Replacing the nuclear plants with an equal mixture of in-state wind, solar thermal, geothermal, and biomass power could result in roughly the same overall tax and employment benefits to the state as provided by the nuclear plants. However, these benefits may be conferred to different localities. The communities currently benefiting from the nuclear plants would lose jobs and revenue unless the nuclear plants were replaced by other income-generating facilities. Notably, several large-scale solar projects are currently being planned in San Luis Obispo County.

Preliminary analysis suggests that replacing the state's two operating nuclear plants with renewable generation and using existing fossil-fuel units for reliability support could incur significant costs. Additional modeling is needed to fully understand the economic and environmental tradeoffs, as well as the implications on the California power grid, of permanently retiring Diablo Canyon and SONGS.

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CHAPTER 10: State Considerations for License Renewal

Diablo Canyon and San Onofre (SONGS) have been operating for approximately half of their 40-year initial license periods, and Pacific Gas & Electric (PG&E) and Southern California Electric (SCE) are exploring the feasibility of seeking 20-year license renewals for the plants.⁸⁰⁶ With license renewals, Diablo Canyon and SONGS could continue to operate until the early to mid 2040s (Table 30).

Table 30: Licensing Dates at California’s Nuclear Reactors

Plant	Unit	Size	Date Commercial Operation Began	Expiration of Current License	Potential License Expiration with Renewal
Diablo Canyon ⁸⁰⁷	Unit 1	1,122 MW	May 7, 1985	Nov. 2, 2024	Nov. 2, 2044
	Unit 2	1,118 MW	Mar. 15, 1986	Aug. 26, 2025	Aug. 26, 2045
SONGS	Unit 2	1,070 MW	Aug. 8, 1983	Feb. 16, 2022	Feb. 16, 2042
	Unit 3	1,080 MW	Apr. 1, 1984	Nov. 15, 2022	Nov. 15, 2042

The U.S. Nuclear Regulatory Commission’s (NRC) license renewal process consists of a safety review, environmental review, plant inspections, and a separate review by the Advisory Committee on Reactor Safeguards.⁸⁰⁸ The safety review focuses on identifying and managing the detrimental effects of plant aging. The environmental review considers plant-specific impacts from license renewal, such as once-through cooling impacts.⁸⁰⁹ Other issues, including examination of seismic hazards, operational issues, environmental review of the existing operations or independent spent fuel storage installations, and analysis of spent fuel storage options are outside the scope of license renewal. The NRC Office of the Inspector General

⁸⁰⁶ Current NRC regulations allow reactors licenses to be extended for 20-year periods. The NRC is investigating the feasibility of a second 20-year license renewal option. U.S. Nuclear Regulatory Commission. “Future Challenges for the Nuclear Science and Engineering Community.” Remarks of NRC Chairman Dale Klein at the International Conference on Nuclear Engineering, Orlando. May 12, 2008.

⁸⁰⁷ The capacity of Diablo Canyon, as reported on PG&E FERC Forms 1, increased from 2,150 MW in 2005 to 2,240 MW in 2006.

⁸⁰⁸ NRC’s license renewal process is discussed in more detail in *Nuclear Power in California: 2007 Status Report* beginning on page 227. The potential role for the state in this process is outlined beginning on page 236.

⁸⁰⁹ MRW & Associates, Inc. “Nuclear Power in California: 2007 Status Report.” Prepared for the 2007 Integrated Energy Policy Report. October 2007, page 230.

completed an audit of the license renewal process in 2007 and concluded that improvements were needed in reporting.⁸¹⁰

The role of the State in the license renewal decision is limited by the NRC's regulatory authority over all radiological aspects of nuclear power. However, state agencies retain authority to issue certain operating permits, such as the National Pollutant Discharge Elimination System (NPDES) permit, which is required for the continued operation of the plants' once-through cooling systems. Consequently, the NRC confers with state agencies as part of the environmental review and defers to agencies with appropriate regulatory authority.

In addition, the limited role of the State within the license renewal proceeding is counterbalanced by the State's much broader authority to set electricity generation priorities based on economic, reliability, and environmental concerns. The California Public Utilities Commission (CPUC) relied on this authority in establishing a framework for considering the cost-effectiveness of the Diablo Canyon license renewal (see "CPUC Framework for Evaluating Cost-Effectiveness of License Renewal"). Should the CPUC determine that a license renewal is not cost-effective, the CPUC could use its rate authority to effectively restrict the operation of the plant through an extended license period, even if a license renewal is granted. Such an action would not conflict with the NRC's regulatory authority over the radiological aspects of nuclear power.

This chapter presents some of the major policy questions from the state's perspective that could arise in considering license renewals for the nuclear plants. It begins with an analysis of how much power the plants might generate over the license extension period and how important the plants are for local and system reliability. It continues with an assessment of state and local impacts from the nuclear plants. Finally, it concludes with a discussion of the impacts of once-through cooling retrofit costs and potentially higher costs for labor, fuel, and security on the overall cost of nuclear power.

Estimated Electricity Production

The largest potential benefit from license extensions would accrue from power generated by the nuclear plants. In 2007 Diablo Canyon and SONGS generated 36,000 gigawatt-hours (GWh) of electricity (12 percent of California's total power supply).⁸¹¹ Under ideal circumstances the plants would continue to produce power at or close to that level for as long as they remain in operation. However, it is difficult to predict plant performance after an additional 20 or 30 years

⁸¹⁰ Among its findings, the Office of the Inspector General noted that the NRC's methodology was not sufficiently documented in the reports and that approximately 76 percent of the reports examined did not include substantive comments about operating experience, but rather, in some cases, included identical word-for-word repetition of text from the renewal application; U.S. Nuclear Regulatory Commission, Office of the Inspector General. "Audit of NRC's License Renewal Program." OIG-07-A-15. September 6, 2007.

⁸¹¹ California Energy Commission. "2007 Net System Power Report." CEC-200-2008-002-CMF. April 2008, page 4. Accessed: May 14, 2008. <<http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>>.

of use. No U.S. commercial reactor has yet operated for a 60-year period, and it is unclear how plant aging processes will affect plant reliability and electricity production.

Annual electricity generation from Diablo Canyon and SONGS has fluctuated since startup. In the initial start-up periods both plants operated with annual capacity factors of less than 70 percent, as operators resolved start-up issues and learned how best to operate and maintain the plant.⁸¹² As operators have gained experience they have been able to run the plants at much higher capacity factors, and over the past five years they have operated Diablo Canyon and SONGS with average capacity factors of 91 percent and 88 percent, respectively. Annual capacity factors still vary according to the number of refueling outages in a given year and the extent of required repairs and maintenance (Figure 37).⁸¹³

CPUC Framework for Evaluating Cost-Effectiveness of License Renewal

The CPUC established a framework for evaluating a possible Diablo Canyon license renewal in response to a PG&E December 2005 request for \$16.8 million for a license renewal feasibility study. The CPUC approved the requested funds and ruled that PG&E must submit the study to the CPUC by June 30, 2011, along with an application that addresses the results of the Energy Commission AB 1632 study, the cost-effectiveness of license renewal, and any legislative framework that may be established for reviewing the costs and benefits of license renewal. The study is to include a scoping analysis to review the structures, systems, and components at Diablo Canyon that would be reviewed under the NRC license renewal process; an aging analysis of the identified components; and a draft environmental assessment, which is required by the NRC application. The CPUC plans to review the study and the application and make a determination regarding license renewal by 2013.

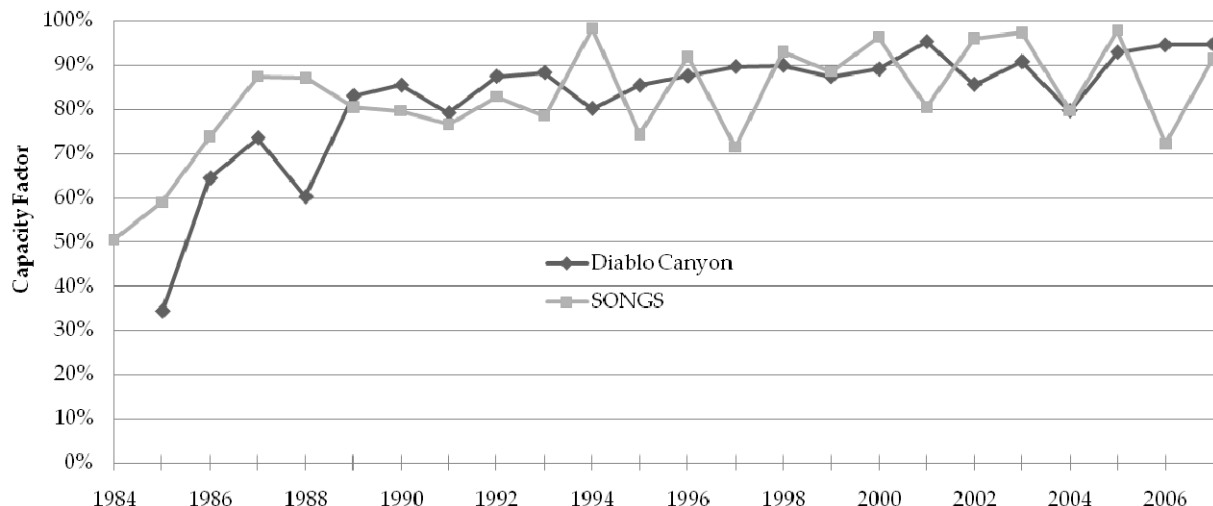
Following the framework established for Diablo Canyon, SCE requested \$17 million for a license renewal feasibility study for SONGS as part of its 2009 General Rate Case. The proposed study has the same scope as the Diablo Canyon feasibility study. SCE proposed to submit the study to the CPUC in 2011 together with an application that includes a cost-effectiveness analysis. Following CPUC approval, SCE would then submit a license renewal application to the NRC. The CPUC is expected to rule on SCE's General Rate Case including funding for the proposed study in late 2008.

Sources: California Public Utilities Commission. "Opinion Authorizing PG&E's General Rate Case Revenue Requirement for 2007-2010." D.07-03-044, pages 102-103; Pacific Gas & Electric. "PG&E Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632, question G.1; and Southern California Edison. "SCE 2009 GRC Testimony Part 2." Volume 2, A.07-11-011, pages 9-11.

⁸¹² The capacity factor is the amount of power produced as a percent of the total possible power production from the plant over a given time period.

⁸¹³ Each reactor is refueled roughly every 18 months. Refueling outages last at least four weeks and sometimes much longer, depending on how much maintenance and repairs are required.

Figure 37: Historical Diablo Canyon and SONGS Capacity Factors



Assessment of Future Electricity Production

The following three scenarios illustrate a possible range of electricity production trends from Diablo Canyon and SONGS during extended license periods (Table 31):⁸¹⁴

- Scenario 1:** Future production is maintained at the level at which the plants have operated over the past five years. Scenario 1 assumes that the operational improvements and expertise gained over the past 20 years are sufficient to keep the reactors operating at high capacity factors over the extended license periods. This is a best case scenario, where no major outages occur due to plant aging, and the reactors successfully operate until the end of their extended licenses.
- Scenario 2:** The mid-case scenario is based on the theory proposed by the Union of Concerned Scientists that, much as at the outset of a reactor's lifetime, a reactor nearing the end of its lifetime will be more likely to experience operational difficulties requiring extended outages and even a possible early shutdown.⁸¹⁵ The replacement of the steam generators at Diablo Canyon and SONGS may be an example of the impact of plant aging on reactor components and the expensive repairs and extended outages that can ensue.⁸¹⁶ To account for these outages, Scenario 2 shows a gradual decline in production beginning at the end of the initial operating license period.

⁸¹⁴ These scenarios were developed for illustrative purposes only. Actual future production may or may not be explained by the scenarios depicted.

⁸¹⁵ Lochbaum, David. "U.S. Nuclear Plants in the 21st Century: The Risk of a Lifetime." *Union of Concerned Scientists*. May 2004. Accessed: May 7, 2008. <http://www.ucsusa.org/assets/documents/clean_energy/nuclear04fml.pdf>.

⁸¹⁶ See MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007, page 128.

- **Scenario 3:** The final scenario represents a more drastic decline than the mid-case scenario. Under Scenario 3, electricity production is assumed to decline after the reactors have operated for only 30 years, and the reactors are shut down five years before the end of the extended license periods.

Table 31: Summary of Future Electrical Production Scenarios

Scenario	Description	Age at First Decline	Capacity Factor at End of 60-year License Period
Scenario 1	Production at most recent 5-year average	Does not decline	Same as most recent 5 year average
Scenario 2	Production declines slowly over 20 years	40 years	50 percent capacity factor
Scenario 3	Production declines rapidly over 30 years	30 years	Reactor is shut down 5 years prior to end of license

Results

Under the three scenarios, Diablo Canyon would generate 120,000-360,000 GWh over the course of an extended operating license period, and SONGS would generate 100,000-310,000 GWh. The results are shown in Figure 38 and Figure 39 and are summarized in Table 32 below.

Figure 38: Estimated Electricity Production at Diablo Canyon

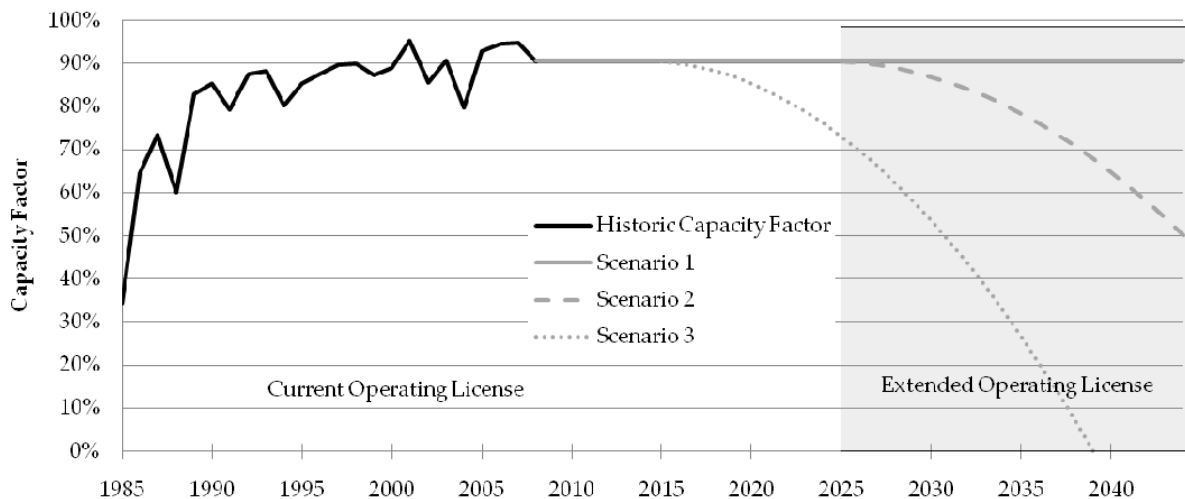


Figure 39: Estimated Electricity Production at SONGS

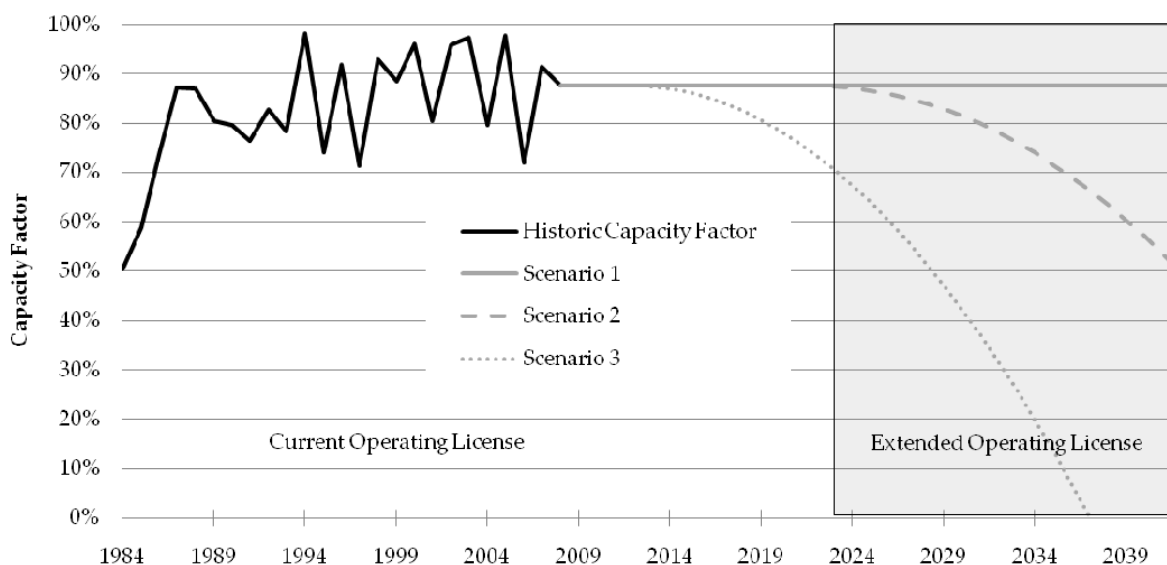


Table 32: Results of Scenario Analysis

		Total Production (GWh)	Capacity Factor: 60-Year Reactor Lifetime	Production: Extended License (GWh)	Capacity Factor: Extended License
Diablo Canyon	Scenario 1	1,030,000	90%	360,000	90%
	Scenario 2	970,000	85%	300,000	75%
	Scenario 3	780,000	65%	120,000	30%
SONGS	Scenario 1	950,000	85%	310,000	90%
	Scenario 2	900,000	80%	260,000	75%
	Scenario 3	730,000	65%	100,000	30%

These results illustrate uncertainty regarding future output from Diablo Canyon and SONGS. They do not represent the full range of possible outputs, and they do not indicate the likelihood of each scenario. Since the amount of expected production from the nuclear plants is one of the most critical factors in determining the cost-effectiveness of a license renewal, this is an area that merits further investigation.

The performance of commercial reactors in the U.S. older than Diablo Canyon and SONGS should shed light on the impacts of plant aging on performance in the years ahead. However, by 2013, the date the CPUC has targeted for making a decision on the Diablo Canyon license renewal, only 14 currently operating reactors will have operated for more than 40 years and

none will have operated for more than 43 years.⁸¹⁷ Without historical experience illuminating the aging process of reactors through year 60, significant uncertainty will remain regarding plant performance at Diablo Canyon and SONGS during an extended license period.

Reliability Benefits

The importance of Diablo Canyon and SONGS to the reliability of California's electricity grid over an extended license period will depend on the rate at which electricity demand in California increases, how much new generation and transmission capacity is built, how much old capacity is retired, and the location of each of these capacity changes. With proper planning, both plants could likely be replaced without eroding the electricity system's reliability.⁸¹⁸ The CPUC proposal to consider license renewal issues (that fall within the state's purview) approximately 10 years prior to potential plant retirements should provide sufficient opportunity for this planning.

One factor that could complicate reliability planning is a proposal by the State Water Resources Control Board to restrict the use of once-through cooling at California's coastal power plants.⁸¹⁹ A recent study by the California Independent System Operator (CAISO) found that the coastal plants that use once-through cooling technology provide important near-term reliability benefits to the state.⁸²⁰ Over the past 5 years these plants have produced between 20 and 35 percent California's power.⁸²¹ The Energy Commission and the CAISO have initiated an aging plant study to determine which of the coastal plants using once-through cooling are essential for grid reliability.⁸²² If new regulation resulted in the early retirement of some of those plants, the reliability benefits provided by the nuclear plants could increase, which would make it more difficult to replace the nuclear plants without eroding reliability.⁸²³

Another factor in the reliability benefits of the nuclear plants is how well they will operate over an extended license period. As discussed above, there is considerable uncertainty regarding the operations of aging nuclear plants. One possibility is that the plants will not provide the same level of reliability benefits over some or all of the extended license period, even if they continue to operate.

⁸¹⁷ The oldest operating commercial nuclear plants in the U.S. Oyster Creek and Nine Mile Point, will turn 40 in 2009, and the oldest pressurized water reactors, Ginna and Point Beach-1, will turn 40 in 2010. U.S. Energy Information Administration. "U.S. Nuclear Reactors." Accessed: May 14, 2008. <http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html>.

⁸¹⁸ Further analysis is required to ensure that a replacement power portfolio would maintain local reliability throughout California.

⁸¹⁹ For a full discussion of this proposed legislation see "Once-through Cooling Retrofit Costs" below.

⁸²⁰ California Independent System Operator. "Old Thermal Generation: Phase 1 Report." February 29, 2008. Accessed: May 16, 2008. <<http://www.caiso.com/1f80/1f80a4a5568f0.pdf>>.

⁸²¹ State Water Resources Control Board (SWRCB), California Environmental Protection Agency. "Water Quality Control Policy on the Use of Coastal and Estuarine Waters For Power Plant Cooling." SWRCB-1000-2008-001. March 2008, page 4.

⁸²² SWRCB, March 2008: 4.

⁸²³ California Independent System Operator, February 2008: 3.

Local Economic Impacts

Diablo Canyon and SONGS are integral components of their respective local economies and the state economy. The local economic benefits these plants provide include the contribution of tax dollars to the local economy, provision of employment opportunities in the local area, and direct purchases of goods and services. In addition, the plants provide significant indirect, or secondary, economic benefits.⁸²⁴ Closing either of the nuclear plants could thus have significant financial repercussions for their respective regions due to loss of plant-related jobs, reduced property tax payments, and foregone local purchases of products and services. (As discussed in Chapter 9, some amount of economic benefit would be transferred to those areas where replacement power is developed.) Property value implications of plant closure are less certain.

Tax and Employment Benefits

Both Diablo Canyon and SONGS pay property taxes based on the assessed value of their plants.

- In fiscal year 2007-2008, PG&E paid \$23.03 million in property taxes to San Luis Obispo County.⁸²⁵ Of that amount, an estimated \$20.42 million was for Diablo Canyon. The \$20 million PG&E paid in property taxes for Diablo Canyon in 2002 made up nine percent of the county's total property tax levy.⁸²⁶
- In 2006, SONGS paid \$4.85 million in property taxes to San Diego County.⁸²⁷ This accounts for just one-tenth of one percent of San Diego County's total property tax levy.⁸²⁸

Estimates of future property tax payments are shown in Table 33.

⁸²⁴ Secondary or "trickle-down" effects include indirect effects from the economic activity of input suppliers to the plants and induced effects generated by the change in household income that result from plant expenditures. Assessing secondary impacts is beyond the scope of this study. A 2003 study by the Nuclear Energy Institute (NEI) estimated the total economic impact of the Diablo Canyon plant, including both the value of the electricity and secondary effects from plant operations, at \$770 million in San Luis Obispo County and \$900 million statewide. A similar study for SONGS is not available U.S. Nuclear Energy Institute. "Economic Benefits of Diablo Canyon Power Station, An Economic Impact Study by the Nuclear Energy Institute." 2004.

⁸²⁵ Pacific Gas & Electric. February 27, 2008.

⁸²⁶ NEI, 2004.

⁸²⁷ Southern California Edison. "AB 1632 Nuclear Power Plant Assessment Data Request for San Onofre Nuclear Generating Station." Docket No. 07-AB-1632. March 21, 2008.

⁸²⁸ San Diego County Treasurer-Tax Collector. "Property Taxes." Accessed: April 10, 2008. <http://www.sdtreastax.com/pt_general.html>.

Table 33: Estimated Future Property Tax Payments⁸²⁹

Year	Diablo Canyon	SONGS
2007	\$20,400,000	SCE declined to provide this information
2008	\$21,200,000	
2009	\$22,900,000	
2010	\$24,900,000	

Both Diablo Canyon and SONGS are large employers. Diablo Canyon employs 1,250 full time workers and an additional 25 to 50 part-time employees during normal operations.⁸³⁰ PG&E reported that 94 percent of the Diablo Canyon workforce resides in San Luis Obispo County.⁸³¹ The average full-time Diablo Canyon salary in 2007 was \$88,148, well above the San Luis Obispo County median household income of \$50,209. The total compensation paid to all Diablo Canyon employees in 2007 was \$114.06 million.⁸³²

SONGS employed 2,043 people in 2007.⁸³³ The average SONGS employee salary of \$102,000 is significantly higher than the 2007 Orange County median family income of \$78,700 or the San Diego County median annual family income of \$63,400.^{834,835,836,837} Unlike Diablo Canyon, SONGS is located in a broad urban area and has employees living in several counties. SCE did not provide a county-by-county breakdown of its employees; therefore, it is difficult to determine SONGS' contribution to employment and expenditures within each county.⁸³⁸

Property Values

Several academic studies have addressed the question of whether proximity of a nuclear plant has an effect on property values. Public opinion surveys have consistently shown aversion to a nearby facility and an expected decrease in property values. However, empirical results are less clear because the presence of a nuclear facility is associated with economic benefits, such as

⁸²⁹ Pacific Gas & Electric. February 27, 2008: K1.

⁸³⁰ Additional workers may be hired for refueling and maintenance outages.

⁸³¹ Pacific Gas & Electric. February 27, 2008: K2.

⁸³² Pacific Gas & Electric. February 27, 2008: K3.

⁸³³ Southern California Edison. March 21, 2008: K1.

⁸³⁴ Southern California Edison. March 21, 2008: K3.

⁸³⁵ San Diego County Treasurer-Tax Collector. "Property Taxes."

⁸³⁶ Orange County. "2008 Orange County Community Indicators." March 2008, page 23. Accessed: June 2, 2008. <<http://egov.ocgov.com/vgnfiles/ocgov/OCGOVPortal/docs/CIR2008.pdf>>.

⁸³⁷ San Diego Housing Federation. "What is area median income." 2007. Accessed: April 30, 2008. <http://www.housingsandiego.org/about_definition.php>.

⁸³⁸ Southern California Edison. March 21, 2008: K3.

employment and property tax income, in addition to the negative effects associated with public risk perception.

Folland and Hough examined the effect of nuclear facilities on the value of farmland across the United States from 1945-1992.⁸³⁹ Their study examined whether the presence of a nuclear facility within 60 miles would have an effect on property values. This distance was chosen as the result of a survey that asked laymen to state the distance from a nuclear reactor that they would accept when choosing a residence location.⁸⁴⁰ By including data from years prior to the installation of any nuclear reactors, the study corrected for the fact that nuclear facilities were often sited in less prosperous areas with lower population densities and that such locations may have had historically depressed property values. Folland and Hough's analysis concluded that the presence of a nuclear facility within 60 miles decreased the value of farmland by approximately 10 percent.⁸⁴¹ Their results also showed that the older the reactor, the larger the negative impact on property values.⁸⁴²

The Folland and Hough study may be limited in its application to the assessment of Diablo Canyon and SONGS. The paper examines the property value of agricultural land, not residential. The risk perception profiles of agricultural and residential land owners may be different and the benefits associated with a nuclear facility may accrue disproportionately to residential owners who are most likely to benefit from employment at the facility. It is therefore unclear whether the effect on agricultural property values can be applied to property values as a whole. In particular, this may be of concern at SONGS, which has less adjacent farmland than Diablo Canyon.

Another study, completed by Clark and Nieves examined the effect of the presence of a nuclear facility on residential property values and on income.⁸⁴³ The study examined data from 1976-1980 for 76 large market areas across the country and measured the effects of a nuclear facility within the study area. Two data sets were used: one quantifying the property value impacts and another analyzing the wage impacts. The results showed that nuclear power plants are "productive disamenities," meaning that they generate income for an area but still reduce property values.⁸⁴⁴

The Clark and Nieves study may be instructive for evaluating impacts from Diablo Canyon and SONGS. However, the analysis is based on data that are over 25 years old. Since that time public perception of nuclear power may have evolved, and property value impacts associated with a nuclear facility may have changed. In addition, the relatively short time-period

⁸³⁹ Folland, Sherman and Robbin Hough. "Externalities of Nuclear Power Plants: Further Evidence." *Journal of Regional Science*. Volume 40 No. 4. 2000, pages 735-753.

⁸⁴⁰ Folland and Hough, 2000: 737.

⁸⁴¹ Folland and Hough, 2000: 749.

⁸⁴² Folland and Hough, 2000: 747.

⁸⁴³ Clark, David and Leslie Nieves. "An Interregional Hedonic Analysis of Noxious Facility Impacts on Local Wages and Property Values." *Journal of Environmental Economics and Management*. Volume 27 (1994), pages 235-253.

⁸⁴⁴ Clark and Nieves, 1994: 235-253.

considered in the study may not be representative of overall trends. Finally, the study provides no indication of the relative magnitude of the observed impacts.

A third study, by Clark, et. al. took a different approach. Whereas the Folland and Hough study and the Clark and Nieves study measure whether the presence of a nuclear plant in a given area affects property values, Clark, et al. instead employed a distance gradient to measure the property value impact of proximity to the plant (i.e. is property valued differently when it is five miles from the plant versus 10 miles from the plant?).

Clark, et. al. examined residential property sales within 25 miles of Diablo Canyon and Rancho Seco for the years 1990-1994.⁸⁴⁵ They found that within this distance, being closer to the plant is associated with an increase in property values.⁸⁴⁶ The authors believe that the increase in property values may be due to the high value of the relatively uncongested areas surrounding the plants. They interpret the result as demonstrating that within the local area, any negative effect associated with being close to the nuclear plant does not overwhelm the desirable attributes associated with proximity to the plant.⁸⁴⁷

While these results appear to contradict the other studies, that is not the case. Because the Clark, et. al. study only examines the effects of proximity to the plant within a short distance from the plant (25 miles), the relevance of these results may also be limited. Folland and Hough found negative impacts associated with a nuclear facility within 60 miles of the study area, and Clark and Nieves found negative impacts from a facility within 1,500 square miles. It is possible that within 25 miles of the plant, the risks associated with the facility have been accepted and are already internalized into the property value. What Clark et. al. does show is that within this acceptance area, there is no aversion related to proximity; that is, there is no preference for being 10 miles away from the plant as opposed to 5 miles away.

The studies described above all seek to measure the effects of the presence of a nuclear facility, including perceived risk of an accident at the facility. While it may be assumed that an accident at one of the facilities would further decrease property values, the literature shows otherwise. To date Three Mile Island has been the only major accident at a commercial reactor in the U.S. Following the 1979 incident, several studies were published examining potential property value impacts. Among them, a study by Nelson and another by Gamble and Downing employed statistical analyses of property sales in the area surrounding the plant and determined that while an immediate decrease in property values near the plant may have been observed, a long term effect was not present.⁸⁴⁸

⁸⁴⁵ Clark, David, Lisa Michelbrink, Tim Allison, and William Metz. "Nuclear Power Plants and Residential Housing Prices." *Growth and Change*. Volume 28 (Fall 1997), pages 496-519.

⁸⁴⁶ Clark, et al. 1997: 496-519.

⁸⁴⁷ Clark, et al. 1997: 509.

⁸⁴⁸ Nelson, Jon P. "Three Mile Island and Residential Property Values: Empirical Analysis and Policy Implications." *Land Economics*, Vol 57 No 3. August 1981, page 970; Gamble, H.B. and Downing, R.H. "Effects of nuclear power plant on residential property values." *Journal of Regional Science*, Vol 22. Pages 457-478.

In the context of California's nuclear facilities, these studies show that the presence of Diablo Canyon and SONGS may have decreased property values surrounding the plants to some extent. However, Diablo Canyon and SONGS are large employers that offer relatively high salaries. These benefits must also be considered when examining the overall economic impact of the plants. Indeed, Clark and Nieves found that nuclear facilities are associated with higher than average income.⁸⁴⁹ In the case of Diablo Canyon, which is situated in largely rural San Luis Obispo County, the plant may provide proportionately larger positive economic benefits for the surrounding communities than SONGS, which is located in a broadly urban area between Orange and San Diego counties.

Economic Implications of Plant Closures

Closure of the two nuclear plants would have complex economic implications for their local communities. Plant closures would inevitably lead to a loss of jobs and property taxes. Adverse impacts would materialize over several years as decommissioning activities progressed. At the same time, property value increases may partially offset this loss of income. If nuclear waste remains on-site, property value implications would be less certain.

Economic impacts in a post-decommissioning period would depend on how the plant sites are developed. As discussed in Chapter 8, residents of San Luis Obispo County expressed a strong preference that the plant site be used for habitat preservation, sustainable agriculture, and public use. The economic benefits of such uses would need to be studied. The SONGS site will remain under control of the U.S. Navy, and the Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use. The local economic impacts of plant closures will depend on the economic benefits from the new land uses. However, benefits from new land use would not accrue for a number of years until the plant is fully decommissioned and the land is developed for future use.

The extent of the local economic impact of plant closure would differ significantly for each plant. Closing Diablo Canyon could have a substantial impact on the regional economy. Based on current tax payments, if Diablo Canyon closed, San Luis Obispo County could lose nearly 10 percent of its tax base.⁸⁵⁰ This loss could be partially offset by an increase in property taxes if property values of nearby properties were to rise upon plant closure, but this is not guaranteed. Plant closure would also result in the loss of high-paying jobs for over 1,000 people in the county. This could result in reduced spending on goods and services by laid-off employees until they find new employment. It could also lead to an exodus of these workers to other areas to find new employment. On the other hand, redevelopment of the Diablo Canyon site for new

⁸⁴⁹ Clark and Nieves, 1994: 235-253.

⁸⁵⁰ San Luis Obispo County could attempt to recover some of the lost tax payments by charging a higher tax assessment for the remaining ISFSI. The town of Wicasset, Maine, attempted this—unsuccessfully—after the Maine Yankee plant closed down, (The town of Wicasset, Maine assessed the ISFSI site at \$15 million per acre based largely on payments offered to Native American tribes to use reservation lands for commercial spent fuel storage. The owners of the plant challenged this assessment, noting that the ISFSI is eligible to store only waste from the retired plant; that it is a cost center, not a revenue producer; and that there are no known potential buyers of the site. The parties settled on an assessed value of the land at the ordinary rate for industrial land.); Frieman, Jack and Barry Diskin. "Nuclear Waste Disposal: A Taxing Real Estate Issue." *Real Estate Issues*. Summer 2006, pages 5-13.

uses could bring economic benefits that may offset the negative impacts of plant closure. In addition, recent announcements of several large-scale solar facilities in San Luis Obispo County indicate that the county has resources to attract other income-generating development and to become less economically dependent on Diablo Canyon.⁸⁵¹ In order to understand the overall economic impacts of a Diablo Canyon closure, costs and benefits and development potentials need to be analyzed further.

Closing SONGS would likely have a much less significant impact on the San Diego and Orange County economies. SONGS provides just one-tenth of one percent of San Diego County's annual property tax revenue, and SONGS employees are spread throughout a large region. In addition, there are many alternate sources of employment and other areas of economic activity in the vicinity of the plant.

In order to quantify the net impacts to local economies from plant closure, area-specific studies would be needed. Property value impacts would need to be assessed through comparison with similar communities that did not have nuclear plants or by comparing property values in the vicinity of the plants over an extended period of time. Employment and income benefits would also need to be quantified and put into context of other economic activity in the region. Absent such an analysis, the net impact of Diablo Canyon and SONGS closures on their local economies remains uncertain.

Potential Increases to the Cost of Nuclear Power

The cost-effectiveness of extending the licenses at Diablo Canyon and SONGS depends on the cost of power from these plants relative to the cost of power from alternate power sources. Over the past five years, power from Diablo Canyon has averaged \$38 (2007\$) per megawatt-hour (MWh).⁸⁵² (SCE declined to provide information on the cost of power from SONGS.) Future costs will depend on the amount of power generated from the plants (discussed above), unanticipated capital projects, future policy decisions and regulatory requirements, and market changes.

This section considers the impact of four potential sources of upward pressure on the cost of power from the nuclear plants: a policy that would require once-through cooling retrofits at the plants, tight supply for skilled labor, an increase in the price of nuclear fuel, and more stringent security requirements.

Once-Through Cooling Retrofit Costs

As discussed in Chapter 9, once-through cooling systems can have significant and negative impacts on the marine life near the cooling system intake and outfall pipes. Due to these

⁸⁵¹ OptiSolar's 550 MW Topaz Solar Farm and SunPower's 250 MW California Valley Solar Ranch are expected to become fully operational in 2012. Pacific Gas & Electric. "PG&E Signs Historic 800 MW Photovoltaic Solar Power Agreements With OptiSolar and SunPower." August 14, 2008. Accessed: September 4, 2008. <http://www.pge.com/about/news/mediarelations/newsreleases/q3_2008/080814.shtml>.

⁸⁵² Pacific Gas & Electric. "PG&E Response to CEC Nuclear Power Plant Data Requests." Docket No. 06-IEP-1N. April 5, 2007, question M1; Pacific Gas & Electric. February 27, 2008: F1.

impacts, both federal and state governments have proposed regulations that limit the use of once-through cooling at new and existing power plants. While the regulations are still being finalized, it appears possible that Diablo Canyon and SONGS will be required to replace their cooling systems or to retrofit them in a manner that significantly reduces marine impacts.⁸⁵³ The alternative and more modern methods for plant cooling include air cooled condensers (dry cooling), in which large fans blow air over the condensers to prevent overheating, and closed-cycle “wet” systems, in which the water used for cooling is recycled.

Proposed Regulations

In July 2004 the U.S. Environmental Protection Agency (EPA) established regulations which required that, beginning in July 2008, all cooling water intake structures at existing power plants must use the best technology available to reduce impingement mortality by 80 to 95 percent and entrainment mortality by 60 to 90 percent in order to be issued a National Pollutant Discharge Elimination System (NPDES) permit. Such a permit is required to continue using a once-through cooling system. Should the cost of compliance significantly outweigh the environmental benefits, this EPA regulation authorized an NPDES permit director to establish site-specific alternative requirements that minimize adverse environmental impacts without resulting in undue costs.⁸⁵⁴ However, the U.S. Court of Appeals for the Second Circuit ruled that the EPA regulations did not comply with the Clean Water Act. In particular, the court found that the Clean Water Act does not allow for a cost-benefit analysis to guide technology selection and ruled that the best technology available or an alternative technology that achieves that same level of results must be used. The court also remanded provisions for compliance through restoration measures.⁸⁵⁵ This decision was appealed to the Supreme Court which will hear the case on December 2, 2008. The examination will be limited to the question of whether the Clean Water Act authorizes the EPA to consider costs in addition to benefits in its determination of the best technology available for impact mitigation.⁸⁵⁶ Pending a court decision, the EPA has currently suspended its regulations and has directed regional offices to exercise their Best Professional Judgment in considering NPDES permit applications.

In April 2006, the California State Lands Commission (CSLC) passed a resolution requiring existing power plants to fully comply (or work toward full compliance) with Clean Water Act regulations as a condition for receiving land lease extensions or amendments.⁸⁵⁷ The draft

⁸⁵³ Modern methods for plant cooling including “dry cooling,” in which large fans blow air to prevent overheating, and closed-cycle “wet” systems, in which the water used for cooling is recycled.

⁸⁵⁴ U.S. Environmental Protection Agency. “National Pollutant Discharge Eliminations System – Final Regulations to Establish Requirements for Cooling Water Intake Structures and Phase II Existing Facilities.” *Federal Register*, Volume 69, No. 131. 2004, page 41576. Accessed: May 6, 2008. <<http://a257.g.akamaitech.net/7/257/2422/06jun20041800/edocket.access.gpo.gov/2004/pdf/04-4130.pdf>>.

⁸⁵⁵ See MRW & Associates, Inc. “Nuclear Power in California: 2007 Status Report.” Prepared for the 2007 Integrated Energy Policy Report. October 2007.

⁸⁵⁶ U.S. Supreme Court. 07-597 Utility Water Act Group V. Riverkeeper, Inc., Et Al. 475 F3d 83. April 14, 2008.

⁸⁵⁷ California State Lands Commission. “Resolution by the California State Lands Commission Regarding Once-through Cooling in California Power Plants.” Adopted April 20, 2006.

resolution includes a provision that would allow CSLC to re-open leases if an environmentally superior alternative technology that can be feasibly installed is identified. It does not include an exemption if the cost of the technology outweighs the environmental benefits.⁸⁵⁸

In June 2006, the State Water Resources Control Board (SWRCB) presented a proposed state-wide policy that would require once-through cooling facilities to achieve the upper end of the impingement and entrainment reduction ranges provided by EPA's Phase II regulation (i.e. 95 percent reduction in impingement and 90 percent reduction in entrainment). This proposed policy would not have allowed for a site-specific determination of the best available technology based on cost considerations. In response to the U.S. Court of Appeals 2007 ruling, the SWRCB issued a revised preliminary draft Statewide Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling in March 2008.⁸⁵⁹ The draft policy would require existing power plants to reduce intake flow and velocity to a level comparable to that which could be attained by a closed-cycle cooling system (Track 1). If this is not feasible, "the power plant must reduce the level of adverse environmental impacts from the cooling water intake structure to a comparable level to that which would be achieved under Track 1, using operational or structural controls, or both." A "comparable level" is defined as a reduction in both impingement and entrainment mortality to at least 90 percent of the reduction that would be achieved under Track 1 with closed-cycle cooling technology.⁸⁶⁰ The compliance date for nuclear power plants would be no later than January 1, 2021, which is near the end of the plants' current operating licenses.⁸⁶¹

Both the recently suspended EPA Phase II regulations and the preliminary draft SWRCB policy recognize the unique safety issues associated with California's nuclear power plants and provide for a site-specific assessment of the best available technology (including operational or structural controls) in the event of a conflict with NRC requirements.

Retrofit Feasibility and Cost

Federal and state regulations limiting the use of once-through cooling technology for power plants have prompted investigations into the feasibility of retrofitting power plants with technologies to reduce impingement and entrainment impacts. The availability of sufficient land is the most limiting factor in assessing the technical and logistical feasibility of retrofitting existing once-through cooling systems with alternative technology.

With regard to nuclear power plants, converting to wet cycle closed-cooling has received the most study, because dry-cooling is not considered a commercially viable option and is not

⁸⁵⁸ In response to a petition from an association of coastal power plant owners whose members include PG&E and SCE, the Office of Administrative Law determined that the CSLC resolution constitutes an "underground law" to the extent that it creates an explicit rule. This determination does not require that the CSLC revoke its resolution but may open the door for future legal challenges; See MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007: 172.

⁸⁵⁹ SWRCB, March 2008.

⁸⁶⁰ SWRCB, March 2008.

⁸⁶¹ Plants with capacity factors below 20 percent would have to comply by January 1, 2015, and non-nuclear plants with higher capacity factors would have to comply by January 1, 2018.

viable at Diablo Canyon due to space constraints. The general consensus from the studies is that retrofitting California's nuclear power plants with wet cycle closed-cooling technology is technically feasible (although challenging due to siting constraints), but the costs would be very high in comparison to retrofitting natural-gas fired power plants. Pertinent studies are described below.

California Energy Commission

In its responses to the CSLC regarding the possible effects of the CSLC Draft 2006 resolution on California's coastal power plants, the Energy Commission stated that there may not be sufficient reclaimed water for use in cooling towers at Diablo Canyon and SONGS and that a retrofit to install these towers would be an expensive engineering challenge.^{862,863}

The Energy Commission's 2007 Environmental Performance Report produced recommendations to retire or repower numerous aging once-through cooling power plants by 2012. However, it recognized that California's nuclear power plants present special circumstances due to their size, costs, and unique contribution to grid stability, fuel diversity, and resource adequacy, and therefore "should be evaluated carefully before new regulations on once-through cooling are finalized in California."⁸⁶⁴

Electric Power Research Institute⁸⁶⁵

The Electric Power Research Institute (EPRI) conducted a study to document the costs of wet closed-cycle cooling retrofits compared to new facility installations, assess the feasibility of dry cooling at certain facilities, and discuss the environmental impacts of wet closed-cycle cooling. EPRI determined that retrofitting the nuclear plants would be very difficult and that the capital cost for retrofitting would be \$750 million - \$1.2 billion for Diablo Canyon and greater than \$650 million for SONGS. These estimates do not include costs for replacement power while the plants are shut down during construction.

The EPRI report also noted that environmental impacts associated with retrofitting nuclear power plants to wet closed-cycle cooling technology include increased air emissions due to decreased plant efficiency, drift and visible plume,⁸⁶⁶ water and wastewater discharge and/or disposal, increased noise, visual impacts from taller cooling towers, temporary construction-related impacts, intake losses,⁸⁶⁷ solid waste from accumulation of suspended solids in cooling

⁸⁶² California Energy Commission. Letter from B.B. Blevins of the California Energy Commission to Paul Thayer of the California State Lands Commission. April 11, 2006.

⁸⁶³ See MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

⁸⁶⁴ California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008.

⁸⁶⁵ Electric Power Research Institute (EPRI). "Issues Analysis of Retrofitting Once-Through Cooled Plants with Closed-Cycle Cooling: California Coastal Plants." October 2007.

⁸⁶⁶ Drift refers to liquid water droplets entrained in the tower exit plume and released to the atmosphere.

⁸⁶⁷ Closed-cycle systems still require some water intake, though ten to seventy times less than once-through cooling. Some impingement and entrainment losses are expected.

tower makeup water, and impacts to terrestrial ecology. Both Diablo Canyon and SONGS pose site-specific siting constraints because of their proximity to sensitive coastal habitat.

California Ocean Protection Council

In April 2006, the California Ocean Protection Council adopted a resolution regarding the use of once-through cooling in ocean waters. The resolution called for the formation of a technical review group to review Clean Water Act related studies of the technical feasibility of converting each of the coastal power plant once-through cooling systems to alternative cooling technologies. The resolution established a benchmark of a 90-95 percent reduction in impingement and entrainment impacts. Pursuant to this resolution, the Ocean Protection Council commissioned Tetra Tech to evaluate the feasibility of converting the cooling systems to wet cooling towers. The feasibility analyses included an engineering assessment and cost profile for each subject facility.⁸⁶⁸

Tetra Tech found that retrofitting the existing once-through cooling system at Diablo Canyon and SONGS with closed-cycle wet cooling towers is technically and logistically feasible, though particularly difficult at Diablo Canyon. Further, retrofitting would reduce cooling water withdrawals from the Pacific Ocean by approximately 96 percent for Diablo Canyon and 95 percent for SONGS. Accordingly, impingement and entrainment impacts would be reduced by similar proportions.

The location of Diablo Canyon along a narrow coastal terrace may pose siting constraints for additional facilities required for retrofitting. Tetra Tech recommended that the retrofit include two conventional wet cooling towers.⁸⁶⁹ However, sufficient area does not exist at the site for the installation of plume-abated towers, which would reduce the aesthetic impact of the cooling towers and which may be required under the California Coastal Act.⁸⁷⁰ In addition, Tetra Tech found that retrofitting would require the relocation of several support facilities including maintenance facilities, warehouses, and employee parking.⁸⁷¹ Because both units share a common water intake structure, retrofit would require both units to be offline concurrently for eight months or more.⁸⁷²

At SONGS, the study recommended installation of two water cooling complexes each with six plume-abated towers.⁸⁷³ Retrofitting SONGS' once-through cooling system would also require an eight month outage. However, the study found that the configuration of SONGS may enable staggered retrofit, causing only one unit to be offline at a time.⁸⁷⁴ The installation and operation

⁸⁶⁸ Tetra Tech. "California's Coastal Power Plants: Alternative Cooling System Analysis." Prepared for the California Ocean Protection Council. February 2008.

⁸⁶⁹ Tetra Tech, 2008: 7C-1.

⁸⁷⁰ Tetra Tech, 2008: 7C-11, 12.

⁸⁷¹ Tetra Tech, 2008: 7C-1.

⁸⁷² Tetra Tech, 2008: 7C-2.

⁸⁷³ Tetra Tech, 2008: 7N-1.

⁸⁷⁴ Tetra Tech, 2008: 7N-1.

of wet cooling towers at SONGS may require additional regulatory approval due to potential impacts to sensitive coastal habitat and special-status plant species.

Tetra Tech estimated the total net present cost for cooling system retrofits at Diablo Canyon and SONGS to be \$3.02 billion and \$2.62 billion, respectively.⁸⁷⁵ These estimates include all costs associated with the construction and installation of cooling towers, annual operations and maintenance, and purchases of electricity from other sources to replace the electricity that would otherwise be generated during the construction periods.⁸⁷⁶

Retrofit of the once-through cooling systems at Diablo Canyon and SONGS would reduce capacity at the plants due to the additional electrical demand of cooling tower fans and pumps and a reduced thermal efficiency.⁸⁷⁷ Compared to a once-through cooling system, a closed-cycle system would decrease plant output an average of 5 percent at Diablo Canyon and 5.5 percent at SONGS.⁸⁷⁸ The use of other power plants to compensate for the reduced energy output could increase emissions from pollutants such as SO_x and NO_x and could result in increased particulate matter emissions that approach maximum permitted levels. In addition, the high salinity content of the once-through cooling discharge would require an NPDES permit and an onshore diffuser system.

In comments regarding the Tetra Tech report, both PG&E and SCE responded that retrofit is not feasible.^{879,880} PG&E noted that there is no nuclear plant in existence that uses mechanical draft salt water cooling towers as suggested by the Tetra Tech report.⁸⁸¹ Both utilities claimed that the Tetra Tech report was limited in scope and should not be considered a comprehensive review. In addition, PG&E found that the 8 months that Tetra Tech estimated it would take to retrofit the cooling system at Diablo Canyon was not reasonable. PG&E estimates that the outage would be 12 to 18 months long. In addition, PG&E claimed that the methods Tetra Tech used to estimate replacement power costs were inaccurate. PG&E estimates that replacement power alone would cost \$1.3 to \$2 billion, at least twice as much as the Tetra Tech estimate. Overall, PG&E estimates that a retrofit project would increase rates by 5 percent.⁸⁸²

⁸⁷⁵ Tetra Tech, 2008: 7C-1, 7N-1.

⁸⁷⁶ Land area restrictions at Diablo Canyon are the main cause of the difference in cost between the two plants.

⁸⁷⁷ Tetra Tech, 2008: 7C-28, 7N-30.

⁸⁷⁸ Tetra Tech, 2008: 7C-26, 7N-31.

⁸⁷⁹ Pacific Gas & Electric. "Response to Scoping Document on Once-Through Cooling." May 20, 2008. Accessed: June 2, 2008.
<http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316_may08/comments/mark_krause.pdf>.

⁸⁸⁰ Southern California Edison. "Response to Scoping Document on Once-Through Cooling." May 20, 2008. Accessed: June 2, 2008.
<http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316_may08/comments/michael_hertel.pdf>.

⁸⁸¹ Pacific Gas & Electric. May 20, 2008: 44.

⁸⁸² Pacific Gas & Electric. May 20, 2008: 55.

Others

PG&E commissioned a study that included examination of the economic benefits of reductions in entrainment losses from installing cooling towers at Diablo Canyon. The study found that the cost to retrofit the once-through cooling technology at Diablo Canyon substantially outweighed the benefits.⁸⁸³ The study determined that retrofitting with a wet closed-cycle cooling system would create “significant adverse environmental impacts including: 1) 7 million pounds of salt drift annually causing negative impacts for flora and fauna and electrical arcing incidences on the 500 kV line; 2) 69 million gallons a day of saltier, warmer discharge water; and 3) significant safety and visual issues from the vapor plume, as well as noise issues.”⁸⁸⁴

Implications for California’s Reactors

A restriction on the use of once-through cooling in California is likely to be implemented in the future. If the SWRCB preliminary draft policy is adopted, Diablo Canyon and SONGS would need to either adopt closed-cycle cooling systems or reduce the negative effects of their once-through cooling systems to a level comparable to the effects of a closed-cycle system.

The studies described above show the closed-cycle cooling system retrofits to be technically feasible, though costly. The most recent cost estimates provided by the California Ocean Protection Council predict that total retrofit costs would be \$3.02 billion at Diablo Canyon and \$2.62 billion at SONGS. Extended outages would be required to complete the project—at Diablo Canyon, both reactors would need to be shut down simultaneously for 8-18 months. Additionally, closed-cycle cooling would decrease the efficiency of the plants by roughly 5 percent, requiring replacement power sources to make up the difference.

Labor Availability

The nuclear industry is facing a potential labor shortage, as discussed in Chapter 5. The labor shortage may result in higher costs to nuclear utilities, as competition to hire employees drives up the price of labor. Further costs may be incurred for recruiting, training, and personnel management.

Nuclear Fuel Prices

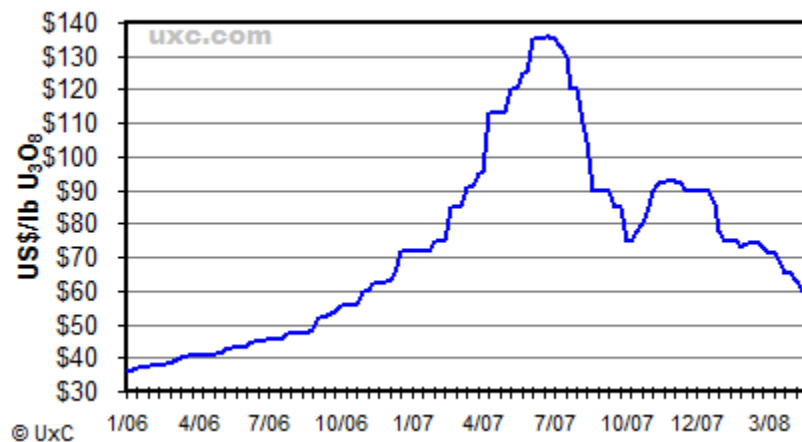
In 2006 and the first half of 2007, spot market prices for uranium rose over 300 percent from approximately \$38 per lb in January 2006 to \$135 per lb in June 2007. Spot market prices have since declined to an average of \$59 per lb in June 2008 (Figure 40).⁸⁸⁵

⁸⁸³ ASA Analysis and Communications, Inc. and Ivar Strand, “Estimation of Potential Economic Benefits of Cooling Tower Installation at the Diablo Canyon Power Plant.” Prepared for PG&E. April 2003, as cited in California Energy Commission. “Issues and Environmental Impacts Associated with Once-Through Cooling and California’s Coastal Power Plants.” June 2005, pages 58, 62.

⁸⁸⁴ Pacific Gas & Electric. “PG&E Responses to CEC Nuclear Power Plant Data Request.” Docket #06-IEP-1N. April 5, 2007.

⁸⁸⁵ Ux Consulting Company, LLC. “Ux U3O8 Prices.” Accessed: July 16, 2008. <<http://www.uxc.com>>.

Figure 40: Uranium (U_3O_8) Nominal Spot Market Prices, January 2006-June 2008⁸⁸⁶



Spot uranium prices do not have a direct impact on PG&E and SCE's nuclear fuel costs because the utilities purchase their nuclear fuel via medium and long-term contracts.⁸⁸⁷ However, since market prices are generally used to set or inform contract prices, over the long term an increase in market prices will increase the utility's fuel costs.

PG&E and SCE both anticipate that their nuclear fuel costs will increase in the coming years and be 70 percent higher in 2014 than they were in 2007.⁸⁸⁸ PG&E anticipates that its fuel costs will decline after 2014, while SCE anticipates that its fuel costs will continue to rise through the end of the SONGS license period (Figure 41). These projected price increases will not have a significant ratepayer impact since fuel prices represent just 10-20 percent of the levelized cost of nuclear power.⁸⁸⁹ For example, had PG&E's nuclear fuel costs been 70 percent higher than they were in 2007, the total cost of power from Diablo Canyon would have increased by just 11 percent, from \$34 per MWh to \$38 per MWh.⁸⁹⁰

⁸⁸⁶ Ux Consulting Company, LLC. "Ux U3O8 Prices."

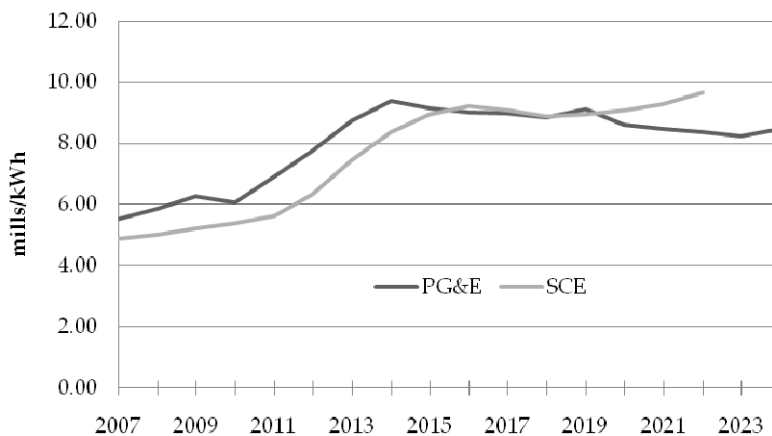
⁸⁸⁷ Worldwide, only 20 percent of uranium is traded through the spot market. World Nuclear Association. "Uranium Markets." March 2008. Accessed: May 12, 2008. <<http://world-nuclear.org/info/inf22.html>>.

⁸⁸⁸ Pacific Gas & Electric. February 27, 2008: F1; Southern California Edison. March 7, 2008: F1 and Attachment A.

⁸⁸⁹ California Energy Commission. "Comparative Cost of California Central Station Electricity." Page 12; Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13. Accessed: May 16, 2008. <<http://cbo.gov/>>.

⁸⁹⁰ Pacific Gas & Electric. February 27, 2008: F1.

Figure 41: Utility Nuclear Fuel Price Predictions⁸⁹¹



Security Requirements

Following the attacks of September 11, 2001, the NRC began to review nuclear power plant security requirements. Following this review, the NRC updated the design basis threat for the plants, increased requirements for security personnel, and enhanced force-on-force exercises.⁸⁹² The NRC also proposed a rulemaking to amend 10 CFR Part 73 requirements for physical protection of the nation's nuclear plants.⁸⁹³

The proposed physical protection rules would enhance requirements for access controls, event reporting, security personnel training, safety and security activity coordination, contingency planning, and radiological sabotage protection. They would also impose additional requirements related to background checks for firearms users and to authorization for enhanced weapons.⁸⁹⁴ The NRC received 48 comments on the proposed rules during the comment period, which closed in March 2007.⁸⁹⁵ Among them, several intervenors noted that the proposed requirements do not include any provisions addressing the threat of an air-based suicide

⁸⁹¹ Pacific Gas & Electric. "PG&E 2008 DR Responses." Question F1; Southern California Edison. "SCE 2008 DR Response." Attachment A.

⁸⁹² U.S. Nuclear Regulatory Commission. "Security Spotlight." January 2, 2008. Accessed: May 16, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-spotlight/index.html>>.

⁸⁹³ Federal Register. "RIN 3150-AG63." Vol. 71, No. 207. October 26, 2006, pages 62666-62667. <www.gpoaccess.gov>.

⁸⁹⁴ U.S. Nuclear Regulatory Commission. "Physical Protection Rulemaking." January 2, 2008. Accessed: April 2, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-spotlight/physical-protection.html>>.

⁸⁹⁵ U.S. Nuclear Regulatory Commission. "Power Reactor Security Requirements Docket." NRC-2008-0019. Accessed: May 13, 2008. <<http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=NRC-2006-0016>>.

attack.⁸⁹⁶ No date for the final ruling has been released, though the ruling is expected by the end of 2008.⁸⁹⁷

Comprehensive security requirements in line with the intervenor request to require protection against an air-based suicide attack could result in significant capital expenditures to build steel shields around the plants. However, the NRC is not likely to impose such requirements. The NRC rejected a proposal to protect against air attack when it was raised in the 2007 design basis threat review, and the NRC continues to maintain that the likelihood of an air attack is low and that it is the responsibility of the federal government and the military, not nuclear plant operators, to protect against any such attack.⁸⁹⁸

Given current and expected NRC security requirements, spending for security is likely to remain a small portion of overall nuclear power costs.⁸⁹⁹ PG&E and SCE estimate that they will spend \$28 million and \$36.5 million, respectively, for security at the nuclear plants in 2008.⁹⁰⁰ For PG&E this represents just 4 percent of the overall Diablo Canyon revenue requirement.⁹⁰¹

Conclusions

The decision whether or not to renew the Diablo Canyon and SONGS operating licenses will have a significant impact on the state's power supply portfolio and on the communities located near the reactors. The full implications of this decision are unknown. Even the most straightforward question of how much power would be impacted by this decision cannot be answered with certainty. While current production levels from the plants are known, it is unclear how performance will change as the plants age – no commercial reactor has yet operated for a full 60 years.

The cost of power from the nuclear plants over the license renewal period will be linked to the performance of the plants. If the plants maintain high levels of performance and safety and do not require significant repairs or capital additions the costs should remain comparable to current levels with relatively minor increases due to higher nuclear fuel costs and potentially stricter security requirements. However, significant equipment failures or extended outages

⁸⁹⁶ See for example: Comments of Riverkeeper on NRC Proposed Rule, "Power Reactor Security Requirements." RIN 3150-AG63. March 26, 2007. <http://riverkeeper.org/campaign.php/indianpoint_security/we_are_doing/1320>; Pilgrim Watch. "RE: RIN 3150-AG63 - Power Reactor Security Requirements." February 22, 2007.

⁸⁹⁷ U.S. Nuclear Regulatory Commission. "Report to the Convention on Nuclear Safety." Remarks Prepared for NRC Chairman Dale E. Klein, Vienna, Austria. April 15, 2008.

⁸⁹⁸ U.S. Nuclear Regulatory Commission. "Security Spotlight."; U.S. Nuclear Regulatory Commission. "NRC Approves Final Rule Amending Security Requirements." January 29, 2007. Accessed: May 16, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/news/2007/07-012.html>>.

⁸⁹⁹ Expenditures for security will continue to some extent after the plants are decommissioned for as long as spent fuel remains on site. According to PG&E, annual ISFSI security costs are expected to be \$900,000. Pacific Gas & Electric. February 27, 2008: D1.

⁹⁰⁰ Pacific Gas & Electric. February 27, 2008: J1; Southern California Edison. March 21, 2008: J1.

⁹⁰¹ Pacific Gas & Electric. February 27, 2008: F1, J1; Southern California Edison. March 21, 2008: F1, J1.

could result in much higher costs. In addition, prior to a license renewal the plants may be required to undertake a retrofit of their once-through cooling systems at a cost of several billion dollars.

In addition, it is important to consider the environmental impacts from plant operations over an extended 20-year license period, including once-through cooling ocean impacts and impacts from continuing waste accumulation at these plants. The extent of the impacts will depend on the outcomes of state and federal policies and requirements for once-through cooling and on whether a long-term solution to the waste disposal problem is found.

The impact that shutting down one or both of the plants would have on the reliability of California's electricity grid is unclear at this time. The impact will depend on what other generating and transmission resources are built or retired over the next two decades and on the pattern of population growth in the regions near the plants. This is an area that needs to be investigated further prior to any decision on license renewal.

The loss of the plants would mean the loss of high-paying jobs and tax revenues for the communities located near the reactors. This loss would be felt more strongly in San Luis Obispo County following the closure of Diablo Canyon than it would be in the much larger San Diego and Orange Counties following the closure of SONGS. Some of the lost jobs or reduced tax revenues could be recouped over time by the use of the reclaimed land for other income-generating enterprises or by the development of renewable energy projects elsewhere in the county to replace the nuclear plants. It is also possible that some of the loss could be offset by a rise in property values, if current property values are depressed by the presence of the plants. However, additional study is required to assess whether this is the case and whether the closure of the plants would reverse this impact, especially if nuclear waste remains on-site.

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Acronyms and Abbreviations

AB	Assembly Bill
CAISO	California Independent System Operator
Camp Pendleton	U.S. Marine Corps Base Camp Pendleton
CBO	Congressional Budget Office
CO ₂	Carbon Dioxide
Coastal Commission	California Coastal Commission
CPUC	California Public Utilities Commission
CSLC	California State Lands Commission
Diablo Canyon	Diablo Canyon Power Plant
DCISC	Diablo Canyon Independent Safety Committee
DOE	U.S. Department of Energy
EIS	Environmental Impact Statement
Energy Commission	California Energy Commission
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
FY	Fiscal Year
g (acceleration)	Gravitational Acceleration, 9.8 m/s/s
g (weight)	Gram
GAO	U.S. Government Accountability Office
GHG	Greenhouse Gas
GNEP	Global Nuclear Energy Partnership
GPS	Global Positioning System
GTCC	Greater than Class C
GW	Gigawatt
GWh	Gigawatt-hour
IAEA	International Atomic Energy Agency
IEPR	Integrated Energy Policy Report
ISFSI	Independent Spent Fuel Storage Installation
KK NPP	Kashiwazaki-Kariwa Nuclear Power Plant
km	Kilometer

kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LNG	Liquefied Natural Gas
LTSP	Long-Term Seismic Program
MFP	Mothers for Peace
mi	Mile(s)
mm	Millimeter
MSPI	Mitigating Systems Performance Index
MTU	Metric Tons of Uranium
MVAR	Million Volt-Amperes Reactive
MW	Megawatt
MWe	Megawatt Electric
MWh	Megawatt-hour
NCO Earthquake	Niigata Chuetsu-Oki Earthquake
NEI	Nuclear Energy Institute
NIFZ	Newport-Inglewood Fault Zone
NIRS	Nuclear Information and Resource Service
NO _x	Nitrogen Oxides
NP26	North of Path 26
NPDES	National Pollution Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
OBE	Operating Basis Earthquake
Palo Verde	Palo Verde Nuclear Generating Station
PGA	Peak Ground Acceleration
PG&E	Pacific Gas & Electric

PSHA	Probabilistic Seismic Hazard Analysis
PV	Photovoltaic
PWR	Pressurized Water Reactor
RCFZ	Rose Canyon Fault Zone
REPP	Renewable Energy Policy Project
RETI	Renewable Energy Transmission Initiative
RPS	Renewable Portfolio Standard
SCE	Southern California Edison
SCOFZ	South Coast Offshore Fault Zone
SDG&E	San Diego Gas & Electric
SEGS	Solar Energy Generation Station
SMUD	Sacramento Municipal Utility District
SO _x	Sulfur Oxides
SONGS	San Onofre Nuclear Generating Station
SP26	South of Path 26
SSC	Systems, Structures, And Components
SSE	Safe-Shutdown Earthquake
SWRCB	State Water Resources Control Board
TAD	Transportation, Aging And Disposal
TEPCO	Tokyo Electric Power Co.
UCERF	Uniform California Rupture Forecast
USC	U.S. Code
USGS	U.S. Geological Survey
VAR	Volt-Amperes Reactive
WECC	Western Electricity Coordinating Council
WIEB	Western Interstate Energy Board

Glossary of Technical Terms

Active components – The components of nuclear power plants that continuously operate or change states to perform their functions. These include pumps, turbines, generators, compressors, process sensors, electric breakers, relays, and switches.

Age-related degradation – The cumulative degradation occurring within a reactor system, structure, or component, which, if unmitigated, may result in loss of function or impaired safety.

Blind thrust faults – A thrust fault that does not rupture all the way up to the surface so there is no evidence of it on the ground. It is "buried" under the uppermost layers of rock in the crust.

Capacity factor – The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period.

Compressive stress– Squeezing stress, the stress component perpendicular to a given surface, such as a fault plane, that results from forces applied perpendicular to the surface or from remote forces transmitted through the surrounding rock.

Dip slip fault - Inclined fractures where the blocks have mostly shifted vertically. If the rock mass above an inclined fault moves down, the fault is termed normal; if the rock mass above the fault moves up, the fault is termed reverse.

Directivity– An effect of a fault rupturing whereby earthquake ground motion in the direction of rupture propagation is more severe than that in other directions from the earthquake source.

Earthquake occurrence frequency curve – A combined assessment of the maximum earthquake magnitude that is physically possible on a fault and a statistical distribution of earthquakes across a range of magnitudes up to this maximum used to develop a distribution of earthquake magnitudes versus time.

Embrittlement – A change in the mechanical properties (or structure) of reactor pressure vessels and associated internal materials as a result of long-term exposure to radiation. Embrittled metals are more susceptible to failure from cracking or fracture.

Entrainment – Taking in marine organisms through power plant pipes used for once-through cooling of electricity generation systems.

Epicenter – The epicenter is the point on the earth's surface vertically above the hypocenter, or focus point in the crust where a seismic rupture begins.

Fault "fling" – Inertial effect of the tectonic displacement on a fault resulting in amplified long-period motions close to fault ruptures.

High-level waste – Highly radioactive waste from reprocessing. Spent fuel, which is also highly radioactive, is sometimes called high-level waste.

Impingement – Trapping marine organisms against the cooling water intake screens used for once-through cooling of power plant generation systems.

Liquefaction – A process by which water-saturated sediment temporarily loses strength and acts as a fluid; can be caused by earthquake shaking.

Low-level waste – Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material.

Metal fatigue – Deterioration of a metal from repeated cycles of thermal or mechanical loads or strains.

Normal fault – A dip slip fault where the rock mass above an inclined fault moves down.

Once-through cooling system – The process of piping water from the ocean to power plants for cooling and then discharging warmer water back into the ocean.

Operating basis earthquake (OBE) – An earthquake that could reasonably be expected to affect the plant site during the operating life of the plant; often designated at half the magnitude of a safe-shutdown earthquake.

Passive components – Components that generally remain in one state over time to perform their functions, such as pipes, tanks, pressure vessels, certain heat exchangers, electrical conduit and wiring, insulation, structures, and structural supports.

Probabilistic seismic hazard analysis (PSHA) – Process used to calculate the probability that design basis earthquakes may occur and to predict how effectively a plant would respond.

Reserve margin – A reflection of the amount of capacity available to the system in excess of anticipated need. Positive reserve margins are required to maintain system stability and prevent blackouts in the event of plant outages or higher than anticipated demand.

Reverse fault – A dip slip fault where the rock mass above an inclined fault moves up.

Safe-shutdown earthquake (SSE) – Maximum earthquake potential considered feasible at a site. Structures, systems, and components that are important to safety are designed to remain functional after sustaining such an earthquake.

Seismic moment – Measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting.

Slip rate – A measure of the average long-term activity of a fault. A fault's average annual slip rate is the total displacement on a fault divided by the period of time over which the total displacement occurred.

Spent fuel – Fuel removed from nuclear reactors.

Strike-slip fault – Vertical (or nearly vertical) fracture where the blocks have mostly moved horizontally.

Tensional stress – The stress component perpendicular to a given surface, such as a fault plane, that results from forces applied perpendicular to the surface or from remote forces transmitted through the surrounding rock.

Tetrapod – Vertebrate animals having four feet, legs, or leg-like appendages.

Thrust fault – A reverse fault with a dip of 45° or less.

Turbidity – Haziness caused by suspended solids in water.

AB 1632 ASSESSMENT OF CALIFORNIA'S OPERATING NUCLEAR PLANTS APPENDICES

Prepared For:
CALIFORNIA ENERGY COMMISSION

Prepared By:
MRW & Associates, Inc.



FINAL CONSULTANT REPORT

October 2008

CEC-100-2008-005-F-AP

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APPENDIX A: FEDERAL WASTE DISPOSAL EFFORTS

It has been more than 20 years since Congress identified Yucca Mountain as the site for a potential repository. The U.S. Department of Energy (DOE) only recently submitted a license application for the repository. The regulatory review of DOE's license application is expected to take years to complete, and final approval of the application is not a foregone conclusion. In light of this delay, options for spent fuel reprocessing and interim waste storage are also being considered. This appendix outlines the status of high-level waste disposal and spent fuel reprocessing initiatives.

Status of Yucca Mountain

The Nuclear Waste Policy Act of 1982, as amended, imposed a January 31, 1998, deadline for the opening of a federal nuclear waste repository at Yucca Mountain. As described in *Nuclear Power in California: 2007 Status Report*, the Yucca Mountain project has been plagued by a series of delays and mismanagement, and today, more than 10 years after the statutory deadline, the opening date for the repository remains at least 10 years away.¹

DOE, which is managing the Yucca Mountain project, submitted a repository license application to the U.S. Nuclear Regulatory Commission (NRC) on June 3, 2008.² If the license application is approved, DOE will be authorized to construct a repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada. Submission of the license application represents a major milestone for DOE. However, the project still faces serious difficulties. Consequently, DOE has abandoned its previously announced "best achievable" goal of having the repository open by 2017 and has not yet set a new date for opening the repository.³

Following is a summary of recent licensing developments, legislative actions, legal developments, and possible management changes being explored for the Yucca Mountain project. For background on the project and a discussion of developments prior to mid-2007, see *Nuclear Power in California: 2007 Status Report*.⁴

Licensing Developments

The NRC is responsible for reviewing the Yucca Mountain license application. There are two steps to the review process: an acceptance review and a technical review. The purpose of the

¹ MRW & Associates, Inc. *Nuclear Power in California: 2007 Status Report*. Prepared for the 2007 Integrated Energy Policy Report. CEC-100-2007-005. October 2007, Chapter 3.

² U.S. Department of Energy. "DOE Marks Milestone in Submitting Yucca Mountain License Application," June 3, 2008. Accessed: June 19, 2008. http://www.ocrwm.doe.gov/info_library/newsroom/documents/060308_la_pr.pdf.

³ Tetreault, Steve, Stephens Washington Bureau. "Lack of money spells uncertainty for Yucca nuke dump, DOE says." February 19, 2008. Accessed: April 21, 2008. <http://www.lvrj.com/news/15760627.html>.

⁴ MRW & Associates, Inc. *Nuclear Power in California: 2007 Status Report*, Chapter 3.

acceptance review is to determine if the application is suitable for performing a detailed technical review. If the application passes the acceptance review, the NRC will have three years to complete the technical review and public hearings process and to determine whether or not to issue the license.⁵ If necessary, the NRC may ask Congress for a one-year extension.

DOE prepared the Yucca Mountain license application based on the U.S. Environmental Protection Agency's (EPA) draft radiation protection standards because the final standards have not yet been released. The NRC does not require final EPA standards in order to complete the application acceptance review and begin the subsequent license review. However, final EPA standards will be required before the license review can be completed.⁶

DOE was required to make electronically available all documentary material relevant to the licensing proceeding at least six months prior to submitting the license application.⁷ In October 2007 DOE certified its collection of over 3.5 million documents for the NRC's public database of license related documents.⁸

In October 2007, DOE released several Draft Environmental Impact Statements (EIS) related to Yucca Mountain. The Draft Repository Supplemental EIS considers the potential environmental impacts of changes that have been made in the repository design and operational plans since the completion of the original Yucca Mountain Final EIS in February of 2002. The Draft Nevada Rail Corridor Supplemental EIS considers potential environmental impacts of spent fuel transport along the proposed Mina rail corridor. The Draft Rail Alignment EIS considers potential impacts of the construction and operation of a railroad in Nevada. DOE held eight public hearings for interested parties to comment on the draft documents. The 90-day comment period ended in January 2008 (see "Comments of California State Agencies on Draft Environmental Impact Statements").⁹

⁵ U.S. Nuclear Regulatory Commission. "Fact Sheet on Yucca Mountain." Accessed: June 19, 2008. <<http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html>>

⁶ If the final EPA standards differ from the proposed standards, the NRC will revise its proposed rule to match these standards. The NRC can do this during the license review process. Weber, Michael. "Examination of the Licensing Process for the Yucca Mountain Repository," October 31, 2007. Accessed: June 19, 2008 <<http://epw.senate.gov/>>.

⁷ 10 CFR 2.1003

⁸ U.S. Department of Energy. "U.S. Department of Energy Certifies Its Document Collection for Yucca Mountain License Application." Press Release. October 19, 2007. Accessed: April 21, 2008. <http://www.ocrwm.doe.gov/info_library/newsroom/documents/LSN_Press_Release_V_10-19-07.pdf>.

⁹ U.S. Department of Energy. "About OCRWM, Budget and Funding." Accessed: April 23, 2008. <<http://www.ocrwm.doe.gov/about/budget/index.shtml>>.

Comments of California State Agencies on Draft Environmental Impact Statements

In comments to DOE, Commissioner James Boyd of the California Energy Commission stated that the Yucca Mountain environmental analyses were incomplete since route-specific transportation analyses and evaluations of potential groundwater impacts in California had not been completed. In addition, Boyd noted that DOE had provided insufficient information to characterize potential impacts from waste shipments and repository operations and to make a decision on the suitability of the Yucca Mountain site.

The California Attorney General and Department of Fish and Game also submitted comments. Attorney General Brown stressed that DOE had not analyzed the risk of terrorism or the economic consequences of sabotage or transportation accidents created by the transportation routes under consideration. The California Department of Fish and Game raised concerns about groundwater impacts, particularly in the Amargosa River and Death Valley regions.

Sources: Public comments of Commissioner James D. Boyd, California Energy Commission, January 10, 2008. "The State of California's Comments on the U.S. Department of Energy (DOE) Draft Environmental Impact Statements Related to a Proposed Geologic Repository at Yucca Mountain, Nevada"; Public comments of Attorney General Edmund G. Brown, Jr., California Department of Justice, January 10, 2008. "Comments on U.S. Department of Energy's National Environmental Policy Act Documents for the Yucca Mountain Repository"; and Public Comments of Denyse Racine, Senior Environmental Scientist, California Department of Fish and Game, January 17, 2008. "Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada"

Legislative Developments

Legislative proposals in support of Yucca Mountain that were introduced in 2006 have languished in Congressional committees.¹⁰ One new proposal that was introduced in January 2008 has also not moved forward. This bill, which would authorize DOE to make non-nuclear infrastructure upgrades at Yucca Mountain prior to NRC licensing, remains in the Committee on Environment and Public Works.¹¹

Some legislators are turning to other waste management solutions. A statement of the Senate Energy and Natural Resources Committee notes that while most of the committee members support constructing new nuclear power plants, they differ over options for waste disposal. Some support a continued focused effort to develop Yucca Mountain while others support reprocessing or other approaches to storage. According to Committee spokesman Bill Wicker,

¹⁰ H.R. 5360/S. 2589 and S. 3962

¹¹ Nuclear Waste Policy Amendments Act of 2008. (S. 2551, Sen. Inhofe, U.S. Senate, Jan 24, 2008).

this reflects a change: “On Senate Energy, there has always been a broad, general consensus on nuclear waste, a consensus that this year no longer exists.”¹²

Senator Domenici, the author of a 2006 bill that would have provided DOE with additional operational and budgetary support for Yucca Mountain, introduced a bill in June 2008 (S. 3215) that supports reprocessing technologies instead.¹³ According to Domenici, Yucca Mountain is not needed since spent fuel could be reprocessed, and the reprocessing waste could be stored in underground locations such as the New Mexico salt formations.¹⁴ Domenici’s focus on alternatives to Yucca Mountain reflects his sense that “[we] have been working at (Yucca Mountain) for 15 to 16 years, and we are nowhere.”^{15, 16}

Congress awarded DOE just \$386.4 million of the \$494.5 million requested for the FY 2008 Yucca Mountain budget, even after the House of Representatives voted to award DOE the full budget request.¹⁷ DOE announced that it would lay off 500 workers as a result of this budget cut, further slowing down work on the repository. DOE also emphasized that these delays are expensive: a three-year delay in opening Yucca Mountain would increase Nuclear Waste Fund-related legal liabilities from \$7 billion (in 2017) to \$11 billion (in 2020).¹⁸ DOE will be liable for costs associated with keeping spent fuel at reactor sites because DOE failed to fulfill its contractual obligation with nuclear power plant operators to take possession of the spent nuclear fuel by 1998.

¹² Knapik, Mike. “US Senate committee now divided over nuclear waste policy.” February 27, 2008. Accessed: April 28, 2008. <<http://www.nucwatch.com/platts/2008/platts080229.txt>>.

¹³ S. 3215, Strengthening Management of Advanced Recycling Technologies Act of 2008, Introduced in the U.S. Senate, June 26, 2008.

¹⁴ Tetreault, Steve, Stephens Washington Bureau. “Plan seeks temporary sites for nuclear waste storage.” April 24, 2008. Accessed: April 24, 2008. <<http://www.lvrj.com/news/18101754.html>>.

¹⁵ Tetreault, Steve, April 24, 2008.

¹⁶ A report of the Union of Concerned Scientists echoed this frustration over the Yucca Mountain process, asserting that “it is critical to identify and overcome technical and political barriers to licensing a permanent repository, and the DOE should identify and begin to characterize potential sites for a permanent repository other than Yucca Mountain.” Gronlund, Lisbeth, David Lochbaum, Edwin Lyman, Union of Concerned Scientists. “Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges.” December 2007, page 1.

¹⁷ U.S. Department of Energy. “U.S. Department of Energy Issues National Environmental Policy Act Documents for Public Comment.” Press Release. October 4, 2007. Accessed: April 21, 2008. <http://www.ocrwm.doe.gov/info_library/newsroom/documents/Press_Release_EIS_10-05-07_Final.pdf>.

¹⁸ Wald, Matthew L. “As Nuclear Waste Languishes, Expense to U.S. Rises.” *New York Times*, February 17, 2008.

In June 2008 the House of Representatives Committee on Appropriation once again recommended approval of DOE's full nuclear waste disposal budget request.¹⁹ However, the Senate has not yet voted on the FY 2009 appropriations bill so actual funding levels may be lower than the requested \$494.7 million.

Legal Challenges

Over the past decade, the State of Nevada has launched numerous challenges against the Yucca Mountain repository. In October 2007 and April 2008, the NRC determined that it could not take action on two outstanding petitions until DOE files its license application.²⁰ The first petition was a request to limit the amount of nuclear waste that could be stored above ground while awaiting underground disposal at the Yucca Mountain site.²¹ The second was a request that Sandia National Laboratories, a major contractor at the nuclear waste site, be suspended from the project and investigated for putting schedule over safety.²²

During this same period, the State issued two new challenges:

- Attorneys for the State of Nevada petitioned in October 2007 to invalidate DOE's document collection certification. According to the petition, key documents about the nuclear waste project have not been posted on the NRC's Licensing Support Network and "millions" of e-mails and irrelevant documents were put on the database to confuse reviewers.²³
- In April 2008, the State of Nevada asked the NRC to reject DOE's plan to rely on metal alloy shields for groundwater contamination protection that would not be installed for at least 100 years. In a letter to NRC Chairman Dale Klein, Bob Loux, chief of the Nevada

¹⁹ U.S. House of Representatives, Committee on Appropriations. "Summary: 2009 Energy and Water Appropriations, Full Committee Markup." June 2008. Accessed: July 7, 2008. <<http://appropriations.house.gov/pdf/EWFY09FCSummary06-08.pdf>>.

²⁰ Tetreault, Steve, Stephens Washington Bureau. "NRC puts complaint about Yucca on hold; Officials say it's too soon to judge request for probe." October 30, 2007. Accessed: April 21, 2008. <<http://www.lvrj.com/news/11882731.html>>.

²¹ State of Nevada. "Petition for Rulemaking to Amend Part 63 to Clarify The Limits on Spent Fuel Storage at The Yucca Mountain Site." Petition to U.S. Nuclear Regulatory Commission. December 22, 2006. Accessed: April 23, 2008. <<http://www.state.nv.us/nucwaste/news2006/pdf/nvag061222petition.pdf>>.

²² State of Nevada. "Petition for an Independent Investigation and Suspension of Sandia National Laboratories from Further Work On the Yucca Mountain Project." Petition to U.S. Nuclear Regulatory Commission. October 16, 2006. Accessed: April 23, 2008. <http://www.state.nv.us/nucwaste/news2007/pdf/nvag071016nrc_petition.pdf>.

²³ U.S. Nuclear Regulatory Commission. "Motion to Strike DOE's October 19, 2007 LSN Recertification and to Suspect Certification Obligations of Others Until DOE Validly Recertifies." Docket No. PAPO-00, ASLBP No. 04-829-01 PAPO, October 29, 2007. Accessed: April 23, 2008. <<http://www.state.nv.us/nucwaste/news2007/pdf/efm071029nrc.pdf>>.

State Nuclear Projects Agency, called the idea of “robots installing expensive and heavy drip shields made of rare metals highly speculative.”²⁴ Loux noted that the robots have yet to be invented and that there is no guarantee that the large quantities of titanium and palladium that will be needed will be available in 100 years.

The NRC had not responded to these petitions as of June 2008.

Potential Management Changes

DOE has proposed to reorganize U.S. nuclear waste management work under a government-owned public corporation or federal authority.²⁵ The corporation would have responsibility for Yucca Mountain, reprocessing initiatives, and any future efforts to collect and store high-level waste on an interim basis until the Yucca Mountain repository is opened. According to the proposal, the corporation would be given access to the Nuclear Waste Fund. This would free the corporation from the annual congressional appropriations process and provide it with budgetary certainty. However, congressional action could be required both to enable the Nuclear Waste Fund to be used for activities other than waste disposal and to free the corporation from congressional budgetary control.

DOE also says it may seek bids for a contract to manage the Yucca Mountain program after the contract for current manager Bechtel SAIC Co. expires at the end of March 2009. DOE holds two one-year options to extend the Bechtel contract, but DOE is investigating other alternatives.²⁶

Status of Reprocessing Initiative

In early 2006 DOE initiated the Global Nuclear Energy Partnership (GNEP), a program to establish a proliferation-resistant nuclear fuel cycle based on a newly established domestic reprocessing capability.²⁷ As discussed in *Nuclear Power in California: 2007 Status Report*, there is substantial opposition to the program from prominent scientists and public interest groups, in

²⁴ Loux, Robert. “NRC Should Not Accept DOE’s Yucca Mountain Application if it Relies on thousands of Titanium ‘Drip Shields’ it Almost Certainly Will Never Install.” Letter from Robert Loux, Executive Director, Nevada Agency for Nuclear Projects to U.S. Nuclear Regulatory Commission Chairman Dale E. Klein. April 15, 2008.

²⁵ *Power News*. “DOE proposing Federal Corporation for Nuclear Waste.” Accessed: April 21, 2008. <http://web.hermesemessenger2.com/tfg/public/Update_Links.asp?EmailAddress=&ScheduleID=1066&IssueID=274&FileName=http://web.hermesemessenger2.com/tfg/public/newsletters/present/ISSUE274/article757.html&ArticleID=757>.

²⁶ *Associated Press*. “Energy Department Seeks bids on Yucca Mountain Management Job.” February 12, 2008. Accessed: April 21, 2008. <<http://www.kolotv.com/home/headlines/15548027.html>>.

²⁷ The long-term global fuel supply aspects of this program are not relevant to California at this stage and are not discussed here.

large part due to the high cost of the program and potential proliferation risks.²⁸ U.S. Energy Secretary Samuel Bodman was scheduled to make a decision in June 2008 on whether to move forward with GNEP and, if so, which technologies to pursue.²⁹ However, as of early July, this decision has not yet been announced.

In anticipation of Secretary Bodman's decision, DOE has been building partnerships with industry and has continued to develop plans for GNEP research and development facilities. DOE has also been responding to critiques of GNEP by reframing the program to focus on research and development rather than on activities that would support near-term commercialization of advanced reprocessing technologies. It is unclear at this time whether this represents a substantive program shift.

In late 2007 the National Academies released a review of DOE's nuclear energy research and development programs, including GNEP. The authors expressed concern that the GNEP schedule would require decisions to be made on whether to go forward with GNEP and on which technologies to pursue before sufficient technical and economic analyses had been conducted and subjected to peer review. The report concluded that GNEP should not go forward as proposed and that it should be replaced by a less aggressive research program (see "Recommendations of the National Academies").³⁰

²⁸ In a December 2007 report, the Union of Concerned Scientists added their voice to the debate. The report concluded that the proposed GNEP program would offer no waste disposal benefits and would increase the risks of nuclear proliferation and terrorism. Gronlund, et al. December 2007: 1. See also, *Nuclear Power in California: 2007 Status Report*, Chapter 4.

²⁹ U.S. Department of Energy. "Global Nuclear Energy Partnership Strategic Plan." GNEP-167312, Rev. 0, January, 2007. Accessed: April 24, 2008. <<http://www.gnep.energy.gov/pdfs/gnepStrategicPlanJanuary2007.pdf>>.

³⁰ National Research Council, Committee on Review of DOE's Nuclear Energy Research and Development Program. "Review of DOE's Nuclear Energy Research and Development Program." ISBN: 978-0-309-11124-9, pp. 5-6. Accessed: April 24, 2008. <http://www.nap.edu/nap-cgi/execsumm.cgi?record_id=11998>.

Recommendations of the National Academies

- DOE should defer the decision on whether to move forward with GNEP. DOE should commission an independent peer review of the state of knowledge as a prerequisite to any decision on future research programs.
- DOE should compare both the technical and financial risks of a reprocessing program with the potential benefits. Such an analysis should undergo an independent, intensive peer review.
- DOE should develop and publish detailed technical and economic analyses to explain and describe the reprocessing technologies under consideration as well as a range of alternatives. An independent peer review group should review these analyses. DOE should pursue the development of multiple processes until a fully fact-based comparison can be made and a decision taken on which process or processes could be carried to engineering scale.
- DOE should bring together other appropriate divisions of DOE and other federal agencies, representatives from industry and academia, and representatives from other nations well before any decisions are made on the technology.

Source: Committee on Review of DOE's Nuclear Energy Research and Development Program, National Research Council, ISBN: 978-0-309-11124-9 . "Review of DOE's Nuclear Energy Research and Development Program" (Source: http://www.nap.edu/nap-cgi/execsumm.cgi?record_id=11998 accessed 4/24/08)

The Government Accountability Office (GAO) conducted a review of DOE's plans for GNEP and released a report in April 2008 noting similar problems. GAO found that DOE's plan to build engineering-scale facilities could meet the GNEP objectives if the advanced technologies are successfully developed and commercialized. Nonetheless, this plan has two shortcomings. First, the lack of industry participation could reduce the prospects for eventual commercialization of the technologies. Second, DOE's plan to build the reprocessing plant before conducting research and development that would help determine the plant's design requirements unnecessarily increases the risk that the spent fuel will be separated in a form that cannot be recycled.³¹

Congress echoed these critiques in the FY 2008 budget authorization, which granted DOE just \$181 million of the \$395 million request for GNEP. The Appropriations Act made it clear that the funds were to be spent on research and development efforts and that "no funds are provided for facility construction for technology demonstration or commercialization."³²

³¹ U.S. Government Accountability Office. "Global Nuclear Energy Partnership: DOE Should Reassess Its Approach to Designing and Building Spent Nuclear Fuel Recycling Facilities." April 2008.

³² U.S. Congress. "Consolidated Appropriations Act, 2008 – Division C – Energy and Water Development and Related Agencies Appropriations Act, 2008 (H.R. 2764, PL 110-161)." January 30, 2008. (House Appropriations Committee Print) pp. 568, 604. Accessed: April 25, 2008.

DOE has responded to these critiques by reframing GNEP to focus on research and development and on building an engineering-scale advanced fuel cycle facility. DOE has announced that it no longer intends to site and develop a commercial-scale recycling center and fast reactor at the present time.³³ The FY 2009 budget request appears to reflect this change: of the \$301.5 million requested, over \$230 million is for research and development activities, with smaller amounts for conceptual studies of GNEP facilities. DOE requested no funding for technology development.³⁴ Yet, the House Appropriations Committee appears unconvinced: the committee approved a FY 2009 Energy and Water appropriations bill in June 2008 that would cut all funding for the GNEP program due to concerns that it “undermines our Nation’s nuclear non-proliferation policy.”³⁵

In fact, DOE is continuing to pursue advanced reprocessing technologies, and there is no indication that DOE’s time frame has been changed. In recent months, DOE has made two sets of awards totaling \$34.3 million to four industry teams to develop plans for a commercial-scale recycling center and fast reactor and has contracted with Tennessee Valley Authority to evaluate the desirability of an integrated intermediate-scale advanced fuel cycle demonstration project.³⁶ The industry teams have completed conceptual design studies, technology development roadmaps, and business plans, and they are now working on detailed studies (see “GNEP Technological Challenges”). Their studies plan for reprocessing start dates between 2018 and 2028 and fast reactor deployment between 2018 and 2025.³⁷ These dates are in line with DOE’s goal to commercialize an advanced reprocessing system in the mid-to-late 2020s.³⁸

<http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_house_committee_prints&docid=f:39564c.xxx.wais>.

³³ U.S. Department of Energy. “Programmatic Environmental Impact Statement Update.” Accessed: April 25, 2008. <<http://www.gnep.energy.gov/peis/gneppeis.html>>.

³⁴ U.S. Department of Energy. “FY 2009 Congressional Budget Request.” Page 663. Accessed: April 25, 2008. <http://www.ne.doe.gov/budget/budgetpdfs/fy09Vol_3_NE.pdf>.

³⁵ U.S. House of Representatives, Committee on Appropriations. “Summary: 2009 Energy and Water Appropriations, Full Committee Markup.” June 2008.

³⁶ U.S. Department of Energy. “Department of Energy Awards More Than \$16 Million for GNEP Technology Development Plans.” Press Release. October 1, 2007. Accessed: April 24, 2008. <<http://www.doe.gov/news/5535.htm>>; U.S. Department of Energy. “DOE Awards \$18.3 Million to Nuclear Industry Consortia for GNEP Studies.” Press Release. March 28, 2008. Accessed: April 21, 2008. <<http://www.doe.gov/news/6100.htm>>; Tennessee Valley Authority. “Memorandum of Understanding between the Tennessee Valley Authority and the U.S. Department of Energy for Advanced Fuel Cycle Demonstration Support.” April 18, 2008, page 1. Accessed: April 24, 2008. <http://www.ne.doe.gov/pdfFiles/TVADOE_AFCDMOU0408.pdf>.

³⁷ Centre for International Governance Innovation. “GNEP Watch: Development in the Global Nuclear Energy Partnership.” Issue 5 (March 2008): page 4. Accessed: April 25, 2008. <<http://www.cigionline.org>>.

³⁸ U.S. Department of Energy, “Spent Nuclear Fuel Recycling Program Plan.” May 2006, page 16. Accessed: April 28, 2008. <<http://www.gnep.energy.gov/pdfs/snfRecyclingProgramPlanMay2006.pdf>>.

Senator Domenici, a strong supporter of reprocessing, introduced a bill in June 2008 (S.3215) that would further encourage the near-term commercialization of reprocessing. The bill would require DOE to offer to enter into one or more agreements with private entities to complete the design of one or two reprocessing technologies. It would also require DOE to share with private entities the cost of obtaining construction and operating licenses for up to two reprocessing facilities.³⁹

As discussed above, DOE has proposed that a new government-owned corporation be created to oversee all nuclear waste management issues, including GNEP. This change, if effected, would provide DOE with budget certainty and with more independence in identifying priorities and directing the course of GNEP.

Status of Centralized Storage Initiatives

Federal interim waste storage proposals have not progressed in the past year. As discussed in *Nuclear Power in California: 2007 Status Report*, these proposals have been met by protest from state leaders and from DOE.⁴⁰

Private Fuel Storage, LLC, a private consortium of utilities attempting to construct an interim fuel storage facility on the Goshute Reservation in Utah, filed a complaint against the U.S. Department of Interior's decisions to reject the proposed lease of tribal land and to disapprove of the use of public lands for an intermodal transfer facility.⁴¹ As of June 2008, no opinion had been issued in this case.

With significant uncertainty remaining as to when – and even if – the Yucca Mountain repository will open, the nuclear industry has mounted a campaign to court communities that might be willing to host interim spent fuel storage sites. According to NEI's senior director for state and local government affairs, talks are moving forward with two or three communities.⁴² No agreements have yet been announced.

³⁹ S. 3215, "Strengthening Management of Advanced Recycling Technologies Act of 2008," Introduced in Senate, June 26, 2008.

⁴⁰ MRW & Associates. *Nuclear Power in California: 2007 Status Report*, pages 63-66.

⁴¹ Private Fuel Storage, LLC. "Skull Valley Band of Goshute Indians and Private Fuel Storage Seek Reversal of Interior Department Rulings." July 17, 2007. Accessed: April 28, 2008. <<http://www.privatefuelstorage.com/whatsnew/whatsnew.html>>.

⁴² Tetreault, Steve, Stephens Washington Bureau. "NEI courts volunteers for interim storage." February 27, 2008. Accessed: April 21, 2008. <<http://www.pahrumpvalleytimes.com/2008/Feb-27-Wed-2008/news/19960495.html>>.

GNEP Technological Challenges

At a November 2007 hearing of the Senate Committee on Energy & Natural Resources, Dr. Terry Wallace of Los Alamos National Lab and Dr. Neal Todreas of the Massachusetts Institute of Technology both spoke to the challenges that will need to be overcome in order to achieve GNEP's technological goals. The key challenges that they identified are 1) the development of separations technologies, transmutation fuels, a source of fast neutrons to test the fuels, and a fast reactor; 2) the development of tools to predict the long-term behavior of new waste forms in the repository; and 3) the development of strong material safeguards.

Three separations technologies are being considered: UREX+, COEX, and NUEX. UREX+ separates spent fuel into uranium, fission products, and transuranics (or simply neptunium plus plutonium). It is being developed by DOE at the national labs. COEX separates spent fuel into a uranium-plutonium mix (sometimes with neptunium), a pure uranium stream, and a mix of other minor actinides and fission products. It is being developed by AREVA and the French Atomic Energy Commission. NUEX separates spent fuel into uranium, fission products, and transuranics. It is being developed by EnergySolutions, Inc. AREVA and EnergySolutions were among the four industry teams to receive DOE funding to develop conceptual design studies for GNEP facilities.

UREX+ 1a, which is the current version of UREX+, has been demonstrated relatively successfully at the bench scale, but only over short times and with fresh solvents. As long-term process chemistry has not yet been demonstrated and scale up has not yet been initiated, bench scale development is expected to continue until roughly 2012. The status of COEX and NUEX has not been directly addressed, but Dennis Spurgeon of DOE and Senator Domenici implied that one or both of these technologies is close to commercial development.

Transmutation fuels are at an earlier stage of development than separations technologies. Three steps will be required before transmutation fuels are commercially ready: fuel development, fuel testing, and fuel refinement. Los Alamos is developing a source of fast neutrons, which will be required for fuel testing.

Sources: U.S. Senate Committee on Energy and Natural Resources, Hearing To Receive Testimony on the Global Nuclear Energy Partnership, November 14, 2007. <http://energy.senate.gov>; "Global Nuclear Energy Partnership" Briefing Paper #117, Uranium Information Centre, October 2007, <<http://www.uic.com.au/nip117.htm>>; and "Spent Fuel Reprocessing Options: Melding Advanced & Current Technology," Presentation of Alan Dobson, EnergySolutions at the GNR2 Conference, June 13, 2007, <<http://www.gnr2.org/html/2007/6-29.pdf>>

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Appendix B: Generation Alternatives Source Material

This appendix describes the source material for the summary information provided in Chapter 9 on the resource potential, cost, environmental impacts, and local impacts of several generation technologies. It also provides additional discussion of some of these impacts. It is not intended as a comprehensive review and comparison of all life cycle impacts of generation technologies. Please refer to Chapter 9 for further discussion of these technologies.

The information in this appendix relates to existing nuclear plants and to new power plants that could be built in California. These include gas-fired power plants and renewable power plants. California law does not allow the siting of new nuclear plants or the building of new coal plants in the state.

Resource Potential

Resource potential in this context refers to the amount of power that could theoretically be derived from a particular resource type. It is discussed in terms of technical potential and economic potential. The technical potential refers to the amount of power that is theoretically attainable after accounting for basic physical, environmental, regulatory, and geographic constraints of the resource. The economic potential is that portion of the technical potential that is cost-effective to develop in the near term.

This section summarizes recent estimates of the technical and economic potentials of generation resources in California. Additional resource potential in neighboring states is not considered.

Nuclear and Gas-Fired Power Plants

The concepts of economic and technical potential are generally used with regard to renewable energy are not directly applicable to nuclear and gas-fired power.⁴³ In addition, they are relevant only to the consideration of new plants. As mentioned above, new nuclear plants are not considered in this report.

Wind-Powered Plants

California's wind resources are extensive and geographically diverse. More than 4,000 km² of land in California is characterized by high quality, Class 4 or higher winds.^{44, 45} California

⁴³ The limiting factors for gas-fired power development are transmission access, availability of natural gas transportation, gas supply and storage, and, in certain locations, air quality restrictions. These are not fundamental restrictions in the same way that a lack of wind fundamentally restricts the ability to develop wind power.

⁴⁴ Black & Veatch. "Renewable Energy Transmission Initiative (RETI) Phase 1A, Draft Report." March 2008.

⁴⁵ Wind power classes are based on wind power density levels (measured in watts per meter squared). Typically, wind sites with a wind power class of four or larger are preferred for utility-scale wind projects.

currently has 2,438 MW of wind power generation,⁴⁶ 95 percent of which is in the Altamont, Tehachapi, and San Geronio passes.⁴⁷ The greatest potential for new wind resource development is in San Bernardino, Imperial, and Kern counties.⁴⁸ In addition, large offshore turbines are being developed.⁴⁹

In 2006 the National Renewable Energy Laboratory (NREL) estimated a technical potential of over 21,000 MW of high quality wind capacity in California (see Table 1).⁵⁰ The Energy Commission's 2007 Intermittency Analysis Project estimated a total technical potential of 22,782 MW.⁵¹

Table 1: California Wind Technical Potential by Wind Power Class⁵²

Wind Class	Technical Potential (MW)
Class 4	11,955
Class 5	4,843
Class 6	3,021
Class 7	1,281
Total	21,100

In 2005, the Energy Commission and consultant Davis Power evaluated the economic potential for wind power in California by 2017 at 4,831 MW and 15,658 GWh.⁵³ For this evaluation, they considered grid benefits, location of resource relative to transmission interconnects,

⁴⁶ American Wind Energy Association. "U.S. Wind Energy Projects – California." January 2008. Accessed: March 11, 2008. <<http://www.awea.org/projects/>>.

⁴⁷ California Energy Commission. "Overview of Wind Energy in California." February 2008. Accessed: March 10, 2008. <<http://www.energy.ca.gov/wind/overview.html>>.

⁴⁸ As of February 2008, Kern and San Bernardino counties accounted for 69 percent of wind capacity in the CAISO generation queue.

⁴⁹ Yen-Nakafuji, D. "California Wind Resources." April 2005. Accessed: March 7, 2008. <<http://www.energy.ca.gov/2005publications/CEC-500-2005-071/CEC-500-2005-071-D.PDF>>.

⁵⁰ Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

⁵¹ Brower, M., and AWS Truewind, LLC. 2007. "Intermittency Analysis Project: Characterizing New Wind Resources in California." California Energy Commission, PIER Renewable Energy Technologies. CEC-500-2007-014.

⁵² Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

⁵³ California Energy Commission. "Strategic Value Analysis: Economics of Wind Energy in California." June 2005.

transmission line and substation upgrade requirements, and the need for additional transmission infrastructure investment.

Solar Thermal Plants

Solar thermal technologies typically involve heating a working fluid to generate electric power. There are three primary solar thermal plant technologies: parabolic troughs, power towers, and parabolic dish-engines. California currently has 354 MW of parabolic trough solar capacity from the Mojave Desert Solar Energy Generating Systems (SEGS), which is the largest collection of parabolic systems in the world.⁵⁴ Currently, there are no power towers or parabolic dish-engines in operation in California; however, Stirling Engine Systems has negotiated power purchase agreements with San Diego Gas and Electric and Southern California Edison for 800 to 1,750 MW of dish-engine capacity.⁵⁵

The technical potential for solar thermal generation is limited to areas with adequate sunlight (i.e., an annual average direct normal solar radiation of 6 kWh per m² per day) and a relatively flat slope of less than one percent. Forests, bodies of water, roads, and cities are not included in the set of technically feasible land.

The Energy Commission estimated in 2005 that the technical potential for solar thermal energy in California is 2,717,545 GWh and 1,061,361 MW.⁵⁶ Sixteen counties in California have technically feasible land for solar thermal development. Among them, San Bernardino and Imperial counties have the greatest technical potential, estimated at 381,159 MW and 220,244 MW, respectively.⁵⁷

NREL employed a Geographic Information System screening approach to identify economically viable solar thermal resource areas. NREL used the technical potential criteria listed above but further restricted the resource areas to locations with an average annual direct normal solar radiation of 6.75 kWh per m² per day. NREL found 6,728 mi² of “economically favorable” land for solar energy development, which translates into an economic potential of 1,900,786 GWh of energy and 803,647 MW of capacity.⁵⁸ Applying more stringent standards requiring a minimum contiguous area of five square kilometers, Black & Veatch estimated a total economic potential of 443,799 MW (see Table 2).⁵⁹

⁵⁴ California Energy Commission. “California Solar Resources.” April 2005.

⁵⁵ Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008.

⁵⁶ California Energy Commission. “California Solar Resources.” April 2005: 19.

⁵⁷ California Energy Commission. “California Solar Resources.” April 2005.

⁵⁸ National Renewable Energy Laboratory (NREL). “Concentrating Solar Power.” Presentation of Mark Mehos to the Committee on Regional Electric Power. April 8, 2008, page 14. Accessed: May 9, 2008. <http://www.westgov.org/wieeb/meetings/crepcsprg2008/briefing/present/m_mehos.pdf>.

⁵⁹ Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008: 6-34 - 6-36.

Table 2: California Solar Thermal Economic Potential by Solar Power Class⁶⁰

Region	Capacity by Solar Power Class					Total Capacity
	1	2	3	4	5	
Owens Valley	1,592	2,688	14,585	18,510	3,469	40,844
Kern County	-	2,154	6,145	17,073	21,135	46,507
Los Angeles Area	2,259	7,390	17,226	7,269	-	34,145
San Diego	-	3,904	480	-	-	4,384
Mohave and Imperial	-	72,226	158,082	59,181	28,430	317,920
Total	3,852	88,363	196,519	102,033	53,034	443,799

Solar Photovoltaic Plants

California contains enormous tracts of land that are technically suitable for solar photovoltaic (PV) development. In 2005 the Energy Commission assessed California's solar PV potential by assuming that PV panels with a capacity factor of 10 percent could be installed everywhere except on bodies of water, environmentally sensitive areas, agricultural lands, and areas with north-facing slopes greater than 5 percent. The Energy Commission found that the technical potential for PV in California is 17 million MW.⁶¹ This estimate does not differentiate stand alone PV plant potential from rooftop PV potential. For economic reasons, only rooftop systems are expected to be installed in the near-term. The Energy Commission estimated that the technical potential of rooftop PV systems alone is greater than 38,000 MW for near-term residential applications and exceeds 37,000 MW for near-term commercial systems.⁶² Over 6,500 MW of utility-scale PV projects were listed in the CAISO Controlled Generation Queue as of March 2008.⁶³

⁶⁰ Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

⁶¹ California Energy Commission. "California Solar Resources." April 2005: 8.

⁶² California Energy Commission. "California Solar Resources." April 2005: 9.

⁶³ California Independent System Operator (California ISO). "The California ISO Controlled Grid Generation Queue, March 21, 2008." Accessed: March 25, 2008. <<http://www.caiso.com/14e9/14e9ddda1ebf0.pdf>>.

Geothermal Plants

California leads the nation in terms of installed geothermal capacity with 1,884 MW.⁶⁴ California's geothermal resources are spread across the state. About 53 percent of installed capacity comes from the Geysers Geothermal Field in Lake and Sonoma counties, 28 percent comes from Imperial County, and 16 percent comes from Coso Hot Springs in Inyo County.

In 2004, GeothermEx, Inc. evaluated the technical potential of California's geothermal resources based on the quality of the resource, geographic location, source temperature, and evidence of a discrete resource. They used statistical methods to forecast minimum, maximum, and most-likely generation capacities based on the heat levels of certain resource areas and found that an additional 2,862 MW of geothermal generating capacity are most likely available for development, mainly in Imperial County, the Geysers Geothermal Field, and Medicine Lake.⁶⁵

Of the available technical capacity, GeothermEx estimated that 1,700 MW could be developed for at most \$2,400 per kW.⁶⁶ Black & Veatch estimated that 2,375 MW of incremental geothermal potential would be developed in California through 2018.⁶⁷

Biomass Plants

Biomass-fired generation in California is concentrated in agricultural, forest, industrial, and municipal areas with steady flows of wood waste. Los Angeles, San Diego, and Orange Counties have the highest gross biomass potential within California.⁶⁸ Other potentially attractive options include wood-fired facilities in northern California and agricultural residue centers in the Central Valley.

The California Biomass Collective estimates that the gross annual stock of biomass is more than 83 million bone dry tons, with 45 percent of that amount from forestry, 27 percent from agriculture, and 28 percent from municipal waste.⁶⁹ The technical potential is significantly smaller at 31 million bone dry tons /year, since this figure takes into account an ecosystem limitation associated with biomass procurement and the 5 million bone dry tons /year consumed by existing biomass power facilities. The California Biomass Collective estimates that

⁶⁴ Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

⁶⁵ GeothermEx, Inc. "New Geothermal Site Identification and Qualification." Prepared for Public Interest Energy Research (PIER) Program, California Energy Commission. April 2004.

⁶⁶ Ibid.

⁶⁷ Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

⁶⁸ California Biomass Collaborative. "Biomass Resource Assessment in California." PIER. California Energy Commission. April 2005.

⁶⁹ California Biomass Collaborative. "California Biomass and Biofuels Production Potential." December 2007.

California's technical biomass potential could generate 34,582 GWh or 4,650 MW of power using current technologies.⁷⁰

Table 3: 2007 California Biomass Potential (Million bone dry tons /year)⁷¹

Sector	Gross Potential	Technical Potential
Agriculture	21	6.9
Forestry	27	11.8
Municipal	35	7.2
Total	83	26

Estimates of California's gross biomass potential provided by NREL differ substantially from those provided by the California Biomass Collective. NREL estimated that roughly 12 million bone dry tons of incremental biomass are available each year, resulting in 2,000 MW of potential capacity.⁷² Black & Veatch noted that the California Biomass Collective relied on local production and disposal data whereas NREL relied on national databases. As such, the technical potential suggested by California Biomass Collective may be more reliable.

Demand-Side Resources

Demand-side resources are mechanisms that reduce or defer the demand for electricity. This section presents research on the technical potentials in California of two types of demand-side resources: energy efficiency and demand response.

Energy Efficiency

In 2006, Itron forecasted the technical, economic, and market potential for energy efficiency savings from the three California investor-owned utilities (see Table 4). In the context of this study, economic potential refers to the savings that would be achieved if all feasible cost-effective energy efficiency measures were undertaken. Market potential is the subset of economic potential that could be achieved from certain scenarios based on market conditions, program design, and three different incentive levels: 1) a continuation of incentives at the 2004 level ("current market potential"); 2) increased incentive level that includes full incremental measure costs ("full market potential"); and 3) incentive levels set to the average of the full incremental costs and current incentive levels ("average market potential").

⁷⁰ GeothermEx, Inc. "New Geothermal Site Identification and Qualification." April 2004.

⁷¹ California Biomass Collaborative. "California Biomass and Biofuels Production Potential." December 2007.

⁷² Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

Table 4: Annual Energy Efficiency Savings Potential by 2016⁷³

	Technical Potential	Economic Potential	Full Market Potential	Average Market Potential	Current Market Potential
Energy (GWh)	63,184	53,150	23,974	20,065	16,226
Peak (MW)	15,483	11,151	4,887	3,772	2,594

In 2007 the Energy Commission evaluated the savings from five possible energy efficiency savings targets: 1) current goals for investor-owned utilities and feasible targets for publicly owned utilities (“current goals”); 2) 80 percent of economic potential for all utilities (“80 percent of economic potential”); 3) 100 percent of cost-effective economic potential for all utilities (“100 percent of economic potential”); 4) 10 percent reduction in consumption in 2016 (“10 percent reduction in 2016”); and 100 percent of technical potential (“technical potential”).⁷⁴ The savings from each scenario are shown in Table 5.

Table 5: Annual Energy Efficiency Savings Potential by 2016⁷⁵

	Technical Potential	100% of Economic Potential	80% of Economic Potential	10% Reduction in 2016	Current Goals
Energy (GWh)	53,000	39,000	32,000	28,000	19,000
Peak (MW)	12,200	6,600	5,300	6,800	3,900

The American Center for an Energy Efficient Economy calculated the energy efficiency potential in California at 18 percent of energy usage,⁷⁶ which would have been 54,000 GWh in 2007.⁷⁷ This figure includes only technologies that are currently ready for wide-spread penetration and is limited to equipment needing replacement over a ten year period.

⁷³ Itron, Inc. “California Energy Efficiency Potential Study, Volume 1.” Submitted to Pacific Gas & Electric. May 2006.

⁷⁴ California Energy Commission. “2007 Integrated Energy Policy Report.” Pages 84-85.

⁷⁵ California Energy Commission. “2007 Integrated Energy Policy Report.” Pages 84-85.

⁷⁶ American Center for an Energy Efficient Economy (ACEEE). “ACEEE Summer Study on Energy Efficiency in Buildings.” August 2004. The savings are counted over a 10 year period from 2003 to 2013.

⁷⁷ California Energy Commission. “2007 Net System Power Report.” April 2008, page 5.

Combined Heat and Power

Combined heat and power (CHP, or cogeneration) is the simultaneous production of electricity and heat from a single fuel source. Typical installations involve either 1) the recovery of waste heat from a gas turbine or engine for use in industrial processes, or 2) the use of excess steam from a steam boiler to generate electricity.⁷⁸ Both types of installations use what would otherwise be a waste product as an energy source. As a result, the original fuel source produces more energy (in the form of heat and electricity) than it would in a system where heating and electricity were managed independently.

The potential for additional CHP in California is significant. In a 2005 study, the Electric Power Research Institute (EPRI) reported that there is a technical potential of 30,000 MW of additional CHP, including 14,000 MW additional potential from existing facilities, 6,000 MW from expected new facilities through 2020, 4,000 MW of combined cooling heating and power (CCHP) projects, and 6,000 MW of export market potential.⁷⁹ EPRI estimated a base case for market penetration of 2,000 MW through 2020, increasing to 7,000 MW in a high deployment case. The high deployment case includes existing incentives, facilitation of the power export market, new incentive payments for transmission and distribution support and greenhouse gas reductions, the rapid development and deployment of advance technologies, and an improvement in customer acceptance of CHP.⁸⁰

Demand Response

Demand response refers to technologies and incentive programs that reduce power consumption during peak periods, either by shifting consumption to off-peak periods or by reducing overall consumption. In 2007 the Energy Commission estimated the potential for demand response savings in California as ranging from a technical potential of 15,360 MW to a market potential of 3,072 MW (see Table 6). The Energy Commission forecast in January 2008 that investor-owned utility demand response programs would exceed the 3,072 MW market potential and achieve peak savings of 4,243 MW in 2008.⁸¹

A 2007 study completed by Lawrence Berkeley National Laboratory estimated a market potential for large commercial and industrial demand response programs of up to three percent

⁷⁸ U.S. Environmental Protection Agency. "Combined Heat and Power Partnership." June 5, 2008. Accessed: September 4, 2008. <<http://www.epa.gov/chp/basic/index.html>>.

⁷⁹ Electric Power Research Institute. "Assessment of California CHP Market and Policy Options for Increased Penetrataion." Cosponsored by the California Energy Commission Public Interest Energy Research Program (PIER). July 2005, page ix.

⁸⁰ Electric Power Research Institute. "Assessment of California CHP Market and Policy Options for Increased Penetrataion." Cosponsored by the California Energy Commission Public Interest Energy Research Program (PIER). July 2005, page ix.

⁸¹ Hungerford, David. "2008 Summer Outlook." Presentation. January 16, 2008. <http://www.energy.ca.gov/2008_summer_outlook/documents/2008-01-16_workshop/presentations/Hungerford_David.PDF>.

of total large customer peak demand.⁸² The rate freeze stipulated by Assembly Bill 1X currently bars 70 percent of residential energy consumption from price-responsive demand response.⁸³ The Brattle Group estimated that voluntary dynamic pricing demand response could have reduced demand in California by as much as 1,500 to 2,000 MW in 2007.⁸⁴

Table 6: California’s Technical, Economic, and Market Potential for Demand Response⁸⁵

Demand Impacts	Definition	Peak Savings⁸⁶	Peak Savings⁸⁷ (MW)
Technical Potential	Outcome if all customers use the best available technology	25 percent	15,360
Economic Potential	Outcome if all customers used cost-effective technologies	12 percent	7,373
Market Potential	Outcome if a cost-effective combination of technologies is adopted at an assumed level of penetration	5 Percent	3,072

Interconnection/Reliability Issues

This section reviews interconnection and reliability issues associated with generation alternatives, such as the need for new transmission infrastructure and the reliability impacts of intermittent output.

⁸² The study defines demand response market potential as “the amount of demand response – measured as short term load reductions in response to high prices or incentive payment offerings – that policymakers can expect to achieve by offering a particular set of demand response options to customers in a particular market or market segment under expected market or operating conditions.” Goldman, C., N. Hopper, et al. “Estimating Demand Response Potential among Large Commercial and Industrial Customers: A Scoping Study.” Lawrence Berkley National Laboratory. January 2007.

⁸³ Assembly Bill 1X. (Keeley, Chapter 4, Statues of 2001).

⁸⁴ The Brattle Group. “The State of Demand Response in California.” September 2007.

⁸⁵ California Energy Commission. “2007 Integrated Energy Policy Report.” December 2007: 95.

⁸⁶ Weighted average across all customer classes.

⁸⁷ Based on Staff’s 2008 forecast for statewide coincident peak demand forecast (61,439 MW).

Nuclear Power Plants

Because of their size and location relative to major load centers, Diablo Canyon and SONGS contribute reliability and resource adequacy benefits to the grid.⁸⁸ SONGS also provides grid reliability benefits because of its location between the Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E) service territories. According to the CAISO, significant transmission and reactive power support would be needed if SONGS were to shut down. Similar support would not be required following a shutdown of Diablo Canyon. However, if Diablo Canyon were to shut down, California's north to south and south to north power transfer capability would be reduced and transmission upgrades could be necessary to maintain transfer capability at current levels.⁸⁹

Nuclear plant reliability and transmission issues associated with a major power disruption are addressed in Chapter 6. Interconnection is not a concern for operating power plants.

Gas-Fired Power Plants

Gas-fired power plants present few reliability or interconnection issues. The reliance on natural gas is the largest reliability concern. However, natural gas supply disruptions are uncommon, and natural gas storage supplies can be used during temporary disruptions.

Wind-Powered Plants

Relatively little investment has been made in new transmission in the U.S. over the past 15 to 20 years, and in recent years it has become clear that lack of transmission access and investment are major barriers to wind development. New transmission facilities are particularly important for wind resource development because of wind's locational dependence and distance from load centers. In addition, there is a mismatch between the short lead times for developing wind projects and the lengthier time often needed to develop new transmission lines. Furthermore, wind's relatively low capacity factor can lead to underutilization of new transmission lines that are intended to serve only wind farms.⁹⁰

Interconnecting wind generation involves both physical and institutional challenges. Unlike conventional sources of energy, harnessing energy from wind requires transmission facilities that interconnect multiple generators, often in remote areas. Wind generation also tends to be added in relatively small increments, and one wind resource area may include several developers across non-adjointing sections of land.

⁸⁸ California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008.

⁸⁹ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007.

⁹⁰ Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007, page 20.

The intermittency of wind also presents a challenge since fluctuations in wind generation require compensating adjustments from other generating resources (or demand side resources) to ensure system reliability and to prevent over-generation.⁹¹ These challenges can be addressed, at least partially, through the geographic dispersion of wind farms, which moderates the extremes of wind generation, and through reliable forecasting of wind generation output.⁹² The CAISO indicates that integrating the wind power that is expected as a result of the state's 20 percent renewable portfolio standard (RPS) is operationally feasible if certain changes to operating procedures are made.⁹³ Several European countries have already successfully integrated large amounts of wind generation into their electrical grids. For example, 18.5 percent of Denmark's energy was generated by wind in 2005,⁹⁴ and Germany integrated more than 20,000 MW of wind by 2006.⁹⁵

Solar Thermal Plants

Solar thermal plants depend on sunshine to generate electricity; unexpected cloud cover can quickly reduce power output. To maintain constant output, solar thermal plants may be hybridized with fossil fuels systems. In addition, solar thermal trough technologies can be adapted to enable thermal energy storage. With backup fossil power or storage capabilities, solar thermal plants can provide dispatchable power and operational flexibility in spite of the intermittency of the sunshine.

Figure 1 characterizes the generation profile of a solar thermal facility with thermal storage capabilities. As shown in the figure, storage enables solar thermal systems to meet peak demands that occur in the evening hours when the sun is no longer well-positioned for direct generation. Storage also reduces the need for generation reserves to "firm-up" the intermittent solar power generation. Current solar trough storage technologies have capacities of up to twelve hours.⁹⁶

⁹¹ Over-generation is most likely to occur if both hydroelectric and wind generation are operating at maximum capacity during very light load conditions. In response, the CAISO may have to reduce generation levels of baseload resources. Better storage solutions for pumped hydro and improved coordination with the State Water Project could also be used to increase load during light load conditions. Porter, K. and Intermittency Analysis Team. "Intermittency Analysis Project: Review of International Experience Integrating Variable Renewable Energy Generation, Appendix A: Denmark." April 2007.

⁹² California Energy Commission. "2007 Integrated Energy Policy Report." December 2007.

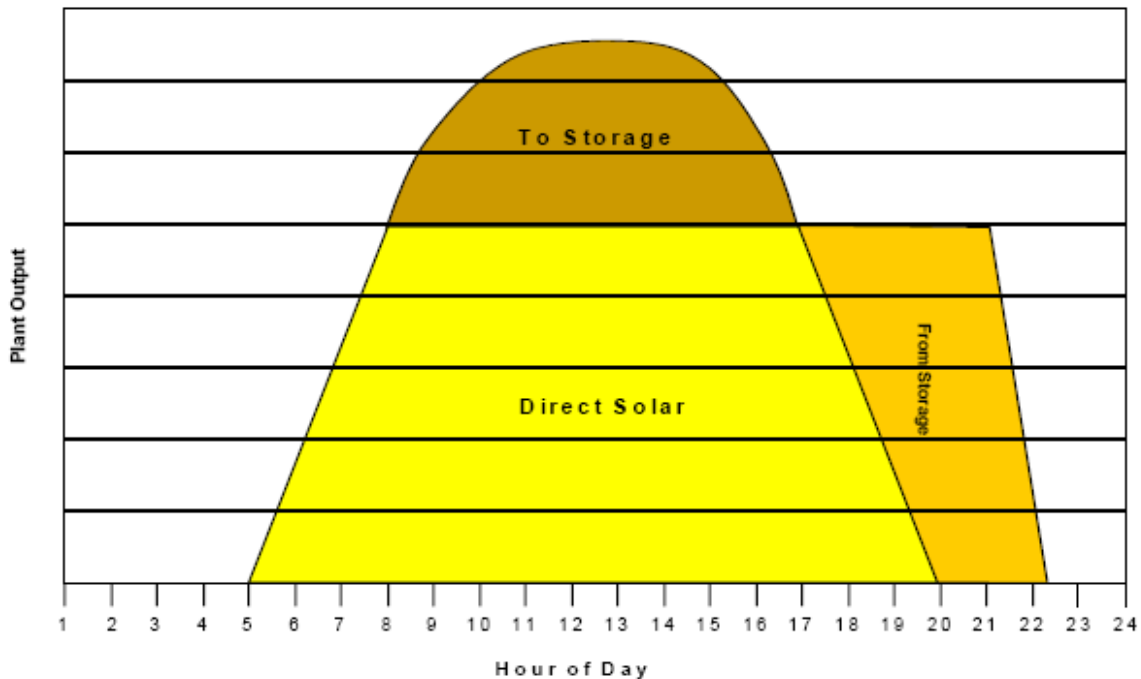
⁹³ California ISO. "Integration of Renewable Resources." November 2007.

⁹⁴ Porter, K. and Intermittency Analysis Team, April 2007.

⁹⁵ California Energy Commission. "PIER Research Development & Demonstration Program." April 2007.

⁹⁶ Black & Veatch. "Arizona Renewable Energy Assessment." Prepared for Arizona Public Service Company, Salt River Project and Tucson Electric Power Corporation. September 2007.

Figure 1: Conceptual California Solar CSP Generation Scenario with Storage⁹⁷



Solar PV Plants

Interconnection and reliability issues for utility-scale PV plants are similar to solar thermal plants. (Storage for PV plants would be in the form of batteries, not thermal storage.) Small-scale PV applications typically do not pose interconnection or reliability concerns.

Geothermal Plants

Interconnecting geothermal resources into the transmission system involves many of the same challenges as interconnecting wind resources: geothermal generation tends to be added in relatively small amounts; generation must be collected from multiple sources in remote areas; and a single geothermal resource area may be characterized by multiple developers across segmented parcels of land. Consequently, developer coordination plays an important role in geothermal interconnection.

Most geothermal power plants are operated as base load generation resources with reliable output levels. However, reliability issues can arise due to output fluctuations or reservoir decline. Output fluctuations occur due to changes in ambient temperature, with higher ambient temperatures reducing output.⁹⁸ These seasonal changes in temperature can generally be easily

⁹⁷ Black & Veatch. "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California." Prepared for NREL. April 2006.

⁹⁸ In general, geothermal production is more efficient when the difference between the primary heat source temperature and the ambient temperature is large.

accommodated. Reservoir decline poses a more serious problem. Since 1988, the maximum capacity of the Geysers Geothermal Field has declined from 1,866 MW to its current level of roughly 1,000 MW due to heavy steam withdrawal and overproduction.

Biomass Plants

Biomass power plants do not require unique interconnection considerations. The economics of fuel availability, supply, and transportation dictate the location of biomass power facilities, and these facilities are usually located near transmission or distribution interconnection points. Biomass plants also do not pose reliability concerns.⁹⁹

Demand-Side Resources

Interconnection and reliability issues associated with demand-side resources vary according to the policy or technology considered. Codes and standards that increase energy efficiency have no associated interconnection or reliability issues. Demand response programs also do not require additional physical interconnection; however, in some circumstances they could negatively impact reliability. Reliability impacts could arise if customers fail to curtail power use as expected, or if demand response programs result in a sharp reduction of load over a short period. Utilities are generally able to manage or forestall these impacts. For example, they can install utility-controlled thermostats that stagger the impact of reduced air conditioning demand on the system. These thermostats ensure that demand is reduced as expected and that the reduction is staggered so that it does not imbalance the transmission system.

Cost of Alternative Generation Sources

An important factor in the assessment of generation alternatives is the cost to construct and operate a power plant. Depending on the technology, costs may be dominated by capital costs or by fuel costs. To compare the costs of different technologies, it is thus useful to consider the levelized cost, which is a measure of total costs (i.e., capital costs, financing costs, and ongoing operating costs) per unit of energy output. This section presents a review of recent studies regarding the levelized costs of *existing* nuclear plants and *new* gas-fired and renewable plants.

Nuclear Power Plants

Nuclear power plants are capital intensive plants with relatively low operating costs. In evaluating the cost of nuclear power it is therefore important to distinguish between operating costs, which do not account for construction costs, and levelized costs, which do. It is also important to distinguish between currently operating plants, whose construction costs have generally been depreciated, and new plants, whose construction costs must be paid for as part of the cost of power.

⁹⁹ California ISO. "Integration of Renewable Resources." November 2007.

Another consideration in evaluating the cost of nuclear power is the likely change in costs over time. In particular, rising nuclear fuel prices, labor shortages, and changing security requirements could increase the cost of nuclear power. These are discussed in Chapter 10.

Nationally, levelized costs for most currently operating nuclear power plants range from approximately \$30 - \$80 per MWh. California's operating nuclear power plants have a lifetime levelized cost of electricity close to the upper end of this range.¹⁰⁰

Gas-Fired Power Plants

Natural gas power plants are relatively cheap to build, but the levelized costs associated with natural gas power depend on the price of natural gas. Currently, California relies on imports from other states and Canada for most of its natural gas. The cost of this gas has risen sharply in the last decade. Liquefied natural gas imports could offer an alternative source for the fuel in the future. This additional supply option could bring prices down; alternatively, increased demand worldwide and a falling dollar could push prices up further.¹⁰¹ Natural gas power plants also face an uncertain economic future as a result of potential greenhouse gas regulations.

A recent Congressional Budget Office report highlighted this uncertainty. The report found that if natural gas fuel prices were to double from their average since the year 2000, the expected levelized cost of natural gas power could reach \$97 per MWh. If, however, fuel costs were to drop by 50% from this average, the levelized cost could fall to \$36 per MWh.¹⁰²

There are two main categories of natural gas power plants: simple cycle combustion turbines and combined-cycle cogeneration plants. Combined cycle plants take advantage of waste heat in order to burn natural gas more efficiently than simple cycle plants. They are used as baseload or intermediate-load plants, while simple cycle plants are used primarily for quick-start peaking. Simple cycle plants are cheaper to build than combined cycle plants in absolute terms. However, the Energy Commission found in a 2007 study that the larger size of combined cycle plants yields economies of scale during construction that enables the otherwise more complex technology to have an installed cost per kW below that of a small simple cycle peaker plant (see Table 7).¹⁰³ This finding remains controversial.

Combined cycle plants are cheaper on a levelized basis than simple cycle plants primarily because they have higher load factors. As shown in the levelized cost comparison in Table 7, the

¹⁰⁰ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007: 140.

¹⁰¹ Liquefied natural gas is transported via ship, not pipeline. This frees natural gas from geographic constraints and makes it available to the global market.

¹⁰² U.S. Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13.

¹⁰³ California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007, pages 7, 18.

simple cycle plants are much more expensive because the capital costs must be recovered over fewer hours of operation.

Table 7: Natural Gas Power Plant Costs, Existing and New (\$ 2007)¹⁰⁴

	New Advanced Combined Cycle, 800 MW	New Small Simple Cycle, 50 MW
Overnight Cost, \$/kW	\$766	\$974
All-In Cost, \$/kW	\$763 - \$834	\$846 - \$1,053
Levelized Cost, \$/MWh	\$81 - \$96	\$352 - \$647
Percent of Levelized Cost from Fuel	59%-75%	12%-24%

Wind-Powered Plants

Average wind power prices have fallen from \$62 per MWh (2007\$) in 1999 to \$37 per MWh (2007\$) in 2006 (see Figure 2).¹⁰⁵ More recently, however, prices have increased. The weakness of the dollar, rising materials costs, a shortage of turbines and other components, and a concerted movement towards increased manufacturer profitability are the primary reasons for this increase. Among projects built in 2006, reported installed costs ranged from \$1,150 per kW to \$2,240 per kW, with an average cost of \$1,480 per kW – up \$220 per kW (18%) from 2005.¹⁰⁶

Wind price trends are shown in Figure 2 and Figure 3 below. Cost estimates provided by Black and Veatch, the Energy Commission, and the American Solar Energy Society (ASES) are shown in Table 8 below.

¹⁰⁴ California Energy Commission. December 2007: 7, 10, 18.

¹⁰⁵ These prices come from the Lawrence Berkeley National Lab database and are reduced by the receipt of any available state and federal incentives, and by the value that might be received through the separate sale of renewable energy certificates. As a result, these prices do not represent wind energy generation costs. Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007, page 10.

¹⁰⁶ Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 15.

Figure 2: U.S. Wind Power Price, 1999-2006, \$/MWh (2006\$)¹⁰⁷

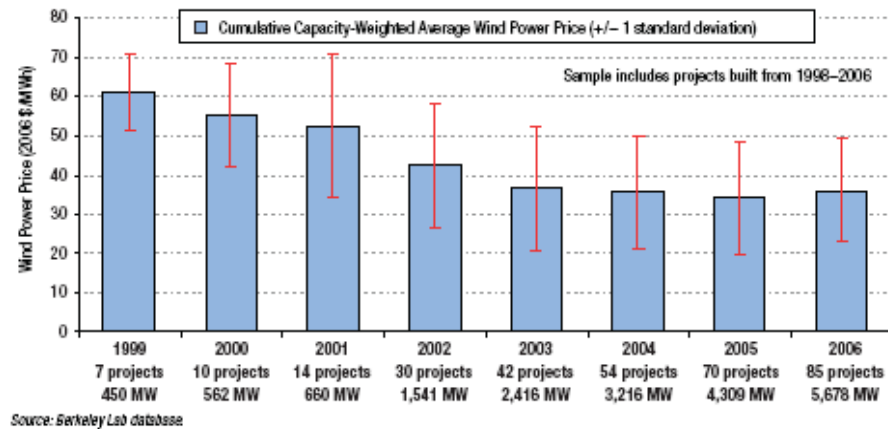
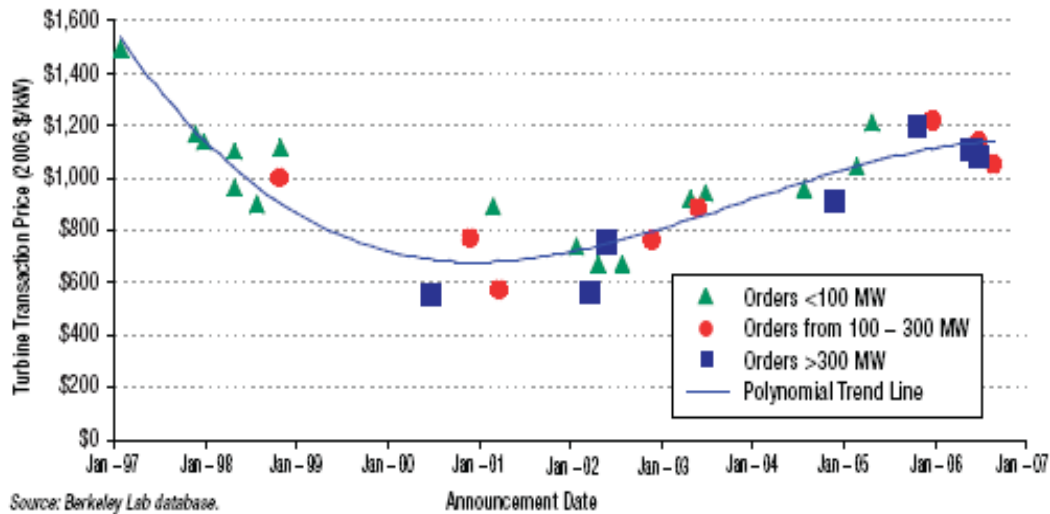


Figure 3: U.S. Wind Turbine Price 2003 - 2006 \$/kW (2006\$)¹⁰⁸



¹⁰⁷ Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 10.

¹⁰⁸ Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 16.

Table 8: Cost of Wind Power (Class 4-6)¹⁰⁹

	Black & Veatch		Energy Commission	ASES
Characteristic	Onshore	Offshore	Class 5	Class 4-6
All-In Cost, \$/kW	\$1,900 - \$2,400	\$5,000 - \$6,000	\$1,972 -\$2,000	\$1,580*
Levelized Cost, \$/MWh	\$59 - \$128	\$142 - \$232	\$61 - \$84	\$49 - \$66

* Deduced from Energy Commission assumptions

Solar Thermal Plants

Current estimates of the cost of concentrating solar power range from \$110 per MWh to \$519 per MWh. The U.S. Department of Energy's Concentrating Solar Power Subprogram funds technology development with the aim of reducing the cost of a trough plant to \$82 per MWh by 2011 and \$27-\$46 per MWh by 2020 (2007\$).¹¹⁰ The Western Governors' Association expects technology development, volume production, and scale-up in plant or project size to decrease costs to \$52-\$73 per MWh for a 2,000-4,000 MW plant in 2015.¹¹¹ Table 9 below provides a summary of solar thermal cost estimates from the Western Governors' Association, Black & Veatch, and the Energy Commission.

¹⁰⁹ Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 5-34; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 18; Milligan, Michael. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Wind by 2030." January 2007: 107.

¹¹⁰ This is a small program. The Subprogram budget appropriation for 2007 was \$7.6 million out of a total of \$124 million for the Solar Energy Technologies Program. U.S. Department of Energy, Solar Energy Technology Program. "About the Program: Budget." Accessed: May 8, 2008. <<http://www1.eere.energy.gov/solar/budget.html>>.

¹¹¹ Western Governors' Association. "Clean and Diversified Energy Initiative Solar Task Force Report." January 2006: 15-16.

Table 9: Concentrating Solar Power Levelized Cost Estimates, \$/Mwh (2007\$)¹¹²

Western Governors' Association	Black & Veatch	Energy Commission
\$110 - \$120	\$137 - \$176	\$199 - \$519 ¹¹³

Solar PV Plants

The cost to purchase and install PV panels is approximately \$6,000 - \$9,000 per kW, with 45 to 50 percent of this cost for the PV modules and 50 to 55 percent for the inverter and installation. Table 10 below provides a summary of PV cost estimates from the University of California Energy Institute (UCEI), the Energy Commission, and Black& Veatch.

Table 10: Solar Photovoltaic Cost Estimates (2007\$)¹¹⁴

	UCEI	Energy Commission	Black & Veatch
System Size	10 kW	1 MW	20 MW
All-In Cost, \$/kW	\$8,000	\$9,632 - \$9,672	\$6,500 - \$7,500
Levelized Cost, \$/MWh	\$337 - \$565	\$469 - \$705	\$201 - \$276

At current prices, PV is not cost competitive with other renewable technologies. The California Solar Initiative and the proposed federal Solar America Initiative aim to reduce these costs by creating a competitive market that spurs technological and process improvements. The Solar America Initiative focuses on bringing down the cost of PV technology through grants to agencies and industry players for research and development as well as market transformation purposes.¹¹⁵ The program's goal is to reduce the cost of residential electricity from solar PV to around \$130 to \$180 per MWh by 2011 and \$80 to \$100 per MWh by 2020 (see Table 11 and Table 12). Costs for commercial scale (10 to 100 kW) and utility scale (1 MW or greater) PV are

¹¹²Western Governors' Association. January 2006: 16; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 1-7; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

¹¹³ The lower end of the range is for parabolic troughs and the upper end is for Stirling dishes.

¹¹⁴ Borenstein, Severin. "The Market Value and Cost of Solar Photovoltaic Electricity." University of California Energy Institute. January 2008, table 4; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 1-7.

¹¹⁵ U.S. Department of Energy, Solar Energy Technology Program. "Solar America Initiative: Funding Opportunities." Accessed: May 9, 2008. <http://www1.eere.energy.gov/solar/solar_america/funding_opportunities.html>.

expected to be lower. The expected price reduction should come from module cost reductions, module efficiency improvements, economies-of-scale for aggregated and larger PV markets, and improved system designs.¹¹⁶

Table 11: Solar America Initiative Solar Photovoltaic Levelized Cost Targets, \$/MWh¹¹⁷

	2005 Benchmark	2011 Target	2020 Target
Utility-Scale	\$130 - \$220	\$100 - \$150	\$50 - \$70
Commercial-Scale	\$160 - \$220	\$90 - \$120	\$60 - \$80
Residential-Scale	\$230 - \$320	\$130 - \$180	\$80 - \$100

Table 12: Solar America Initiative Solar Photovoltaic 2020 Installed Price Targets, \$/kW¹¹⁸

Utility-Scale	\$1,500 - \$2,250
Commercial-Scale	\$2,000 - \$2,750
Residential-Scale	\$2,250 - \$3,000

Southern California Edison submitted an application to the California Public Utilities Commission in March 2008 seeking authority to implement a program that aims to build up to 250 MW of solar PV on large commercial rooftops capable of accommodating one to two MW systems. Southern California Edison aims to reduce the cost of solar PV to \$3,500 per kW by deploying approximately 50 MW each year. The utility claims that economies of scale and technology and efficiency advancements will enable the major cost reduction.¹¹⁹ This price target is in-line with the 2011 cost targets for the Solar America Initiative.

¹¹⁶ Denholm, Paul et al. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Solar Photovoltaics by 2030." January 2007: 96.

¹¹⁷ U.S. Department of Energy. "Solar Energy Technologies Multi Year Program Plan 2007 – 2011." January 2006, page 17. <http://www1.eere.energy.gov/solar/pdfs/set_myp_2007-2011_proof_1.pdf>; US Department of Energy. January 2006: 33.

¹¹⁸ U.S. Department of Energy. January 2006: 33.

¹¹⁹ California Public Utilities Commission. "Application of Southern California Edison Company for Authority to Implement and Recover in Rates the Cost of its Proposed Solar Photovoltaic Program." California Public Utilities Commission Proceeding A.08-03-015. March 27, 2008. <<http://www.cpuc.ca.gov/EFILE/A/80609.pdf>>.

Geothermal Plants

The western states in the U.S. and southern Canada share a capacity of almost 13,000 MW of geothermal energy that can be developed on specific sites within a reasonable timeframe. The Western Governors' Association Geothermal Task Force estimates that 5,600 MW of this capacity is viable for commercial development by 2015 at levelized costs of roughly \$55-\$82 per MWh, with the remaining capacity viable for development at levelized costs of up to \$200 per MWh. These cost estimates assume commercial project financing conditions and the extension of a production tax credit.¹²⁰ They are similar to estimates released by Black & Veatch and the Energy Commission in 2007 (see Table 13).

Table 13: Geothermal Levelized Cost Estimates, \$/MWh (2007\$)¹²¹

Western Governors' Association	Black & Veatch	Energy Commission
\$55 - \$82	\$54 - \$107	\$65 - \$76

Biomass Plants

A major challenge to biomass power is that dispersed feedstock and high transportation costs generally preclude plants from being built larger than 50 MW. By comparison, coal power plants rely on the same fundamental power conversion technology but can have much higher unit capacities, exceeding 1,000 MW. As a result of this larger capacity, modern coal plants are able to obtain higher efficiency at lower cost. One of the most economical methods to burn biomass is to cofire it with coal in existing plants. Through cofiring, biomass benefits from this higher efficiency and has a more competitive cost than a stand-alone, direct-fired biomass plant.¹²² Due to potential differences in the price of coal and the price of biomass, the incremental cost of cofiring biomass in an existing coal plant can be as little as -\$1 per MWh.¹²³

¹²⁰ Without a production tax credit, levelized costs would be \$23/MWh higher. Western Governors' Association. "Clean and Diversified Energy Initiative: Geothermal Task Force Report." January, 2006, page 9.

¹²¹ Western Governors' Association. January 2006: 9; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 5-36; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

¹²² Black & Veatch. March 2008: 5-6.

¹²³ Black & Veatch. March 2008: 5-9.

Table 14: Biomass Power Plant Costs (2007\$)¹²⁴

	Energy Commission	Black & Veatch (Solid Biomass)	Black & Veatch (Cofired Biomass)¹²⁵
All-In Cost, \$/kW	\$2,263 - \$5,925	\$3,000 - \$5,000	\$300 - \$500
Levelized Cost, \$/MWh	\$51 - \$144	\$67 - \$150	-\$1 - \$22

Demand-Side Resources

Many different technologies, regulations, and measures are considered demand-side resources, each with a different cost. State policy prioritizes implementing cost-effective energy efficiency and demand response programs to meet electricity demand before building new generation resources.¹²⁶ Cost-effectiveness is defined in comparison to the market price of electricity. For example, if the cost of subsidizing more efficient light bulbs or appliances is deemed lower than the cost (including capital costs) of the electricity that would have been necessary without the efficiency advancement, then the energy efficiency measure is considered economical. Thus, the incremental cost of new demand-side resource measures that are implemented in California are on par with the market cost of electricity.

In order to determine the economic potential for energy efficiency, the CPUC uses the total resource cost test to compare cost estimates of energy efficiency resources to cost estimates of generation resources, such as building and operating new power plants.¹²⁷ This test takes into account the fact that many energy efficiency measures involve initial capital purchases and years of cost savings. It compares the incremental costs of each efficiency measure to the savings delivered by the measure to produce estimates of energy savings per unit of additional cost.¹²⁸

¹²⁴ California Energy Commission. December 2007: 7, 18; Black & Veatch. March 2008: 5-5, 5-9.

¹²⁵ Figures for cofired biomass reflect the incremental cost of cofiring biomass at an existing coal plant.

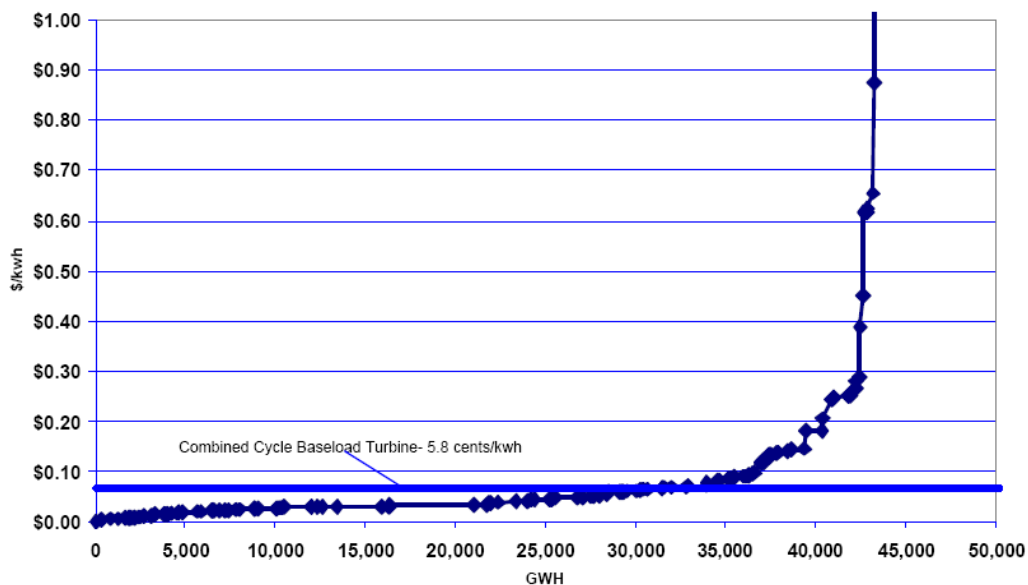
¹²⁶ California Energy Commission and California Public Utilities Commission. "Energy Action Plan II." September 21, 2005, page 2. <http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF>.

¹²⁷ Total resource cost ratios greater than or equal to one are generally considered to be cost-effective. However, total resource cost ratios do not include program administration costs associated with individual measures. Itron, Inc. "Assistance in Updating the Energy Efficiency Savings Goals for 2012 and Beyond, Task A4.1 Final Report: Scenario Analysis to Support Updates to the CPUC Savings Goals." March 24, 2007. Page 13.

¹²⁸ Itron, Inc, March 24, 2007: 13.

A 2002 study by XENERGY for the Energy Foundation evaluated the California energy efficiency supply curve (see Figure 4).¹²⁹ The study found that it would be cost-effective to pursue savings of 29,300 GWh per year if the levelized market power cost was 5.8 cents per kWh. The study also found that cost rose steeply to save more than 35,000 GWh a year, costing more than \$1.00 per kWh to save 45,000 GWh a year. In general, the cost of incremental savings will increase as the most cost effective measures are completed and will decrease with improved technology and lower technology costs.

Figure 4: Energy Efficiency Supply Curve (GWh)¹³⁰



Environmental Impacts

Different generation alternatives have widely varying impacts on the environment. This section presents an overview of several common impacts, such as greenhouse gas (GHG) emissions and land use, as well as resource-specific impacts.

Greenhouse Gas and Other Emissions

Greenhouse gas emissions related to electric power generation are a great concern for the State of California. All power sources emit greenhouse gases during plant construction. Nuclear

¹²⁹ Rufo, M. and Coito, F. "California's Secret Energy Surplus: The Potential for Energy Efficiency." Prepared by XENERGY Inc. for the Energy Foundation and Hewlett Foundation. October 2002. Cited in California Energy Commission's "Proposed Energy Savings Goals For Energy Efficiency Programs In California." October 7, 2003, page 8. <http://www.energy.ca.gov/reports/2003-11-05_100-03-021F.PDF>.

¹³⁰ California Energy Commission. "Proposed Energy Savings Goals For Energy Efficiency Programs In California." October 7, 2003: 8.

plants additionally emit greenhouse gases during fuel production and enrichment, and gas-fired plants additionally emit greenhouse gases during combustion. This section presents a summary of recent literature on the level of life cycle GHG emissions from each of the generation alternatives.

Nuclear Power Plants

Operation of nuclear power plants does not require combustion of fossil fuels and therefore emits very few GHGs or other pollutants. The major sources of GHG emissions for the nuclear power life cycle are uranium enrichment, plant maintenance, and plant construction.¹³¹

Estimates of life cycle GHG emissions vary widely depending on the assumptions used in the assessment and the region in which the assessment is conducted. Assumptions regarding the percentage of enrichment that is done via centrifuge technology, the fuel source for energy inputs, and the reactor lifetime contribute to the widest variation in GHG estimates.¹³² Also, emissions from decommissioning and from disposing of high-level waste are difficult to estimate and may be considered speculative because there is limited experience with these components of the nuclear life cycle.

Estimates of GHG emissions from nuclear power generation range from 5 grams carbon dioxide (CO₂)-equivalent per kilowatt-hour (kWh) to 140 grams CO₂-equivalent per kWh.^{133, 134} An analysis by Fthenakis and Kim provides a likely range of life cycle GHG emissions of 25-55 grams CO₂-equivalent per kWh.¹³⁵ Life cycle GHG emissions for nuclear power plants are discussed further in *Nuclear Power in California: 2007 Status Report*.¹³⁶

Gas-Fired Power Plants

The emissions of most concern from the natural gas power production life cycle are CO₂ and nitrogen oxides (NO_x).¹³⁷ Additionally, methane can be emitted when natural gas is not burned completely or if leaks occur, and nitrogen deposition into plant and animal communities adapted to nitrogen-poor conditions can result in direct toxicity and/or facilitate the

¹³¹MRW & Associates, Inc. "Nuclear Power in California: Status Report." Prepared for the 2005 Integrated Energy Policy Report. March 2006.

¹³² MRW & Associates, Inc. "Nuclear Power in California: Status Report." March 2006.

¹³³ AEA Technology Environment. "Environmental Product Declaration of Electricity from Torness Nuclear Power Station." Technical Report prepared for British Energy. May 2005.

¹³⁴ Storm and Smith. "Nuclear Power and Global Warming." October 2006.

¹³⁵ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

¹³⁶ MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

¹³⁷ Northwest Power Planning Council. "Natural Gas Combined-cycle Gas Turbine Power Plants." August 2002. Accessed: March 27, 2008. <http://www.westgov.org/wieb/electric/Transmission%20Protocol/SSG-WI/pnw_5pp_02.pdf>.

establishment of non-native plants that would not have otherwise been able to survive in a nitrogen-limited environment.¹³⁸

A modern natural gas-fired power plant emits approximately 469-499 g CO₂ per kWh, with 81 percent from direct fuel combustion and much of the remaining from the fuel cycle (i.e., exploration, production, storage, and processing of natural gas).¹³⁹ Some more efficient plants may be capable of emitting only 400 g CO₂ per kWh.¹⁴⁰

Natural gas plants often require air emission offsets in order to operate without impacting air quality. Offsets are in scarce supply in many areas of California, and the use of offsets for power plants has been controversial. The National Resources Defense Council (NRDC) and others recently filed suit against the South Coast Air Quality Management District regarding this issue.¹⁴¹

Wind-Powered Plants

Wind-powered plants do not emit GHGs or criteria pollutants during generation. Raw material inputs and the manufacture of all turbine components account for approximately 70 percent of the CO₂ and SO_x life cycle emissions and 50% of the NO_x life cycle emissions (see Figure 5).¹⁴²

GHG emissions from wind-powered plants vary considerably, from about 10-150 grams of CO₂ per kWh depending on the wind quality, turbine lifespan, and CO₂ intensity of the steel.¹⁴³ The median U.S. life cycle emissions rate is in the vicinity of 45 grams of CO₂ per kWh, while California's median is higher at approximately 65 grams of CO₂ per kWh.¹⁴⁴

¹³⁸ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

¹³⁹ Meier, Paul. "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis." August 2002; Spath, Pamela and Margaret Mann. "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System". NREL/TP-57027715, National Renewable Energy Lab. September 2000, page 29. Accessed: December 6, 2006. <<http://www.nrel.gov/docs/fy00osti/27715.pdf>>.

¹⁴⁰ Gagnon, Luc, Camille Belanger, and Yohji Uchiyama. "Life-cycle assessment of electricity generation options: The status of research in year 2001." Energy Policy 30. (2000), page 1271.

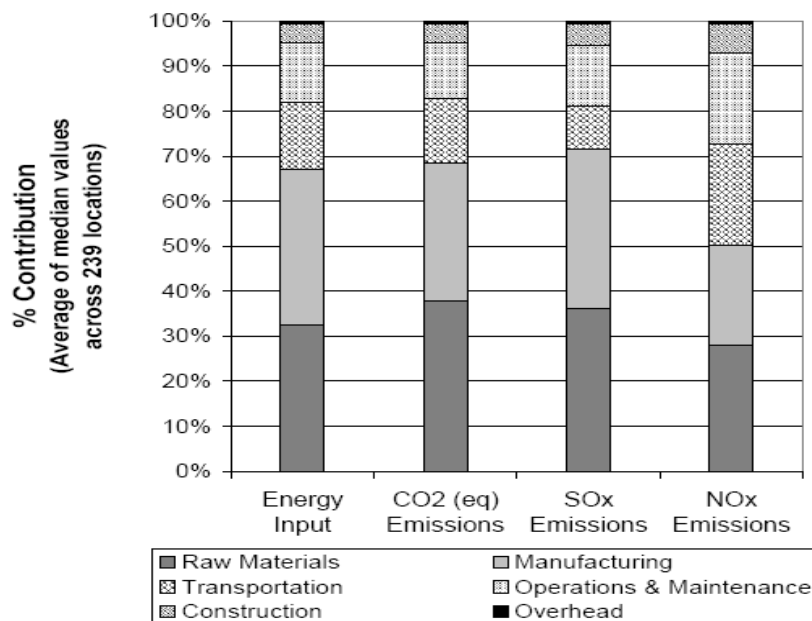
¹⁴¹ National Resources Defense Council (NRDC). "Notice of Intent to Initiate Citizen Suit Action under Section 304 of the Clean Air Act." April 2008.

¹⁴² Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." Defense Technical Information Center, March 2003, Appendix H. Accessed: March 24, 2008. <<http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA415268&Location=U2&doc=GetTRDoc.pdf>>.

¹⁴³ Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." March 2003.; Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002): 1271.

¹⁴⁴ Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." March 2003.

Figure 5: Lifecycle emissions of wind generation¹⁴⁵



Solar Thermal Plants

There is limited life cycle data on the GHG emissions from solar thermal plants. Emissions from non-hybrid plants are primarily from the manufacturing and installing of solar thermal components.¹⁴⁶ Cooling tower drift from solar thermal systems can also contribute slightly to air pollution, although dry cooling presents a possible solution.

Direct GHG emissions from solar thermal plants vary depending on whether the plant has natural-gas backup capability (hybrid system). The proposed Carrizo solar facility is an example of a non-hybrid facility. GHG emissions for this facility were estimated in the project application to be at most 1.46 metric tons per year, primarily from the operation of a diesel firewater pump engine (assumed to operate 26 hours per year).¹⁴⁷ Hybrid solar/ gas facilities such as the proposed Ivanpah project emit relatively higher amounts of GHGs, due to the partial use of fossil fuels. For this project, less than five percent of the total energy will come from fossil fuels, with 95 percent or more from solar. The direct annual emissions of GHGs from

¹⁴⁵ Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." March 2003.

¹⁴⁶ Emissions from hybrid systems are primarily from natural gas combustion. Emissions from natural gas combustion are discussed above.

¹⁴⁷ URS Corporation. "Application for Certification for the Carrizo Energy Solar Farm, Volume 1." October 2007.

the proposed Ivanpah SEGS were estimated in the project application to be 25,626 metric tons/year.¹⁴⁸

Solar PV Plants

GHG emissions from solar PV systems arise primarily from production of the PV panel. Fthenakis and Kim calculated the lifecycle emissions of CO₂, methane, NO_x, and chlorofluorocarbons from solar systems as 22-49 grams of CO₂-eq per kWh.¹⁴⁹ Alsema and de Wild-Scholten calculated CO₂ emissions at 30-45 grams per kWh.¹⁵⁰

Geothermal Plants

Geothermal fluids contain noncondensable gases. These include greenhouse gases (CO₂, methane, NO_x, and hydrogen), sulfur dioxide, hydrogen sulfide, and ammonia. In binary plants, the geothermal fluid stays in a closed loop, and does not make contact with the atmosphere. However, in dry steam and flash steam plants, noncondensable gases are vented to the atmosphere. Emissions estimates for flash steam, binary and flash/binary, as well as dry steam geothermal plants are provided in Table 15. The level of emissions during construction and decommissioning are similar to that during operations.

Table 15: Emission Estimates for Geothermal Power Plants¹⁵¹

Type of Plant	Nitrogen Oxides (g/kWh)	Sulfur Dioxide (g/kWh)	Carbon Dioxide (g/kWh)	Particulate Matter (g/kWh)
Flash steam	0	.16	27	0
Binary and flash/binary	0	0	0	negligible
Dry steam	.0005	.0001	40	negligible

¹⁴⁸ CH2M Hill Companies Ltd (CH2M Hill). "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

¹⁴⁹ Fthenakis, V.M. and H.C. Kim. "Greenhouse-gas Emissions from Solar Electric and Nuclear Power: A Life-cycle Study." Accepted for publication in Energy Policy. 2006. Accessed: February 28, 2008. <http://www.clca.columbia.edu/papers/Greenhouse_Gas_Emissions_Solar_Nuclear_Energy_Policy-inPress.pdf>.

¹⁵⁰ Alsema, E.A and M.J. de Wild-Scholten. "Environmental Impacts of Crystalline Silicon Photovoltaic Module Production." 13th CIRP International Conference on Life Cycle Engineering. May 31-June 2, 2006. Accessed: February 28, 2008. <http://www.nrel.gov/pv/thin_film/docs/lce2006.pdf>.

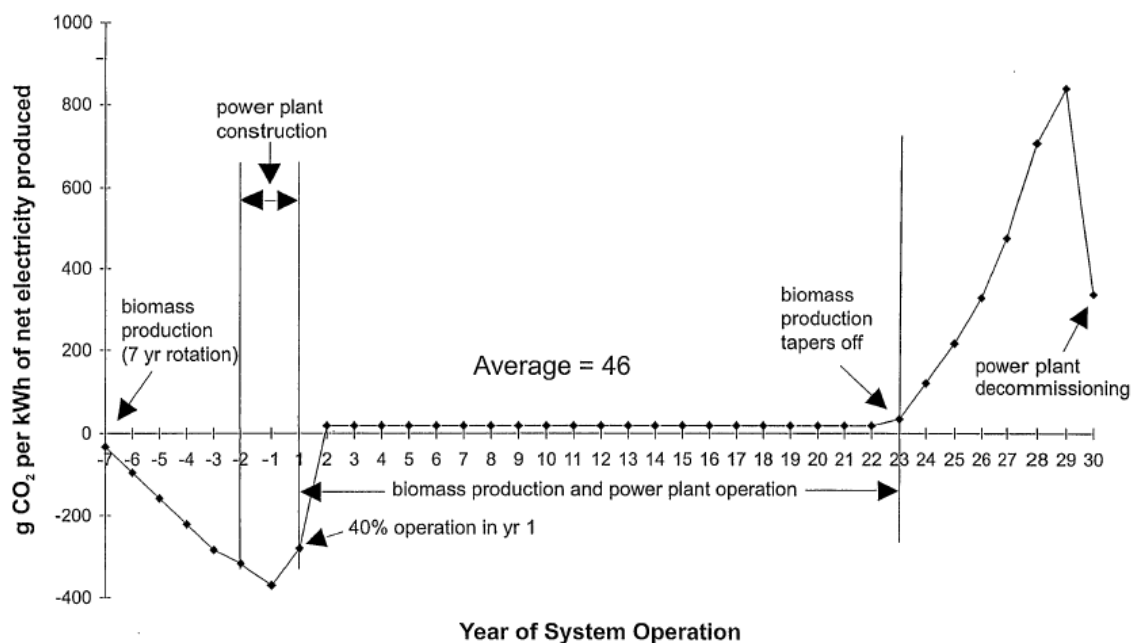
¹⁵¹ Kagel, A., D. Bates, and K. Gawell. "A Guide to Geothermal Energy and the Environment." Geothermal Energy Association. Washington, D.C. April 2007. Accessed: February 13, 2008. <www.geo-energy.org/publications/reports/Environmental%20Guide.pdf>.

Hydrogen sulfide (not a greenhouse gas, but of particular health concern) can be removed from the vent stream by scrubbing or conversion to elemental sulfur. While not an issue during normal plant operations, the odor can be a nuisance even at very low concentrations during drilling and plant start up.

Biomass Plants

Biomass life cycle GHG emissions arise from the burning of biomass, feedstock transportation, plant construction, and ecosystem conversion or land-use changes. Some of these emissions are offset by the carbon dioxide absorbed during the growth process. Mann and Spath calculated net life cycle emissions of 46 g CO₂ per kWh (see Figure 6).¹⁵² Gagnon et al. estimated that the typical biomass plant in the northeastern region of North America emits 118 g CO₂ per kWh.¹⁵³

Figure 6: Net annual carbon dioxide emissions over the life of the system.¹⁵⁴



¹⁵² Mann, M. and P. Spath. "Life Cycle Assessment of a Biomass Gasification Combined-Cycle System." NREL. December 1997, pages 46-50. Accessed: July 13, 2008. <http://www.nrel.gov/biomass/process_analysis.html>.

¹⁵³ Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002): 1271.

¹⁵⁴ Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002).

Demand-Side Resources

Energy efficiency and demand-side resources in California encompass a myriad of different programs, measures, and standards. The environmental impact of each individual program will vary depending on the technologies involved and whether manufacturing or incremental construction is required. For example, some demand response programs require the use of additional metering devices, which must be manufactured, installed, and ultimately disposed of. Compact-fluorescent light bulbs contain mercury. Even building standards could have environmental impacts from incremental construction activities. However, the level of environmental impact caused by demand-side resources is generally small compared to impacts from fossil fuel generation or even renewable sources of energy. The Energy Commission noted that “[combined] heat and power, in particular, offers low levels of greenhouse gas emissions for electricity generation, taking advantage of fuel that is already being used for other purposes.”¹⁵⁵

Land Use

To assess the land use impacts from generation alternatives, the amount of land required and the intensity and duration of the land use must all be considered. This section presents an overview of the direct land use impacts from nuclear, gas-fired, and renewable generation alternatives.

Nuclear Power Plants

Nuclear power plants require approximately 0.75 acres per MW for generation.¹⁵⁶ This figure, however, does not include indirect land use requirements such as fuel production and waste storage. These indirect impacts may be 200 times as large as the generation-only footprint.¹⁵⁷ In addition, land impacts would be much greater in the unlikely event of a radiation release from the plant.

Gas-Fired Power Plants

As is the case with nuclear power plants, gas-fired power plants have a relatively low average generation land use profile of 1.65 acres per MW.¹⁵⁸ This figure does not include the indirect impacts related to fuel exploration and production.

Wind-Powered Plants

Wind farms occupy a relatively large area, approximately 5.4 acres per MW.¹⁵⁹ However, only a small portion of that land is required for electricity generation. The footprint of an individual

¹⁵⁵ California Energy Commission. “2007 Integrated Energy Policy Report.” December 2007, page 7.

¹⁵⁶ California Energy Commission. “2007 Environmental Performance Report.” January 2008.

¹⁵⁷ Gagnon, et al. “Life-cycle assessment of electricity generation options: The status of research in year 2001.” (2002): 1267-1278.

¹⁵⁸ California Energy Commission. January 2008.

wind turbine is generally 0.25 acres, and turbines must be spaced out in order to allow the blades to rotate effectively. Land between turbines is generally available for agriculture and grazing.¹⁶⁰

Solar Thermal and Solar PV Plants

Solar plants require a relatively large amount of land. This has raised concern about habitat elimination and the creation of barriers to movement for the threatened desert tortoise and Mohave ground squirrel. In the 1980s and 1990s, the U.S. Fish and Wildlife Service, California Department of Fish and Games, and the Energy Commission mandated a habitat compensation ratio of 5:1 when licensing the LUZ SEGS in the Mojave Desert.

Proposed non-hybrid solar thermal projects in southern California would require 5.0-8.5 acres per MW (see Table 16).¹⁶¹ Utility-scale PV systems use 2.5-13.3 acres of land per MW.¹⁶² In California, 1,330 acres on average are needed to produce 100 MW.¹⁶³ The land use requirements for rooftop PV are essentially zero since the rooftop would generally not be otherwise utilized.

Table 16: Land Usage for Selected Proposed Solar Thermal Projects in California¹⁶⁴

Project Name	Nameplate Capacity (MW)	Acreage	Acre/MW	Technology
Harper Lake	250	1,250	5.00	Parabolic Trough
Victorville 2	50 Solar Trough/ 563 Natural Gas	250	0.41	Hybrid Gas/Solar
Ivanpah SEGS	400	3,400	8.50	Solar Tower
Stirling 1 & 2	4,275	32,600	7.63	Parabolic Dish

¹⁵⁹ California Energy Commission. January 2008.

¹⁶⁰ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

¹⁶¹ California Energy Commission. January 2008.

¹⁶² U.S. Department of Energy- Energy Efficiency and Renewable Energy. "PV FAQs: How much land will PV need to supply our electricity?" February 2004. Accessed: February 27, 2008. <<http://www.nrel.gov/docs/fy04osti/35097.pdf>>.

¹⁶³ California Energy Commission. January 2008.

¹⁶⁴ California Energy Commission. January 2008.

Geothermal Plant

An average of 1.7 acres per MW is needed for a geothermal power plant.¹⁶⁵ The plant must be built on or near a geothermal reservoir, often on previously undisturbed land. However, the well pad covers only about two percent of the area of the well field, and regrowth and revegetation can partially offset vegetation cleared for plant installation.¹⁶⁶

Biomass Plant

Acreage requirements for biomass plants depend on the source of the feedstock. Residue biomass (i.e., leftovers and wastes from forestry, agriculture, and cities) does not directly require land and water for growth. However, if crops and trees are grown expressly to fuel the plant, hundreds of acres of agricultural land can be required per MW of power production. Conversion of natural ecosystems to such cropland also has effects on biodiversity, carbon storage, and water supplies.

Water Use and Pollution

Water is often used in the process of electric power generation. The quantity of water required for operation and the content of the discharge can have adverse environmental impacts. These issues are discussed below. For a discussion of once-through cooling, see Chapter 9.

Gas-Fired Power Plants

Natural gas-fired power plants can impact water quality via effluent and thermal discharge; spills from fuel transport tankers or pipelines; deposition of nutrients, toxins, and salts from power plant emissions into bodies of water; and storm water runoff.¹⁶⁷ Wastewater, which is produced during cooling processes and also during construction activities, can impact surface and groundwater resources. Disposal methods include discharge into evaporation ponds, surface waters, local sewer systems, or underground injection.

Solar Thermal Plants

Water requirements for a solar thermal plant depend on the plant configuration. Water used for the proposed Ivanpah project would come from one of two onsite wells. The groundwater would undergo treatment for later use as boiler make-up water and to clean the mirrors. In order to conserve water, Ivanpah 1 and 2 would each use a dry-cooling condenser. As a result, estimates for water consumption are relatively low: less than 100 acre-feet per year for all three project phases.¹⁶⁸ The proposed Carrizo project would obtain all of its raw water requirements

¹⁶⁵ California Energy Commission. January 2008.

¹⁶⁶ Massachusetts Institute of Technology. "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century." U.S. Department of Energy- Idaho National Laboratory, Idaho Falls, Idaho. 2006. Accessed: February 13, 2008. <http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf>.

¹⁶⁷ California Energy Commission. January 2008.

¹⁶⁸ CH2M Hill. "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

from the Carrizo Plant Groundwater Basin by means of an existing on site groundwater well. The estimated average water usage for the proposed Carrizo project is 21.8 acre-feet per year.¹⁶⁹

The solar thermal steam cycle results in similar environmental impacts as a steam power plant (i.e., chemical wastes from water treatment and effluent water from boiler blowdown and cooling water system blowdown). It additionally poses the risk of water pollution due to accidental solar system coolant leaks, which would most likely occur during coolant replacement.¹⁷⁰ The SEGS plants have reduced spills from accidents and pipe ruptures to very low levels. When a spill does occur, the impacted soil is removed to a passive bio-remediation facility where microbes restore the soil to a normal condition.¹⁷¹

Geothermal Plants

Geothermal plants use five gallons of freshwater per MWh.¹⁷² The plants lose water to evaporation during well-drilling, circulation, and water-cooling, and they often use surface water as replacement. Water supplies are limited in California's geothermal range, much of which falls in relatively dry or desert areas. Air-cooling of geothermal fluids does not require water, but is not as effective during the summer. Hybrid air-water cooling systems, such as at the Mammoth Pacific plant, are being considered for future developments.

Geothermal fluid can contain poisonous boron, mercury, and arsenic, with increased concentrations in high temperature reservoirs. Well casings and holding ponds are used to prevent leakage into adjacent aquifers or surface runoff.

Biomass Plant

Cooling water needs for biomass-powered generation can be high; for example, a one MW gasifier requires 20,000 gallons of water per hour.¹⁷³ Once used, this water is treated for reuse or discharge. Liquid wastes require careful monitoring and treatment.

Other Environmental Issues

This section examines other environmental impacts of each power alternative. See also the discussions of tritium leaks in Chapter 9 and of spent nuclear fuel in Chapter 7.

¹⁶⁹ URS Corporation. "Application for Certification for the Carrizo Energy Solar Farm, Volume 1." October 2007.

¹⁷⁰ Tiwari, G., and M. Ghosal. "Renewable Energy Resources: Basic Principles and Applications." Alpha Science International, Ltd. June 2005.

¹⁷¹ Aspen Environmental Group. "Solar Thermal Power." Unpublished Report for the California Energy Commission. December 2003.

¹⁷² Aspen Environmental Group. December 2003.

¹⁷³ Global Energy Collaborations. "Technical Details of a 1MW Biomass Gasifier." 2004. Accessed: February 26, 2008. <<http://www.biomassgasifier.com/TechDetails.htm>>.

Nuclear Fuel Production

The traditional way of extracting uranium from the ground is to mine it. However, some of the uranium that is mined is not usable for fuel. Separating high from low grade ore leaves behind piles of low grade ore, which release radioactive dust and radon gas. From the high grade ore, uranium nuclides are then extracted at a mill; this leaves additional waste piles called mine tailings, which are left on the ground. Although both piles release radioactive dust and radon gas, the tailings from the high grade ore are the most hazardous. Approximately 85 percent of the radioactivity from the original ore remains in the tailings.

An alternative to conventional mining is in-situ leaching, in which a chemical solution is used to dissolve ore that it is in the ground. The liquid solution is then pumped upward to a uranium recovery plant. In in-situ leaching, the solid ore is not extracted so there are no waste piles, and the ground is not much disturbed. The chief environmental concern is potential ground water contamination from the leaching solution.¹⁷⁴ In addition, the uranium recovery plant generates liquid radioactive waste, which is typically disposed of in surface impoundments or in deep disposal wells.

Natural Gas Drilling and Transport

Drilling wells to extract natural gas disrupts the surface of coastal zones and onshore environments. Drilling also produces wastes, such as drilling mud, crushed rock, and produced waters, which may contain chemicals that are harmful to the environment if untreated.

Advances in natural gas exploration technologies have reduced these impacts by improving the resource recovery rate (i.e., there are now fewer dry holes and fewer drilling attempts) and increasing the ability to tailor operations to avoid sensitive resources. Also, improved horizontal drilling technologies allow for reduced surface disruption.¹⁷⁵

The majority of LNG liquefaction occurs outside of the U.S. in areas with less stringent environmental regulations than California. Environmental impacts of LNG liquefaction facilities may include habitat disruption, air quality impacts, and waste discharge. Transport of LNG via tanker may have direct adverse impacts to marine mammals, and potential leaks may adversely affect ocean water quality. Regasification of LNG using seawater has the potential to severely impact the marine environment similar to the thermal, impingement, and entrainment impacts of once-through cooling. While none of the LNG facilities that have submitted applications for a California site would use seawater for gasification, some of the facilities that could ultimately provide LNG to California employ this method. Additionally, offshore LNG facilities for liquefaction or regasification of LNG may require artificial night lighting, which may be disorienting or disruptive to seabirds and marine mammals.

¹⁷⁴ Uranium Information Centre. "In-situ Leach Mining of Uranium." Accessed: February 28, 2008. <<http://www.uic.com.au/nip40.htm>>.

¹⁷⁵ U.S. Department of Energy, Office of Fossil Energy. "Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology." October 1999.

Construction of natural gas pipelines results in temporary impacts that can generally be remediated once construction is complete. However, in arid environments habitats may require decades to recover.¹⁷⁶

Avian and Other Impacts of Wind-Powered Plants

Wind turbines can disturb and even kill birds through collision, habitat disruption, and displacement.¹⁷⁷ Bird collisions with wind turbine blades is the biggest challenge to siting wind farms and presents the greatest potential for significant environmental impacts. Large wind farms are in operation in the Altamont Pass and Montezuma Hills wind resource areas, which are in a major avian migration corridor and winter foraging area for several raptor species. The Center for Biological Diversity estimates that wind turbines at Altamont Pass kill an estimated 880 to 1,300 birds of prey each year, including up to 116 golden eagles, 300 red-tailed hawks, 380 burrowing owls, and additional hundreds of other raptors including kestrels, falcons, vultures, and other owl species.¹⁷⁸ Bird collision reports by the Energy Commission of the Tehachapi and San Geronio wind resource areas found far lower levels of mortality. Bird mortality at the Altamont Pass and Montezuma Hills wind resource areas appear to represent worst-case scenarios.

Bat mortality is closely related to avian mortality. Bats have been found dead due to collision with wind turbine blades and support structures in Colorado, Minnesota, Oregon, Wisconsin, and Wyoming. Bat fatalities from wind turbines were not identified as a major concern until 2004, when hundreds of dead bats were found at wind farms in West Virginia and Pennsylvania.¹⁷⁹ Unlike avian mortality, there have not been any documented reports of endangered bat species fatalities due to collisions with wind turbines.¹⁸⁰ However, the deaths are still a concern because of the possible impacts on local ecosystems as bat fatalities compound.

In response to the controversy surrounding bird and bat collision with wind turbines, all new wind farm sites are evaluated for the presence of sensitive bat and bird populations, especially

¹⁷⁶ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

¹⁷⁷ National Wind Coordinating Committee. "Wind turbine interactions with birds and bats: a summary of research results and remaining questions." November 2004. Accessed: March 26, 2008. <http://www.nationalwind.org/publications/wildlife/wildlife_factsheet.pdf>.

¹⁷⁸ Center for Biological Diversity. "Fact Sheet on Altamont Pass Bird Kills". 2005. Center for Biological Diversity: San Francisco, CA. Accessed: March 13, 2008. <<http://www.biologicaldiversity.org/swcbd/Programs/bdes/altamont/factsheet.pdf>>.

¹⁷⁹ Blum, J. "Researchers Alarmed by Bat Deaths from Wind Turbines." *The Washington Post*. January 1, 2005, page A-1. Accessed: March 12, 2008. <<http://www.washingtonpost.com/wp-dyn/articles/A39941-2004Dec31.html>>.

¹⁸⁰ Bat Conservation International. "Key Facts". 2007. Accessed: March 12, 2008. <<http://www.batcon.org/home/index.asp?idPage=55&idSubPage=32>>.

raptors. The *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development* provides recommendations for assessing bird and bat activity at proposed wind energy sites, designing pre- and post-permitting monitoring plans, and developing and implementing impact avoidance, minimization, and mitigation measures.¹⁸¹ In addition, the greater power of contemporary turbines means that fewer turbines are required.¹⁸² The slower speed of the rotors may also translate into the reduced probability of a bird or bat collisions, although monitoring is ongoing.¹⁸³

Visual pollution is another environmental impact from construction and operation of wind farms. Turbine blades may be up to 130 feet in length, and the support structure may be up to 300 feet tall. Wind turbines are typically sited on open landscapes with relatively high winds and are therefore visible from large distances. Shadow flicker, or the intermittent shadow created by turbine blades repeatedly moving across the sun, has been identified as a potential visual impact.

Wind turbines are typically constructed on mountainous topography where erosion can be a concern or in the desert where the hard-packed soil surface must be disturbed to install the support structure. Erosion can be prevented through proper design.

Noise pollution was an issue with early turbine designs but has largely been eliminated through improved engineering and increased setbacks from residential areas.¹⁸⁴ Noise emanating from wind turbines is now considered to be low-level. At 0.3 miles from the turbine, the noise level would be approximately 25-35 db(A),¹⁸⁵ comparable to the sound in the reading room of a library.

Hydrogen Gas Use at Solar Thermal Plants

Hydrogen gas is used as the fuel source for parabolic dish and Stirling engines. Occupational Safety and Health Administration regulations must be strictly followed for containment of the gas, and the gas piping systems must be regularly tested to ensure that they meet design working pressure standards. The systems are designed to shut down the facility automatically in the event of a leak.

¹⁸¹ California Energy Commission. "California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development." October 2007.

¹⁸² The dominant turbine size at the Altamont Pass wind resource areas is 100 kW, 15 times less powerful than typical turbines installed today. California Energy Commission. October 2007.

¹⁸³ California Energy Commission. "A Roadmap for PIER Research on Avian Collisions with Wind Turbines in California." December 2002.

¹⁸⁴ American Wind Energy Association. "Facts about wind energy and noise." Accessed: March 26, 2008. <http://www.awea.org/pubs/factsheets/WE_Noise.pdf>.

¹⁸⁵ British Wind Energy Association. "Are wind turbines noisy?" Accessed: March 12, 2008. <<http://www.bwea.com/ref/noise.html>>.

Hazardous Materials in Solar PV Systems

Silica mining involves open pit mining or dredging, which creates land and habitat disturbance but does not produce tailings that are associated with other types of mining. The major hazards from manufacturing silicon modules include hydrofluoric acid burns and silane gas (SiH_4) explosions. Amorphous silicon (a-Si) technology uses less than one percent of the silicon that crystalline technologies use, although with the tradeoff of lower sunlight conversion efficiency.

PV panels contain toxic materials such as cadmium, selenium, and lead.¹⁸⁶ These materials are often enclosed or insoluble and considered non-hazardous. Some modules, however, are considered hazardous. Large scale disposal may pose concerns as more PV cells reach the end of their 30 year life span. Recycling of intact PV components could eliminate the disposal problem and reduce lifecycle energy requirements.

Local Economic Impacts

By supplying employment opportunities and contributing taxes to local governments, power plants can have a positive impact on their surrounding communities. Some plants can also have negative economic impacts. This section describes the local economic impacts associated with the generation alternatives. A comparison of tax and employment impacts is provided in Chapter 9.

Nuclear Power Plants

Nuclear power plants tend to be larger, more capital intensive, and take longer to construct than other conventional power plants. This results in a large amount of property taxes, sales taxes, and employment, as discussed in Chapter 9.¹⁸⁷

In the event of an earthquake or other disaster, areas around nuclear facilities can experience a loss of revenue from decreased local tourism. For example, after an earthquake hit the Kashiwazaki-Kariwa nuclear plant, the local tourism board reported massive cancellations at local hotels and beach houses on account of fears of radiation, even though there were no

¹⁸⁶ Different PV technologies pose different hazards. CdTe and CIS technologies require less energy for manufacture and contain smaller amounts of toxic materials and carbon dioxide emissions than amorphous silicon technology. However, CdTe modules pose potential hazards from cadmium toxicity and carcinogenicity, and CIS modules pose risk from hydrogen selenide toxicity. Fthenakis, V. and E. Anselma. "Photovoltaics Energy Payback Times, Greenhouse Gas Emissions, and External Costs: 2004-early 2005 status." *Progress in Photovoltaics: Research and Applications*, Volume 14. (2006): 275-280; Fthenakis, V.M. "Overview of Potential Hazards." National PV EHS Assistance Center, Brookhaven National Laboratory, 2003. Accessed: March 24, 2008. <http://www.pv.bnl.gov/art_170.pdf>.

¹⁸⁷ Approximately seven percent of San Luis Obispo County's annual revenue is derived from Diablo Canyon.

reported health hazards associated with the plant.¹⁸⁸ The perception of a hazard can negatively impact local tourism revenues, whether or not the hazard is real.

Gas-Fired Power Plants

Plant employment typically swells during peak construction periods, which may boost local sales and payroll taxes during the construction phase. Operations and maintenance jobs have a more sustained impact on local tax bases; however, they make up a small proportion of power plant jobs. For example, combined cycle plants in California constructed in 2001 employed roughly 250 peak construction workers and were anticipated to create 25 permanent operations jobs.¹⁸⁹ Modern natural gas-fired plants have fewer operations jobs relative to older steam-boiler plants, employing just 2 to 24 operations and maintenance workers whereas the older plants employ 40 to 50.¹⁹⁰

The construction of gas-fired plants adjacent to private property may decrease property values, although there is little concrete evidence to support this claim. Two studies concluded that individuals find gas-fired power plants more desirable relative to coal or nuclear power plants in terms of land usage.^{191, 192} The gas-fired plants considered in these studies have emissions levels comparable to coal-fired power plants.¹⁹³

Wind-Powered Plants

The direct economic impacts of wind include increased revenues for local governments and private land owners, increased employment and demand for local goods and services due to construction and operation, and additional property tax revenues.

Using data from the California Energy Commission, the California Public Interest Research Group estimated the economic impacts of adding 3,700 MW of wind by 2010. The estimated effects on job creation are shown in Table 17 below. Relative to conventional power plants, wind facilities require fewer permanent operations employees.

¹⁸⁸ Kashiwazaki, Niigata. "Tourists Spurn Kashiwazaki." *Japan Times*. August 4, 2007. Accessed: April 2, 2008. <<http://search.japantimes.co.jp/cgi-bin/nn20070804a3.html>>.

¹⁸⁹ California Energy Commission. "2001 Environmental Performance Report of California's Electric Generation Facilities." July 2001.

¹⁹⁰ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

¹⁹¹ Lindell, M., and Earle, T. "How Close is Close Enough: Public Perceptions of the Risks of Industrial Facilities." *Risk Analysis*, Volume 1, No. 4 (1983), pages 245-253.

¹⁹² Clark, D., and L. Nieves. "An Interregional Hedonic Analysis of Noxious Facility Impacts on Local Wages and Property Values." *Journal of Environmental Economics and Management*, Volume 27 (1994), pages 235-253.

¹⁹³ McCann, T., and P. Magee. "Crude oil greenhouse gas life cycle analysis helps assign values for CO2 emissions trading." *Oil & Gas Journal*, Volume 97 (1999), pages 38-44.

Table 17: Economic Impacts of Adding 3,700 MW of Wind Capacity by 2015¹⁹⁴

Jobs Created	Construction	Operations (jobs/year)
Total	21,574	740
per MW	5.88	0.2

Wind generation creates an economic opportunity for private property owners. A large wind turbine generally occupies only 0.25 acres of land but may generate \$2,000 to \$4,050 in royalties.¹⁹⁵ Farming and grazing practices can continue on the land while the landowner generates additional income from royalties.

Opponents to wind development have contended that lands within the viewshed of wind turbines may have lower property values than similar parcels of land not adjacent to wind turbines. In order to evaluate this claim, the Renewable Energy Policy Project (REPP) used a regression analysis to estimate the effect of wind turbines on property values. REPP found no statistically significant evidence that areas within the viewshed of wind developments experience relatively lower property values relative to other comparable areas. The majority of lands affected by wind development considered in the study had higher property value growth rates than non-affected areas.¹⁹⁶

Solar Thermal Plants

Compared with conventional resources, the construction of solar thermal facilities provides relatively higher direct and indirect economic benefits. Black & Veatch estimates that each dollar spent on solar thermal construction adds \$1.40 to \$1.50 to the California gross state product, while each dollar spent on the construction of a natural gas-fired facility adds an additional \$0.90 to \$1.00 to gross state product.¹⁹⁷

In 2006, Black & Veatch estimated the direct and indirect fiscal impacts associated with high and low deployments of solar thermal in California. Considering revenues from sales taxes during construction, income taxes paid by construction workers, income taxes paid by plant operators, income taxes collected from jobs indirectly created due to plant construction, and corporate income taxes assuming private ownership of the project, they estimated fiscal impacts

¹⁹⁴ Heavner, B., and S. Churchill, for California Public Interest Research Group Charitable Trust. "Renewables Work: Job Growth from Renewable Energy Development in California." June 2002.

¹⁹⁵ California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

¹⁹⁶ Renewable Energy Policy Project (REPP). "The Effect of Wind Development on Local Property Values." May 2003.

¹⁹⁷ Black & Veatch. "Economic, Energy, and Environmental Benefits of CSP in California." April 2006.

associated with the low and high deployment scenario of \$1.3 billion and \$2.4 billion dollars (2005\$), respectively.¹⁹⁸

The impacts of a particular plant depend on size, ownership, and location. The Carrizo Solar Farm has an estimated total construction cost of \$500 million. Of this, \$55 million is attributed to employee salaries, wages, and benefits.¹⁹⁹ The Ivanpah SEGS will primarily benefit Clark County, Nevada. Just five percent of the \$1.1 billion (2007\$) estimated cost of construction is expected to be spent in California.²⁰⁰ The proposed AB 1451 (Leno bill) would exempt both Carrizo and Ivanpah SEGS from paying county and local property taxes as long as the facilities do not change ownership.²⁰¹

Solar PV Plants

To assess the economic impacts of solar PV development in the U.S., the Renewable Energy Policy Project (REPP) developed a scenario that assumes a total of 9,260 MW of incremental PV capacity installed at a price of \$3.68 per watt by 2015.²⁰² This represents a total investment of \$34 billion in PV manufacturing, construction, and installation. The manufacturing investment was allocated to each state based on the number of firms in the regions with technical potential to manufacture PV systems, and the installation investment was distributed on the basis of potential demand for installations of PV systems. REPP found that California would lead the nation in PV manufacturing, construction, and installation in terms of investment dollars and jobs created under this scenario (see Table 18).

Table 18: Total Solar PV Investment and Jobs in California for REPP Scenario²⁰³

Manufacturing (Jobs)	Manufacturing (\$Million)	Construction and Installation (Jobs)	Construction and Installation (\$Million)	Total (Jobs)	Total (\$Million)
6,858	5,500	3,578	3,037	10,437	8,538

¹⁹⁸ Black & Veatch. "Economic, Energy, and Environmental Benefits of CSP in California." Prepared for NREL. April 2006. Assumes a state income tax rate of 8.7 percent and a corporate tax rate of 8.84 percent.

¹⁹⁹ URS Corporation. "Application for Certification of the Carrizo Energy Solar Farm, Volume 1." October 2007.

²⁰⁰ CH2M Hill. "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

²⁰¹ Kinnee, M., California State Board of Equalization. "Draft Staff Legislative Bill Analysis: AB 1541 (Leno et. al)." June 2007.

²⁰² REPP. "Solar PV Development: Location of Economic Activity." January 2005.

²⁰³ REPP. January 2005.

Geothermal Plants

The development of geothermal power facilities creates permanent jobs as well as contractor services. A typical 50 MW geothermal plant can create between 30 to 50 full time jobs and 90 to 150 new secondary jobs.²⁰⁴ Some counties receive a significant share of their total property tax revenue from the geothermal power plants located within the county. Inyo county's three geothermal power plants pay approximately \$6 million annually in property taxes and are collectively the second largest taxpayer in the county.²⁰⁵

Geothermal plants located on state and federal lands pay royalties to the governments for use of the land and the steam produced.. In 2003 the operators of the Geysers Geothermal Field in Lake and Sonoma counties paid \$6.15 million in royalties to the federal government for geothermal resources owned by the federal government in California and an additional \$4.1 million in lease fees to the State of California for using the steam produced on state property for geothermal power.²⁰⁶

Biomass Plant

Biomass power facilities provide payroll, property, and sales tax revenues but are exempt from city and county sales taxes in California.

A large share of the fuels and feedstocks used by biomass power facilities are harvested in rural agricultural areas of California. The increased development of biomass resources could yield additional economic benefits to these regions. Biomass production creates additional opportunities for agriculture through the improved use of the non-crop share of agricultural production and the potential use of new crops.²⁰⁷

Demand-Side Resources

Demand-side resources are intended to reduce the demand for electricity. As such, they reduce customer electricity bills and prevent the need for costly power plant procurement. They do not provide a substantial tax and employment benefit to the local communities in which the efficiencies occur in the same way that a power plant or other industrial facility does. However, demand-side resources do provide local employment for engineers, implementation contractors, and utility personnel.

²⁰⁴ National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008. <http://www.geocollaborative.org/publications/Geothermal_Energy_and_Economic_Development.pdf>.

²⁰⁵ National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008.

²⁰⁶ National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008.

²⁰⁷ California Energy Commission. "Recommendations for a Bioenergy Plan for California." Prepared for the Bioenergy Interagency Working Group. April 2006.

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Appendix C: Literature Review - Diablo Canyon and SONGS Seismic Settings

Index of Literature Reviewed

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Number	Reference	Title
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Summaries of Literature Reviewed

Title 01	A Probabilistic Seismic Safety Assessment of the Diablo Canyon Nuclear Power Plant
Year	1977
Study Area	Onshore/offshore central California within 100 km of the DC site
Authors	A. H-S. Ang and N.M. Newmark
Source	Report to the Nuclear Regulatory Commission
Scope	A quantitative evaluation of levels of safety for certain critical components and subsystems of the DC NPP against seismic hazards for an interim 2 year period and assuming a plant retrofit design level of 0.75 g
Data Used	Earthquakes $M \geq 4.0$ between 1934 and 1971, active faults of west-central California including the Hosgri
Methodology	Probabilistic evaluation of annual exceedance frequencies associated with specified maximum accelerations using fault-rupture models and random background earthquakes along with evaluation of damage probabilities to critical components.
Summary Results	<ol style="list-style-type: none"> 1. Two-year damage probabilities of the existing plant in the presence of the Hosgri fault are considerably lower (by a factor of about 2 to 7) than the corresponding thirty-year damage probabilities of the plant if the Hosgri fault did not exist. 2. If the plant were retrofitted for an SSE of 0.75 g, and assuming that the same safety factors can be approximately maintained for the upgraded plant, the thirty-year damage probabilities of the upgraded plant in the presence of the Hosgri fault are also consistently lower (by a factor 2 to 3) than the original thirty-year damage probabilities considered acceptable during the design of the plant.
Strengths	This early PSHA application models both fault sources and random background earthquakes which is a fundamental approach in current PSHA procedure.
Limitations	Small exceedance frequency estimates (i.e., long return periods) are based on only a short, 37 year history of earthquakes in the region, which was common for this era since paleoseismological studies of active faults were only in their infancy.
Comparisons/	This interim safety assessment apparently addressed the short time

Implications	period over which retrofit or other design changes were planned to be executed. The probabilistic results are consistent with respect to other results addressing longer exposure times..
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Title 02	DC NPP: Probabilities of Peak Site Accelerations and Spectral Response Accelerations from Assumed Magnitudes up to and Including 7.5 in All Local Fault Zones
Year	1977
Study Area	Onshore/Offshore Point Arguella on the south to Santa Cruz on the north to about 20 km west of the San Andreas fault
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume V, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 11, p. D11-1 to D11.29.
Scope	Probabilistic seismic hazard analysis (PSHA) of peak ground acceleration (PGA) at the DC facility based on recorded earthquakes in the study area
Data Used	456 earthquakes in the study area between 1930 and 1977 and locations of the Hogri, Nacimiento, Rinconada-Ozena, and Santa Lucia Banks faults at closest horizontal distances from the DC site of 6, 25, 33 and 50 km, respectively.
Methodology	PSHA using a fault-contained rupture model assuming that magnitudes from 4.0 up to and including 7.5 can occur on four faults in the DC site region with the faults having equal probabilities of activity that was developed from recurrence frequency analysis of earthquakes in the study area
Summary Results	<ol style="list-style-type: none"> 1. Based on a comprehensive study of the seismic history of a large representative area surrounding the site, all faults in the region, all magnitudes up to and including 7.5 on local faults and 8M or greater on the San Andreas fault, and detailed probabilistic analysis, it is found that the probabilities of exceedance of the project ground accelerations and spectral response accelerations in 50 years 9or less) are exceedingly small. The average return periods are correspondingly large. 2. From table 11.8, the probability of exceeding instrumental PGA of 0.40 g in 50 years is 1.9%. The probability of exceeding instrumental PGA of 0.80 g in 50 years is 0.3%.
Strengths	An early state-of-the-art PSHA application to a site-specific problem that developed procedures for fault-rupture modeling, the concepts of which underpin modern PSHA applications.
Limitations	Small exceedance frequency estimates (i.e., long return periods) are based on only a 47 year history of earthquakes in the region, which was common for this era since paleoseismological studies of active faults were

	only in their infancy.
Comparisons/ Implications	Results differed from those of Anderson and Trifunac (1976), "Uniform Risk Absolute Acceleration Spectra for the Diablo Canyon Site, California", report to the Advisory Committee on Reactor Safeguards, US NRC. The PSHA was based on a short history of recorded earthquakes and was subsequently augmented by an additional study addressing all faults in the region and geologic data regarding their long-term displacements.

Title 03	Probabilities of Peak Site Accelerations Based on the Geologic Record of Fault Dislocations
Year	1977
Study Area	Onshore/offshore central California Point Sur south to the western Transverse Ranges including the San Andreas fault
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 41, p. 41-1 to D41.28.
Scope	Probabilitistic seismic hazard analysis (PSHA) of peak ground acceleration (PGA) at the DC facility based on long-term fault slip-rate data on faults of west-central California for time periods of 10,000 years (Holocene) and 20,000,000 (mid-Miocene)
Data Used	Total offset data during the two time periods that were provided by D.H. Hamilton. Faults addressed were: San Andreas, Sur-Nacimiento, San Simeon, Hosgri, Santa Lucia Bank, West Huasna-Suey, Rinconada, La Panza, Ozena, San Juan, Lion's Head-Los Alamos, Santa Ynez, Big Pine.
Methodology	PSHA using a fault-contained rupture model that implements a moment rate formulation and regional b-value of 0.92 to develop fault-specific recurrence frequencies and estimates of instrumental PGA exceedance frequencies at the DC site. Fault depth is taken as 15 km for San Andreas and 10 km for all others. Mmax is 8.25 for the San Andreas and no lower than 7.5 for all other faults. Hosgri Mmax is 7.5 with a fault length of 120 km at a distance of 6 km from the DC site.
Summary Results	<ol style="list-style-type: none"> 1. Probabilities of peak instrumental accelerations at the site based upon dislocation rates of the 13 faults are consistent with those obtained from the more recent history of earthquake activity in the area as shown in report D-LL 11. 2. Increasing the number of faults to 13 from 4 used in report D-LL 11 had no significant effect on the results. 3. The annual rate of activity of the San Andreas fault has increased considerably as indicated by the 10,000-yr data as compared to the 20x10⁶-yr data but this fault has no significant effect on the plant site accelerations except at very low values of acceleration. 4. The dislocation rate on the other faults west of the San Andreas and generally parallel to the coastline has decreased as indicated by the differences in the last 10,000 years as compared to the last 20x10⁶ years. 5. Of all the faults used in the analysis, only the Hosgri and

	<p>Rinconada have any significant effect at the plant site and the Hosgri alone determines the maximum accelerations.</p> <ol style="list-style-type: none"> 6. The probabilistic study based upon fault dislocations rates indicates that the 10,000-year more recent period of time is less critical in producing accelerations at the plant site than the 20×10^6-yr period of time extended back into the middle Miocene epoch. 7. The ratio of the average annual dislocation in a fault to the maximum annual dislocation, which ratio is designated α in this study, is not a strong parameter in the probabilistic analysis. 8. The maximum assigned value of the rupture length as compared to the fault length was found to be a very weak parameter in this probabilistic analysis except at extreme accelerations. 9. The Trifunac and Brady attenuation procedure using the same geologic input as for the Blume SAM attenuation procedures leads to similar results at low accelerations and to greater probabilities of exceedance of about an order of magnitude greater at 1.0 g, and somewhat greater probabilities at higher accelerations. This result is consistent with the data shown in report LL 43 in which the SAM results (by other comparisons) appear to be more consistent with recorded data and the values obtained by others for short epicentral distances than the Trifunac and Brady results. 10. The most reasonable solution is considered to be the 10,000-yr time period with the curve of log probability versus log acceleration falling very close to $\alpha = 1.0$ and $I_{\max} = L$ as shown in Figure 41-J. The peak instrumental acceleration of 1.15 g from this curve has an average return period of 106,000 years as compared to 52,600 years in report D-LL 11 11. In general, the analyses based upon dislocations determined by geologic evidence for the 10,000-yr and the 20×10^6-yr time periods provide results that are remarkably consistent with those from current time as used in report D-LL 11 and are reasonably consistent with each other. The average return period of 1.15 g instrumental acceleration based upon the average of all three time period determinations is 66,600 years. 12. All of the results indicate that the probability of high peak accelerations at this site are not only very low but also that there is no evidence to indicate that the probabilities are abnormally low in view of the geologic history of the area. In other words, there is no evidence found in this work that would support the concept of the Hosgri fault having been less active in the last 100 or 200 years than it has been for thousands of prior years. It can be concluded therefore that its activity would remain nominal, as it has been in the past, for thousands of years into the future.
Strengths	<p>A supplement to D-LL 11 (Title 2) to examine the effect of long-term fault slip-rate data on the PGA hazard at DC NPP in order to address the issue of using only a short period of recorded earthquakes in the previous</p>

	assessment.
Limitations	Mid-Miocene slip-rate basis samples geologic data from a different tectonic regime, which is not relevant to the current seismotectonics of the region. Nonetheless, it appears useful for an upper-bound estimate. The author notes that the 10,000-yr data is considered the most reasonable, although the total displacement data that was available in this era was highly uncertain and is still a matter of debate in geological literature. There was relatively little knowledge at the time on the continuity and exact location of the Hosgri fault offshore.
Comparisons/ Implications	Part of this study addressed the discrepancy between the Trifunac and Brady results which were higher than the D-LL 11 study. Differences are traced to the early form of ground motion attenuation relationships that were used in each of the assessments. This study concludes that the Blume SAM attenuation model is more consistent with recorded data. Even today, modeling differences among published, authoritative ground motion attenuation relationships [epistemic uncertainty] remains a primary source of uncertainty in PSHA.

Title 04	Diablo Canyon Plant: Plat-Boundary and Diffused Areal Probabilistic Considerations
Year	1977
Study Area	Western California state, Mendocino to Mexico international border
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 45, p. 45-1 to D45.11
Scope	Probabilistic sensitivity studies on the effect of alternative modeling and proportioning of the total seismicity of the California plate boundary on faults and as diffused earthquakes in the vicinity of DC
Data Used	45-yr earthquake record for western California plate boundary zone and assessed recurrence frequency by Dr. S.W. Smith
Methodology	Probabilistic determination of the exceedance frequency and corresponding return periods for 1.15 g instrumental acceleration under various proportioning assumptions of the total earthquake rate for western California on faults and in the area of the DC site using two alternative recurrence frequency b-values.
Summary Results	<ol style="list-style-type: none"> 1. Various methods of distributing the total California plate boundary seismicity on faults and throughout the area of the DC site results in the longest average return periods when compared to results of the D-LL 11 and DL 41, except for one extreme and illogical model for which the results are essentially equivalent to the previous investigations.
Strengths	The strength of this study perhaps lies in the fact that, in even another alternative modeling scenario that accounts for proportioned earthquake recurrence frequencies using a 45-year earthquake record from the entire western California plate boundary region, return periods are quite long..
Limitations	Physical reasons for the proportioning schemes that were investigated are not given, although as a sensitivity study, the objective was only to examine a range of cases from what seemed extreme to reasonable, regardless of physical underpinnings.
Comparisons/ Implications	Results were the lowest among the three PSHA studies at the DC site, but used only as a sensitivity study and not a design basis.

Title 05	The San Gregorio – Hosgri Fault Zone: An Overview
Year	1978
Study Area	Coastal central California San Francisco to Point Arguello
Authors	E.A. Silver
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 1 – 2.
Scope	Overview with summaries of work contained in the volume
Data Used	Existing stratigraphic and geological data.
Methodology	Review of existing knowledge, and new data and interpretations contained in papers of the volume
Summary Results	<ol style="list-style-type: none"> 1. Major outstanding problems include details of fault location, continuity between San Gregorio and Hosgri segments, offset history of each segment, evidence for Holocene movement, and seismicity 2. Volume contains some papers from a symposium on the fault zone held in April 1977, which provide a good overview on the current state of knowledge. 3. From results in the volume's papers, the bulk of the evidence at least allows continuity between the Sur fault (through point Sur) and the Hosgri to the south. 4. The San Gregorio – Hosgri appears to be the largest subsidiary fault of the San Andreas system in both length and offset.
Strengths	Volume is an early compilation of geological research papers focused on the Hosgri fault zone that addresses outstanding issues of location and continuity between onshore and offshore faults that comprise the zone..
Limitations	N/A - Summary and overview of papers in the volume
Comparisons/ Implications	Refined location, fault continuity, and slip rate data is apparent in this volume from earlier Hosgri fault models used in earlier PSHA assessments that were included in D LL-11 and DL-41 (Titles 03 and 04).

Title 06	Apparent Offsets of On-Land Geologic Features Across the San Gregorio – Hosgri Fault Trend
Year	1978
Study Area	West central California
Authors	S.A. Graham and W.R. Dickinson
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p13 – 23.
Scope	Detailed attempt to reconcile differences in stratigraphic sequences across the San Gregorio fault
Data Used	Fault zone trends and morphology, stratigraphy and basement rock types
Methodology	Geological synthesis of observations on the data
Summary Results	<ol style="list-style-type: none"> 1. San Gregorio fault is continuous southward with the Sur, San Simeon, and Hosgri fault zones with the linked traces of these fault termed the San Gregorio – Hosgri fault trend. 2. The San Gregorio – Hosgri fault trend is part of the San Andreas fault system and apparently controls the position of the modern coastline in central California. 3. Cumulative post-middle Miocene age right-lateral slip on the fault trend is estimated to be 115 km.
Strengths	An original work to suggest that the San Gregorio is continuous southwards with the Hosgri and that the San Gregorio does not turn inland to connect with the onshore Palo Colorado fault.
Limitations	Limited offshore data on the fault zone at the time
Comparisons/ Implications	Title 03 and 04 modeled the Hosgri fault zone as turning inland to connect with the onshore Palo Colorado fault, which this work now refines into a continuous offshore zone faulting between the San Gregorio and Hosgri faults. Post mid-Miocene displacement of 115 km in this work is an order of magnitude greater than the 10 km of post-mid-Miocene displacement used in D D-LL 11 (Title 03) and would give correspondingly higher long-term slip rate.

Title 07	Origin and Development of the Lompoc-Santa Maria Pull-Apart Basin and its Relation to the San Simion-Hosgri Strike-Slip Fault, Western California
Year	1978
Study Area	Central Western California
Authors	C.A. Hall
Source	California Division of Mines and Geology Special Report 137, The San Gregorio - Hosgri Fault Zone, California, p. 25 - 31.
Scope	Interpretation of onshore Santa Maria basin stratigraphy and structural development as related to local faults
Data Used	Local stratigraphy and geologic age data
Methodology	Geological synthesis addressing the stratigraphic and tectonic origin of the onshore Santa Maria basin.
Summary Results	<ol style="list-style-type: none"> 1. The onshore Santa Maria basin developed as a wedge-shaped pull-apart structure in pre-late Miocene time with a maximum pull-apart of 50 km within a strike-slip system of faults bounded by the Santa Maria River fault on the north and the Lompoc - Solvang fault of the western Transverse Ranges on the south. 2. Following pull-apart rifting and sedimentation, the western part of this basin was displaced 80 - 95 km to the NW (right-lateral sense) since Pliocene time along the San Simeon - Hosgri fault zone.
Strengths	A novel interpretation for post-Mesozoic structural development of the Santa Maria Basin - Lompoc region
Limitations	A speculative model according to author based mostly on overall basin morphology and stratigraphic timing.
Comparisons/ Implications	80 - 95 km total post-Pliocene right-lateral offset estimate would appear to be in ball-park agreement with 115-km post mid-Miocene offset along the Hosgri-San Gregorio estimate in Title 06 with the same implications with regard to slip rate estimates used in D D-LL 11 (Title 03).

Title 08	Morphology, Recent Activity, and Seismicity of the San Gregorio Fault Zone
Year	1978
Study Area	Coastal California, Pillar Point south to Point Sur
Authors	K.J. Coppersmith and G.B. Griggs
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 33 – 43.
Scope	Resolution of faulting style and latest movement of the San Gregorio fault
Data Used	Contemporary seismicity, field fault data, focal mechanisms, geodetic strain, existing fault maps
Methodology	Examination and synthesis of data into resolution of faulting style and age of latest displacement
Summary Results	<ol style="list-style-type: none"> 1. San Gregorio is a complex active fault zone up to 3 km wide. 2. A number of fault traces within the zone exhibit late Pleistocene and Holocene offsets. 3. Limited field investigations and triangulation data indicate no fault creep or strain accumulation along the fault zone. 4. Focal mechanisms of earthquakes associated with the fault indicate right-lateral shear and compressive stress.
Strengths	Compiles early observational data onshore/offshore with limited field data demonstrating Holocene right-lateral displacement on the San Gregorio fault. Indicates the potential for further Quaternary geological investigations along the fault zone
Limitations	According to the author, the second-order triangulation precision probably cannot resolve the long-term rate of fault offset. An estimate of slip rate is not provided.
Comparisons/Implications	Demonstrates fault displacements in the last 10,000 years (Holocene) supporting the fact that the Hosgri-San Gregorio fault zone is active, as has been acknowledged in the previous seismic hazard investigations (Titles 01-04).

Title 09	Seismicity and Tectonics of the Central California Coastal Region
Year	1978
Study Area	Central coastal California and offshore between Point Conception and San Francisco
Authors	W.H. Gawthrop
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 45 – 56.
Scope	Earthquake relocations and seismicity patterns in central coastal California and offshore
Data Used	Historical intensity, instrumental earthquake data from the northern and southern California networks
Methodology	Master event relocations using the HYPOELLIPSE computer program and an assumed velocity model of the region.
Summary Results	<ol style="list-style-type: none"> 1. Based on an improved crustal velocity model for the region, the 1927 Lompoc earthquake (M_s 7.3) was located near the coast just west of Point Sal compared to the previous 1930 location of Byerly, which was 70 km west of Point Arguello. Relocation of aftershocks suggests the probable limit of rupture was 50 – 70 km, possibly along the Hosgri fault. 2. The possibly continuous Hosgri – San Simeon – San Gregorio fault system is likely responsible for a large part of earthquake activity west of the San Andreas fault. 3. Regional seismicity pattern indicates most of the earthquake activity is occurring along several NW-trending faults throughout the region and at least some of the 2.3 cm/yr plate motion not attributable to the San Andreas must be relieved in this manner. 4. Focal mechanisms suggest that the driving motion has a component normal to the NW-trending faults resulting in some thrust faulting and folding. The relative motion vector is oblique to the main trend of the San Andreas Fault in central California. 5. Future earthquakes of magnitude 7 or greater should be expected in this region. 6. If continuous, the Hosgri – San Simeon – San Gregorio fault system is long enough to produce magnitude 8 earthquakes rupturing in excess of 200 km with greater than 4 m of displacement and a recurrence of 250 years.
Strengths	An original attempt at making the best use of sparse seismological data for the central coastal California at the time, but controversy prevails as other researchers have come to different conclusions.

Limitations	<p>According to author, bias still exists in the reprocessed seismological data due to the lack of data to the SW (offshore) of the relocated epicenters.</p> <p>Considerable controversy surrounding the proposed location and mechanism of this earthquake is documented a series of published papers between 1978-79.</p>
Comparisons/ Implications	<p>Gawthrop (1978) more specifically suggests that this earthquake is associated with the southern Hosgri fault based on the right-oblique focal mechanism. However, he notes that geodetic data suggests a much larger component of thrust than can likely be accommodated on the Hosgri.</p> <p>Hanks (1979) locates the epicenter near 34.6° N and 120.9° W, approximately 40 km SW and farther offshore of Gawthrop's location, based on seismological observations in the local area.</p> <p>Based on analyses of teleseismic and regional seismograms, Helmberger et al. (1992) locates this earthquake 40 km west of Point Conception at 34.35° N and 120.9° W, consistent with tsunami modeling results of Satake and Somerville (1992) that indicates the event occurred below at least 200 m of water near the same coordinate position and about 25 km south of Hanks (1979) location. Helmberger et al. (1992) further find that the earthquake focal mechanism indicates a NW-striking reverse fault as the earthquake source with the fault parameters being; strike = N20° W, dip = 66° NE, rake = 95° with a source dimension of about 30 km. Their surface wave magnitude is 7.0 as well as that derived from tsunami data by Satake and Somerville (1992), as opposed to previous estimates of 7.3.</p> <p>These latest analyses (1992) are judged to be the most reliable to date because of the data brought to bear on the location and magnitude determinations. The surface wave magnitude assessment of 7.0 is significantly lower than the 7.5 magnitude used in assessments of seismic hazard at the DC site (Titles 01 through 04).</p> <p>Additional references:</p> <p>Hanks, T.C. (1979), "The Lompoc, California Earthquake (November 4, 1927; M=7.3) and its Aftershocks", <i>Bulletin of the Seismological Society of America</i>, Vol. 69, No. 2, p. 451-462.</p> <p>Helmberger, D.V., P.G. Somerville and E. Garnero (1992). "The Location and Source Parameters of the Lompoc, California Earthquake of 4 November 1927", <i>Bulletin of the Seismological Society of America</i>, Vol. 82, No. 4, p. 1678-1709.</p> <p>Satake, K., and P.G. Somerville (1992). "Location and Size of the 1927 Lompoc, California, Earthquake from Tsunami Data", <i>Bulletin of the Seismological Society of America</i>, Vol. 82, No. 4, p. 1710-1725.</p>

Title 10	Post-Miocene Compressional Tectonics Along the Central California Margin
Year	1984
Study Area	Near-offshore area from approximately 20 km N of Point Sal southwards around points Arguello and Conception, then eastwards across the northern Santa Barbara Channel to Capitan with extrapolated interpretations to all of central coastal California
Authors	J.K. Crouch, S.B. Bachman, and J.T. Shay
Source	"Tectonics and Sedimentation Along the California Margin": Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM), Vol. 38, p. 37 - 54.
Scope	Interpretation of high-resolution seismic reflection data offshore of the Santa Maria basin on the north and the western Transverse Ranges on the south with generalization to the broader area of west-central California
Data Used	High-resolution, deep-penetration (2.5 - 3.0 sec.) 36-fold, 400 cu-in, dual-water gun profiles.
Methodology	Geophysical interpretation of third-party high-res reflection data and synthesis with regional tectonics
Summary Results	<ol style="list-style-type: none"> 1. Many of the major faults along the offshore central California margin are either thrust or high-angle reverse faults that flatten and become thrust faults at depth. Northern Santa Barbara Channel faults trend E-W, dip north, and probably have left-lateral as well as dip-slip motion. Thrust and reverse faults trend about N55°W and dip N-NE offshore of points Conception and Arguello. Offshore of the Santa Maria Basin, thrust and reverse faults trend about N35°W and dip predominantly NE. Right-lateral slip has probably occurred on some of these faults, however associated folds are usually asymmetric and their axes closely parallel the fault traces indicating compression is playing a dominant role in structural development. 2. Similar fault and fold relationships have been reported in the adjacent onshore region. Compressional structures are well known in the western Transverse Ranges. NW-trending structures in the Southern Coast Ranges are generally regarded as related to right-lateral wrench tectonics. Because many of the faults in this region are steeply dipping, high-angle reverse faults at the surface, the role of compressional tectonics is not fully appreciated. Many of these high-angle reverse faults flatten and become thrust faults at depth, like those in the offshore region. 3. Resolution of present-day plate motions coupled with estimates

	<p>of the amount of crustal shortening suggest that in the past 5.5 my at least 30 km and perhaps as much as 70 km of NE-SW crustal shortening has occurred across the central California margin. These are comparable to estimates of right-lateral offsets along the NW-trending faults of the San Anreas.</p> <ol style="list-style-type: none"> 4. Accommodation of major crustal shortening shallower than 12 km over the last 5.5. my along the central California margin is proposed to occur along an aseismic zone of detachment, which is possibly the top of an old oceanic crustal layer. Thrust faults extending upward from this zone are compressed into high-angle reverse faults at shallow crustal depths. 5. Compressional tectonics may be an important element of basin development along the central California margin. The offshore and onshore Santa Maria, the Huasna and Cuyama Basins all appear to have undergone NE-SW-directed compression in post-Miocene time. The predominance of thrust faults and parallelism of folds within these basins suggest that compression rather than right-slip has dominated the late stages of basin development. 6. New petroleum discoveries along the central California margin may come from subtle traps associated with compressional folding and faulting. Exploration concepts that have been used to discover petroleum in the Rocky Mountain Overthrust belt may also apply to major zones of crustal shortening along the California coast, perhaps only on a smaller scale.
Strengths	A provocative extrapolation of structural interpretations based on original data in a relatively confined offshore area to the whole of west-central California in order to illustrate the types of traps and oil potential that may exist in the region.
Limitations	Acknowledgement is given to Nekton, Inc. for providing the geophysical data, but processing, quality and limitations of the data are not discussed. One cross-section shows original data, while six cross-sections are only interpretive line drawings. Well control is available down to Oligocene stratigraphic units in at least the northern Santa Barbara Channel, but has not been incorporated as a constraint on interpretations. Descriptions of deep fault geometries outside of the areas of actual geophysical data are speculative and model-driven assuming a homogeneous tectonic process for all structures of the west-central California region.
Comparisons/ Implications	The primary implication of this paper is that late-stage basin development in west-central California is dominated by compressive tectonics, and accompanying reverse and thrust faulting rather than strike-slip faulting. Thrust and reverse faults and associated subparallel fold trends are mapped for more than 40 km along the southern segment of the Hosgri fault zone and the authors note that similar compressional features have been noted off Puisima Point and along the San Gregorio

	<p>fault south of Point Sur.</p> <p>The general implication is that the Hosgri fault is dominantly a thrust or reverse fault with a NE dip. In detail, however, the authors are actually noncommittal with regard to a long central segment of the Hosgri fault offshore of the DC site. Their summary figure 11, which shows faults of the Southern Coast Ranges with varying degrees of certainty for having thrust and reverse displacement, shows the long central segment of offshore Hosgri fault as simply dashed lines with no indication of thrust or reverse faulting. This is more pointedly taken to indicate that authors have no specific evidence for thrust or reverse displacement on the section of the Hosgri fault of most importance to the DC site. A generalization of their thoughts is illustrated in a schematic block diagram in figure 13, which provocatively shows the Hosgri as a thrust fault along its entire offshore length. However, as is clear from summary conclusion item #6 above, the primary purpose of this paper is to illustrate a model with respect to the oil-trap potential for this region, and not to seriously address the earthquake hazard.</p>
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Title 11	PG&E Final Report of the Diablo Canyon Long Term Seismic Program
Year	1988
Study Area	Central coastal California and offshore
Authors	PG&E and its consultants
Source	PG&E Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323
Scope	Reevaluation of the seismic design basis for DC
Data Used	Existing data and a wealth of new geological, geophysical, seismological and neotectonic data on and offshore bearing on the seismotectonic setting of DC
Methodology	Review of existing data and collection and analyses of a wide range of new geoscience data by a diverse team of experts with synthesis into a coherent seismotectonic model for the DC site region and implementation of the models elements in deterministic and probabilistic seismic hazard and risk analyses for DC.
Summary Results	<p>Element 1 of the license condition:</p> <ol style="list-style-type: none"> 1. Rotation of the Transverse Ranges has resulted in north-northeast-directed shortening east of the Hosgri fault zone, which is accommodated by W-NW-trending reverse faults and by uplift, subsidence or tilting of intervening crustal blocks. DC is located on the San Luis/Pismo structural block, which is bounded on the NW by the Hosgri fault zone, the most significant seismogenic structure for DC. 2. Crustal blocks east of the Hosgri are separated from the offshore Santa Maria Basin by the Hosgri fault zone. The Santa Maria Basin is characterized by gradual subsidence and scattered N-NW-trending reverse and thrust faults oriented sub-parallel to the Hosgri. Faults are mostly in the southern Santa Maria Basin south of Point Sal with little evidence of contemporary compressional deformation west of the Hosgri between Point Sal and the northern end of the Hosgri. 3. DC is located in the SW part of the San Luis/Pismo structural block, which is bounded on the NE by the Los Osos fault zone, on the SW by a diffuse zone of minor faults, and on the W-NW by the Hosgri fault zone. 4. Folding of the Pismo syncline ceased at least 1 – 2 my ago. Previously mapped faults within the block indicate an absence of activity in the past 500,000 years (late Quaternary) and demonstrate that these faults are not active. Marine and fluvial terrace mapping demonstrates the absence of any previously unrecognized Quaternary faults and folds.

	<ol style="list-style-type: none"> 5. Tertiary age folds within the San Luis/Pismo block may have been associated with displacement on low-angle detachment faults at depth during a previous deformational episode that ceased 1 – 2 my ago. Lack of Quaternary age deformation of these folds demonstrates that, if low-angle faults are present, they are not active. 6. The Hosgri fault zone, extending from an echelon step with the southern part of the San Simeon fault (offshore of Cambria) to its termination NW of Point Pedernales, has been characterized by high-angle, strike-slip displacement for the last 2 – 3 my. 7. A compressive tectonic episode prior to 2 – 5 my ago (pre-Pliocene) produced reverse and thrust faults within and immediately west of the Hosgri, which are imaged in geophysical data. However, these data show many of these faults are truncated by erosional horizons and overlain by sediments 2 my old or older that are not displaced by the faults. These data demonstrate that these thrust faults are not active in the current tectonic environment. 8. Lateral slip on the north end of the Hosgri is evaluated to be 1 – 3 mm/yr and decreases significantly southward. The upper bound estimate of the vertical component due to uplift and subsidence along the fault zone adjacent to the San Luis/Pismo block is about 0.4 mm/yr in Estero and San Luis Obispo bays. 9. The Los Osos fault zone is a reverse fault that dips to the SW and forms the NE margin of the San Luis/Pismo block. The fault is a segmented, 2-km-wide zone of discontinuous, subparallel and en echelon fault traces that extends from Morro Bay SE to the Lopez Regulating Reservoir for a distance of 36 km. The fault has four segments with distinct physical and behavioral differences and displacement histories. Displacements of marine and fluvial deposits indicate a late Quaternary net slip rate of no more than 0.2 – 0.5 mm/yr. 10. The SW boundary of the San Luis/Pismo block is a diffuse zone of minor deformation consisting of NW-trending faults and monoclinical folds. The San Luis Bay, Wilmar Avenue, Pecho, and Oceano faults constitute a zone that is 4 – 6 km wide and about 60 km long. 11. Using waveform modeling of the original teleseismic records of the 1927 Lompoc earthquake and comparisons to modern western California earthquakes, the Lompoc earthquake was found to have a nearly pure reverse fault mechanism striking N20°W and dipping 66° NE. Surface wave magnitude was reevaluated to be 7.0 rather than 7.3 or 7.5 reported in earlier studies. The epicenter was constrained based on good-quality seismic recordings to be approximately 34.5° N and 120.9° W, about 25 km west of Point Arguella. These parameters for the earthquake do not allow it to be located near Point Sal or along the southern reach of the Hosgri fault zone.
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	<p>Element 2 of the License Condition</p> <ol style="list-style-type: none"> 1. Based on data developed in Element 1, PG&E reevaluated the magnitude of the earthquakes used to determine the seismic bases for the DC NPP and confirmed the Hosgri fault to be the controlling seismic source and exhibits dominantly strike-slip style of offset with a minor dip-slip component. 2. A multifactor logic-tree analysis indicated a best-estimate magnitude of M_w 7.0; however, a conservative maximum earthquake magnitude is M_w 7.2 at a distance of 4.5 km and was used in subsequent ground motion analyses. <p>Element 3 of the License Condition</p> <ol style="list-style-type: none"> 1. Of three different approaches, it was found that response spectra developed from strong ground motion attenuation relationships from regression analyses envelope the corresponding response spectra obtained from the statistics of near-source records and those from numerical ground motion modeling studies. 84 %-tile level regression results were conservatively chosen for use in the seismic margin studies. <p>Element 4 of the License Condition</p> <ol style="list-style-type: none"> 1. <u>Soil/Structure Interaction effects (SSI)</u>: SSI was found to be substantial in short, stiff containment interior and the auxiliary building. SSI due to coherent ground motion input was found to be relatively small for taller more flexible containment shell and the turbine building. Spatial incoherence of ground motions generally results in reductions in the SSI responses that increase gradually with increasing frequency. Base-uplift of the containment structure generally results in small reductions in the horizontal acceleration responses and in base shear and overturning moment. However, it causes small increases in the horizontal and vertical displacements. 2. <u>Seismic Hazard Analysis</u>: Addressed all seismic sources that could affect DC. Logic trees were developed for the Hosgri, West Huasna, offshore Lompoc, Rinconada, Nacimiento and San Andreas faults. The Hosgri fault zone dominates the seismic hazard at the site. The Los Osos and San Luis Bay faults together only constitute 3 to 5% of the total hazard. Contributions from other faults are insignificant. 3. <u>Seismic Fragility Analysis</u>: Safety-related structures and equipment have high median seismic capacities. 4. <u>Probabilistic Risk Assessment</u>: Integrated the results of the seismic hazard and seismic fragility evaluations. Offsite power is potentially a large contributor when coupled with other component failures. Mean core damage frequency was determined to be 3.7×10^{-5}. The seismic component is a small contributor to the total mean core damage frequency of 2.0×10^{-4}. DC design is well-balance with no outstanding weak links. 5. <u>Deterministic Comparisons</u>: The deterministic 1977 Hosgri
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	<p>evaluation spectrum envelopes the site-specific 50th percentile at all frequencies and the 84th percentile spectrum below about 15 hz. Exceedance for frequencies above 15 hz is approximately 10%. Floor response spectra showed some exceedances over floor response spectra developed as part of the original design. However, the average of these exceedances at certain key frequencies are within approximately 10% of the design spectrum and are not significant in terms of design adequacy because they are accommodated by the existing design margin.</p>
Strengths	<p>PG&E's final report on the Long Term Seismic Program brings a wealth of new geological, seismological and geophysical data to bear on the wide range of seismic hazard issues relevant to the DC site. These new data and investigations identified previously unrecognized faults and also provided new constraints on the ages and styles of movement on known faults in the region. Integration of this data into a coherent model of crustal block rotations related to clockwise rotation of the western Transverse Ranges and the Quaternary transpressional tectonic stress environment of the Coast Ranges provides a compelling synthesis of the data. Comparison of DC seismic design criteria to results of state-of-the-art seismic hazard analyses generally provides a high level of confidence in the design ground motions.</p>
Limitations	<p>For the abundance of new field data collected as part of the PG&E seismic program, there is a rather striking lack of global positioning data (GPS) that could serve an important role in confirming the project's seismotectonic interpretations, or perhaps suggest alternative interpretations. Worldwide, GPS data has been an important tool in deciphering the contemporary seismotectonics of regions. As an example, one implication of the proposed crustal-block rotation model is that inter-block faulting would be expected to have a left-lateral strike-slip component, providing that the shortening rate is relatively uniform N-S throughout the region. However, focal mechanism data indicates a ubiquitous right-lateral component to the oblique-slip earthquakes. High-quality GPS data, over time, could serve to confirm, deny, or refine the block rotation model that has been synthesized from the current data.</p>
Comparisons/ Implications	<p>Seismological data from the network established as part of the LTSP indicates that the offshore Hosgri fault is a steeply dipping fault throughout the brittle crust (See also Title 26).</p> <p>While the original seismic design criteria for DC assumed that the 1927 Lompoc earthquake occurred on the southern Hosgri fault zone and have a magnitude 7.5, the most recent seismological work on this earthquake both by the USGS and PG&E places the epicenter farther seaward than Gawthrop's original interpretation where it is highly unlikely to have</p>

	been associated with the Hosgri fault (See Title 09 and discussion therein). The reassessed magnitude has also been lowered from 7.5 to 7.0. Nonetheless, the 7.5 assumed in the DC seismic design is an element of conservatism.
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Title 12	Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California
Year	1990
Study Area	Onshore Santa Maria Basin and southern Coast Ranges to the western Transverse Ranges
Authors	J. Namson and T.L. Davis
Source	The American Association of Petroleum Geologists Bulletin, Vol. 74, No. 4, p. 467-492
Scope	Implications of regional fold structures in the study area to potentially hidden faults at depth and to hydrocarbon trapping and timing
Data Used	Structural geologic data on folds and faults. Local and regional stratigraphy and stratigraphic correlations.
Methodology	Geometrical reconstruction analysis of fold structures using balanced cross sections and implied deep crustal faulting styles and mechanics
Summary Results	<ol style="list-style-type: none"> 1. Fold structures of the Santa Maria, Pismo, and Huasana basins, and southern Coast Ranges are interpreted to be the result of a seismically active, basement-involved, fold and thrust belt. The anticlines are fault-bend and fault-propagation folds associated with thrust ramps that step up from thrust flats and a regional detachment at 11-14 km depth. 2. The range front of the San Rafael Mountains is interpreted to be uplifted above a ramp in the point San Luis blind thrust. The length and continuity of the range front across the northern margin of the Santa Maria basin suggests it is underlain by an important regional fault. 3. Total convergence across the southern Coast Ranges from the San Andreas fault to the Santa Lucia Bank is 26.8 km. The convergent structures probably began to develop between 2 - 4 Ma and the convergence rate is 6.7 - 13.4 mm/yr. The total convergence across the onshore western Santa Maria basin is 9.2 km, yielding a convergence rate of 2.3 - 4.6 mm/yr. 4. Compressive earthquakes, broad bands of seismicity, geodetic measurements, and folded Quaternary deposits indicate the fold and thrust belt is undergoing active convergence. The ramp parts of these thrusts are the most likely seismogenic sources. Most of the thrusts are blind, presenting a major problem with existing seismic evaluations of the region, which generally have considered only strike-slip and reverse faults with surface expression. 5. The historic record of compressive earthquakes in central and

	<p>southern California and the 15 – 80 km length of the thrust ramps suggest the faults are capable of generating moderate to large earthquakes ($5.0 < M_w < 7.5$). If the convergence is relatively uniform over the last 2 – 4 my and is taken up seismically along the thrust ramps, then our slip rates indicate that moderate to large earthquakes can be expected every 75-299 yr on or near the southern Coast Range cross-section. These recurrence intervals do not account for areas away from the section lines and the regional recurrence interval for moderate to large compressive earthquakes of the entire area is probably more frequent. Additional structural analysis will be required to evaluate the recurrence interval of moderate to large earthquakes for the entire region.</p> <p>6. Cross-section restoration shows early formed hydrocarbon trap settings along the Casmalia-Orcutt anticlinal trend and under the Santa Maria Valley and accounts for the major hydrocarbon accumulations along these trends. Miocene and early Pliocene normal faults have played an important role in oil maturation and trapping. Two relatively untested hydrocarbon trap styles are present in the Santa Maria basin: concealed normal faults along the flanks of major anticlines and the subthrust structures along the north flank of the Camalia-Orcutt trend.</p>
Strengths	<p>A detailed geometrical reconstruction of fold-fault kinematics using techniques that have provided geological reasons and justification for buried thrusts in the highly compressed Los Angeles basin region, some of which have been associated with recent earthquakes.</p>
Limitations	<p>Geometric reconstructions are nonunique and are based on estimates of lateral shortening in the planes of the crustal cross-sections that are being modeled. To the extent that crustal material has moved in and out of the planes of the cross-sections (i.e., strike-slip movement perpendicular to the section lines) over the time period of the reconstructions, errors are introduced into the convergence and slip rate estimates. The method is predisposed to expecting and predicting thrust and compressive fault movements and must infer mid- and deep-crustal faults and movements in order to replicate surface folds and structure. An underlying assumption is that virtually all lateral Pacific-NA plate margin slip is accommodated by the San Andreas, which is not supported by earthquake focal mechanisms in the area [26].</p> <p>No additional resolution of faulting geometry in the brittle crust is gained in this modeling procedure. The summary cross-section in Figure 7 of this paper shows the Hosgri fault zone as a steeply dipping reverse fault that abruptly stops at a depth of approximately 7 km. No resolution of a possible intersection with the Point San Luis Thrust, if it exists, is provided by the method.</p>

Comparisons/ Implications	<p>Marine terrace data indicate folding of anticlines and synclines has not been active in the Pleistocene.</p> <p>Alternative geometric models have been proposed for the evolution of the Santa Maria basin and the Orcutt, Purisimal anticlines that allow for steeply dipping shallow crustal faults without the requirement for mid- and deep-crustal thrust ramps (i.e., Seeber and Sorlien, 2000). An alternative model has been proposed for the accommodation of deep and sub-crustal strain in a compressive/transpressive environment that does not require detachment faulting and associated thrust ramps (See Title 24).</p>
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Title 13	Review of Geological and Geophysical Interpretations Contained in "Pacific Gas and Electric Co. Final Reports of the Diablo Canyon Long Term Seismic Program for the Diablo Canyon Power Plant"
Year	1991
Study Area	Central coastal California and offshore
Authors	U.S. Geological Survey staff
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34, Appendix C
Scope	Geological/geophysical review and comments on PG&E's LTSP
Data Used	LTSP geoscience data and interpretations and existing geoscience data in the region
Methodology	Examination and review of LTSP geological/geophysical data and interpretations in the context of state-of-the-art understanding of central coastal California geology and tectonics
Summary Results	<ol style="list-style-type: none"> 1. Acknowledges that the LTSP is perhaps the most comprehensive study to date of earthquake hazards at an operating power plant, but that some issues remain unresolved or controversial due to the lack of definitive evidence. 2. Confirms the five capable faults identified in the LTSP near DC, four of which are newly identified (Los Osos, Olson, San Luis, and Wilmar Avenue) and one which was known to exist (Hosgri). Confirms the magnitudes expected along these faults. 3. Disagrees with the LTSP interpretation that the Hosgri is a strike-slip fault with little or no vertical component of slip that is chiefly supported by surface and shallow trench investigations near San Simeon Point. This data must be weighed with other lines of evidence relevant to the character of the Hosgri at depth. 4. Interprets the Hosgri fault as a broader fault system that includes the Hosgri fault zone and San Simeon faults as well as fault and fold belts towards the southwest, some of which neither cut nor deform the seafloor. Structures in the system are primarily compressional but may also exhibit right-lateral strike-slip (as the San Simeon fault). 5. Data for the seafloor fault zone and broader fault system suggest NE dips of 50 - 70° at depths of 4 - 10 km. Evidence is taken to include the focal mechanism of the Lompoc earthquake ($M_s = 7.0 - 7.5$). 6. Los Osos fault and others on the SW side of the Pismo syncline are lower hazard than the Hosgri, but surface measurements of low dips are largely discounted by PG&E. Segmentation

	<p>arguments for the Los Osos fault are model-dependent and unconvincing but the probabilistic magnitude of 6.8 for an earthquake on this fault appears appropriate. Lower magnitudes and hazard posed by the faults on SW side of Pismo syncline appear appropriate although other, less likely, tectonic models could be chosen that would increase the hazard from these faults.</p> <p>7. A logic-tree for the Hosgri fault is biased to favor a strike-slip faulting model and yields probability distribution functions for the fault that are similarly biased. Observed data over model-based values would increase the weight for oblique-slip and thrust earthquakes. Some questionable procedural steps in the logic tree also bias the number of outcomes in the same way. Greater reliance on the LTSP data will tend to raise the mean magnitude for the probabilistic earthquake and change its standard deviation. Many of these points apply to the seismic hazard analysis tree that is used in the PRA of DC.</p> <p>8. Most significant differences with PG&E interpretations concern the dip and earthquake slip-mechanism for the Hosgri fault at depths of 4 – 10 km. If ground motion depends on fault characteristics, values for a vertical strike-slip fault may underestimate those for oblique slip, reverse or thrust faults.</p>
Strengths	USGS staff has considerable experience addressing complex geological problems.
Limitations	Most significant differences with PG&E regarding Hosgri fault geometry at 4 – 10 km deep is where there is no direct imaging of the fault plane.
Comparisons/ Implications	<p>USGS comments on the Hosgri fault appear to be based on acceptance of a more ubiquitous compressive thrust seismotectonic model for the central Coast Ranges region (See Titles 10 and 12). However, the authors of these compressive tectonic models themselves are either noncommittal on the dip of the Hosgri fault zone (Title 10) or show the Hosgri in cross-section as a steeply-dipping fault (Title 12). Nonetheless, NRC redefined PG&E's logic-tree PSHA Hosgri inputs to higher values for thrust faulting and required PG&E to demonstrate adequate seismic margins (See Title 15).</p> <p>The USGS broadens the definition of the Hosgri fault zone to include structure SW of the fault, including the 1927 Lompoc earthquake, which latest seismological research indicates is unlikely associated with the southern part of the Hosgri fault zone (See Title 09 and Additional References therein).</p> <p>Shallow surface dips of some fault traces in the Hosgri zone may be related to flower structure in a transpressional strike-slip fault zone (See Title 28) and are not indicative of fault attitude at depth.</p>

Title 14	Independent Assessment of the Earthquake Potential at the Diablo Canyon Power Plant, San Luis Obispo County, CA
Year	1991
Study Area	Central coastal California and offshore
Authors	D.B. Slemmons and D.G. Clark
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34, Appendix D
Scope	Independent geological evaluation of the earthquake potential at DC in support of USNRC review of PG&E's LTSP
Data Used	Independent field data collected and analyzed by the University of Nevada, Reno (UNR), and PG&E LTSP geoscience data and interpretations along with existing geoscience data in the region
Methodology	Review and synthesis of LTSP geological/ geophysical data with independent UNR field data and interpretations of local fault zones in proximity to DC
Summary Results	<ol style="list-style-type: none"> 1. UNR's parameterization of the Hosgri fault zone and its earthquake potential is similar to PG&E's with somewhat different weighting in the logic-tree characterization and somewhat different segment boundaries. 2. The Hosgri fault is primarily a strike-slip fault although it may have a subordinate oblique-slip component. Weightings are: Strike-slip = 0.65; oblique-slip = 0.30; thrust = 0.05. The fault extends to 12 km deep and is well segmented. Segment lengths and weightings are: less than 22 km = 0.20; 50 km = 0.55; 70 km = 0.20; 110 km = 0.05. Average displacement per event is expected to be 1 m (0.5) or 2 m (0.5). The slip rate is 2 – 3 mm/yr and within the range of slip rates estimated by PG&E (i.e., 1 – 3 mm/yr). The recurrence frequency is 300 to 2,000 yrs with a preferred frequency of 1,000 years. The maximum credible earthquake (MCE) is 7.2. 3. The characterization of the Los Osos fault is similar to that of PG&E although the UNR estimated MCE is slightly lower than PG&E's estimate. The fault is part of a zone 2 or 3 km wide and is strongly partitioned along the San Luis/Pismo subblocks. The activity rate may decrease eastwards. Weightings are: reverse-slip = 0.9; oblique-slip = 0.1; 60° dip = 0.7; 30° dip = 0.3. Full segment rupture 18 km long is preferred with an average displacement of 2.1 – 2.5 m. MCE is estimated to be 6.5 – 6.8. The vertical component slip rate is 0.2 mm/yr. 4. Although the PG&E model of the southwest border zone is

	<p>consistent with field observations, an alternative also fits the seismologic and structural relationships. Active faults are considered to be distributed over a zone 4 km wide opposite the Irish Hills subblock and the zone is strongly segmented. Similar weighting for reverse-slip as the Los Osos fault. Irish Hills subblock rupture length is approximately 13 km. Vertical component slip rate is 0.2 mm/yr with about 70% of the deformation occurring on the Olson fault and San Luis Bay fault zones and about 30% occurring offshore on the Pecho and perhaps other unidentified structures. The integrated boundary zone gives an MCE of 6.5 with a seismogenic depth of at least 5 – 7 km.</p>
Strengths	<p>A detailed review and alternative assessment of geological evidence bearing on the earthquake potential of the DC region and PSHA logic-tree interpretations supported by independent field study, apparently commissioned by NRC in response to USGS review comments on the PG&E logic-tree inputs.</p>
Limitations	<p>Review appears very thorough with respect to fault lengths and segmentation that bears on estimates maximum earthquakes.</p>
Comparisons/Implications	<p>Independent field studies of fault zones in the vicinity of DC commissioned by the NRC yielded relatively minor differences with PG&E LTSP interpretations, mostly related to the segment lengths of the faults that result in little impact on the estimated fault MCE's.</p>

Title 15	Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2; Dockets Nos. 50-275 and 50-323
Year	1991
Study Area	Diablo Canyon NPP Site and surrounding area
Authors	USNRC
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34
Scope	NRC staff review and conclusions regarding PG&E license condition regarding the Long-Term Seismic Program (LTSP)
Data Used	Data and materials submitted by PG&E related to the geological and seismological setting of the power plant site
Methodology	USNRC technical review and interaction with PG&E since submittal of the LTSP final report in July, 1988
Summary Results	<ol style="list-style-type: none"> 1. PG&E has met its operational license condition, subject to submittal of analyses to confirm its statements that plant seismic margins are adequate to accommodate spectral exceedances discussed in the SSER. 2. Element 1: The geological, seismological and geophysical investigations conducted by PG&E for the LTSP are the most extensive, thorough, and complete ever conducted for a nuclear facility in the U.S. 3. Element 2: The Hosgri fault causes the maximum ground motion at the site and has a maximum credible magnitude of 7.2. Maximum credible earthquakes associated with other on any other fault in the site vicinity would produce smaller ground motions at the site. 4. Element 3: PG&E reevaluated ground motion at the site using a slip distribution on the Hosgri fault that is 65% strike-slip, 30% oblique-slip, and 5% thrust-slip. NRC staff concludes that that ground motion at the site should be evaluated for an earthquake on the Hosgri fault that is 2/3 strike-slip and 1/3 reverse slip. 5. NRC staff's own analysis of ground motions at the site from their preferred slip model of the Hosgri fault shows that both their 50th and 84th percentile horizontal ground-motion spectra at the site is equal to or less than the PG&E spectra at frequencies above 1 Hz, but exceeds PG&E spectra at frequencies below 1 Hz. The staff's 84th percentile vertical spectra exceed PG&E vertical spectra over the frequency range of 1 – 10 Hz. To fully satisfy Element 4, PG&E demonstrate that the plant can withstand these exceedances.

	<ol style="list-style-type: none"> 6. Element 4: NRC staff found that the PG&E soil-structure interaction (SSI) analyses to determine the effect of dynamic interaction between the plant structures and foundation rock under the plant were comprehensive, thorough, and acceptable. 7. PRA analysis by PG&E for internal and external events estimated that the core damage frequency is 2×10^{-4}, which is similar to other nuclear plants. The NRC staff estimate is 4×10^{-4}. Internal events contribute 63% to the PG&E estimate, seismic contributes 18%, and other external events 19%. NRC staff estimates are 70%, 10% and 20%, respectively. 8. PG&E LTSP ground motion estimates show adequate margin for major plant structures. PG&E plans to modify all safety-related masonry walls. 9. NRC agrees that the seismic margins are adequate to accommodate horizontal and vertical spectral exceedances resulting from the staff's ground motion estimates, but requires PG&E to confirm its conclusion through analyses. 10. Subject to confirmation of seismic margins (#9 above), NRC concludes that PGE has met Element 4 of the license condition.
Strengths	NRC position was developed following extensive review of PG&E LTSP results from three years of investigations and the commissioning of independent verification studies..
Limitations	N/A - a regulatory document. Conditions of findings are stated above.
Comparisons/ Implications	Based on USGS review comments and NRC-commissioned independent evaluations, NRC raised the probability of thrust faulting on the Hosgri fault above PG&E's estimate and performed their own PSHA. NRC agreed that the DC seismic margins are adequate to accommodate horizontal and vertical spectral exceedances resulting from these modified ground motion estimates, but required PG&E to confirm its conclusion through analyses.

Title 16	Seismotectonic Framework of Coastal Central California
Year	1994
Study Area	Central coastal California
Authors	D.G. Clark, D.B. Slemmons, S.J. Caskey and D.M. dePolo
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 9-30.
Scope	Regionalization of central coastal California between Monterey Bay on the north and Los Angeles on the south into five distinctive seismotectonic domains.
Data Used	Physiographic relief, Quaternary fault and fold styles, basement rock types, historical earthquakes $M \geq 5.0$ and contemporary earthquakes $M_L \geq 2.5$ between 1969-89, earthquake focal mechanisms, regional tectonic stress.
Methodology	Synthesis of the data into a descriptive model of domains exhibiting distinctive deformational styles along with definitions of the domain boundaries.
Summary Results	<ol style="list-style-type: none"> 1. Contemporary deformation of coastal central California consists of 5 distinctive domains separated by major faults that accommodate much of the tectonic strain release in the region. The domains are. 1. The Transverse Ranges on the south; 2. The Santa Maria – San Luis Range domain on the west (host domain to DC NPP); 3. The Coastal Franciscan domain bordering the Santa Maria – San Luis Range domain on the east; 4. The Salinian domain neighboring the San Andreas fault on the west; and 5. The Western San Joaquin Valley domain neighboring the San Andreas fault on the east. 2. Styles of deformation progressively change from pure reverse and left-lateral reverse-oblique faulting in the Transverse Ranges and Santa Maria Basin – San Luis Range domains to reverse and right-lateral reverse-oblique displacement in the Coastal Franciscan domain and pure right-lateral faulting in the Salinian domain. The western San Joaquin Valley domain exhibits principally compressional deformation. 3. The Transverse Ranges domain exhibits a relatively high level of small earthquakes and the frequent occurrence of moderate and large earthquakes along with locally high rates of active tectonism. The Santa Maria Basin – San Luis Range domain is characterized by deformation similar to the Transverse Ranges,

	<p>but with lower strain rates. The Salinian domain exhibits relatively little deformation compared to neighboring domains that is attributed to a high-strength crystalline basement that tends to resist deformation. Details of deformation in the Coastal Franciscan domain is poorly understood but earthquake data indicate broad internal deformation in the low-strength Franciscan Complex basement rocks. Deformation in the Western San Joaquin Valley domain east of the San Andreas Fault is characterized primarily by thrust and reverse faulting associated with folding, which is concentrated along the domain's eastern margin.</p>
Strengths	A concise overview and synthesis of "map view" tectonic information available.
Limitations	Focus of the article is primarily on "map view" geology with relatively little discussion and constraint provided in the vertical crustal dimension of the defined domains.
Comparisons/ Implications	Provides the regional tectonic framework for Titles 17 – 22.

Title 17	Los Osos Fault Zone, San Luis Obispo County, California
Year	1994
Study Area	Northeastern boundary of the San Luis Range/San Luis – Pismo structural block, which is host to DC NPP
Authors	W.R. Lettis and N.T. Hall
Source	Geological Society of America Special Paper 292, “Seismotectonics of the Central California Coast Ranges”, I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 73-102.
Scope	Detailed geological investigation of the Los Osos fault zone including surface geological mapping and paleoseismic investigations.
Data Used	Original field geologic, geomorphic and geophysical data.
Methodology	<i>Onshore:</i> Interpretation of black & white, color infrared, and low sun-angle aerial photographs; field geologic surface mapping; subsurface exploratory drilling; excavation and mapping of trenches across fault traces; marine and fluvial terrace mapping and correlation. <i>Offshore:</i> Interpretation of sea-floor bathymetry, side-scan sonar, and high-res seismic reflection profiles.
Summary Results	<ol style="list-style-type: none"> 1. The Los Osos fault zone is a complex reverse or thrust fault along the northeastern margin of the San Luis – Pismo structural block that extends a distance of at least 36 km between Morro Bay on the northeast and the Lopez reregulating reservoir on the southwest. The fault may extend another 13 km northwesterly offshore and intersect with the Hosgri fault as well as an additional 8 km southeasterly and intersect with the West Husana fault near Twichell Reservoir for a total possible length of 57 km.. 2. The Irish Hills and Lopez Reservoir are two well-defined central segments that total 36 km. 3. The Irish Hills segment has subparallel traces up to 2 km wide, multiple late Pleistocene and Holocene surface ruptures, and a slip rate of 0.2 to 0.8 mm/yr. 4. Although the Lopez Reservoir segment is interpreted to have been active in the Quaternary, it has poor geomorphic expression, no definitive evidence for late Quaternary faulting, and a slip rate less than 0.1 mm/yr. 5. The northwestern and southeastern extensions of the Los Osos fault zone are not clearly expressed in the geomorphology and are not clearly active in Quaternary time. These are the Estero Bay and Newsom Ridge segments, respectively.

	<p>6. The Los Osos fault zone accommodates regional NE-SW-directed Quaternary crustal shortening and appears to accommodate motion between the uplifted San Luis – Pismo structural block from the subsiding or tilting Cambria block. If this deformational style is representative of the domain as a whole, late Quaternary crustal shortening is occurring primarily as rigid block uplift, subsidence and tilting controlled by reverse displacements on NW-trending faults.</p>
Strengths	<p>Significant new and detailed geological and geophysical data is developed and synthesized into a coherent deformational fault model for the NE boundary of the San Luis – Pismo structural block, which is the host structural feature to the DC NPP.</p>
Limitations	<p>Lack of deeper geophysical data to define fault geometry greater than about a few hundred meters deep.</p>
Comparisons/ Implications	<p>Provides the geological basis for faulting along the NE boundary of the San Luis – Pismo block in the LTSP (Title 11).</p>

Title 18	The Wilmar Avenue Fault: A Late Quaternary Reverse Fault Near Pismo Beach, California
Year	1994
Study Area	Southwestern San Luis Obispo County, California. Southeast margin of the San Luis Range.
Authors	S.P. Nitchman and D.B. Slemmons
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 103-110.
Scope	Report on field investigation of the 7-km long Wilmar Avenue fault along the southeastern boundary of the San Luis Range.
Data Used	Local stratigraphy, uplifted and offset marine terraces, water well logs to constrain interpretations at shallow depths.
Methodology	Geological mapping and field methods
Summary Results	<ol style="list-style-type: none"> 1. Wilmar Avenue fault strikes N60°W along a 7-km length on land between Arroyo Grande Creek and Wilmar Avenue Beach at the southeastern margin of the San Luis Range and has been the primary structural boundary of the range at this location since late Pliocene time. The fault is part of the seismogenic southwestern boundary of the San Luis – Pismo structural block. 2. Two discrete structural sections of the fault are recognized: A western section of the fault that exhibits block uplift and an eastern section marked by a monoclinal warp that is interpreted to be a fault propagation fold above a blind reverse fault. 3. Vertically offset marine terraces indicate vertical displacement along the fault since the late Pleistocene at a rate approximately between 0.04-0.07 meters per thousand years (i.e., 0.04-0.07 mm/yr).
Strengths	An insightful synthesis of field mapping with available data to explain a rather complex relationship of faulting and folding over a relatively short distance.
Limitations	This paper is well-focused on structural delineation of the Wilmar Avenue fault on land. A possible continuation with inferred faults offshore is implied in Figure 2 and suggests follow-up offshore studies to better define an offshore extension, if any.
Comparisons/ Implications	Provides the geological basis for faulting style and rate along the SW boundary of the San Luis – Pismo block in the LTSP (Title 11).

Title 19	Quaternary Deformation of the San Luis Range, San Luis Obispo County, California
Year	1994
Study Area	San Luis Range, San Luis Obispo County, California
Authors	W.R. Lettis, K.I. Kelson, J.R. Wesling, M. Angell, K.L. Hanson, N.T. Hall
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 111-132.
Scope	Quaternary deformational model specific to the San Luis Range is placed in a regional context of central coastal California and the broader Pacific/North American plate boundary.
Data Used	Local stratigraphy, fault-specific mapping and trenching data, uplifted and offset marine terraces.
Methodology	Synthesis of the data into a Quaternary deformational model specific to the San Luis Range and placed in a regional deformational context.
Summary Results	<ol style="list-style-type: none"> 1. NE margin is the Los Osos fault zone; a SW-dipping reverse fault with recurrent late Pleistocene and Holocene displacement and a slip rate of 0.2-0.7mm/yr. Range uplift is facilitated along this zone. 2. SW margin is complex Quaternary reverse faults including the Wilmar Avenue, San Luis Bay, Olson, Pecho and Oceano faults that dip moderately to steeply NE. Cumulative net dip-slip displacement rate is about 0.16 – 0.30 mm/yr. Slip rates on individual faults generally range from 0.04 to about 0.11 mm/yr. The complex of faults separates the uplifting or tilting San Luis Range from the subsiding Santa Maria Basin to the SW. 3. Styles and rates of deformation in and bordering the San Luis Range are inferred to be representative of that occurring in the Los Osos – Santa Maria (LOSM) domain. Crustal shortening is accommodated by reverse faulting and uplift/subsidence, or tilting, of blocks. In the southern and SE LOSM, shortening also may be accommodated by folding and thrust faulting. The LOSM is transitional between the western Transverse Ranges on the south and the N-NW trending structures of the Santa Lucia and San Rafael Ranges on the NE. 4. Quaternary deformation in the LOSM is related to: a) transpression along the NA/Pacific plate margin, b) clockwise rotation of the western Transverse Ranges, and c) convergence of LOSM against the rigid Salinian crust that underlies much of the Santa Lucia and San Rafael Ranges to the NE.

Strengths	A compelling synthesis that brings together a wide range of new geological data and interpretations in a coherent model of Quaternary deformation of the San Luis Range and its bordering fault zones.
Limitations	Proposed block deformation model for the San Luis Range, and the LOSM in general, is based on surface, or very near surface, geological data. Deeper crustal geophysical/seismological data that might bear on the block deformation model is not part of this discussion.
Comparisons/ Implications	Provides the geological basis for faulting style and rate along the margins of the San Luis Range in the LTSP (Title 11). Issue of deeper seismological data bearing on block boundaries was later addressed in Title 26, supporting the block-model concept proposed here.

Title 20	Estimated Pleistocene Slip Rate for the San Simeon Fault Zone, South-Central Coastal California
Year	1994
Study Area	South-central coastal California, generally Point San Simeon on the south to Ragged Point on the north.
Authors	K.L. Hanson and W.R. Lettis
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 133-150.
Scope	Determination of style and rate of movement on the San Simeon fault zone primarily from detailed mapping and analysis of deformed and offset marine terraces.
Data Used	Detailed geologic field map data, marine terrace elevations and ages, shoreline configurations, geomorphic drainage deflections
Methodology	Age dates of marine terraces and displacement amount and sense by strands of the San Simeon fault are used to determine the slip rate and offset style along the San Simeon fault zone.
Summary Results	<ol style="list-style-type: none"> 1. Terraces are offset and warped within a zone of shearing 500 m wide with ratios of vertical-to-horizontal (V:H) slip between 8:1 and 50:1 demonstrating the San Simeon fault zone is dominantly right-lateral strike-slip. 2. Based on present locations of strand lines on the marine terraces and reconstruction of past shoreline configurations, slip rates range between about 0.4 - 11 mm/yr. Best constrained values are 1 - 3 mm/yr. Slip rates from offset drainages across the fault corroborate the 1 - 3 mm/yr slip rate estimates from the marine terrace study. This geologically determined rate is comparable to geodetically modeled estimates of shear west of, and parallel to, the San Andreas fault. 3. The San Simeon fault zone accommodates a significant amount of transpressional strain along the NA/Pacific plate margin and is part of the larger San Gregorio-San Simeon-Hosgri near-coastal fault system.
Strengths	Careful treatment and analysis of difficult data and uncertain paleogeographic reconstructions to obtain constraints on slip rate.
Limitations	Large uncertainties are inherent in the type of geological data and shoreline reconstructions that are used in this investigation, although corroboration of several lines of evidence lends credibility to the best

	constrained slip values of 1-3 mm/yr.
Comparisons/ Implications	Provides geological constraints on the faulting style and slip rate along the San Simeon fault zone as a basis for modeling the fault zone in the LTSP (Title 11).

Title 21	Holocene Behavior of the San Simeon Fault Zone, South-Central Coastal California
Year	1994
Study Area	San Simeon and a few km to the NW
Authors	N.T. Hall, T.D. Hunt, P.R. Vaughan
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 167-189.
Scope	Detailed geologic investigation of the San Simeon fault to determine the style of faulting, slip rate, slip per event, and recurrence frequency.
Data Used	Geological fault-trench mapping and related field data, radiocarbon and TL age dates, geomorphic analysis, auger borings and exploratory pits.
Methodology	Detailed fault trenching; shallow boring and pit excavation geologic investigation methods, marine terrace analysis
Summary Results	<ol style="list-style-type: none"> 1. Approximately 2.5 km NW of San Simeon, the San Simeon fault consists of two and possibly four or more strands across a 400-m-wide zone that narrows to about 120 m wide at San Simeon. 2. Geologic and soils data from four sites indicate that the San Simeon strands are NW-striking, vertical to near-vertical, right-slip faults exhibiting sub-horizontal slickensides. 3. Strike-slip to dip-slip ratios range from about 8:1 to greater than 10:1. 4. Slip rate is 0.9 - 3.4 mm/yr. Best constrained value is 1.0 -1.4 mm/yr along one major fault strand with marine terrace analysis suggesting that this estimate may approximate the slip rate for the fault zone as a whole. 5. Net slip estimates are 1 - 2 m per event with recurrence frequency of 265 - 2,000 years. Best constrained values are between approximately 600 - 1,800 years with events not occurring at uniform intervals.
Strengths	Most detailed paleoseismological investigation performed on the San Simeon fault zone.
Limitations	Holocene slip rates are regarded as preliminary and are sensitive to assumptions including flat-lying beds. As an example, slip rate increases approximately 33% for an initial bed dip of 2°. Limits of measurements lie within 1° to 2°.
Comparisons/	Provides additional geological constraints on the faulting style and slip

Implications	rate along the San Simeon fault zone as a basis for modeling the fault zone in the LTSP (Title 11).
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Title 22	Hosgri Fault Zone, Offshore Santa Maria Basin, California
Year	1994
Study Area	Hosgri fault zone, defined as the southern section (south of Purisima Point) of a 435 km-long major coastal fault system.
Authors	J.W. Steritz and B.P. Luyendyk
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 191-209.
Scope	Structural and geological interpretation of more than 1,500 mi of processed offshore seismic reflection profiles to define the southern termination of the Hosgri fault zone (HFZ), its style of faulting and its relationship to neighboring structures.
Data Used	More than 1,500 mi of processed offshore seismic reflection data
Methodology	Mapping of a Miocene-Pliocene age unconformity and reflective upper Miocene horizons from the seismic reflection data to discern the early deformational history of the HFZ.
Summary Results	<ol style="list-style-type: none"> 1. The HFZ is a structural boundary separating the offshore Santa Maria Basin structure to the west from the onshore Santa Maria Basin and western Transverse Ranges to the east. Fold and fault trends east of the HFZ generally trend 20°- 25° more westerly than these trends west of the HFZ and fold wavelengths east of the fault are approximately one-third of those west of the fault. 2. The HFZ changes trend over three sections: a southern section south of the Honda fault of the western Transverse Ranges trends close to N 47° W, a middle section from the Honda fault to south of Purisima Point trends close to N 5° W, and a northern section that trends N23° W. 3. The middle section is best imaged in the reflection data and shows two major fault traces with subvertical offsets of Pliocene and Miocene reflectors with fault widths not exceeding 300 m wide. The two HFZ strands bound a central graben with the sense of separation reversing across a "scissors pivot" from north to south along the structure. HFZ fault planes appear subvertical for more than 4,000 ft deep extending along narrow zones of faulted deformation. Vertical separation is variable on the main trace which is nearly linear in map view. Drag folds are consistent with right-lateral movement and reverse fault features are absent. 4. The southern HFZ section trends more northwesterly and widens to an average width of 1.8 km. On two lines, fault planes of the

	<p>zone were dipping 30° to the northeast. Left-lateral oblique faults of the western Transverse Ranges do not offset the HFZ but their motion appears to be accommodated along the HFZ. Oblique right-slip and reverse-slip is expected on this southern segment of the HFZ.</p> <ol style="list-style-type: none"> 5. The northern segment displays characteristics intermediate between the northern and central segments, although interpretation of fault planes and inter-fault zone reflectors is difficult. Where observed, the HFZ exhibits subvertical eastward dips through the upper 3,000 ft that are interpreted to be flower structure consistent with right-slip movement. 6. The HFZ pre-dates widespread Pliocene orogeny when compression across the NA-Pacific boundary increased. Contractile structures and thrust faults of the offshore Santa Maria Basin are clearly distinguished from the HFZ, which is better described as an oblique right-slip fault. Discrepant estimates of total offset along the HFZ over the years might be explained by releasing right-steps in the HFZ south of Point Sur and dissipation of right slip by folding and faulting east of the HFZ. However, larger offsets likely may have been accommodated west of the HFZ along the Santa Lucia Bank fault.
Strengths	The most detailed geophysical investigation of the HFZ to date examining a large data base of nonproprietary seismic reflection profiles. The HFZ appears to be well imaged by the data in at least its central and southern segments lending credibility to the interpretations.
Limitations	Seismic lines across the northern section of the HFZ are more widely spaced than along the central and southern segments and interpretation is more difficult lending less certainty the nature of the fault in this area.
Comparisons/ Implications	Provides geophysical constraints on faulting style along the offshore Hosgri fault zone fault zone as a basis for modeling the fault zone in the LTSP (Title 11). Notably, The change in offset style N-S along the fault and the interpretation of flower structure in the upper part of the central segment ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 23	Shallow Geologic Structure, Offshore Point Arguello to Santa Maria River, Central California
Year	1994
Study Area	Offshore central California, Point Arguello to Santa Maria River
Authors	D. Cummings and T.A. Johnson
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 211-222.
Scope	Collection and interpretation of seismic reflection profiles for assessment of potential shallow geological hazards within the 3-mi. zone of state waters.
Data Used	A total of 1,338 km (831 statute mi.) of geophysical lines with five separate seismic data sets recorded simultaneously: a) 24-channel digital watergun (deep data quality poor to fair) , b) analog watergun (deep data quality poor to fair), c) boomer (poor to fair data quality), d) subbottom profiler (poor to fair data quality), and d) echo sounder (good data quality).
Methodology	Interpretation of the collected geophysical data
Summary Results	<ol style="list-style-type: none"> 1. West of Point Sal and east of the HFZ, the informally named the Offshore Point Sal fault is newly identified and follows a strike mostly parallel to the HFZ. The Offshore Point Sal fault offsets the more westerly trending Lions Head fault with a right-lateral sense. The Offshore Point Sal fault does not appear to offset a Pleistocene erosional surface and is considered to be potentially active. 2. The HFZ does not cut the Pleistocene erosion surface but does exhibit flower structure in the shallow subsurface consistent with strike-slip faulting in a convergent wrench tectonic system. 3. Southern splays of the HFZ appear to merge with the onshore Lompoc-Solvang and Santa Ynez River faults of the western Transverse Ranges. 4. Potential geologic hazards from earthquakes in the study area include ground shaking, slumps, debris flows, liquefaction and sediment de-gassing. There is a tsunami potential from subsea landslides or surface fault movement. 5. Focal mechanisms and structure in the region are consistent with approximate N-S horizontal compressive stress.
Strengths	A new source of geophysical data that bears on the shallow structure and

	structural relationships of the HFZ.
Limitations	Interpretations restricted to the upper 0.2-sec two-way travel time, approximately 500 m (1,600 ft) deep due to deep data quality and processing limitations.
Comparisons/ Implications	Provides geophysical constraints on faulting style along the offshore Hosgri fault zone fault zone as a basis for modeling the fault zone in the LTSP (Title 11). The interpretation of flower structure in a convergent wrench tectonic system in the upper part of the fault zone ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 24	Seismotectonic Patterns Across a Part of the Central California Coast Ranges
Year	1994
Study Area	65-km-wide corridor across the central California Coast Ranges between Lopez Point on the north and point Estero on the south.
Authors	D.P. Dehlinger and B.A. Bolt
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 223-229. <i>See also:</i> Bulletin of the Seismological Society of America, 1987, Vol. 77, p.2056-2073, "Earthquakes and Associated Tectonics in a Part of Coastal Central California" by the same authors.
Scope	Upper crustal structures in an area west of the San Andreas fault to seaward of the HFZ.
Data Used	Focal mechanisms, focal parameters (M_L 2.3 - 6.0, 1976 - 86) , and crustal basement rock types
Methodology	Geological/seismological synthesis of the data
Summary Results	<ol style="list-style-type: none"> 1. The study area is divided into three provinces: a) the seismically active San Andreas province, b) the seismically quiescent province from the San Andreas fault westwards to near the Nacimiento fault, which is underlain by crystalline Salinian crust, and c) a compressive belt along both sides of the coastline that extends from the Nacimiento fault to about 15 km seaward of the HFZ. 2. San Andreas is characterized by horizontal shear. Faulting in compressive belt either side of the coastline is predominantly oblique reverse along moderate to steeply NE-dipping planes and right-lateral horizontal components where displacements are horizontal along NE-dipping planes. 3. The provinces appear to be relatively rigid blocks of contrasting upper crustal strength whose focal mechanisms are rotated relative to one another and that are separated by narrow transition zones. The base of the seismogenic zone is interpreted to be a thermally controlled boundary rather than a lithologic boundary. 4. No earthquake evidence has been observed to indicated a the presence of a detachment surface within the seismogenic zone (12 km deep) and no direct evidence of a deeper detachment has

	<p>been observed. 33 earthquakes across the domains indicated fault planes that dip more than 35° which appears inconsistent with thrust faults that sole into near-horizontal detachment faults at the base of the crust.</p> <p>5. Any detachment associated with horizontal shortening, if present, will be restricted to the region of reverse faulting southwest of the Nacimiento fault. But the need for invoking deep detachment for conservation of crust in shortening is obviated by a model of creep and deep plastic deformation in ductile rocks. The stress and fault patterns in the study corridor are more consistent with creep and flow modes of deformation beneath the upper crust than with a widespread detachment surface.</p>
Strengths	An original interpretation of deep/sub-crustal strain dissipation not requiring horizontal detachment faulting and accompanying thrust ramps (i.e., See Title 12)
Limitations	Distinctions between upper crustal stress distribution and resulting strains between a deep crustal detachment and deep “creep and flow modes” are alluded to but not made explicitly clear.
Comparisons/ Implications	Offers an alternative concept to detachment faulting (i.e., Title 12) for the accommodation of deep crustal shortening in which more heterogeneous stress and strains are allowed in the brittle upper crust.

Title 25	Block Rotation and Termination of the Hosgri Strike-Slip Fault, California, from Three-Dimensional Map Restoration
Year	1999
Study Area	South-Central California offshore including the Santa Maria Basin
Authors	C.C. Sorlien, J.J. Kamerling, D. Mayerson
Source	Geology, Vol. 27, No. 11, p. 1039-1042
Scope	Implications of geological block models to displacement style and amount of the Hosgri fault.
Data Used	Digital structure contour maps developed from offshore seismic reflection data, well logs from 77 exploration wells, and published geologic and subsurface maps.
Methodology	Post-Miocene finite block displacements for the study area are inferred by restoring faults and folds to their pre-deformed horizontal attitude using a computer algorithm.
Summary Results	<ol style="list-style-type: none"> 2. Total post-Miocene right-lateral strike-slip displacement on the Hosgri fault is determined to be 10.5 km. 3. 3.5 km of the total slip along the southern Hosgri is absorbed by folding, thrust overlap, and rotation of elongate blocks between fault strands. 4. The Hosgri fault terminates southeastward into east-trending folds and reverse-separation faults of the western Transverse Ranges Province. 5. A decollement thrust in the lower crust interpreted by others beneath the Santa Maria Basin could facilitate proposed block rotations in the upper crust. 6. Block rotations between the Hosgri fault on the west and an inferred dextral (right-lateral) shear zone onshore will be accompanied by oblique-sinistral (left) reverse earthquakes along northwest-southeast-trending block boundary faults.
Strengths	Novel application of an existing algorithm to gain insight to issues regarding the Hosgri fault as well as offering a predicted deformational style of the study area in general.
Limitations	The algorithm (UNFOLD) requires a fixed reference line against which maps are "unfolded". Algorithm assumes no layer-parallel displacements occur during deformation. Errors will be introduced if these conditions do not actually exist.
Comparisons/	Demonstrates the geometric plausibility of the tectonic block-rotation

Implications	model for the south-central California coastal region (See Title 26) that underlies the seismotectonic model for the DC site in the PG&E LTSP (Title 11).
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Title 26	Seismicity of South-Central Coastal California: October 1987 through January 1997
Year	2001
Study Area	South-central coastal California and offshore
Authors	M.K. McLaren and W.U. Savage
Source	Bulletin of the Seismological Society of America, Vol. 91, p. 1629-1658
Scope	Seismological analyses of 9 years of earthquake data recorded by PG&E's 20-station Central Coast Seismic Network (CCSN) and interpreted in the context of previously recorded seismicity, Quaternary faults, and tectonic features of the central coast region.
Data Used	October 1987 – January 1997 CCSN earthquake recordings augmented with recordings from the USGS northern and southern California seismological networks.
Methodology	Development of S- and P-wave velocity models to improve location accuracy accounting for laterally inhomogeneous crustal rocks and for establishing calibrated duration magnitudes with corresponding station corrections. CCSN magnitudes were calibrated to the two USGS networks. Final catalog is 1184 well-constrained earthquake locations using HYPOINVERSE with 212 well-constrained focal mechanisms using FPFIT.
Summary Results	<ol style="list-style-type: none"> 1. Detailed network seismicity delineates the northern Hosgri fault as a near-vertical fault through the brittle crust exhibiting dextral strike-slip focal mechanisms. 2. The geophysically-defined step-over between the Hosgri and San Simeon faults exhibits strike-slip seismicity within the step-over. 3. The Santa Lucia Range, north of the Hosgri fault and Los Osos domain, is a seismically active compressive stress domain buttressed on the north by the Salinian terrane. 4. The Hosgri fault separates the Los Osos domain in the east from the offshore Santa Maria Basin. 5. Uplifting blocks of the Los Osos domain exhibit reverse and reverse-oblique focal mechanisms while structurally low areas are quiescent. 6. The Santa Maria Basin is seismically quiescent the northern and central basin areas and seismically active in the southern area exhibiting reverse focal mechanisms and Quaternary deformation. 7. The observed patterns of micro- and macroseismicity are consistent with observed locations and style of Quaternary

	<p>deformation and transpressional deformation of the Hosgri fault zone overprinted with rotation and west-migration of the western Transverse Ranges.</p> <p>8. Seismicity in south-central California extends to a maximum depth of 12 km and overlies, and is decoupled from, the subducted remnant of oceanic crust.</p>
Strengths	Refined crustal velocity models and related sensitivity tests, and careful event processing, provides a level of confidence in small-magnitude hypocenter locations and subsequent associations/interpretations that are made regarding faults and tectonic features of the region.
Limitations	Station distribution is entirely onshore (See Figure 2). Most of the San Simeon fault and the entire Hosgri fault zone (and Santa Maria Basin) lie offshore to the west of the network coverage. While ample background is provided documenting the history of network development onshore, no discussion is provided of possible biases (if any) in offshore event locations and magnitudes due to their locations outside of the network. This issue plagued early seismological investigations of offshore earthquakes in this region and was exacerbated by poor velocity models at that time.
Comparisons/ Implications	This study was performed in association with Lettis et al. (2004; Title 26) and Hanson et al. (2004, Title 28). This work cites these other papers with a pre-published year of 2001. The tectonic model for the study region is the same among the trilogy of papers. The proposed model is the most compelling to date due to the broad range of geoscience evidence that has been brought to bear and the consistency among the various lines of evidence that have been presented. This paper focuses on the seismicity aspect of the tectonic model. Interestingly, these authors avoid any implications of subordinate lateral displacements between the blocks of the Los Osos domain and only refer to these block boundaries as accommodating shortening (reverse) displacements. As previously mentioned under the other two papers, a kinematic model of block rotation in the Los Osos domain driven by clockwise rotation of the western Transverse Ranges to the south implies subordinate sinistral slip along the block boundaries in the Los Osos domain. Apparently, however, only dextral components of slip have been observed in the block-bounding seismicity to date.

Title 27	Quaternary Tectonic Setting of South-Central Coastal California
Year	2004
Study Area	South-central California coast and near offshore
Authors	W.B. Lettis, K.L. Hanson, J.R. Unruh, M. McLaren, W.U. Savage
Source	USGS Bulletin No. 1995, Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province, Chapter AA, 21 p.
Scope	Geological, seismological and geophysical synthesis of the triangular region bounded by the San Simeon-Hosgri fault system, the southern Coast Ranges and the western Transverse Ranges, (informally named the “Los Osos domain”) to ascertain the kinematics of Quaternary deformation.
Data Used	Results from previously published investigations that include: <i>Onshore</i> : marine terrace mapping; fault zone geological studies; borehole and water well records; aerial photography; seismic reflection data. <i>Offshore</i> : near-shore bathymetry, high-resolution shallow seismic reflection, side-scan sonar, deep (2-4 sec) seismic reflection, bottom sampling. In addition, instrumental seismicity, deep-crustal seismic reflection and refraction, and plate kinematic data.
Methodology	Synthesis of a wealth of existing data based on authors’ experience.
Summary Results	<ol style="list-style-type: none"> 1. Locations of active and potentially active faults in the Los Osos domain are compiled at a scale of 1:250,000. 2. Active and potentially active north-west-trending reverse faults partition the domain into distinct structural blocks. 3. These reverse faults and localized folds accommodate northeast-directed crustal shortening across the domain while the block interiors exhibit little or no deformation. 4. Hangingwall blocks are uplifted at rates of up to 0.2 mm/yr while footwall blocks are either static or subsiding at rates of 0.1 mm/yr or less. 5. Cumulative shortening across the northern domain is 1-2 mm/yr. Cumulative shortening across the central and southern domain is poorly constrained but may be as much as 2-3 mm/yr. 6. Seismicity is associated with the uplifted blocks and the high-angle border reverse faults to about 10 km deep.

	<ol style="list-style-type: none"> 7. Geological, seismological, and deeper crustal geophysical imaging indicate that the reverse faults penetrate the entire brittle crust at a high angle. The base of the brittle crust may be a decollement or mid-crustal detachment into which the reverse faults root. 8. The Los Osos domain is structurally detached from the offshore Santa Maria Basin along the San Simeon-Hosgri fault zone. Crustal shortening west of the San Simeon-Hosgri (the Santa Maria Basin) is occurring at only one-tenth the rate or less than is occurring in the Los Osos domain. 9. Post-Miocene clockwise rotation of the western Transverse Ranges along the southern boundary is accommodated by northeast-directed crustal shortening across the Los Osos domain.
Strengths	A compelling synthesis that brings together a broad range of existing geological, geophysical and seismological data and interpretations in a coherent model of Quaternary deformation.
Limitations	A limited number of seismological focal mechanisms from small earthquakes that appear to be spatially associated with proposed reverse faults of the Los Osos domain block boundaries indicate a dextral (right-lateral) slip component when the deformational model implies that these faults should exhibit a component of sinistral (left-lateral) slip.
Comparisons/ Implications	The Quaternary kinematic model from this synthesis fits well with, and expands upon, the kinematic model proposed by Sorlien et al. (1999) (Title 25) that was based on retrodeformed post-Miocene structure contour maps. Both papers conclude that the Hosgri fault is a steeply dipping dextral strike slip fault through the brittle crust that might root into a mid-crustal decollement or detachment surface.

Title 28	Style and Rate of Quaternary Deformation of the Hosgri Fault Zone, Offshore South-Central California
Year	2004
Study Area	Near-shore south-central California
Authors	K.L. Hanson, W.R. Lettis, M.K. McLaren, W.U. Savage, N.T. Hall
Source	USGS Bulletin No. 1995, Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province, Chapter BB, 33 p.
Scope	A complimentary study to Title 002 by mostly the same authors that provides more detailed analyses and data syntheses specific to faults of the Hosgri fault zone.
Data Used	Shallow high-res and deep crustal seismic reflection, geologic and geomorphic data, near-coastal seismicity, tectonic kinematic data, worldwide analogous fault zones.
Methodology	Synthesis of a wealth of existing data based on authors' experience.
Summary Results	<ol style="list-style-type: none"> 1. The Hosgri fault zone is a convergent right-slip (transpressional) fault exhibiting deformational features characteristic of slight changes in strike relative to northeast-oriented compressive tectonic stress. 2. Quaternary slip rate is 1-3 mm/yr 3. Strike-slip faulting is indicated by the long, linear, narrow zone of faulting; kinematically consistent restraining and releasing bends and features with right lateral strike-slip; asymmetric flower structures; changes in sense and magnitude of vertical separation along trend and vertically within the fault zone; strike-slip focal mechanisms within the fault zone; a distribution of seismicity that delineates a high-angle fault through the brittle crust; high ratios of vertical-to-horizontal (V/H) slip; separation of the Santa Maria Basin and Los Osos domain that are undergoing different styles of deformation and orientations of crustal shortening. 4. Net slip of 1-3 mm/yr is transferred from the San Simeon fault to the Hosgri in the north probably decreases southward as it is consumed by shortening along more west-trending faults and folds in the Los Osos domain. 5. Based on deformation of a Pliocene unconformity, a compressional component of slip also exists along the Hosgri in the present tectonic setting, consistent with implications of relative plate motions that suggest the Hosgri is in a

	<p>transpressional tectonic environment.</p> <p>6. Post-Pliocene vertical slip rates across the Hosgri range from 0.1-0.4 mm/yr, but may be as high as 0.44 mm/yr if the rate of right-slip is greater than 1 mm/yr.</p>
Strengths	A well-reasoned, compelling synthesis that brings a broad range of existing geological, geophysical and seismological data and interpretations to bear in a coherent model of deformational and displacement styles exhibited along the Hosgri fault system.
Limitations	Lateral displacements in and out of section are, at best, difficult to identify in seismic reflection data along strike-slip fault zones. Authors provide discussion of this topic and are mindful of this limitation in the seismic reflection data.
Comparisons/ Implications	Hosgri fault system tectonic model is consistent with the Los Osos domain tectonic model of Title 27 and serves to refine the kinematics of previous model block boundaries in the south-central California offshore that provided in Title 25. The interpretation of changing structural style of the Hosgri fault in a convergent wrench tectonic system ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 29	Diablo Canyon Spent Fuel Storage Installation (ISFSI) Safety Analysis Report (SAR)
Year	2002
Study Area	10-mile radius of the DC site (i.e., DC site region)
Authors	PG&E
Source	2.6. Geology and Seismology; ISFSI SAR Amendment 1, October 2002
Scope	Description and evaluation of geologic and seismologic conditions in the site region
Data Used	Geologic and seismologic data for the DC power plant including the LTSP with further geotechnical/geologic investigations for the ISFS and CTF sites
Methodology	Description and evaluation of information in compliance with Appendix A of 10 CFR 100, and 10 CFR 72.102
Summary Results	<ol style="list-style-type: none"> 1. The ISFSI and CTF sites are approximately the same distance from the Hosgri fault zone, the controlling earthquake source for the DC power plant. The foundation conditions and ground motion response characteristics are the same as those at DCP. 2. Because the ground-motion response characteristics at the ISFSI are the same as those at the DCP, the DCP earthquake ground motions are appropriate for use in the licensing of the ISFSI, in accordance with 10 CFR 72.102(f). 3. Because the ISFSI pad sliding, slope stability and stability of the transporter are affected by longer-period ground motions than those characterized by the DCP ground motions, response spectra having a longer-period component were developed that incorporates the near-fault effects of rupture directivity and fling. 4. Several minor bedrock faults were observed at the ISFSI and CTF sites. These minor faults are not capable. There is no potential for surface faulting at the ISFSI or CTF sites. 5. The bedrock that underlies the ISFSI and CTF sites has sufficient capacity to support the loads imposed by ISFSI pads and casks and the CTF without settlement or differential movement. 6. There are no active landslides or other evidence of existing instability at the ISFSI and CTF sites, or on the hillslope above the site. 7. The slopes have ample factors of safety under static conditions. The cutslope above the ISFSI site may experience local wedge movements or small displacements if exposed to the DBE. Mitigation measures to address these movements are developed.

	<p>8. The transport route follows existing paved roads, except for a portion of the route that will be constructed to avoid a landslide at Patton Cove along the coast. The route will have foundation conditions satisfactory for the transporter. Small debris flows could potentially close portions of the road during or immediately following severe weather. Because the transport route will not be used during severe weather, the flows will not be a hazard to the transporter.</p>
Strengths	Augmentation of long-period motions specifically for facilities for the ISFSI and inclusion of transport route geologic hazards
Limitations	Much DCCP material is included by reference and not directly available herein
Comparisons/ Implications	Seismic hazard assessment and design earthquakes are adopted from DCCP with augmentation at long periods accounting for near source effects.

Title 30	A Kinematic Model of Southern California
Year	1986
Study Area	Southern California offshore to the San Andreas Fault
Authors	R. Weldon and E. Humphreys
Source	Tectonics, Vol. 5, No. 1, p. 33-48
Scope	A kinematic model based on late Quaternary fault slip rates and orientations of major faults in the region.
Data Used	Quaternary fault slip rates from various authors, major mapped faults of southern California, and tectonic plate velocities from trilateration networks in southern California.
Methodology	Velocities of tectonic blocks are calculated along several paths in southern California that begin in the Mojave Desert and end off the California coast.
Summary Results	<ol style="list-style-type: none"> 1. The existence of a zone of active deformation in southern California that is interpreted to include the western Transverse Ranges and northwest trending, predominately strike-slip faults close to the coast both north and south of the Transverse Ranges. 2. Strain on this system accounts for about a third of the total North American-Pacific plate motion. 3. The kinematic model developed is a block model of the upper crust (upper 10 km) and assumes that no deformation occurs within the interior of the blocks. 4. Convergence in the western Transverse Ranges is due to a left step in the coastal system faults, and is unrelated to the San Andreas fault. 5. The magnitude of the offshore activity (seismicity) implies that the region between the San Andreas Fault and the coastal system is neither part of the North American plate nor the Pacific plate and may be considered a miniplate.
Strengths	Provides a regional context to the style of fault movements and their relation to published fault slip rates and tectonic plate velocities.
Limitations	The major uncertainties in the tectonics of southern California are due to motion external to the region modeled. The opening of the Great Basin appears to control the motion of the Sierran block, which in turn controls

	then amount of convergence along the central California coast.
Comparisons/ Implications	The primary tectonic elements of Southern California are major block-bounding strike-slip faults. One third of the plate tectonic motion is assumed to be distributed on the faults of the western Transverse Ranges and northwest-trending, predominately strike-slip faults close to the coast both north and south of the Transverse Ranges.

Title 31	Crustal Strain Partitioning: Implication for Seismic-Hazard Assessment in Western California
Year	1991
Study Area	Western central California
Authors	W.R. Lettis and K.L. Hanson
Source	Geology, Vol. 19, p. 559-562
Scope	A theoretical study to delineate seismogenic surface faults from non-seismogenic faults for use in seismic hazard analysis.
Data Used	Geologic and geomorphic data, seismicity, tectonic kinematic data, worldwide analogous fault zones.
Methodology	Synthesis of a model to determine seismic and non-seismic sources for inclusion to seismic hazard analysis.
Summary Results	<ol style="list-style-type: none"> 1. The concept of strain partitioning affects the assessment of seismic hazard primarily with respect to the identification and characterization of seismic sources. Critical to this assessment is the scale of partitioning and whether structural features should be treated as individual seismic sources or collectively as a single seismic source. 2. Oblique strain in the lower lithosphere may partition upward in the brittle crust into nearly pure strike-slip and dip-slip deformation, the dip-slip component being expressed as reverse faults and folds. 3. Depending on the depth of partitioning, these partitioned structures may be independent regional sources of seismicity or they may be dependent local structures above a single seismic source at depth. 4. The upper seismogenic part of the lithosphere is divided into a region of low-moment release and a few large earthquake above 5 km depth, and a region of high-moment release during large earthquakes below 7 km depth, separated by a 2 km thick zone transition zone from 5-7 km depth.. 5. Faults in western California confined to the upper crust above a depth of 5 to 7 km are capable of releasing small earthquakes, not larger events. These faults are located within a zone of less than 3 to 6 km from a main seismogenic fault (i.e. San Andreas Fault) and are dependent on movement on the main seismogenic fault.

	6. Faults that originate deeper than 5 to 7 km generally extend more than 3 to 6 km from the main seismogenic fault are considered independent seismic sources.
Strengths	A general guideline for determining seismic source parameters to be considered in seismic hazard analysis with possible application to some of the offshore fault zones in southern California.
Limitations	Usefulness of application outside of California is dependent on locally available geological and seismological data and its quality.
Comparisons/ Implications	The dependent and independent nature of subsidiary faults to main seismogenic faults could affect the nature of fault modeling for the proposed blind thrust under the San Joaquin Hills that has been proposed in Titles 32, 37, and 38.

Title 32	Neotectonic Uplift and Ages of Pleistocene Marine Terraces, San Joaquin Hills, Orange County, California.
Year	1992
Study Area	San Joaquin Hills, Orange County, California
Authors	D. Barrie, T.S. Tatnall, and E. Gath
Source	The Regressive Pleistocene Shoreline, Southern California: South Coast Geological Society, Inc. Annual Field Trip Guide Book No. 20. Heath, E.G. and Lewis, W.L, (eds.), p. 115-122.
Scope	Establishing the age and tectonic uplift rates for of the northern San Joaquin Hills
Data Used	Marine terrace ages included oxygen-isotope chronology, amino acid racemization, zoogeographic signatures, geomorphic correlation, and comparison of shoreline angle elevations with a paleo-sea level curve.
Methodology	The study of the attitudinal spacing of a suite of uplifted (emergent) marine terraces makes is possible to draw conclusions about marine terrace ages and tectonic uplift in coastal areas.
Summary Results	<ol style="list-style-type: none"> 1. Investigation of a locally well-preserved suite of elevated marine terraces on the western flank of the San Joaquin Hills between Newport Beach and Laguna Beach indicates a uniform uplift rate of approximately 0.25 m/1000 years. 2. Terrace ages range from about 80,000 years for the lower (18 m) terrace to about 1,230,000 years for the upper (335 m) terrace. 3. All terrace platforms exhibit seaward dips comparable to modern wave-cut platforms, suggesting little or no progressive seaward rotation during Pleistocene time indicating that the uplift was nearly vertical with no folding of the San Joaquin Hills. 4. Assuming a constant uplift rate, the San Joaquin Hills became emergent as a positive topographic feature approximately 1,230,000 years.
Strengths	Documentation that where the Newport-Inglewood fault is very close to, or comes on shore (just north of the San Joaquin Hills), there has been a persistent uplift that has lasted 1.23 million years. The uplift of the San Joaquin Hills seems to have been nearly vertical, because all the terrace platforms exhibit seaward dips comparable to modern wave-cut

	platforms that would rule out folding as the mechanism of uplift.
Limitations	The process of uplift that persists for 1.23 million years without deformation or rotation of the marine terraces remains unclear.
Comparisons/ Implications	The authors of Title 37 determined that San Joaquin Hills are an anticline and therefore deformation of the marine platforms is required.

Title 33	The Cristianitos Fault and Quaternary Geology, San Onofre State Beach, California.
Year	1992
Study Area	San Onofre State Beach, California
Authors	R. J. Shlemon
Source	The Regressive Pleistocene Shoreline, Southern California: South Coast Geological Society, Inc. Annual Field Trip Guide Book No. 20. Heath, E.G. and Lewis, W.L, (eds.), p. 9-12.
Scope	Determining the age of the last movement on the Cristianitos Fault that is in close proximity to the SONGS site.
Data Used	Geologic field observations and dating of sediments using marine isotope dates along with amino-acid and uranium-series age dates.
Methodology	Geologic field observations.
Summary Results	<ol style="list-style-type: none"> 1. The Cristianitos fault is overlain by about 3.3 ft. of marine gravels and sands and does not offset the marine deposits. 2. Mollusks collected from the overlying marine deposits are of a late Sangamon (marine isotope substage 5e) about 125,000 years old. 3. The marine sediments have also been dated using amino-acid and uranium-series methods from this and other localities on the southern California coast confirming the age of the marine deposits. 4. Because these marine deposits are clearly not offset by the Cristianitos fault, last displacement took place at least 125,000 years ago and most likely well before that time.
Strengths	A compelling set of geologic field observations that limits the last age of movement on the Cristianitos fault to happening at least 125,000 years ago.
Limitations	None
Comparisons/ Implications	The determination that the Cristianitos fault has not been active in the last 125,000 years removes it from being considered as an active fault for both local surface offset and seismic hazard calculations.

Title 34	Late Quaternary Geology of the Dana Point-San Onofre-Carlsbad Margin, California
Year	1992
Study Area	Dana Point to Carlsbad, California
Authors	P.J. Fischer, D.S. Gorsline, and R.J. Shlemon
Source	South Coast Geological Society, Inc., 1992 Annual Field Trip Guide Book No. 20, "The Regressive Pleistocene Shoreline Coastal Southern California", E.G. Heath and W.L. Lewis, eds., p. 195-218.
Scope	Tectonics and sedimentary history of Dana Point to Carlsbad, California
Data Used	Seismic reflection profiling and borehole data.
Methodology	Synthesis of the data into a Late Quaternary deformational model specific to the Dana Point to Carlsbad continental margin, California.
Summary Results	<ol style="list-style-type: none"> 1. Late Quaternary sedimentary history of the coastal shelf from Dana Point to Carlsbad, California 2. From Newport Beach 43 km south to Las Pulgas Canyon (10 km south of San Onofre) the Newport-Inglewood fault zone is narrow (about 500 meters or less in width). From seismic reflection profiles the fault is a positive flower structure. 3. Activity on the Newport-Inglewood fault decreases southward from Newport Beach, where Holocene faulting and related seafloor "bowing" are present. At Dana Point the last fault activity was some 5,500 years ago. At San Mateo Point Holocene sediments are not displaced. 4. "Near San Onofre, Holocene faulting and related bowing and displacement of the shelf surface are present along the Newport-Inglewood fault, in direct contrast to the findings of Southern California Edison's study for San Onofre Nuclear Generating sites 2 and 3. This active part of the Dana Point segment was named the San Onofre subsegment by Fischer and Mills (1991)"
Strengths	Sedimentary history of the shelf from Dana Point to Carlsbad, California was the main focus of the paper. Tectonics was a minor part.
Limitations	A line drawing from Fischer and Mills (1991) of a seismic reflection section directly adjacent to San Onofre that is included in this paper shows the Newport-Inglewood fault with approximately 150 meters of

	undeformed Holocene sediments overlying the fault. Contrary to the conclusions in this paper, this figure indicates that there is no faulting and related bowing present for at least as long as it took to deposit 150 meters of sediment across the fault.
Comparisons/ Implications	A contradiction exists between the conclusions of the paper and the seismic reflection data illustrated in the paper.

Title 35	Holocene Activity of the Rose Canyon Fault Zone in San Diego, California
Year	1995
Study Area	San Diego, California
Authors	S.C. Lindvall and T.K. Rockwell
Source	Journal of Geophysical Research, Vol. 100, No. B12, pp. 24,121-24,132
Scope	Determination of slip-rate, recurrence interval, and sense of slip for the onshore segment of the Rose Canyon Fault in San Diego, California over the last 10,000 years of activity
Data Used	Stereo air photo analysis, 3-D fault trenching, ¹⁴ C radiometric age dating, geomorphology, and total station surveying.
Methodology	Fault location using stereo aerial photography and 3-D trenching of identified surface fault traces to determine slip-rate, recurrence intervals, and sense of slip for the onshore segment of the Rose Canyon Fault.
Summary Results	<ol style="list-style-type: none"> 1. Trenches across the Mount Soledad strand of the onshore Rose Canyon Fault demonstrate a minimum of 8.7 meters of right-lateral strike slip displacement on a distinctive gravel-filled channel that crosses the fault zone. 2. Radiocarbon dates on detrital charcoal from beneath the gravel filled channel yield a maximum age of about 8,100 ± 200 years. 3. Stratigraphic evidence from the trenches that indicate that the 8.7 meters of offset of the gravel-filled channel was the result of three different surface faulting events. 4. The most recent surface rupture displace the modern soil, suggesting that this event probably occurred within the past 500 years. 5. The minimum slip rate of 1.07±0.03 millimeters per year was determined from the trench site. Taking into account limiting factors at the site the authors estimate a maximum slip rate of 2 mm/yr and a best estimate of 1.5 mm/yr. 6. Stratigraphic and structural relationships observed in the trenches suggest the return time for surface-rupturing earthquakes is no more than about 4 thousand years.
Strengths	This is a good example of basic paleoseismological research that is needed for developing a broader regional tectonic picture. Authors present their results with a clear description of the limitations of the data and interpretation.
Limitations	Extrapolating the slip rate determined at the trench site for the Rose Canyon Fault to the offshore Newport-Inglewood Fault to where the two

	faults meet offshore north of San Diego. The authors did not make this extrapolation, but others have.
Comparisons/ Implications	If the Rose Canyon and Newport-Inglewood fault are considered to be extensions of the same fault system, then the slip rate for the Rose Canyon in this study can be applied to the offshore segment of the Newport-Inglewood fault.

Title 36	Paleoseismicity of the North Branch of the Newport-Inglewood Fault Zone in Huntington Beach, California, from Cone Penetrometer Test Data
Year	1997
Study Area	Huntington Beach, California where the Newport-Inglewood Fault comes onshore.
Authors	L.B. Grant, J.T. Waggoner, T.K. Rockwell, and C. von Stein
Source	Bulletin of the Seismological Society of America, Vol.87, No. 2, p. 277-293.
Scope	Detailed geological investigation of the Newport-Inglewood fault zone including surface geological mapping and paleoseismic investigations.
Data Used	Original field geologic studies, soil borings, radiocarbon age dates, seismic reflection profiles, and cone penetrometer data.
Methodology	Cone penetrometer data were used to establish different stratigraphic horizons and the depth of the stratigraphic horizons across a previously mapped trace of the Newport-Inglewood onshore at Huntington Beach area. Soil borings were taken at specific locations to correlate the cone penetrometer data and to also obtain organic material for radiocarbon age determination.
Summary Results	<ol style="list-style-type: none"> 1. The Newport-Inglewood fault zone at the study site has generated at least three and most likely five recognizable surface ruptures in the past $11,700 \pm 700$ years. 2. The minimum right-lateral Holocene slip rate of the Newport-Inglewood Fault at the site is estimated to be 0.34 to 0.55 mm/yr. The actual slip rate may be significantly higher. 3. Mapped surface trace of the Newport-Inglewood fault at the study site is graben structure produced by a right step in a right-lateral strike-slip fault.
Strengths	Documentation of the presence, location, and the number of faulting events during the last 11,700 years for the Newport-Inglewood Fault where it comes onshore at Huntington Beach.
Limitations	Estimates of slip rates for the studied faults rely on data published in an abstract from another researcher.
Comparisons/	Although this region of the Newport-Inglewood fault had previously been identified by other investigators, these authors used a proven

Implications	geotechnical investigation method (cone penetrometer) to help identify the location, number of faulting events, and slip-rate for the onshore segment of the Newport-Inglewood fault.
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Title 37	Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California
Year	1999
Study Area	San Joaquin Hills, Orange County, California
Authors	L.B. Grant, K.J. Mueller, E.M. Gath, H. Cheng, R.L. Edwards, R. Munro, and G.L. Kennedy
Source	Geology, Vol. 27, No. 11, p. 1031-1034.
Scope	Analysis of emergent marine terraces in the San Joaquin Hills with implications for paleo-earthquake magnitudes
Data Used	²³⁰ Th dating of corals found on marine terraces and geologic field examination of uplifted marine terraces using geotechnical investigations, borings, natural exposures and topography.
Methodology	Synthesis of the data into a descriptive model that employs a blind thrust fault beneath the San Joaquin Hills to account for the uplift of the area for a period of 122,000 years.
Summary Results	<ol style="list-style-type: none"> 1. The late Quaternary uplift rate, anticlinal structure, and indications of Holocene uplift imply that the San Joaquin Hills are the surface expression of an active contractile fold formed above a potentially seismogenic thrust fault. 2. A fault-bend fold model with movement on a northeast-vergent thrust best explains the elevation of marine terraces on the northeast limb of the San Joaquin Hills anticline. 3. The magnitude of a maximum credible earthquake is estimated by assuming that the San Joaquin Hills thrust extends to the base of the seismogenic crust at 17 km, dips between 20° and 30°, and extends upward to within 2 km of the surface. In this interpretation the San Joaquin Hills thrust is a back thrust that soles into the Oceanside detachment as part of a wedge-thrust structure. 4. Dating of corals reveal that the San Joaquin Hills have risen at a rate of 0.21-0.27 m/1000 years during the last 122,000 years. Movement on a blind thrust fault has uplifted the San Joaquin Hills and has the potential to generate an M_w 7.3 earthquake.
Strengths	Provides a mechanism to explain the uplift of the San Joaquin Hills by a blind thrust fault that could be seismogenic. The determined uplift rate is

	in good agreement with those determined by previous workers (Title 032)
Limitations	The authors prefer to interpret movement of the San Joaquin Hills blind thrust to be the product of partitioned strike slip and compressive shortening across the southern Newport-Inglewood fault zone. If the San Joaquin Hills are the result of movement on Newport-Inglewood fault and not related to movement Oceanside thrust then the fault geometry determine in number three of the Summary Results section is in question.
Comparisons/ Implications	<p>The determination that the San Joaquin Hills is an anticlinal fold contradicts previous findings of no folding of the marine terraces on the uplift (Title 32).</p> <p>Title 38 cites the San Joaquin Hills as a back thrust to the proposed Oceanside thrust fault. Yet, this paper prefer interprets the San Joaquin Hills to be related to movement on the Newport-Inglewood fault.</p>

Title 38	Oceanside and Thirtymile Bank Blind Thrusts: Implications for Earthquake Hazards in Coastal Southern California
Year	2000
Study Area	Southern offshore California (Inner California Borderland) and coastal southern California
Authors	C. Rivero, J.H. Shaw, and K Mueller
Source	Geology, Vol. 28, No. 10, p. 891-894
Scope	Report that proposes that the Thirtymile and Oceanside low angle offshore faults of southern California are present day thrust faults that are reactivated older normal extensional faults.
Data Used	Seismic reflection profiles, digital elevation data, geologic stratigraphy, earthquake locations, and earthquake focal mechanisms
Methodology	Geologic interpretation of offshore seismic reflection profiles coupled with earthquake aftershock sequences and onshore mapping of surficial folds.
Summary Results	<ol style="list-style-type: none"> 1. The Oceanside and Thirtymile faults in the offshore Borderland of southern California are interpreted as active thrust faults. 2. The Oceanside and Thirtymile faults originally formed as extensional detachment faults in the Miocene. 3. Large portions of these detachment faults have been reactivated to form the Oceanside and Thirtymile Bank blind thrust faults, which compose the Inner California Borderland blind thrust system in the Pliocene. 4. The Oceanside thrust dips at 14° to 25° to the northeast, occupies the surficial feature of the Coronado Banks, and extends from San Joaquin in the north southward to the international border near San Diego. 5. The onshore anticline fold of the San Joaquin Hills is at the onshore projection of the Oceanside thrust and is interpreted to be a structural wedge formed as a back thrust to the Oceanside thrust. 6. Uplift rates of 0.07-0.17 mm/yr for the Oceanside thrust were calculated and are considered to be a minimum value because they are derived from uplift rates. 7. Maximum uplift rate of 2.2 mm/yr for the Oceanside thrust is

	<p>calculated from geodetic observations that indicate as much as 2 mm/yr of northeast-southwest convergence between Catalina Island and the coast.</p> <p>8. Four possible fault interaction models are proposed for the intersection of the Oceanside and San Joaquin thrust faults with the intervening Newport-Inglewood strike-slip fault. A.) The younger strike-slip fault (Newport-Inglewood) cuts and precluding further activity on older thrusts (Oceanside and San Joaquin faults). B.) The thrust faults terminate in the strike-slip faults. C.) The thrust faults may cut the strike-slip fault zones. And D.) The thrust and strike-slip faults may merge into a single structure at depth.</p>
Strengths	<p>A novel reinterpretation of the tectonics of the Inner California Borderlands influenced by the 1994 Northridge earthquake that was a blind thrust in the Los Angeles basin.</p>
Limitations	<p>This paper sites the onshore anticline at the San Joaquin Hills is the result of back thrusting from movement on the Oceanside thrust fault. This requires the Oceanside thrust extends under the coast of California in the vicinity of San Joaquin California. Between the mapped trace of the Oceanside thrust and the San Joaquin anticline resides the mapped Newport-Inglewood strike-slip fault. If the Oceanside thrust extends eastward under the coast it then must limit the depth extent of the Newport-Inglewood fault to be above the Oceanside thrust. Projecting a 25° eastward dip of the Oceanside thrust would result in the depth of the thrust to be about 7 km under the coast. This would limit the depth of the Newport-Inglewood fault to be 7 km.</p> <p>Continued movement on the Oceanside thrust would carry the Newport-Inglewood fault westward. Since the mapped surface trace of the Newport-Inglewood fault extends north of the surface intersection of the two faults there should be a marked right sense of displacement on the surface trace of the Newport-Inglewood fault were the two faults intersect near San Joaquin. The fault activity map of California shows no such offset in the surface trace of the Newport-Inglewood fault.</p>
Comparisons/Implications	<p>This paper explains the San Joaquin Hills as the result of a back thrust to the Oceanside thrust fault. Title 37 infers that the San Joaquin Hills results from movement on the Newport-Inglewood fault.</p> <p>Title 41 determined the offshore portion of the Newport-Inglewood Fault extends to a depth of 13 kilometers. This would require that the Newport-Inglewood fault terminates the Oceanside Thrust since the thrust is limited to 7 km deep at the intersection with the Newport-Inglewood fault.</p>

Title 39	A Northward-Propagating Earthquake Sequence in Coastal Southern California?
Year	2002
Study Area	Northern Baja California, Mexico, the offshore boarder lands of southern California, and the Los Angeles Basin.
Authors	L.B. Grant and T.K Rockwell
Source	Seismological Research Letters, Vol. 73, No. 4, pp. 461-469
Scope	The concept of stress transfer and earthquake triggering along strike slip faults has been documented for the North Anatolian Fault in Turkey. The authors suggest that an analogous rupture sequence spanning the last few centuries may be in its later stages along southern California coastal faults.
Data Used	Historic seismicity, paleoseismic investigations, and radiocarbon age dating.
Methodology	Analysis of historic seismicity and paleoseismic investigations along the entire length of kinematically linked faults (Coastal Fault Zone) to determine if there is a temporal sequence of propagating fault movement.
Summary Results	<ol style="list-style-type: none"> 1. Recently published fault investigations in the northern Baja California peninsula (Mexico) and coastal southern California (USA) reveal evidence for geological contemporaneous or sequential earthquakes along a > 300-km-length, predominantly strike-slip zone. This coastal fault zone includes structures previously mapped as the Agua Blanca, Rose Canyon, San Joaquin Hills, and southern Newport-Inglewood Fault zones. 2. Radiocarbon dating and historic records indicate that moderate to large earthquakes occurred after A.D. 1640 \pm 160 on the Agua Blanca fault, 1523 to 1769 on the Rose Canyon fault, 1635 – 1855 on the San Joaquin Hills fault, and a Mw 6.4 earthquake in 1933 on the southern Newport-Inglewood fault. 3. The 1933 earthquake on the southern Newport-Inglewood fault increased the Coulomb stress on the northern Newport-Inglewood zone in the Los Angeles basin. 4. The date of the last surface rupture of the northern Newport-Inglewood Fault (Los Angeles basin) is not known. 5. A sequence of moderate magnitude earthquakes in late 2001 in the Los Angeles basin suggests the possibility that the northern Newport-Inglewood fault zone is close to failure and that a future earthquake on this fault segment may culminate a multi-century

	northward-propagating sequence of earthquakes.
Strengths	Compares the 300-km-long strike-slip fault zone of the Agua Blanca, Rose Canyon, San Joaquin Hills, and Newport-Inglewood fault zone of southern California and northern Mexico to the North Anatolian strike-slip fault of Turkey. Stress transfer and earthquake triggering have been documented on the North Anatolian Fault with a historic sequence of earthquakes that progressed from east-to-west with time along the fault.
Limitations	The authors imply that the San Joaquin Hills are a structural part of the 300-km-long strike-slip fault zone. The San Joaquin Hills are to the east of the mapped trace of the Newport-Inglewood fault zone, which brings the linkage of the two structures into question. Removing the San Joaquin Hills from the analysis yields two earthquakes at the southern end of 300-km-zone (Agua Blanca and Rose Canyon) at about the 1600's and a 1933 earthquake on the southern Newport-Inglewood fault at the north end of the zone.
Comparisons/ Implications	The concept of stress transfer and earthquake triggering along strike slip faults would advance the clock on earthquakes in the Los Angeles Basin.

Title 40	Coastal Uplift of the San Joaquin Hills, Southern Los Angeles Basin, California, by a Large Earthquake Since A.D. 1635
Year	2002
Study Area	The San Joaquin Hills of coastal Southern California.
Authors	L.B. Grant and L.J. Ballenger, and E.E. Runnerstrom
Source	Bulletin of the Seismological Society of America, Vol. 92, No. 2, pp. 590-599
Scope	Radiocarbon dating of uplifted Holocene marsh deposits at the San Joaquin Hills, southern California indicates that the marshes were uplifted after A.D. 1635. Uplift of the marshes is attributed to tectonic movement that produced a $M > 7$ earthquake.
Data Used	Geomorphology, shoreline platforms, surveying techniques, pollen analysis, historic seismicity, and radiocarbon age dating.
Methodology	Analysis of uplifted marine platforms and marshes to determine the amount of and timing of the uplift event. Radiocarbon ages were derived for organic materials on the platforms and marshes to determine the age of the uplift. Surveying techniques were used to determine the amount of uplift.
Summary Results	<ol style="list-style-type: none"> 1. Late Holocene marsh deposits and a shoreline along the coast of the San Joaquin Hills, southern Los Angeles basin, range from 1 to 3.6 meters above the active shoreline. 2. Radiocarbon dating of the marsh deposits shows that emergence occurred after A.D. 1635. 3. The age, distribution, and geomorphic expression of the elevated marsh and shoreline are best explained by tectonic uplift due to a $M > 7$ earthquake. 4. Radiocarbon dates and the historic record of seismicity suggest the earthquake occurred between A.D. 1635 and 1855, possibly in 1769.
Strengths	Constrains a range of dates for the timing of the latest uplift event on the San Joaquin Hills anticline. The study also determines an amount for the uplift event to be between 1 to 3.6 meters.
Limitations	Although the authors state the San Joaquin Hills are an anticline, they do not present basic geologic structural data of strike and dip measurements on strata that would confirm the structure is an anticline. The authors of Title 32 (Barrie and others) indicate that uplifted marine terraces on the San Joaquin Hills are not warped away from angles that are comparable with modern wave cut terraces. This would indicate that there is no

	folding of the San Joaquin Hills and that the structure is not an anticlinal fold.
Comparisons/ Implications	Expands and refines the study of the San Joaquin Hills done by Grant and others in Title 37.

Title 41	Activity of the Offshore Newport-Inglewood Rose Canyon Fault Zone, Coastal Southern California, from Relocated Microseismicity
Year	2004
Study Area	Southern offshore California (Inner California Borderlands)
Authors	L.B. Grant and P.M. Shearer
Source	Bulletin of the Seismological Society of America, Vol. 94, No. 2, p. 747-752
Scope	Determining if the Newport-Inglewood Rose Canyon fault is a through going feature from San Diego north to Newport beach or if it is offset by the Oceanside and San Joaquin thrust faults.
Data Used	Analysis of clusters of microseismicity.
Methodology	Application of waveform cross-correlation algorithm to identify clusters of microseismicity consisting of similar events.
Summary Results	<ol style="list-style-type: none"> 1. An offshore zone of faulting connects the strike-slip Newport-Inglewood fault in the Los Angeles metropolitan region with the strike-slip Rose Canyon fault in the San Diego region, here referred to as the offshore Newport-Inglewood Rose Canyon fault (ONI-RC). The activity and seismic potential of the ONI-RC has been the subject of debate for decades. Recent attention has focused on blind thrusts that may intersect the ONI-RC fault zone and accommodate some of the regional deformation (Titles 37 and 38). Interaction with the thrust system could limit the magnitude of earthquakes on the strike-slip faults in the ONI-RC fault zone, if they are active. 2. Two clusters of microearthquakes within the northern and central ONI-RC fault zone were identified, relocated and analyzed to examine the fault structure, minimum depth of seismic activity, and source fault mechanism. 3. The first cluster of examined microearthquakes were from a 1981 swarm of 19 $M < 3.0$ earthquakes approximately 10 km northwest of Oceanside. Results showed that the events align along a north-northwest trend about 0.5 km long. In cross section, the events define a nearly vertical plane between 12.5 and 13.0 km depth. The strike, dip, and location of a plane fit by these events are consistent with active strike-slip faulting on the ONI-RC fault zone. 4. The second set of microearthquakes examined were from a cluster of seven events near Newport Beach in 2000 at a depth of

	<p>6.5-7.0 km. In cross section five of the seven events are aligned in a pattern consistent with a shallow (7 km), north-northwest-striking vertical or steeply dipping active fault.</p> <p>5. If strike-slip faults do not terminate the Oceanside thrust, the authors of Title 37 estimate an Mw 7.5 maximum magnitude earthquake could result from rupture of the entire thrust fault. However, the location and ~13 km depth of the Oceanside cluster suggests that the Ocean side thrust is terminated by active strike-slip faults. According to Title 37 authors, this geometry would lead to an Mw 7.3 maximum magnitude earthquake on the Oceanside thrust.</p>
Strengths	A good study using microseismicity to determine that the Newport-Inglewood Rose Canyon fault system is a through going active strike-slip fault zone that extends to seismogenic depths of 13 km.
Limitations	None
Comparisons/ Implications	This conclusion limits the possible fault geometry relationships listed by the authors of the Title 38 paper.

Title 42	San Onofre 2&3 FSAR (Updated)
Year	2005
Study Area	320-km radius of site
Authors	Southern California Edison Company
Source	San Onofre 2&3 UFSAR, 2.0 – Site Characteristics, p. 2.5-1 - 2.5-281
Scope	Review and assessment of geological and seismological conditions and hazards for the San Onofre NPP site
Data Used	Geological/geomorphic field data, seismological network data, geotechnical boring and laboratory test data
Methodology	Analysis of original data and synthesis with existing data to establish interpretations of geological and seismic hazards at the plant site
Summary Results	<ol style="list-style-type: none"> 1. The San Onofre site is located near the SW margin of the Peninsular Ranges geomorphic province of southern California, which is characterized by NW-trending mountain ranges that extend southward into Mexico. The Peninsular Ranges Province is physiographically distinct from the offshore basin-and-range topography of the Continental Borderland Province between Point Conception and Central Baja California. 2. The present tectonic environment within 320 km of the site is dominated by interaction between the Pacific and North American crustal plates. The Pacific plate is moving northwestward at about 6 cm/yr relative to North America. The main plate boundary extends northward from the Gulf of California and Salton Trough to Cape Mendocino with most of the interpolate motion accommodated by right-slip on the San Andreas fault. Smaller faults and a reduced order of seismicity are associated with structural adjustment away from the plate boundary. The San Onofre NPP is located 92 km (57 mi) to the southwest of the San Andreas fault. 3. The most compatible model of known geologic and tectonic conditions combines the effect of the interference of the Pacific and North American plate motions due to the bend in the San Andreas fault at the Transverse Ranges, and the variable rates of crustal spreading in the Gulf of California. This model accommodates the compressive stress field in the Transverse Ranges, which would block the northward motion of the crust immediately to the west of the San Andreas system and would require right-lateral shear motion to be concentrated on faults to the east and west of the Transverse Ranges. This could be occurring on the San Clemente or Coronado Banks faults to the west and on the San Andreas, San Jacinto, and Elsinore faults to

	<p>the east. In this manner a lower stress field would exist south of the Transverse Ranges in the area of the hypothesized Offshore Fault Zone. This suggested lower stress field is consistent with the observed lower degree of activity and low total offset on the hypothesized Offshore Fault Zone as compared to faults to the east and probably to the west.</p> <ol style="list-style-type: none"> 4. The 32-km-long (20 mi) Christianitos Fault is located approximately 0.8 km (0.5 mi) south of Units 2&3 and forms the eastern boundary of the Capistrano Embayment. The fault dies out offshore into a series of folds. The last movement on the fault is limited by undisturbed marine terrace deposits that have been dated at 125,000 years old. The fault is therefore not a capable fault as defined by 10CFR100, Appendix A. 5. The Newport-Inglewood Fault Zone (NIFZ), the South Coast Offshore Fault Zone (SCOFZ), and the Rose Canyon Fault Zone (RCFZ) are structural components of a hypothetical continuous zone of capable faults within 8 km (5 mi) of the site. The US Geological Survey (USGS) expressed an opinion that these three structural components of the trend cannot be dissociated. Southern California Edison contends that the hypothesized Offshore Fault Zone comprises independent faults zones that are dissociated based on structure, trend, and strain pattern differences between the three components. They note that the NIFZ terminates at the compressive San Joaquin Structural High where local faults exhibit reverse movement. Fault styles on opposite sides of the South of the San Joaquin Structural High were produced by different strain patterns and are not directly associated. The 40-km-long South Coast Offshore fault was active after the San Joaquin Structural High was formed. Differences in timing of movements and tend serve to dissociate the SCOFZ from the Rose Canyon Fault zone to the south. 6. The 1933 Long Beach earthquake, M 6.3, occurred on the northern part of the hypothesized Offshore Fault Zone, which is the Newport-Inglewood fault zone. No historical seismicity is associated with the central part offshore of SONGS. The southern part, the Rose Canyon fault, has not been associated with earthquakes greater than M 4.0. No historically reported earthquakes can be reasonably associated with faults within 5 miles of the site. 7. The apparent alignment of structural features offshore along the southern California coast has resulted in the hypothesis of a continuous Fault Zone, extending from the Santa Monica Mountains to Baja California for a distance of 200 km (125 mi) or more. Extensive geophysical investigation indicates that the hypothesized OFZ is in actuality composed of three structural features; from north to south: The Newport-Inglewood Fault Zone (NIFZ), South Coast Offshore Fault Zone, and Rose Canyon fault zone. In the interest of conservatism, the hypothesized OFZ has been evaluated as a continuous Fault Zone capable of
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	<p>generating significant shaking at the site. The hypothesized OFZ quantitative earthquake potential has been based on the conservative assumption that the maximum earthquake which could occur anywhere along the length of the zone could occur offshore of the SONGS site at the closest approach of 8 km (5 mi). Slip rate is not directly available for the OFZ. However, 0.5 mm/yr calculated for the NIFZ is considered to be conservative for the OFZ.</p> <p>8. Conclusions regarding the maximum earthquake of the hypothesized OFZ are summarized as follows: $M_s = 6.5$ is a reasonable maximum earthquake magnitude consistent with geological and seismological features of the Newport-Inglewood Fault Zone (NIFZ). Because the NIFZ is considered to conservatively represent the earthquake potential of the hypothesized OFZ, transferring $M_s = 6.5$ to the OFZ provides a degree of conservatism for the maximum magnitude estimate for the OFZ opposite the site. However, based on incorporation of additional conservatism through evaluation of ranges in the slip-rate data and review of other elements for assessing the degree-of-fault-activity of the hypothesized OFZ, the most conservative maximum magnitude is $M_s = 7.0$. A larger earthquake is inconsistent with the geological and seismologic features of the hypothesized OFZ and is therefore not credible.</p> <p>9. 56 earthquake records were selected to correspond closely to the conditions of the estimated maximum earthquake and analyzed to develop the 84th-tile spectrum for $M_s = 6.5$ and carefully extrapolated to $M_s = 7.0$. The resulting 0.67 g bedrock acceleration is conservative based on subsequent work that developed $M_s = 7.0$ as the maximum magnitude on site-specific analysis of empirical data showing a corresponding peak instrumental acceleration of 0.63 g. Comparison to the Design Basis Earthquake (DBE) of empirical response spectra scaled to 0.67 g shows that the DBE time history used for the site is much more severe than the scaled real earthquake records, which include acceleration spikes up to 0.75 g.</p>
Strengths	Compilation and synthesis of wide range of geological, geophysical and seismological data to assess hazards at the SONGS site with interpretations that acknowledge uncertainty in the data and accommodate alternate, conservative hypotheses.
Limitations	Newer concepts of possibly widespread compressive thrust faults in the Continental Borderland Province offshore and at the southern end of the NIFZ are not addressed in the UFSAR, but are subsequently investigated with respect to ground motion hazard implications in more recent probabilistic seismic hazard analyses in 2001.
Comparisons/ Implications	Historical regulatory document.

Title 43	Seismic Hazard At Son Onofre Nuclear Generating Station
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Risk Engineering, Inc.
Source	Report for Southern California Edison Co.
Scope	Assessment of annual probabilities of exceedance for spectral accelerations at SONGS incorporating seismological and fault data including representation of data variability and modeling uncertainty for application in IPEEE vulnerability assessments
Data Used	Southern California earthquake data from USGS, NOAA, and California Institute of Technology, length-width-depth dimensions of active faults with slip-rate data, five published strong-motion attenuation relationships
Methodology	Logic-tree probabilistic seismic hazard assessment implementing fault and area seismic sources
Summary Results	<ol style="list-style-type: none"> 1. The hypothesis of a nearby fault (either connected to the Newport-Inglewood or the Rose Canyon-SCOFZ faults) dominates the hazard for the larger ground motions (spectral accelerations ≥ 0.15 g). At lower ground motions the San Andreas, Elsinore and San Jacinto faults contribute most to the hazard. Area sources do not contribute much to the hazard compared to the faults. 2. 0.25 Hz (0.04-sec period) mean and median SSE spectral acceleration is determined to be 0.735 g and 0.681 g, respectively, on generic stiff soil at a return period of 7,215 years. 3. Deaggregation of the 10 Hz hazard (0.1-sec period) at the SSE level results in a magnitude 6.7 earthquake at 9.3 km from the site. Deaggregation of the 1 Hz hazard (1.0-sec period) results in a magnitude 7.0 at 17 km from the site.
Strengths	A state-of-the-art PSHA incorporating aleatory variability and epistemic uncertainty.
Limitations	Newer concepts of possibly widespread compressive thrust faults in the Continental Borderland Province offshore and at the southern end of the NIFZ are not addressed in the UFSAR, but are subsequently investigated with respect to ground motion hazard implications in more recent probabilistic seismic hazard analyses in Title 47.
Comparisons/Implications	Incorporates seismic sources and earthquake parameters presented in Titles 44 through 46.

Title 44	Appendix A (to Title 43) - Seismic Source Characterization
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Definition of seismic sources (faults and area sources) for input to the IPEEE PSHA documented in Title 43
Data Used	Length-width-depth dimensions of active faults with slip-rate data, regional tectonic data, historical earthquakes
Methodology	Synthesis of available fault, regional tectonic, and historical earthquake data into a coherent model that describes earthquake potential of all seismic sources within 100 km of the SONGS site using a logic-tree format to incorporate modeling uncertainties
Summary Results	<ol style="list-style-type: none"> 1. Offshore faults included the 1) the Newport-Inglewood (NI) /South Coast Offshore Fault Zone (SCOFZ)/Rose Canyon, 2) Palos Verdes-Coronado Bank-Aqua Blanca, 3) San Diego Trough, and 4) San Clemente-San Isidro fault zones. Onshore faults included the 1) Elsinore, 2) Whittier, 3) Aguanga-Agua Tibia, 4) San Jacinto, 5) San Andreas, 6) Malibu Coast-Santa Monica, 7) Hollywood-Raymond, 8) Sierra Madre, 9) Cucamonga, 10) Peralta Hills-Norwalk, 11) Temescal, and 12) La Nacion faults. Earthquake potential of buried or blind thrust faults were implicitly subsumed in regional background area seismic source zones. 2. NI fault extends 70 km from Santa Monica Mountains to offshore of Newport Beach and is a through-going zone of right-lateral strike slip in basement rocks. Two segments identified that are separated by a 2+ km-wide restraining bend north of Long Beach. The 1933 Long Beach earthquake (Ms 6.3) ruptured most of the 30-km-long southern segment. 3. Fault continuity offshore (the SCOFZ) less well known. Offshore seismic data indicate wrench-related fold and flower structure. North (43 km) and south (32 km) segments offshore are recognized with apparent subsegments in each. Holocene activity recognized in both the north and south segments. Rose Canyon fault (approx. 62 km) lies in-board of the the SCOFZ-south segment and also has a north and south segment (32 km and 24-30km, respectively). 4. NI-SCOFZ-Rose Canyon fault system modeled with two alternative segmentation hypotheses, both with equal weight. Model A assumes the NI fault zone and SCOFZ is one fault in

	<p>which ruptures can propagate across the step-over segment boundary and the Rose Canyon fault is treated as an independent fault source. Model B assumes NI fault zone is independent from the SCOFZ-Rose Canyon combined fault source and has a lower activity rate. Model A median slip rate is 1.5 mm/yr with a range of 0.8 to 3.0 mm/yr. Model B NI model median slip rate is 0.8 mm/yr with a range of 0.1 to 1.5 mm/yr. Model B SCOFZ-Rose Canyon median slip rate is 1.5 mm/yr with a range of 1.0 to 3.0 mm/yr. Fault dips for the zone are all assumed to be 90° from the horizontal.</p> <p>5. Based on uniform uplift of marine terraces in the nearby vicinity of SONGS, anticlinal folding related to blind thrust faults is not occurring thereby precluding the existence of these faults in the site region that are capable of generating significant earthquakes. Unknown sources including small-scale blind thrusts are subsumed in the area seismic sources.</p>
Strengths	A careful synthesis of existing data related to known southern California faults.
Limitations	Existence of possible blind thrust ramps and faults are implicitly included in background area seismic source zones and not explicitly modeled.
Comparisons/ Implications	Developed models were used in the PSHA (Title 43). Subsequent explicit representation of thrust faulting models was included in a 2001 PSHA (Title 47).

Title 45	Appendix B (to Title 43) - Maximum Magnitude Distributions
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Establishes maximum magnitude ranges for seismic sources defined in Appendix A (Title 31)
Data Used	Fault rupture parameters of Appendix A (Title 44)
Methodology	Empirical regression analysis between magnitude and subsurface rupture length and rupture area using the Wells and Coppersmith (1994) equations
Summary Results	<ol style="list-style-type: none"> 1. Modal values for NI-SCOFZ-Rose Canyon fault Models A and B (Title 31) are between approximately M 6.6 and 6.8 with low probability values extending up to M 7.5. 2. Southern San Andreas fault modal value is approximately 7.6 with lower probability of M 8+.
Strengths	Newest worldwide empirical correlation equations were used at the time of this study.
Limitations	Very terse treatment of the maximum magnitude topic. Tabulated values would be beneficial for recognition of exact values rather than the distribution plots that are provided. A rather unnatural division of topics related to seismic source characterization.
Comparisons/Implications	Developed magnitude distributions were used in the PSHA (Title 43).

Title 46	Appendix C (to Title 43) - Earthquake Recurrence Relationships for Fault Sources
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Establishes maximum magnitude ranges for seismic sources defined in Appendix A (Title 44)
Data Used	Fault rupture parameters of Appendix A (Title 44)
Methodology	Development of exponential and characteristic earthquake recurrence frequency distributions for fault sources using the fault-rupture parameters and slip-rate estimates from Appendix A (Title 30)
Summary Results	<ol style="list-style-type: none"> 1. Recurrence relationships established for the NI-SCOFZ-Rose Canyon are the most important to the hazard analysis due to proximity to SONGS. 2. Median estimate of M 7 recurrence frequency on the NI-SCOFZ-Rose Canyon fault scenarios is approximately 10,000 years as indicated by recurrence frequency plots.
Strengths	
Limitations	The descriptions of the NI-SCOFZ-Rose Canyon Models A and B are reversed in this text compared to the model descriptions presented in Appendix A (Title 44).
Comparisons/Implications	Contradictory descriptions of Models A and B concerning the NI-SCOFZ-Rose Canyon fault zone in Appendix A (Title 44) and this appendix creates confusion as to which model description was actually implemented in the PSHA (Title 43).

Title 47	San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults
Year	2001
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants and GeoPentech
Source	Report for Southern California Edison Co.
Scope	Logic-tree PSHA incorporating explicit models of postulated blind thrust faults in the vicinity of San Onofre as well as "near-source" directivity and fling ground motion effects
Data Used	Fault-specific geologic data, regional tectonic data and interpretations, local and region GPS data
Methodology	Logic-tree PSHA procedures incorporating three weighted seismic source models that account for blind thrust faults following a critical review and evaluation of the blind thrust hypothesis
Summary Results	<ol style="list-style-type: none"> 1. <u>Model 1</u>: Assumes that the NI-SCOFZ-RC is an active strike-slip fault zone that truncates and displaces the Oceanside detachment of Rivero et al. (2000). This model is similar to Model A described in Appendix A of the 1995 PSHA (Title 31). <u>Model 2</u>: Allows for independent active strike-slip and blind thrust faults to be present in the inner continental borderland adjacent to SONGS. This model includes an active Oceanside blind thrust (OBT) as well as independent NI and RC strike-slip faults. <u>Model 3</u>: The OBT and SCOZ-RC represent strain-partitioning above an oblique, shallow-dipping (14° - 24°) fault plane depth in the vicinity of SONGS. A maximum magnitude of M 7.6 is used with a range of slip values of 1.19 and 2.91 as given by Rivero et al. (2000). Based on critical evaluation of available tectonic and fault data, weighting of seismic source models 1, 2 and 3 in the PSHA were 0.70, 0.25, and 0.05, respectively. The very low weight given to Model 3 is based on the highly unlikely association of the oblique strike-slip component of faulting on the shallow-dipping fault plane. 2. A detailed evaluation of GPS data regarding implications of compressive strain across southern California (south of the Transverse Ranges) that could drive thrust components on generally NW-trending faults throughout the region is summarized as follows: 1) The overall patterns of relative displacement rates indicate that no compressional relative displacement fields exist behind the hanging wall of the OBT postulated as part of Model 2 and 3. 2) Both total and incremental relative displacement rates associated with 4 selected

	<p>pairs of SCIGN GPS stations are adequately consistent with the slip rates associated with Model 1 sources. 3) Both total and incremental relative displacement rates associated with the 4 selected pairs of SCIGN GPS stations appear to become significantly inconsistent with the slip rates associated with the postulated Model 2 and 3 fault sources, with Model 3 being slightly less consistent than Model 2. 4) There may be some compressive stress occurring between some coastal areas near the SONGS site and Catalina Island. The small compressive strain that may be occurring is considered inadequate to load or drive the OBT. 5) The systematic evaluation of GPS data indicates that the weights assigned to Models 2 and 3 may be significantly lower than those used in the PSHA. 6) The absence of unaccounted compressional components in the direction perpendicular to the major strike-slip faults in the region of SONGS makes it difficult to postulate significant active thrust faults in the region.</p> <p>3. When associated with 0.67g on the combined PGA hazard curve, the SSE uniform hazard spectrum from Model 1 (base result) corresponds to an annual probability of 1.74×10^{-4} (5,747 yrs.) and is shifted somewhat to lower frequencies than the compared to the previous IPEEE spectrum (Title 43). The equivalent IPEE annual probability is 1.39×10^{-4} (7,194 yrs). The previous IPEEE spectrum is significantly higher at 5 Hz. These differences are primarily due to different attenuation relationships between the studies.</p> <p>4. From the study summary: 1) In general, the hazard curves, response spectra, and weighted hazard curves for the the combined OBT case are higher than those from Model 1 with the differences being greater at lower annual frequency of exceedance levels. 2) The effects of directivity appear to be no more than about a 2% increase at 1 Hz and 8% increase at 0.5 Hz for the SSE level. 3) Given the above observation and given that the evaluation of GPS data indicates that the weights assigned to Models 2 and 3 may be too high, the results of this PSHA for the combined OBT case should be conservative. 4) The effects of the fling step appear to be even less at no more than about a 2% additional increase in spectral acceleration values at 0.5 Hz and about 1% additional increase at 1 Hz.</p> <p>5. The NI/OFZ/RC/OBT completely dominates the hazard for annual probabilities lower than about 3×10^{-3} (333 yrs return period and greater). Overall, the weighted hazard curve from this study is comparable to the SONGS IPEEE weighted hazard curve.</p>
Strengths	A careful evaluation of the implications of proposed blind thrust faults in the vicinity of SONGS.
Limitations	Proponents of blind thrust models may disagree with weights associated with these models in the logic-tree PSHA.

Comparisons/ Implications	As a result of the fault and ground motion models in this investigation, the return period of the SSE bedrock acceleration value of 0.67 g has dropped from 7,194 years in Title 43 to 5,747 years. Safety of the SONGS power plant therefore depends on adequate engineering safety margins.
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