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AB 1632 ASSESSMENT OF CALIFORNIA'S OPERATING NUCLEAR PLANTS

DRAFT REPORT

DRAFT CONSULTANT REPORT

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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 "Study 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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Abstract

This consultant report was prepared in response to Assembly Bill 1632 (AB 1632), 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 (Blakeslee, Chapter 722, Statutes of 2006). 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, nuclear power, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Hosgri, Fault, seismic, earthquake, tsunami, operating basis earthquake, safe shutdown earthquake, design basis, Kashiwazaki-Kariwa, aging, degradation, vulnerability, Nuclear Regulatory Commission, NRC, nuclear waste, waste storage, waste disposal, Department of Energy, DOE, spent fuel, safety culture, Independent System Operator, CAISO, transmission, production simulation, outage, replacement power, reliability, low-level waste, land use, property values, renewable power, life cycle, once-through cooling, license renewal, relicensing, electricity, policy, California, dry cask, independent spent fuel storage installation, ISFSI, greenhouse gas emissions, GHG emissions

Executive Summary

In 2006 the California Legislature enacted 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 overall 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 needs a long-term plan to prevent major disruptions and to be ready should a disruption occur.

This report, *AB 1632 Assessment of California's Operating Nuclear Plants*, provides information to policymakers and stakeholders about Diablo Canyon and SONGS to assist energy policy planning. A key element of the report is a review of existing scientific studies concerning 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 prescribed in AB 1632, relies on existing literature, studies, and data where possible. The interdisciplinary Study 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 articles and reports. Despite the depth and breadth of data and literature reviewed, the Study Team in some instances encountered areas where data are either limited or unavailable. For these areas, the report identifies questions and issues that merit additional review and analysis.

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[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>.

For the seismic vulnerability assessment, the Study Team provided early drafts to several seismic staff experts in 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 Study Team and the team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS.

Members of the public also contributed to this assessment by identifying studies for review and providing comments on a draft study plan. In order to maintain the independence of the assessment, the Study 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 will be provided the opportunity to submit written comments on the draft report until October 2, 2008.

Seismic Vulnerability Assessment

The seismic vulnerability assessment undertaken for this study was performed in two steps. In the first step, the Study Team considered the geology and seismic hazards in the vicinity of Diablo Canyon and SONGS. In the second step the Study 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 Study 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, via the Long-Term Seismic Program (LTSP), has extensively explored the seismology and geology of the Diablo Canyon site. SCE does not have an analogous program 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 therefore be ascertained 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. Uncertainties exist regarding the regional tectonic setting surrounding Diablo Canyon and the nature of the Hosgri Fault. Current published data, much of which has been developed through the LTSP, support the interpretation that the Hosgri Fault is a strike-slip fault.[4] There is, however, a currently less-favored model of the fault that considers the Hosgri Fault a thrust fault. If it is a thrust fault, the seismic hazard at Diablo Canyon could be greater than currently anticipated.

3. Diablo Canyon is located within the San Luis-Pismo geologic 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

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[4] 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.

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. A consensus fault model for California indicates that the bounding faults of the San Luis-Pismo block have lower dip angles toward one another than has previously been modeled by PG&E. This fault geometry suggests that the occurrence of an earthquake directly beneath Diablo Canyon of similar nature to the 2003 San Simeon earthquake cannot be conclusively ruled out. An assessment of this possibility, if conducted, should include an analysis of the expected ground motions and vulnerabilities of plant components that might be sensitive to pulse-type, 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 a 33 percent chance of 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 serve to prove or disprove the existence of subsurface faults in the San Luis–Pismo tectonic block and could also serve to 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. Establishment of a permanent global positioning system (GPS) array in the onshore region of the Diablo Canyon site could clarify the nature of local crustal movements through repeated surveys. Results of these surveys might alter fault parameters that are used in existing seismic hazard assessments.

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 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 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 years 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 incorporating estimates of ground motion variability in the near-source region of faults.

10. The U.S. Geological Survey (USGS), California Geological Survey, and the Southern California Earthquake Center have developed a detailed, updated ("UCERF-2") database of faults and rupture probabilities in California. 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 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 they are most critical for SONGS. This is because the SONGS seawall is just 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 would need to 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 factor most likely would be the location of the damage, i.e., whether the repair is one the nuclear side or

the non-nuclear side of the power plant. 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 fail 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, roughly six to eight kilometers west of Diablo Canyon, creates the primary seismic hazard at the plant site. Uncertainty exists 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.

Geologic and seismologic research literature supports the interpretation that the Hosgri Fault is 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. Other scientists, however, disagree with this characterization.

The implications of a thrust fault characterization for the seismic vulnerability of Diablo Canyon are uncertain. PG&E evaluated the seismic hazard at Diablo Canyon from the Hosgri Fault for probabilities of 67 percent strike-slip faulting and 33 percent thrust faulting. PG&E 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, although 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, in part, 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 well enough understood 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 would be significant for engineering vulnerability assessments.

The Diablo Canyon seismic setting has been extensively studied, largely under the Long-Term Seismic Program.[5] Further study using advanced technology may help resolve the Hosgri Fault debate. For example, high quality three-dimensional seismic data could aid in identifying the true dip and structure of the Hosgri Fault, direct imaging of subsurface structure at Diablo Canyon could determine if faults exist near the site that do not break to the surface, and establishment of a permanent GPS array in the region surrounding the plant could refine models of tectonic movements in the plant vicinity.

Finally, characteristics of ground motions that could result from earthquakes is an area of continuing research. Recent studies have found that ground motion in close proximity to a fault could be stronger and more variable than previously thought. This could be important at Diablo Canyon since the plant lies within eight 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 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 an eroding safety margin at the SONGS site. The estimated frequency of a 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. There is no program at SONGS similar to PG&E's Long-Term Seismic Program at Diablo Canyon.

An important element of the seismic hazard at SONGS is 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. 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.

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[5] 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.

Also 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.

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.

It appears that 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. Even a moderate increase in the estimated maximum tsunami run-up 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 of Diablo Canyon and SONGS are designed to remain safe during safe-shutdown earthquakes of magnitude 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.

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 Study Team cannot assess the plants’ true seismic vulnerabilities since seismic evaluations of the non-safety portions of the plants were not available to the Study Team.

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. 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.

The turbine building and tank areas might also be susceptible to damage. The turbine building at Diablo Canyon is large with an expansive open space inside. The turbine building's roof could collapse in an earthquake. At SONGS, the tank areas for the condensate storage tank and the refueling water storage tank are low-lying areas susceptible to water damage in the event of a tsunami that exceeds the design basis. Ground movement near the support pads for the tanks could cause underground pipes to burst and damage the tanks.

Diablo Canyon or SONGS could be shut down following earthquakes for as little as one week to as much as four 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. 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. A collaborative study involving the utilities, manufacturers, and researchers with the appropriate expertise could be beneficial to estimating power plant restart time.

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 appear to be the primary cause of the lengthy shut down, suggesting that repairing or replacing damaged components may not be the primary driver of how long a nuclear power plant is shut down following a major seismic event. Research and investigations into the earthquake and the root causes of damage at the nuclear power plant are ongoing; the Energy Commission and California's nuclear plant owners should stay informed as new information becomes available.

Vulnerability of Spent Fuel Storage Facilities

There are two general types of spent ("used") nuclear fuel storage, pool and dry cask storage. Diablo Canyon and SONGS currently use pools for spent fuel storage; however, dry cask storage facilities have also been constructed for 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. If not mitigated, such an event could result in overheating of the stored spent fuel and the subsequent release of radioactive material. The design of spent fuel storage pools reduces the possibility of drainage leading to water levels lower than the stored fuel; nevertheless, loss of any amount of water is undesirable. The spent fuel pools at Diablo Canyon and SONGS are supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis.

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. While regulations permit Diablo Canyon and SONGS to use re-racking, a loss-of-coolant event in a re-racked spent fuel pool could result in extensive radiation release and contamination.

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. Spilled water in one reactor building leaked into the Sea of Japan from leaks in the reactor building floor. Although the SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of sloshing, PG&E is investigating the water-tightness of conduits in its reactor buildings.

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.

Although the primary focus of this report's vulnerability assessment of the spent fuel storage facilities was earthquake-related, the AB 1632 Study Team also reviewed published risk analyses for terrorist events or sabotage at dry cask storage facilities. Limited information is available on the vulnerability of dry cask storage to sabotage, which is consistent with the National Academies' finding when it conducted a study of spent fuel storage safety. 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 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. 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. If the traffic overwhelmed the highway system, it could halt highway access and impede emergency response. This occurred in Texas and Louisiana ahead of the 2006 hurricanes.

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 Study 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 Study Team are:

1. Aging plant components must be adequately monitored, maintained, and repaired to have a safe and reliable nuclear power supply. 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 and benefits from the oversight of the Diablo Canyon Independent Safety Committee. There is no similar independent safety oversight committee for SONGS.

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 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. Simulations find that no electricity supply shortages would occur as the result of either Diablo Canyon or SONGS being unexpectedly shut down for an extended period in the near term, nor would remedial action, such as additional demand response, energy efficiency, or additional capacity be needed for reliability purposes.[6] 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.

5. The simulations did not assess local reliability impacts of an extended outage at either of the nuclear plants or the availability of adequate generation resources after 2012. More complete studies and detailed modeling will be needed periodically to reassess the

[6] The simulations modeled specifically the year 2012.

availability of replacement power at a system and local level as supply and demand conditions evolve and local transmission constraints change.

6. A prolonged shutdown of Diablo Canyon would not pose reliability concerns. However, a prolonged plant shutdown at SONGS could result in serious grid reliability shortfalls unless transmission infrastructure improvements are completed. Replacement power for SONGS would be available.

Vulnerability to Plant Aging-Related Degradation

The state's nuclear plants are now approaching their fourth decade of operation. As they age, their systems, structures, and components are all subject to age-related degradation, which, if unchecked, could lead to a loss of function and impaired safety.

There is a clear correlation between the age of a nuclear plant and the number of degradation occurrences it experiences. Effective maintenance programs and regulatory oversight are critical to ensure that aging plant equipment and components are identified and either repaired or replaced 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 the 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 provide the first indication of an impact of age-related degradation. 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, up to now, 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 on account of degraded materials or operational failures.

Plant component aging problems have surfaced at some U.S. nuclear plants. 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

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[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.

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.

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, 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 benefits from the oversight of the Diablo Canyon Independent Safety Committee, which investigates concerns that do arise. SONGS may benefit from a similar independent safety oversight committee.

The workforces at Diablo Canyon and SONGS are also aging, 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 these programs 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 an earthquake, age-related plant or equipment failure, or other event leads 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 an extended outage would depend on what time of the year the outage occurred and what replacement power was available.

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[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 Study Team agrees with this recommendation.

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 maintenance shutdowns to avoid periods of peak 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 Study Team simulated the operations of the electricity market for the year 2012 with and without one or both of the nuclear plants operational. The simulations suggest that no electricity supply shortages would occur as the result of either Diablo Canyon or SONGS being unexpectedly shut down for an extended period in 2012, nor would remedial action, such as additional demand response, energy efficiency, or additional capacity be needed for reliability purposes.

Based on simulations, replacement power in the event of 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 increased generation would come from in-state gas-fired plants, while the remainder would come from out-of-state gas-fired plants along with a small amount of increased coal generation. The cost of that replacement power would include the operating costs of in-state units and market costs to acquire power from out-of-state.[9] For a year-long loss of either nuclear plant, the simulations found that these costs would be $470 million higher than the cost to generate power from the nuclear plant. The added cost would increase average rates for customers of either PG&E or SCE/SDG&E by approximately half a cent per kilowatt-hour (kWh) while the outage continued. Plant repair costs likely would further increase rates.

An outage would also pose environmental consequences, since the replacement power would be largely natural gas-fired. The simulations found that an 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 CO_2. Out-of-state replacement generation would add an additional 2.2 to 2.8 million tons of CO_2, for a total greenhouse gas impact of approximately 7 million tons of CO_2.

The 2012 simulation finding regarding available replacement power in the event of an outage at either nuclear plant is similar to current assessments of the California Independent System Operator that show sufficient reserve margins to accommodate the loss of either or both nuclear plants. This assessment of near-term replacement power options is not applicable to the post-2012 period and does not consider local transmission constraints that may restrict the deliverability of power to certain areas. More complete studies will be needed periodically to reassess the availability of replacement power at a system and local level given updated supply and demand conditions and local transmission constraints.

[9] 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 MARKETSYM model.

Previous studies have shown that while Diablo Canyon represents a significant generation resource and supports power flows through Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. During a major disruption at Diablo Canyon, replacement power can be supplied by existing and new resources, albeit at additional cost and with a greater environmental impact since most of the replacement power would come from natural gas-fired plants. SONGS, on the other hand, appears to be a more integral part of the Southern California transmission system, and when it is shut down, imported power flows are also restricted. While replacement power for SONGS would be available (at similar costs and environmental impacts as for Diablo Canyon), a prolonged shutdown could cause serious grid reliability shortfalls unless transmission system infrastructure improvements were made. The extent of the transmission system changes would depend on the transmission configuration in place at the time of the SONGS shutdown.

Economic, Environmental, and Policy Issues Assessment

The AB 1632 Study 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 Study 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. PG&E is planning to build sufficient on-site dry cask storage so that Diablo Canyon can continue operating past the plant's current license period or the spent fuel pool can be decommissioned when the current license expires without additional storage being required. Based on SCE's current plans for dry cask storage, SCE will run out of spent fuel storage space at SONGS several months before the end of the plant's current operating license.[10] At that time, the plant will not be able to continue operating and the spent fuel pool will not be able to be decommissioned unless SCE builds additional on-site dry cask storage or secures offsite storage.

3. 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

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[10] SCE is expected to run out of storage capacity towards the end of 2021, and the earliest feasible date for a repository opening is sometime after 2017, with a more likely opening date sometime after 2020 (see Appendix A and *Nuclear Power in California: 2007 Status Report)*. It is thus unlikely that sufficient spent fuel will be moved from SONGS to a repository before SCE runs out of storage capacity.

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 estimates of disposal costs that were established in the most recent regulatory proceeding on decommissioning costs in 2005 are outdated.

4. 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.

5. From a pure resource potential perspective, given adequate time California could license and build new renewable generation to replace the energy from Diablo Canyon and SONGS. However, since there are no large-scale renewable units with the same characteristics as baseload nuclear plants, current renewable technologies 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.

6. One of the challenges in replacing the nuclear plants with renewable power generating facilities would be the different impacts of this decision on different communities. If the new plants were built in California, the total economic benefit from employment and taxes statewide would be comparable to the benefits currently provided by the nuclear plants. 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. Recent announcements of several planned large-scale solar facilities in San Luis Obispo County suggest that renewable power development could benefit San Luis Obispo County, thereby limiting the transfer of benefits away from the County.

7. The economic impacts of 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.

8. 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 additional large capital improvements, the cost of power from the nuclear plants will likely remain lower than the cost of power from new renewable resources. However, significant equipment failures could result in extended outages and expensive repairs. 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 is extremely radioactive, must be stored in a water-filled pool for a minimum of five years following removal from the reactor core to shield 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 produced over the period of their 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 on-site dry cask storage facilities at Diablo Canyon and SONGS. PG&E has designed and permitted a dry cask storage facility for Diablo Canyon that will allow the utility to transfer and store 100 percent of the spent fuel produced during the current operating license. This would allow PG&E to decommission Diablo Canyon's spent fuel pool at the end of the current license if needed. SCE has designed a dry cask storage facility for SONGS with a capacity to store 36 percent of the spent fuel generated during the current license period and intends to rely on its spent fuel pool to store the remaining spent fuel. Additional storage space would be required if SONGS were to continue operating past its current license or if SCE wanted to decommission the SONGS spent fuel pools before off-site spent fuel storage is available. Moreover, the total planned combined storage capacity at SONGS will be sufficient to store just 98 percent of the spent fuel expected to be produced during the plant's current operating license. In order to accommodate the remaining spent fuel, SCE will need to secure offsite storage or develop additional capacity. SCE has not yet determined how it will manage the extra spent fuel.

The costs for constructing and loading the dry cask storage facilities are substantial. On a present value basis, the total cost is $160 million for Diablo Canyon and $300 million for SONGS. Since the dry cask storage facility at SONGS is just 40 percent the size of the Diablo Canyon facility and nearly twice as expensive, the SONGS facility is three to four times as expensive per fuel assembly.

In June 2008 the U.S. Department of Energy (DOE) filed a license application 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, over 20 years after the January 1998 statutory and contractual deadline for beginning to accept spent fuel from utilities. PG&E and SCE have sued DOE for reimbursement of their ISFSI 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. 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). DOE 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 the 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; 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 an alternate facility is available. 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 current estimates of disposal costs during decommissioning are based on outdated cost information. Costs could be substantially higher than estimated during the most recent California regulatory proceeding on decommissioning costs in 2005.

Land Use and Economic Implications of On-Site Waste Storage

There is 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 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. The Diablo Canyon plant site will likely be converted to recreational use. The SONGS plant site, which is located on military land, will presumably 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.

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 the available surveys appear to be unreliable predictors of economic effects. 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, and the California Air Resources Board 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."[11]

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

The primary ways to meet California's growing energy demand while lowering greenhouse gas emissions are energy efficiency, renewable resources, and distributed generation.[12] From a pure resource potential perspective, given adequate time California could license and build new renewable generation to replace the energy from Diablo Canyon and SONGS. However, since there are no large-scale renewable units with the same characteristics as baseload nuclear plants, current technologies would require support of some fossil fuel units to replace all the attributes of the nuclear plants. Operational and local transmission issues must be studied more carefully to identify which attributes of these plants would need to be replaced should the plants be shut down. In addition, the costs of renewable energy are uncertain, and a switch to renewable power resources away from nuclear power could result in an overall increase in the cost of electricity. Technological advances could ameliorate some or all of the potential cost and reliability concerns.

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. 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 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 would result in roughly the same overall tax and employment benefits to the state as provided by the nuclear plants. However, these benefits would 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 modeling suggests that replacing the state's two 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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[12] 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.

License Renewal Issues for State Policymakers

Diablo Canyon and SONGS have been operating for roughly half of their 40-year initial license periods, and PG&E and SCE are exploring the feasibility of seeking 20-year license renewals from the U.S. NRC. 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. Unfortunately, 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 any 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, the costs could remain comparable to current levels with relatively minor increases due to higher nuclear fuel costs and potentially stricter security requirements. However, degradation of major components or extended outages could result in much higher costs. In addition, the plants may be required to retrofit their once-through cooling systems prior to a license renewal. In a study for the Ocean Protection Council, Tetra Tech estimated that the retrofit and outage would cost a net present value of $2.6 billion at SONGS and $3.0 billion at Diablo Canyon.

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 plants. Given current economic conditions, 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 or all of this loss 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 by 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 enacted Assembly Bill 1632 (AB 1632), introduced by Assemblyman Sam Blakeslee.[13] 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.[14] 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 account for 12 percent of the state's overall electricity supply and, by some measures, 24 percent of the state's low-carbon electricity supply.[15] 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 needs 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.

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[13] AB 1632 (Blakeslee, Chapter 722, Statutes of 2006).

[14] 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.

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

Figure 1: Diablo Canyon Power Plant[16]

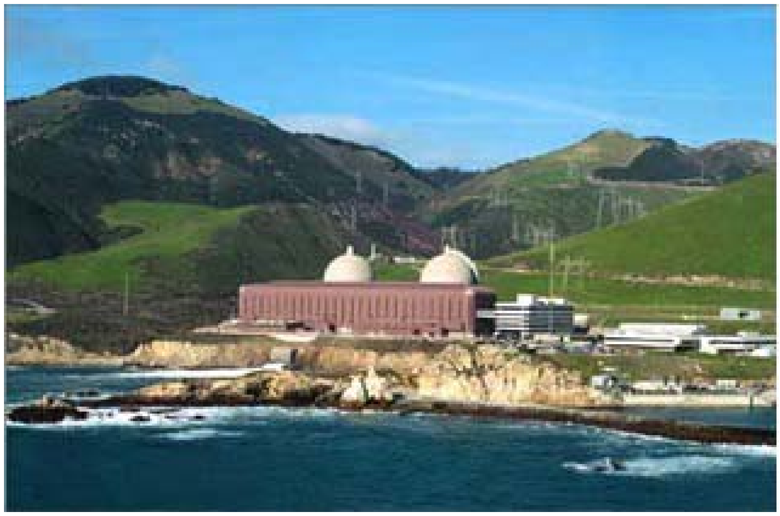
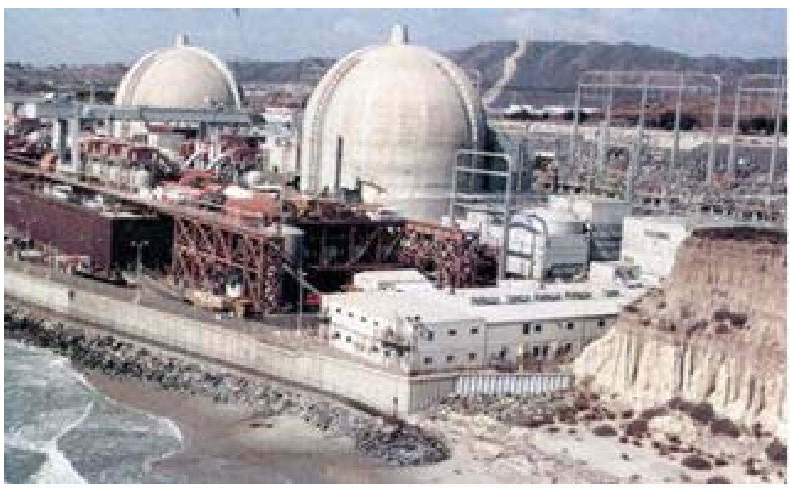


Figure 2: San Onofre Nuclear Generating Station (SONGS)[17]



If an earthquake, age-related plant or equipment failure, or other event leads 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

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

[17] 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 and the risk to the state 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 prescribed 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 Study 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 articles and reports.

Despite the depth and breadth of data and literature reviewed, in some instances the Study Team encountered 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 Study Team provided early drafts to several seismic staff experts in 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 Study Team and the team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS.

Public Involvement

Nuclear power has been and continues to be a controversial technology; supporters and opponents are both vocal and impassioned. For this reason, the public and interested stakeholders were given several opportunities to be involved in 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 Study Team. Comments on the draft study plan were submitted by a number of parties.[18] The Study 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 Study Team. In order to maintain the independence of the assessment, the Study Team did not meet with the nuclear plant owners or other interested parties during the development of the draft report.

A public workshop will be held on September 25, 2008, at which the Study Team will present a draft of this report. The public and interested stakeholders will be provided the opportunity to submit written comments on the draft report by 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 vulnerability of the Diablo Canyon and SONGS sites based on the current understanding of site-specific geology and seismic hazards.
- Chapter 3 assesses the current state of knowledge on the seismic vulnerability of the power plant buildings and structures.
- 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.

[18] 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 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 Vulnerability of 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 Study 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 Study 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).[19] 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

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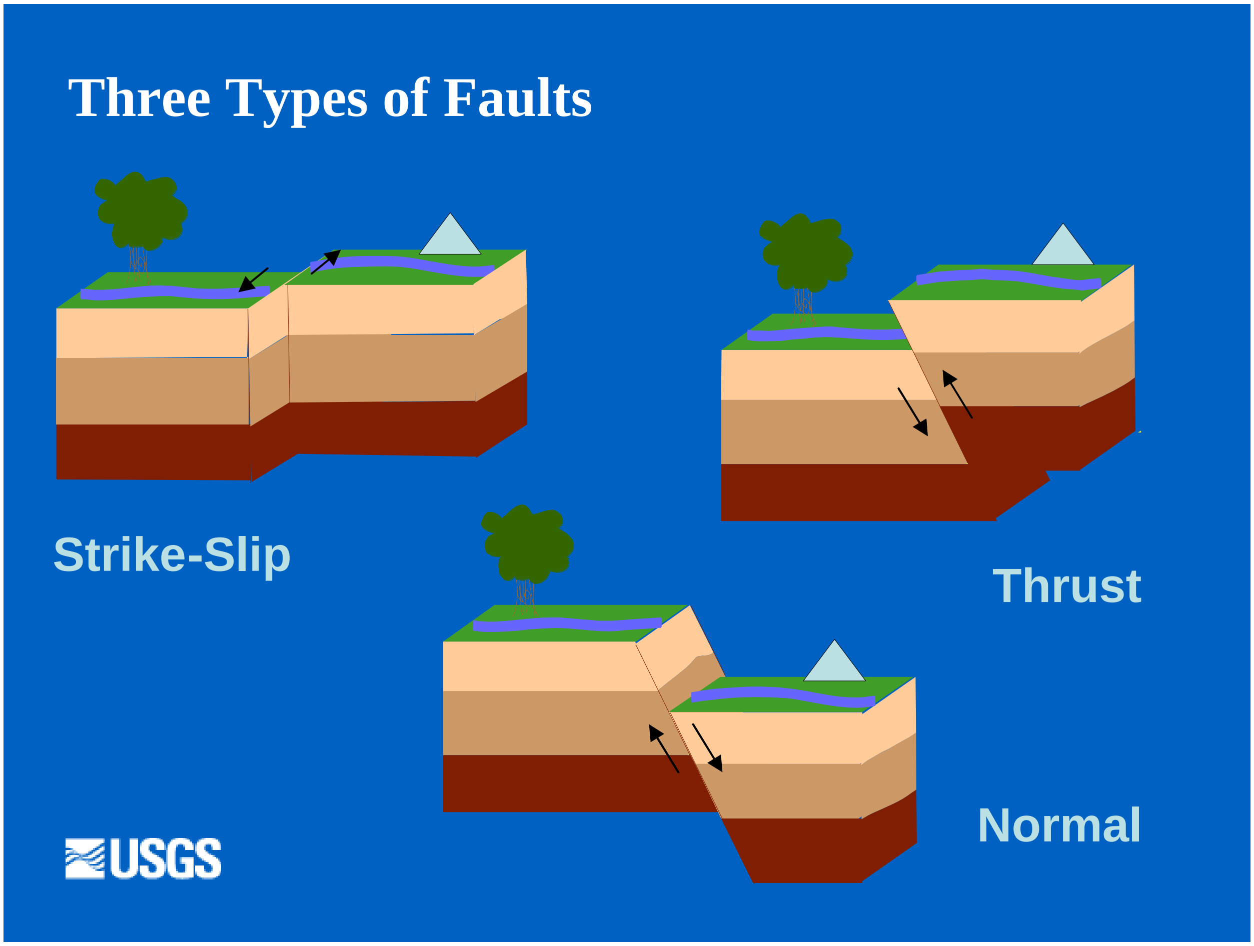
[19] Thrust faults have angles less than 45 degrees (shallow dipping). A fault with the same type of movement as a thrust fault but with an angle greater than 45 degrees (steeply dipping) is called a reverse fault.

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. Movement on these types of faults during earthquake rupture is vertical. 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).[20]

Both vertical and horizontal movement can occur during an earthquake. The combination of vertical and horizontal movement 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.

Figure 3: Three Types of Faults



[20] 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.

The ground motion hazard from earthquakes is directly proportional to the distance that a site is located from a fault rupture. 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 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).

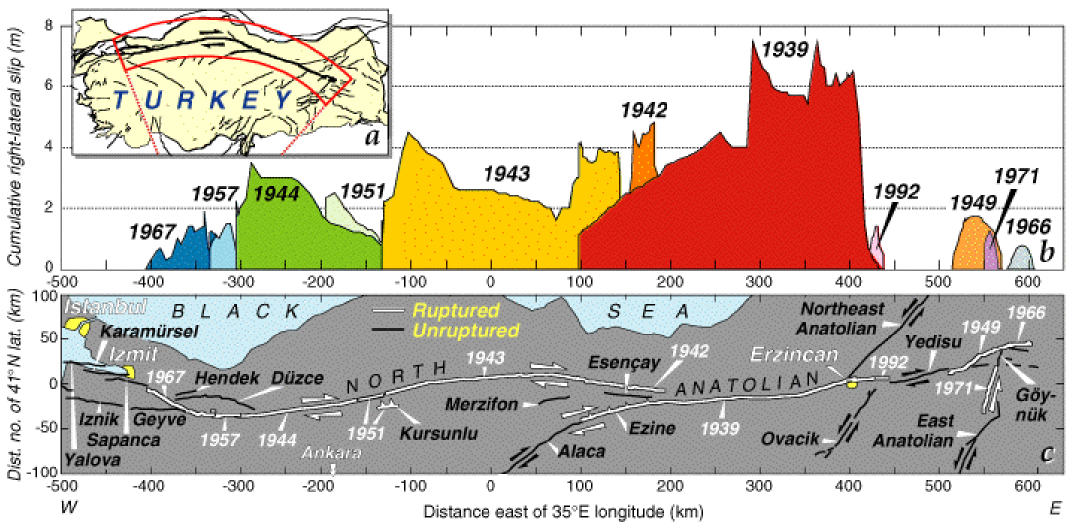
The estimate of the maximum earthquake is very important to evaluating the seismic hazard posed by a fault. The larger the maximum earthquake, the lower will be the frequency of occurrence of smaller earthquakes and vice-versa.

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 Fault[21]



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: smaller earthquake magnitudes produce smaller ground motions, and larger earthquake magnitudes produce larger ground motions. Ground motions are thus the 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

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[21] 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.

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 Study Team of this report 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 Study Team reviewed, assessed, and summarized nearly fifty scientific papers (see summaries in Appendix C). In addition, the Study 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), the U.S. Geological Survey (USGS), and University of Nevada-Reno prior to publication, and it forms an important basis for the seismotectonic knowledge of the region today.

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.

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

Generally, the Study 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 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 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

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[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.

[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.

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.

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

	Slip Rate (mm per year)[30]	**Maximum Earthquake (magnitude)**
Los Osos Fault	0.07-0.80	6.81 ± 0.28
Southwest Boundary Fault	0.16-0.30	6.15-6.5
Hosgri Fault	≤ 1.0-3.0	6.5-7.5 (likely, 6.75-7.25)

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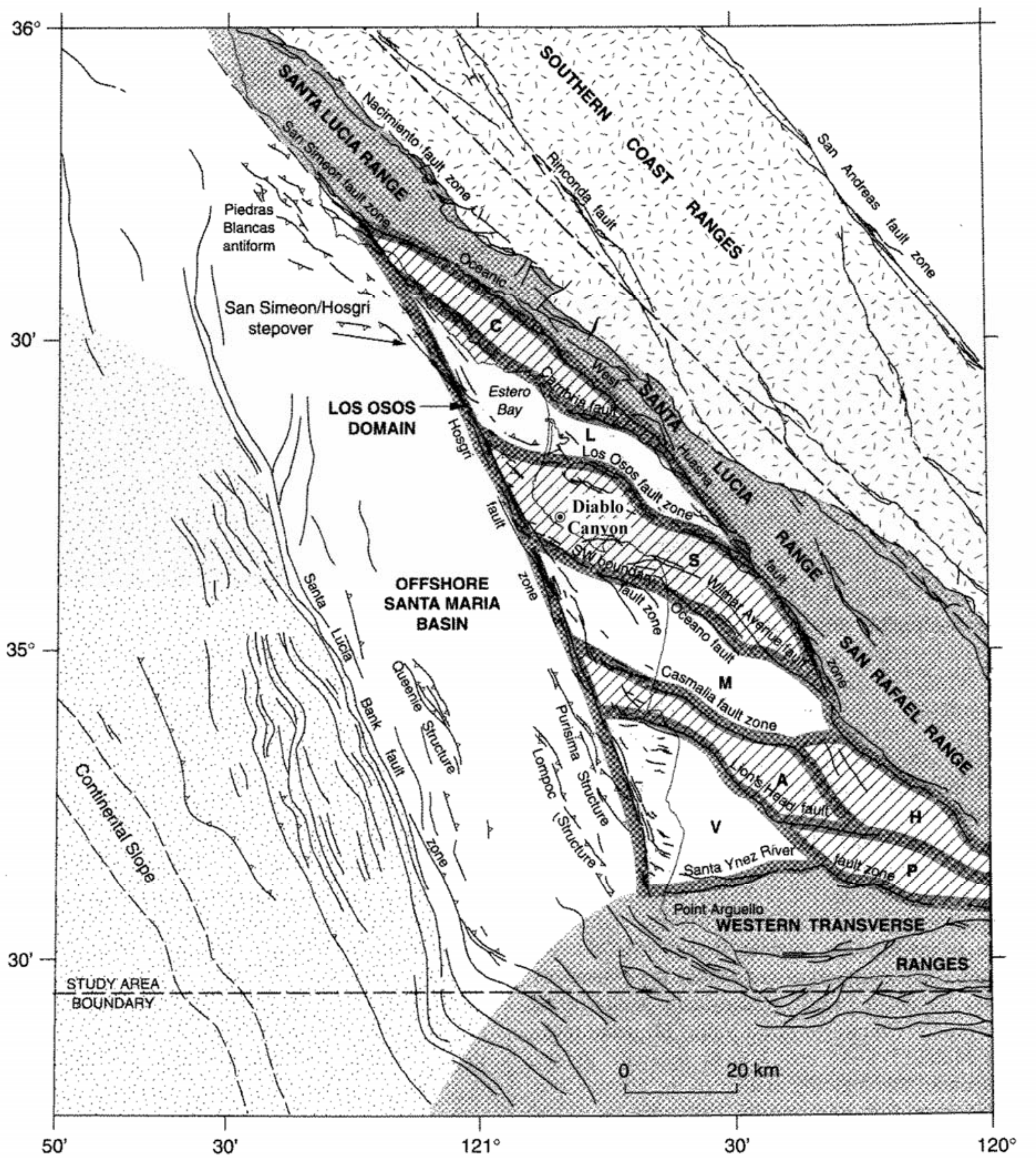
[28] Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2." NUREG-0675, Supplement No. 34. Docket No. 50-275 and 50-323,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

[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.

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.[31] 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.

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

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.[32] 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 21 km in length.[33] 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.[34] 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, that is, nearly vertical along the fault plane. This is evidenced by striations preserved on the fault plane and the lack of laterally offset surface geomorphic features that cross the fault.

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 0.07-0.33 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

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[32] 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.

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

[34] Pacific Gas & Electric. 1988; Slemmons, D.B. and D.G. Clark. 1991.

[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.

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 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]

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[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.

[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.

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]

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]

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

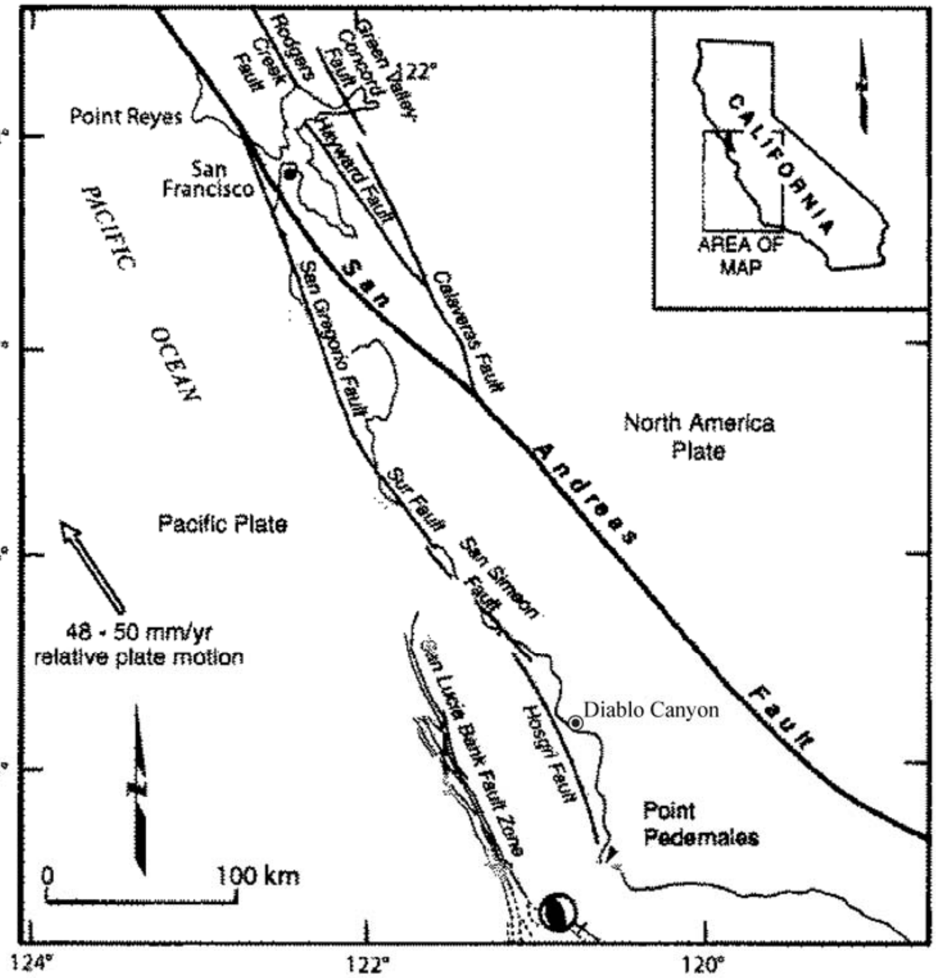
[47] Blume, J.A. "Diablo Canyon Plant: Plate-Boundary and Diffused Areal Probabilistic Considerations." Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site. PG&E, Volume VII, USNRC Docket No. 50-275 and 50-323, Appendix D, D-LL 45. 1977, pages 45-1 to D45.11; Blume, J.A. "Probabilities 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.

respectively. The entire zone is generally referred to as the San Gregorio–Hosgri Fault zone or fault system (Figure 6).

Figure 6: Elements of the San Gregorio-Hosgri Fault System[51]



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.

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

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

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.[52] However, other interpretations of offshore geophysical 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.[53]

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 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

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[52] 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 Fatul Zone, Coastal California: Geological Evidence and Tectonic Implications," 2005, Geological Society of America Special Paper 391, 43 pages.

[53] 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.

[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.

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 22 and 110 km, with multi-segment rupture lengths of 45 km and 70 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 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 earthquake[62] as well as waveform analysis and modeling[63] indicate that the earthquake was located approximately 40 km to the west of Point Conception and had a reverse fault mechanism (66º dip) along a N20º 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]

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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.

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.

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 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]

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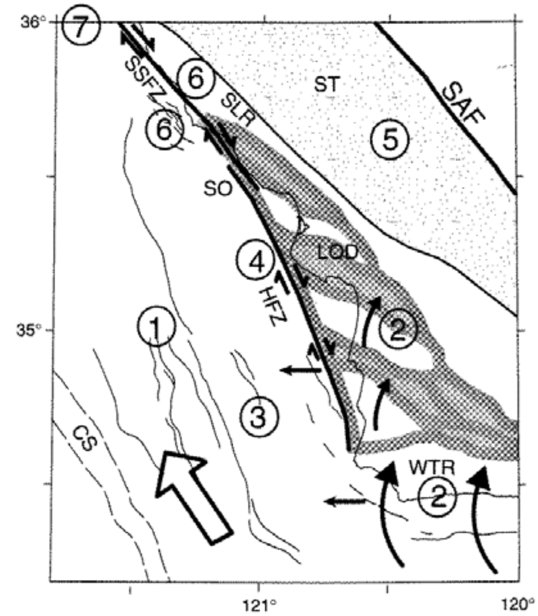
[65] Hornafius J.S. "Neogene Tectonic Rotation of the Santa Ynez Range, Western Transverse Ranges, California, Suggested by Paleomagnetic Investigation of the Monterrey Formation." *Journal of Geophysical Research*, Vol. 90, No. B14. 1985, pages 12,500 –12,522.

[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.

Figure 7: Kinematic Block Model of the Los Osos Domain[68]



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.

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.[69] 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.[70] 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).

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[68] McLaren, M.K. and W.U. Savage. 2001.

[69] 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.

[70] Namson, J. and T.L. Davis. 1990.

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

The Diablo Canyon LTSP geologists and seismologists believe that the Hosgri Fault 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.

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]

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

[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.

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 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 required PG&E to evaluate the Hosgri Fault for probabilities of 67 percent strike-slip and 33 percent thrust faulting.[77] The NRC also required that PG&E apply a somewhat more shallow eastward dip to the fault. 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 reverse motion of the earthquake is inconsistent with vertical strike-slip motion of the Oceanic Fault. According to the USGS, the earthquake did not occur on the Oceanic Fault

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

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.

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]

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

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[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.

[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.

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 analogous in part to PG&E's proposed vertical uplift of the San Luis-Pismo block in which Diablo Canyon is located. However, there is a large difference in the dips of the faults seismologically inferred for the San Simeon rupture and the steeper dips that PG&E has assigned to the Los Osos Fault zone that bounds the San Luis-Pismo block on the north and the Southwest Boundary Fault (i.e. San Luis Bay Fault) that bounds the block on the south. Given the poor constraints on fault dips, lower dips at seismological depths than was assigned by PG&E cannot be ruled out. The USGS has assigned dips of 45 degrees each to the Los Osos Fault and the San Luis Bay fault, with each fault dipping 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 USGS fault geometry is that an earthquake analogous to the San Simeon earthquake cannot conclusively be ruled out 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. We have 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.

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."[88, 89]

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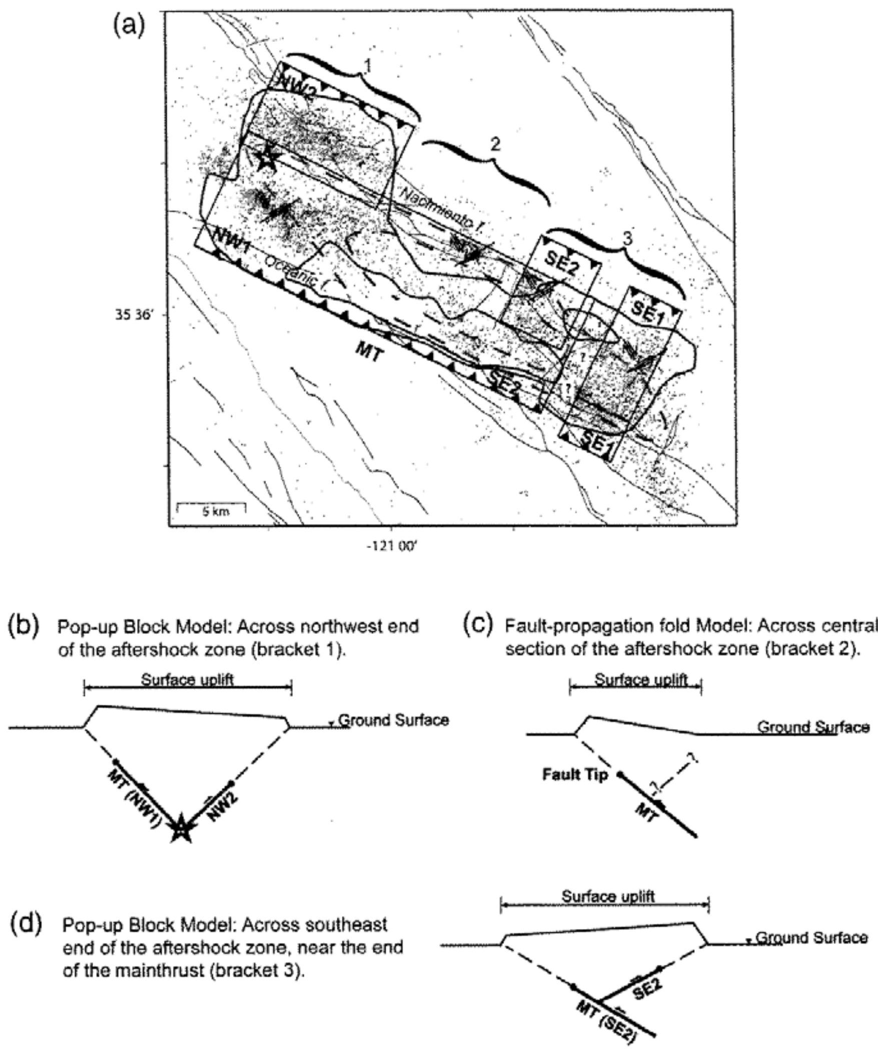
[86] McLaren, M.K. and W.U. Savage. "Seismicity of South-Central Coastal California." 2001.

[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] 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.

Figure 8: Summary Map of Complex Faulting from the 2003 San Simeon Earthquake[90]



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.

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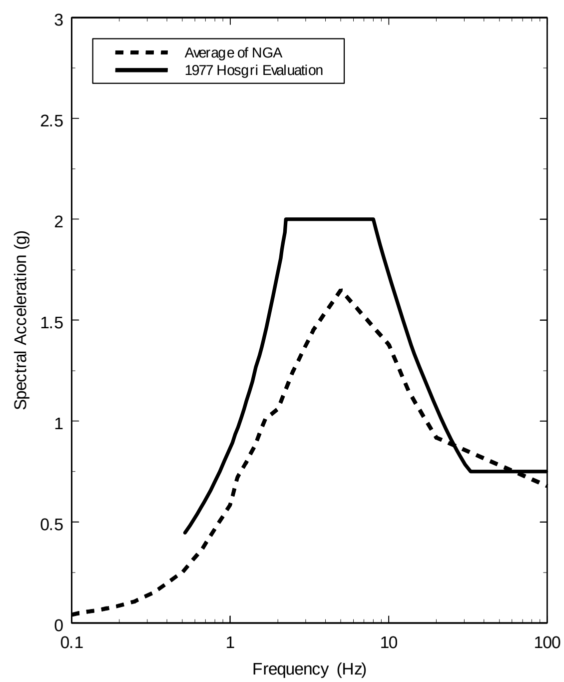
[89] Directivity rupture effects were not addressed in this simple test (See Technical Note 7), but these effects would only affect spectral amplitudes beyond about 0.6-second period (1.7 Hz).

[90] 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 serve to 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.[91] 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.[92]

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.

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[91] 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.

[92] 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.[93]

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.[94] 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.[95] Where exposed in the sea cliff, the fault is overlain by undisturbed marine deposits that have been dated as 125,000 years old.[96] 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).

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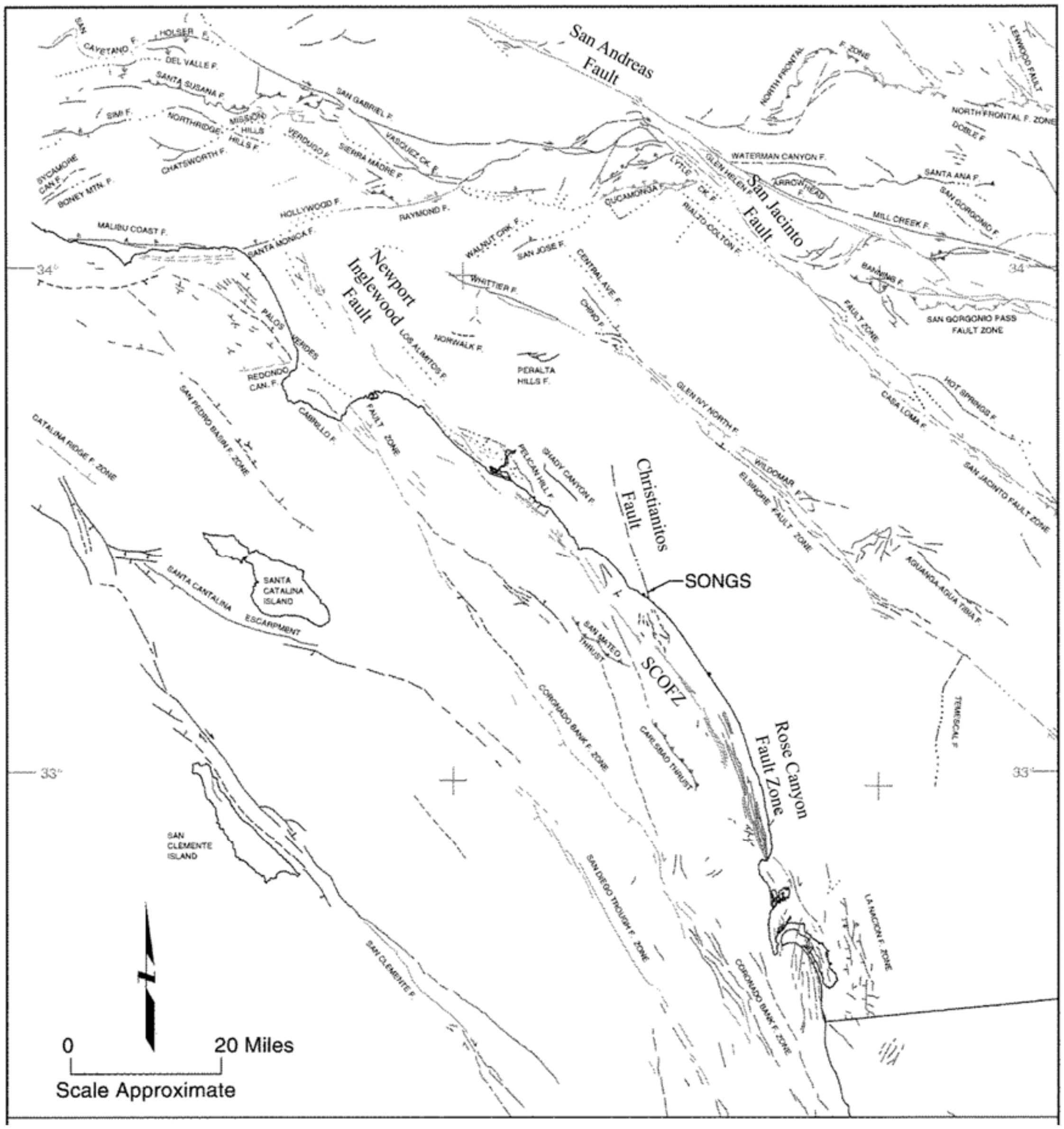
[93] Southern California Edison. "San Onofre 2&3 FSAR (Updated)." *San Onofre 2&3 UFSAR, 2.0 – Site Characteristics. 2005*, pages 2.5-1 - 2.5-281.

[94] 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.

[95] Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

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

Figure 10: Location of SONGS Site[97]



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.[98] The deep structure of the

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[97] 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.

[98] 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.[99] 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.[100] Evidence of geologically young movement mostly comes from geophysical investigations along the offshore extensions of the NIFZ and the RCFZ.[101] 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").[102] 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.[103]

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.[104] 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.[105] Hypothetically, strain release in earthquakes along this system may load neighboring segments and prime them for future earthquakes.[106]

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.[107] The SCOFZ and NIFZ have therefore been shown rather conclusively to be part of

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

[100] Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

[101] 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.

[102] Fischer, J.P. and G.I. Mills. 1991.

[103] 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.

[104] Southern California Edison. "San Onofre 2&3 FSAR (Updated)." 2005.

[105] 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.

[106] 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.

[107] 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.[108]

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.[109] 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, 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.[110] 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.[111]

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.[112] 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.[113] 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.[114] 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

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108 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.

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

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

111 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.

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

113 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.

114 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.[115] 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.[116] 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[117]
Onshore NIFZ	≥ 0.34-0.55[118]
RCFZ	1.0-2.0[119]
SCOFZ (inferred)	0.8-3.0 (median value: 1.5)[120]

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.[121] 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.[122]

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115 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.

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

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

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

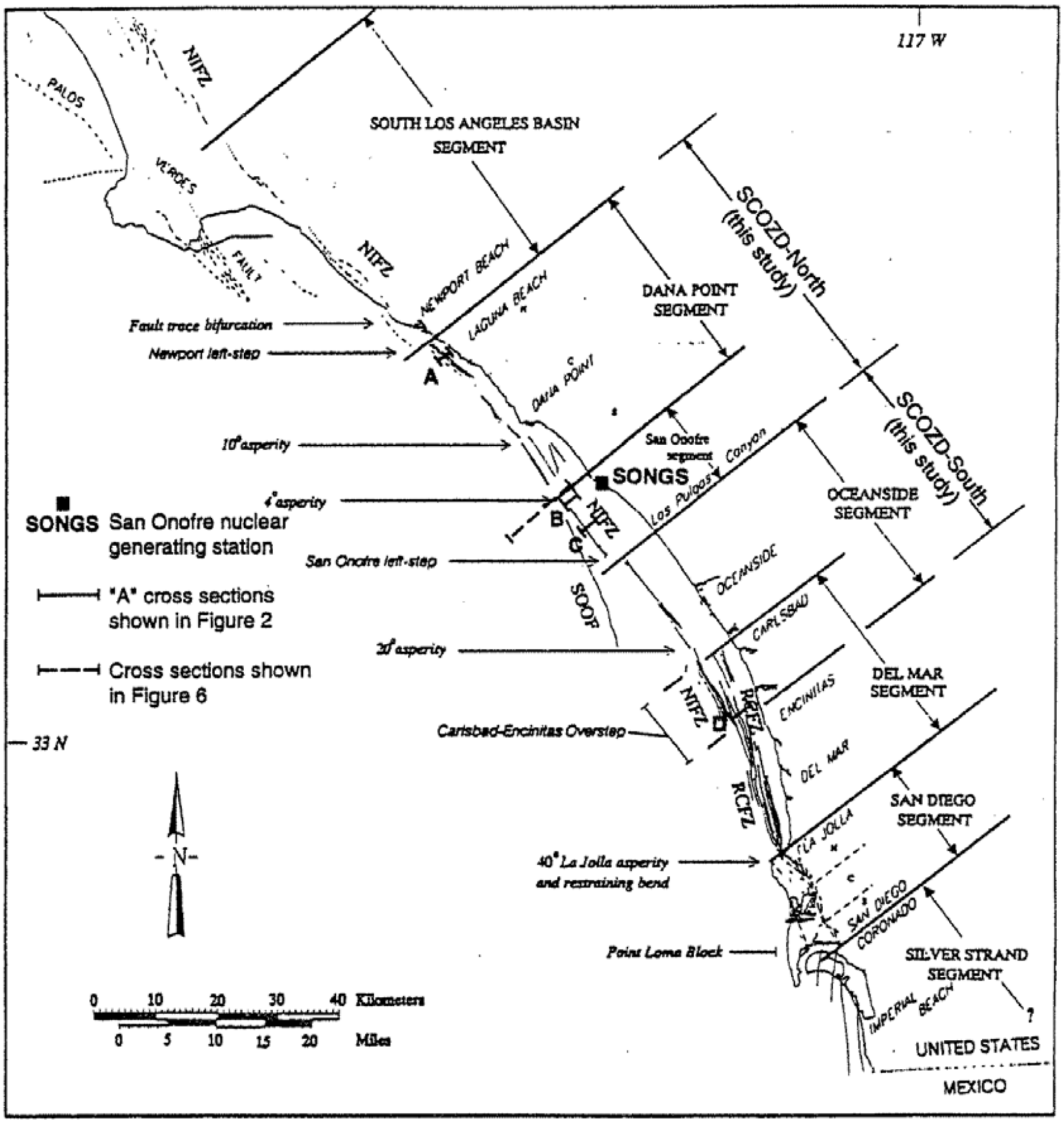
119 Lindvall, S.C. and T.K. Rockwell. "Holocene Activity of the Rose Canyon Fault Zone in San Diego, California." *Journal of Geophysical Research*, Vol. 100, No. B12. 1995, pages 24,121 – 24,132

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

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

122 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[123, 124]



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

124 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. [125, 126] While such faults have long been postulated to exist in the Continental Borderland,[127] only recently have two such regional faults been interpreted to exist: the Oceanside thrust fault and the Thirtymile Bank thrust fault.[128] Both faults extend southward from Laguna Beach and Catalina Island, respectively, to at least the international border with Mexico.[129] 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,[130] 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.[131]

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.[132] 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

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[125] 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.

[126] 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.

[127] 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.

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

[129] Rivero, C. J.H. Shaw and K Mueller. 2000.

[130] 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.

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

[132] 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.[133] It is also possible that combined blind thrust faulting with vertical strike-slip faulting contribute to the uplift of the area.[134] 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.[135] 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.[136] 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.[137] 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,[138] 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 a greater seismic hazard at the SONGS site than initially expected.

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[133] 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.

[134] 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.

[135] Rivero, C. J.H. Shaw and K Mueller. 2000.

[136] 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.

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

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

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:[139]

> 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)."[140] 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 national seismic hazard maps of the United States.[141] The fault definitions and parameters were 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

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[139] California Coastal Commission. "W15a – Revised Findings." Application File No. E-00-014, Southern California Edison Company, San Diego Electric Company, City of Anahem 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.

[140] 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.

[141] 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.

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.[142]

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.[143] 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 southern California. This reflects the fact that, while such hypotheses might be found in the

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

143 Geomatrix Consultants and GeoPentech. 2001.

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.[144] 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 on account 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:[145]

- The USGS national seismic hazard data are distributed on a 0.1^{o} 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. At the latitude of Diablo Canyon, 0.1^{o} of longitude corresponds to approximately 9 km in distance, meaning that the site could be as far as 4.5 km from the closest USGS calculation grid point. Both Diablo Canyon and SONGS are in close proximity to active faults, and ground motion calculations are extremely sensitive to the distance of the site from the nearest active fault. The USGS ground motion values that are available in the vicinity of the power plant sites cannot therefore be considered representative of 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.[146] Instead, the Code of Federal Regulations (CFR) is the ultimate guide

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[144] Personal communication between Annie Kammerer, U.S. Nuclear Regulatory Commission, and Barbara Byron, California Energy Commission. August 13, 2008.

[145] 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.

[146] U.S. Nuclear Regulatory Commission. "Screening Analysis for Gl-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.[147]) 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

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[147] 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. However, as discussed in Chapter 4, Diablo Canyon is located in a remote location with limited road access.

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.[148] The tsunami hazards at the

[148] 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.[149]

Submarine landslides have spanned a range of five orders of magnitude in volume: from less than 0.01 km^3 to more than 1,000 km^3. 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 Point Arguello, California earthquake, which produced waves of about seven 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.[150] 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.[151] 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.

149 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.

150 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.

151 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.[152] As of May 2008, this study had not been completed.

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.[153] 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 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

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[152] Statement of Lloyd Cluff to the Seismic Safety Commission in June 2006.

[153] 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."[154] 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.[155] 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.[156]

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.[157] 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.[158]

PG&E and SCE are not required to conduct probabilistic tsunami hazard assessments for their plants or to update existing assessments using data from SIFT. The Study Team does not know whether PG&E is using these tools in the updated Diablo Canyon tsunami study, and the Study Team is unaware of any recent or planned updates to the SONGS tsunami study.

Updates to Seismic Safety Studies

The seismic hazards for Diablo Canyon and SONGS were assessed during the plant design and design review processes. However, the scientific understanding of seismology and geology has continued to evolve since that time. As discussed above, PG&E has an ongoing program to reevaluate the seismic safety of Diablo Canyon as new information emerges. SCE does not have an analogous program for SONGS.

The regulatory requirements for updating seismic safety studies and the major advances in science and technology that could impact these assessments are discussed below.

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154 Pacific Marine Environmental Laboratory. May 2007: 105.

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

156 Pacific Marine Environmental Laboratory. May 2007: 77.

157 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/>.

158 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.

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.

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 an analogous program to PG&E's LTSP and is not required to update the seismic studies for SONGS on an ongoing or routine basis. 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.[159] SCE subsequently updated the probabilistic hazard assessment in 2001 to account for new information on the site seismology. The Study Team is not aware of any plans or regulatory requirements for additional updates.

Current Geologic Investigations by Plant Owners

The Study Team is awaiting information from PG&E and SCE to complete this section.

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 in the near-source region of earthquake fault ruptures.[160] 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).

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[159] 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.

[160] 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.

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 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 always 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.[161]

Ground motion recordings for the magnitude 6.0 earthquake that struck Parkfield, California in September 2004 indicate significantly higher variability in near-fault motions than was previously expected across a broad frequency range, with peak ground accelerations ranging from 0.13 g to over 1.8 g.[162] 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.[163] Researchers are constantly updating and refining these strong ground motion attenuation models. For example, under the auspices of the Pacific Earthquake Engineering Research Center, a multi-institution, multi-investigator, multi-sponsor

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161 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.

162 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 Bullletin, 2006. Vol. 96, pages S90 – S118.

163 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.

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.[164]

As described above, SCE updated the SONGS PSHA to account for rupture directivity and fling effects, along with other advances, and their results revealed that there is a greater seismic hazard at SONGS than previously believed. The Study Team recommends that SCE update the PSHA again to incorporate the latest results of the next generation attenuation program and new approaches to incorporating estimates of ground motion variability in the near-source region of faults. SCE and PG&E should both continue to consider the impacts of new insights on near-source ground motion variability for the seismic hazards at their plants and dry cask spent fuel storage facilities.

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 pin-point 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

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164 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.

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.[165] 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.

A similar evaluation has not been conducted for the Diablo Canyon site due to an apparent lack of modern GPS data in the central coastal California region. Also, because there are no islands off the coast as there are in southern California, there is a lack of control points offshore. An older onshore geodetic survey does exist.[166] However, stations for that survey were only sparsely distributed and little can be resolved regarding movements of individual blocks of the Los Osos domain. An onshore modern GPS program consisting of permanent GPS stations could provide insight on the regional seismology and local block movements within the Los Osos domain.

There are many other studies that could be proposed to investigate the seismic hazard of the nuclear plant sites. The Study Team believes that more definitive answers to the outstanding questions will come from a well-planned, long-term program of interrelated investigations among a number of geoscience and engineering disciplines. The actual form of such a program, its content, and funding merits discussion and debate from a forum of geoscience professionals, nuclear engineers, and policymakers.

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

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[165] Geomatrix Consultants and GeoPentech. 2001.

[166] Feigl, K.L., R.W. King, and T.H. Jordan, "Geodetic Measurement of Tectonic Deformation in the Santa Maria Fold and Thrust Belt, California." Journal of Geophysical Research, Vol. 95. 1990, pages 2679-2699.

near the site that do not appear at the surface. Finally, such imaging at strategic locations could serve to 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.

Lack of a permanent GPS monitoring system and database is perhaps the most obvious omission of the LTSP for the Diablo Canyon region. A well-planned, permanent GPS program within the Los Osos domain could serve over time to either refine or dismiss the proposed block tectonic model for this region. A GPS network across the domain would aid the resolution of strain accumulation and the definition of block movements within the Los Osos domain and improve understanding of fault movements and faulting styles.

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 is currently completing an updated assessment. Recent advances in tsunami hazard research, if considered, could improve the quality of this assessment.

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. This can be seen in comparing the 1995 Risk Engineering assessment to the 2001 Geomatrix assessment: the return period associated with the design level safe-shutdown earthquake bedrock ground acceleration decreased from 7,194 years in the 1995 study to 5,747 years in the 2001 study, which considered newer ground motion and geologic models.[167]

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

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[167] 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.

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 and the faulting that connects 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 of the Oceanside thrust fault at San Joaquin Hills.[168] 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.[169] 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.[170]

Another area that warrants further study is the tsunami hazard at the site. It appears that 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. Even a moderate increase in the estimated maximum tsunami run-up could raise significant concerns about the adequacy of the site's seawall.

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168 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.

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

170 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:

$$\text{Log N}(m) = a - b\text{m} \qquad (1)$$

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

$$N(m) = N(m^0)\frac{\exp(-\beta(m-m^0)) - \exp(-\beta(m^u - m^0))}{1-\exp(-\beta(m^u - m^0))} \text{ for } m \le m^u \qquad (2)$$

where m^0 is an arbitrary reference magnitude, m^u is an upper-bound magnitude where $n(m) = 0$ for $m > m^u$, and $\beta = b \bullet \ln 10$. 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.[171] 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

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

where μ is the rigidity or shear modulus of the fault, usually taken to be $3\times10^{11} dyne/cm^2$, 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,

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

$$M_o(M) = c\,M + d \tag{4}$$

Based on both theoretical considerations and empirical observations, c and d are rationalized as 1.5 and 16.1, respectively.[172] However, to be consistent with the definition of moment magnitude, d should be set equal to 16.05.[173]

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,

$$M_o^T = \mu A_f S \tag{5}$$

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.[174]

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.[175, 176] 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.[177] 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.[178]

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

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

[173] Kanamori, H. Quantification of Earthquakes. *Nature* 271, 1978, pages 411-414.

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

[175] 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.

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

[177] Scholz, D. H. *The Mechanics of Earthquake Faulting*, Cambridge University Press. 1990.

[178] 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,

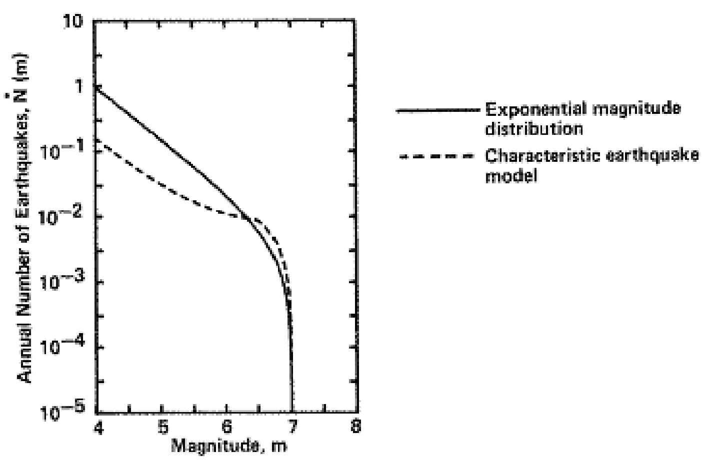
$$N_e = M_o^T \frac{1 - e^{-\beta(m_u - 0.25)}}{M_o e^{-\beta(m_u - 0.25)} \left(\frac{b10^{-c/2}}{c-b} + \frac{b10^b (1 - 10^{-c/2})}{c} \right)} \tag{6}$$

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

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

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



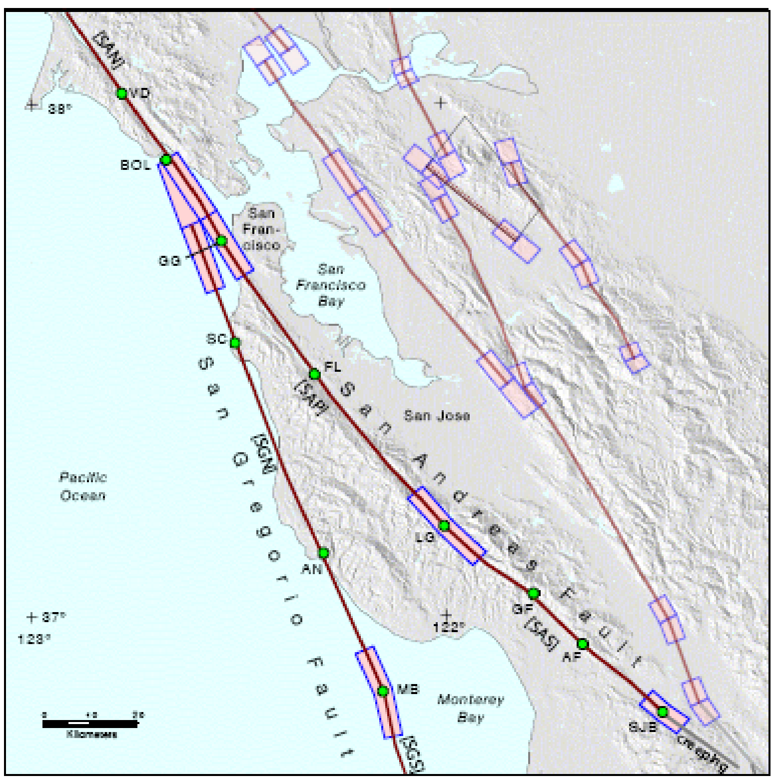
Source: Youngs and Coppersmith[179]

[179] 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.[180] 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).[181] 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.

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[180] 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.

[181] 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.[182] 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.[183] 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.[184]

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.[185, 186]

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.

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[182] 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.

[183] Scholz, D. H. *The Mechanics of Earthquake Faulting*, Cambridge University Press. 1990.

[184] McCalpin, J.P. Paleoseismology, Volume 62, International Geophysics Series, R.Dmowska and JR. Holton, eds. Academic Press, San Diego, 1996.

[185] 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.

[186] 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.[187] 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.[188] 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.[189, 190] 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.

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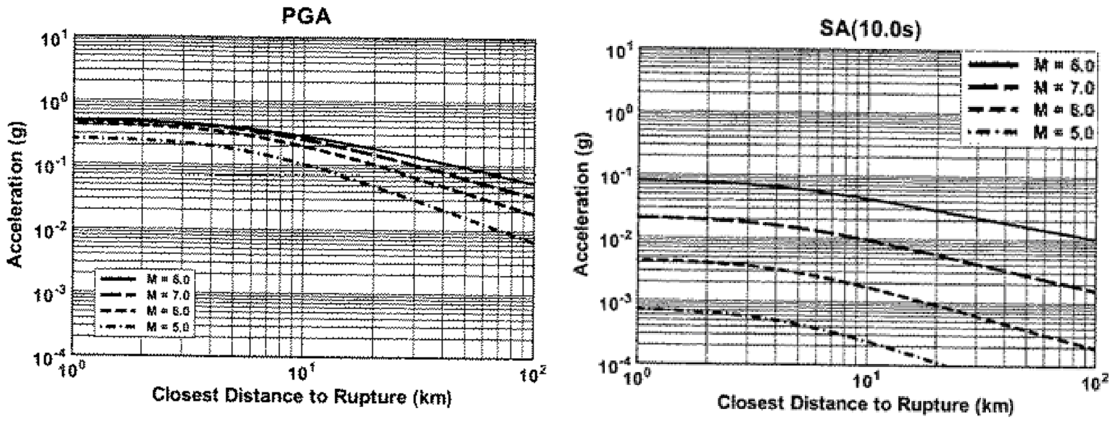
[187] Campbell, K.W. *Engineering Seismology*, Encyclopedia of Physical Science and Technology, Vol. 5, Academic Press, Inc. 1987.

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

[189] 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.

[190] 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, 2008[191]

[191] 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.

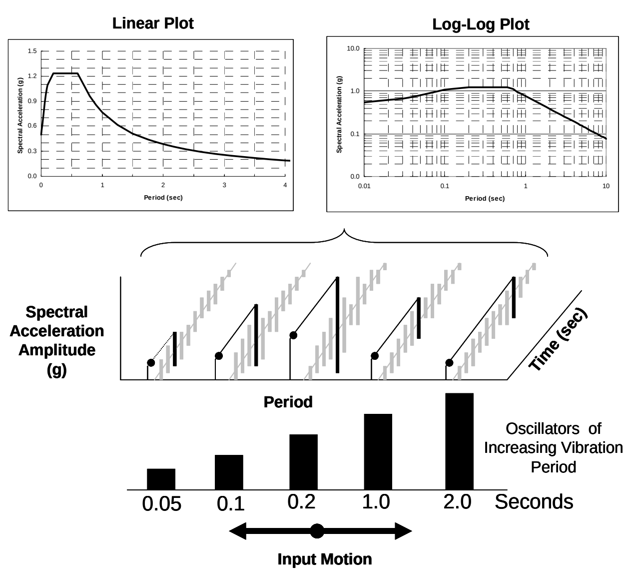
Technical Note 4: Earthquake Response Spectra

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.[192] 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 Kramer[193]

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

[193] 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 a *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.[194]

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.

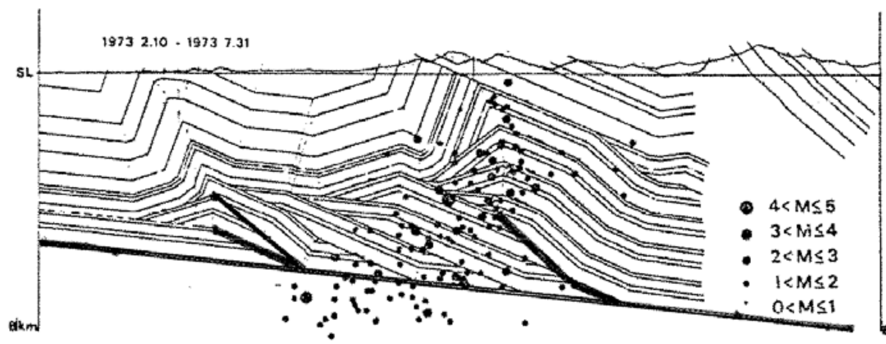
Notwithstanding the foregoing paragraphs III(g) (1), (2) and (3), structural association of a fault with geologic structural features which are geologically old (at least pre-Quaternary) such as many of those found in the Eastern region of the United States shall, in the absence of conflicting evidence,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

[194] 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.[195] 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.

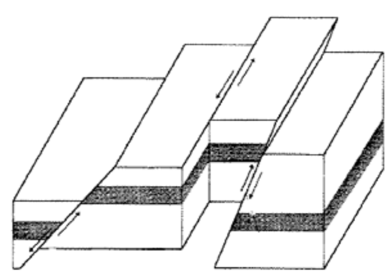
Figure 16: Thin-Skinned Tectonic Model



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.[196]

"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).[197]

Figure 17: Thick-Skinned Deformation (Block Faulting)[198]



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[195] Nemcok, M., S. Schamel, and R. Gayer. Thrustbelts, Cambridge University Press, 2005, 554 pages.

[196] Suppe, J. "Imbricated Structure of Western Foothill, Belt, Southcentral Taiwan." *Petroleum Geology of Taiwan*, No. 17. 1980, pages 1-16.

[197] Nemcok, M., S. Schamel,and R. Gayer. 2005.

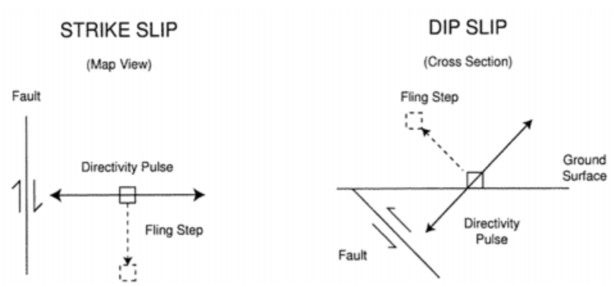
[198] Suppe, J. 1980.

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. 2001[199]

[199] 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.

Works Cited

Two sets of references accompany this chapter. Appendix C contains concise summaries of 47 papers that were reviewed and documented in the literature review. These documents and other supporting documents that are cited in Chapter 2 are listed below.

Abrahamson, N.A. Effects of Rupture Directivity on Probabilistic Seismic Hazard Analysis, Proceedings of the 6th International Conference on Seismic Zonation, Palm Springs. 2000.

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.

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

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.

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

Bender, E.E. "Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California: Comment." Geology, Vol. 28. 2000.

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.

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.

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

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

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

California Coastal Commission. "W5a, Revised Findings." Application File No. A-3-SLO-04-035, Pacific Gas and Electric. 2004.

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

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

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.

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

Cornell, C.A. Engineering Seismic Risk Analysis, Seismological Society of America Bulletin, Vol. 58, 1968, pages 1583-1537.

Clark, D.G. D.B. Slemmons, S.J. Caskey and D.M. dePolo. "Seismotectonic Framework of Coastal Central California." Geological Society of America Special Paper 292. 1994.

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.

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.

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.

Cummings, D. and T.A. Johnson. "Shallow Geologic Structure, Offshore Point Arguello to Santa Maria River, Central California." Geological Society of America Special Paper 292. 1994.

Dehlinger, D.P. and B.A. Bolt. "Seismotectonic Patterns Across a Part of the Central California Coast Ranges." Geological Society of America Special Paper 292. 1994.

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 Fatul Zone, Coastal California: Geological Evidence and Tectonic Implications," 2005, Geological Society of America Special Paper 391, 43 pages.

Earthquake Engineering Research Institute (EERI) Committee on Seismic Risk. The Basics of Seismic Risk Analysis, Earthquake Spectra, Vol. 5, 1989, pages 675-702.

Feigl, K.L., R.W. King, and T.H. Jordan, "Geodetic Measurement of Tectonic Deformation in the Santa Maria Fold and Thrust Belt, California." Journal of Geophysical Research, Vol. 95. 1990, pages 2679-2699.

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.

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.

Fischer, P.J. D.S. Gorsline and R.J. Shlemon. "Late Quaternary Geology of the Dana Point-San Onofre-Carlsbad Margin, California." 1992.

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.

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.

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.

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.

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

Geomatrix Consultants. "Appendix B (to Title 43) - Maximum Magnitude Distributions." Report for Southern California Edison. 1995.

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.

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.

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.

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.

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.

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.

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.

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.

Hall, C.A. "Origin and Development of the Lompoc-Santa Maria Pull-Apart Basin and its Relation to the San Simeon-Hosgri Strike-Slip Fault, Western California." California Division of Mines and Geology Special Report 137, *The San Gregorio – Hosgri Fault zone, California*. 1978, pages 25 – 31.

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.

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.

Hanks, T.C. and H. Kanamori. A moment-magnitude scale. J. Geophys. Res. 84, 1979, pages 2348–2350.

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.

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.

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.

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.

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.

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.

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.

Kanamori, H. “Quantification of Earthquakes.” Nature 271, 1978, pages 411-414.

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.

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.

Lettis, W.B. K.L. Hanson, J.R. Unruh, M. McLaren and W.U. Savage. “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.

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.

Lettis, W.R. and N.T. Hall. “Los Osos Fault Zone, San Luis Obispo County, California.” Geological Society of America Special Paper 292. 1994.

Lettis, W.R. and K.I. Kelson, et al. “Quaternary Deformation of the San Luis Range, San Luis Obispo County, California.” Geological Society of America Special Paper 292. 1994.

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.

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

McGuire, R.K. Seismic Hazard and Risk Analysis, EERI Monograph Series No. 10, 2004, page 221.

McLaren, M.K. and W.U. Savage. “Seismicity of South-Central Coastal California: October 1987 through January 1997.” *Bulletin of the Seismological Society of America*, Vol. 91. 2001, pages 1629-1658.

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.

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

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.

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

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.

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/>.

Pacific Gas & Electric. "Diablo Canyon Spent Fuel Storage Installation (ISFSI) Safety Analysis Report (SAR)." 2.6. *Geology and Seismology*; ISFSI SAR Amendment 1. October 2002.

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.

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.

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.

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.

Risk Engineering, Inc. "Seismic Hazard At San Onofre Nuclear Generating Station." Report for Southern California Edison. 1995.

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.

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.

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

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.

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.

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 Bullletin*, 2006. Vol. 96, pages S90 – S118.

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

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.

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.

Slemmons, D.B. and D.G. Clark, U.S. Nuclear Regulatory Commission, 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.

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.

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." *Geology*, Vol. 27, No. 11. 1999.

Southern California Edison. "San Onofre 2&3 FSAR (Updated)." *San Onofre 2&3 UFSAR, 2.0 – Site Characteristics*. 2005.

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.

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

Steritz, J.W. and B.P. Luyendyk. "Hosgri Fault zone, Offshore Santa Maria Basin, California." Geological Society of America Special Paper 292. 1994.

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.

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.

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

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.

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.

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

U.S. Geological Survey staff, U.S. NRC, Office of Nuclear Reactor Regulation. "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'." NUREG-0675, Supplement No. 34, Appendix C. 1991.

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.

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.

Weldon, R. and E. Humphreys. "A Kinematic Model of Southern California." *Tectonics*, Vol. 5, No. 1. 1986.

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

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.

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.

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.

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.

Yeats, R.S. K. Sieh and C.R. Allen. <u>The Geology of Earthquakes</u>. *Oxford University Press*. 1997.

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.

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 as well as their structural integrity. The seismic safety 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."[200] 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."[201] 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

[200] U.S. Nuclear Regulatory Commission. 10 CFR Part 100, Appendix A.

[201] 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.[202, 203]

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.)[204] 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.[205] 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."[206] 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.[207] In particular, the

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202 U.S. Nuclear Regulatory Commission. "Seismic Design Classification." Regulatory Guide 1.29.

203 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.

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

205 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>.

206 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>.

207 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.[208] 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 earthquake experienced to date by Diablo Canyon was just 25 percent of the OBE design conditions. On December 22, 2003, an earthquake occurred on the San Simeon fault, which lies to the north of Diablo Canyon and is in-line with the Hosgri fault. The low intensity did not automatically shut down the reactor, 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.[209] This was a 1975 magnitude 5.5 earthquake centered 15 miles south of the Humboldt Bay nuclear power plant in northern California.[210] The plant was inspected following the earthquake; the inspection took two days, and, based on information available to the Study Team, it appears that the plant was subsequently restarted without incident.[211]

Diablo Canyon Design Earthquakes

Diablo Canyon was initially designed for an SSE with peak ground acceleration of 0.40 g.[212] (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

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

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

210 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.

211 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>.

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

San Andreas earthquake.[213] The design value of the peak horizontal ground acceleration for the OBE is 0.20 g.[214]

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 6 to 8 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 motion[215] and to probabilistically assess the ground motions from a magnitude 7.5 earthquake on the Hosgri Fault and throughout area sources around the plant.[216] 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.[217]

Later, as part of the Long-Term Seismic Program, PG&E reevaluated the location and magnitude of the November 4, 1927, Lompoc earthquake[218] and determined that it was further

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213 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.

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

215 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.

216 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.

217 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.

218 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.

seaward than previously thought.[219] 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.[220]

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.[221]

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 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."[222]

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

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219 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.

220 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.

221 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.

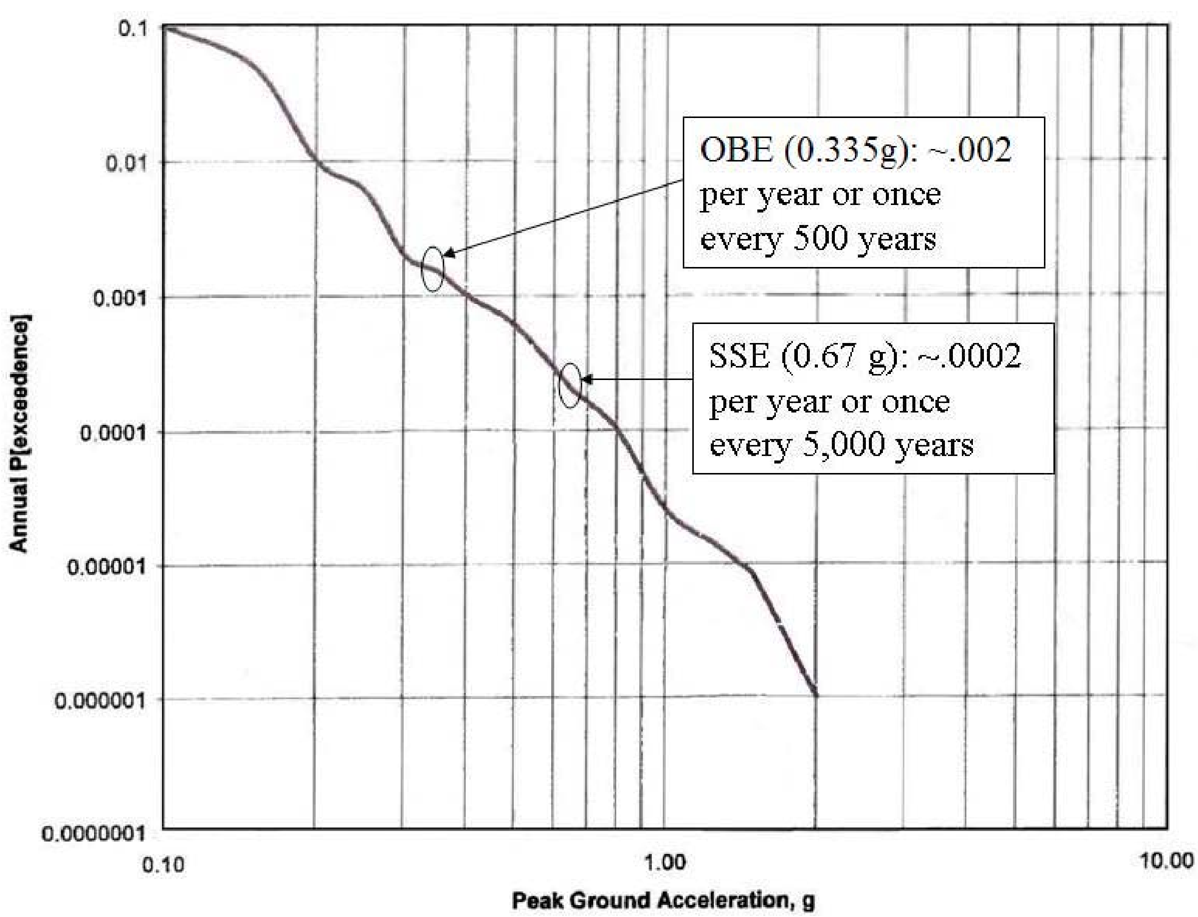
222 Southern California Edison. "San Onofre Nuclear Generating Station Units 2 and 3 - Updated Final Safety Analysis Report." June 2005.

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).

Figure 19: Seismic Probability Assessment for SONGS[223]



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

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.

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.[224]

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.[225] As mentioned above, to date no OBEs have occurred at the plant so the SSCs have been only minimally stressed from earthquakes.

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.[226] 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

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224 San Onofre 2&3 Updated FSAR, section 2.5.1.2.5.3

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

226 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.

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.[227] 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, 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 Study 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.[228] 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

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[227] The General Design Criteria are contained in Appendix A to 10 CFR Part 50.

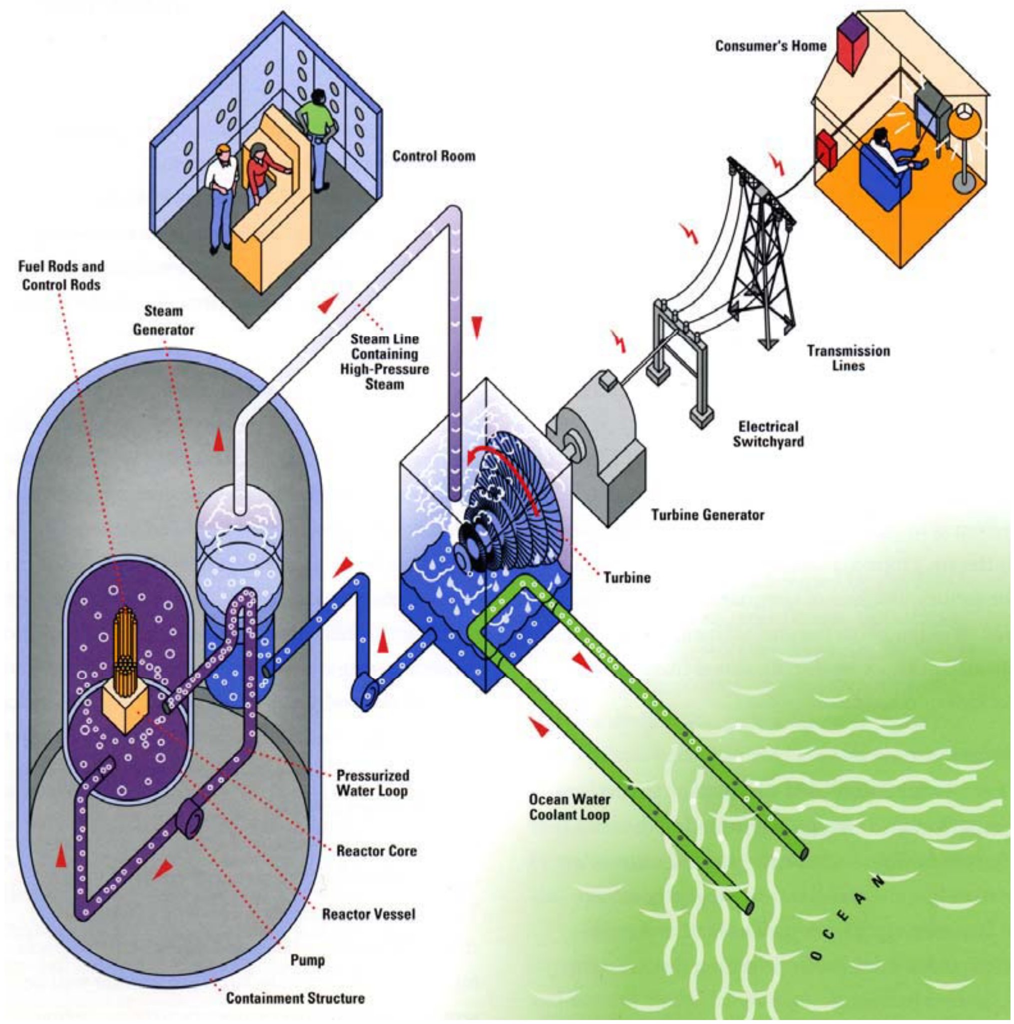
[228] Surveillance schedules are specified as part of a plant's operating license. Pacific Gas & Electric. "Diablo Canyon Power Plant Units 1 and 2 - Final Safety Analysis Report Updated, Revision #17." November 2006.

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.[229]

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).

Figure 20: Nuclear Plant Layout[230]



[229] 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).

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

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 required. The Study 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.

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 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.[231] 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.

[231] 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.

Table 3: Major Plant Buildings and Structures[232]

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[233]
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[234]	Back-up power source	Balance of plant, safety-related
Turbine Building	Electricity generation	Balance of plant, not safety-related
Switchyards	Transformers and electricity transmission lines	Balance of plant, not safety-related

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.

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232 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.

233 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.

234 There is no diesel generator building at Diablo Canyon. Instead, diesel generators are housed in self-contained units in the turbine-generator building.

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.

The Study Team may update this section after completing a review of information recently provided by PG&E and SCE.

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.

As discussed below, the estimated times to repair or to replace components within a nuclear power plant may range from one week to four years. The determining factor 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. 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.

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.

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.

The estimates of time to repair presented in this section (and throughout this chapter) are based solely on the experience and judgement of the Study 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 Study 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 will become inoperable until emergency diesel generators power emergency load busses.
- 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.[235] A reactor could likely return to service immediately following inspections, with repairs continuing in areas that are separate from those supporting nuclear power generation.

Impact of an SSE

As with an OBE, an SSE 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

[235] 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>.

support systems. 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.
- 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.
- Lighting in portions of the building 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.[236] The majority of this time would be spent in repair of the turbine and restoration of the switch yard equipment.

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

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 collapse.
- 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. This would be the most likely form of radioactive material release.
- 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.
- 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 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 Study 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 Study 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.[237] [238] [239] [240] [241] [242] [243] [244] [245] [246] [247] [248] [249] [250] [251] [252] [253] [254] [255] [256]

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[237] 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>.

[238] 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>.

[239] 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>.

[240] 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>.

[241] 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>.

[242] 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>.

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

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

[245] 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>.

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

[247] Shukla, Girija S., NRC DCPP 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.

The Study 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.[257]

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

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

249 Reserved for Humbolt Event - The status of this item is on hold until Patrick Mullen of PG&E, Government Affairs obtains the project report. Due date was 5-1-2008.

250 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.

251 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>.

252 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_simpo_doc.html>.

253 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_simpo_doc.html>.

254 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_simpo_doc.html>.

255 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_simpo_doc.html>.

256 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_simpo_doc.html>.

257 The Study 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.

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. 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.

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."[258] This equipment, located in the switchyards, is not safety-related and is part of the balance of 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.[259]

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.[260],[261]

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[258] 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>.

[259] 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.

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

Four live-tank circuit breakers were severely damaged, and transformers and disconnect switches were also damaged.[262] 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.[263] In all, it took several weeks to restore operations at Moss Landing.[264]

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 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. 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. 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.[265] 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

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[261] The Study 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.

[262] 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.

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

[264] 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>.

[265] 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.

susceptible to these vulnerabilities. The status of switchyard upgrades at Diablo Canyon and SONGS to newer industry standards is not known at this time.[266]

Figure 21: Moss Landing Switchyard after the Loma Prieta Earthquake, 1989[267]

Turbine Building

The turbine building at Diablo Canyon is extremely large with an expansive open space inside.[268] As a consequence, the current design analysis predicts that during a large earthquake the turbine building would be damaged by bending near the roof. In a beyond design basis

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[266] 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.

[267] 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>.

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

earthquake, the turbine roof may collapse. The resultant damage to the building and to equipment housed on the turbine deck could take two to three years to repair.

Tank Areas

SONGS and Diablo Canyon both have outdoor tank areas that are used to store refueling water, condensate, and other water supplies. If a condensate storage tank or fire protection tank were damaged, an extended outage would be required for repair or replacement. Loss of the tanks would not significantly compromise safe shutdown capability or fire safety since the raw water reservoir would provide a backup supply of water.

At SONGS, the condensate storage tank and refueling water storage tank, which are shared between both units, are located in low-lying areas. As such, they are vulnerable to water damage from a beyond design basis tsunami. In addition, during a beyond design basis earthquake the ground near the support pads for the tanks could shift, bursting underground pipes and damaging the tanks. This occurred at Japan's Kashiwazaki-Kariwa nuclear plant during the Niigata Chuetsu-Oki earthquake.

At Diablo Canyon, each unit has its own refueling water storage tank, primary makeup water storage tank, and condensate storage tank and a shared fire protection water tank and storage transfer tank. The tanks would not be subject to any unusual post-accident environment; however, they could incur damage during an earthquake.

Tsunami Damage

The Diablo Canyon design basis states the potential flood depth for the plant is zero or not credible due to the water runoff capability away from the plant.[269] There is no discussion about the ground level buildings and whether flood doors are used to protect against spray, slosh, or waves from tsunami run-up events. If water accumulated in the turbine buildings and emergency diesel generator rooms, damage could occur. It is unclear what types of administrative controls are in place to ensure equipment bay doors and other openings are closed immediately after earthquakes are detected in the region. In addition, as discussed previously in Chapter 2, 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.

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 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

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[269] During the winter storms of 1981, the Diablo Canyon protective breakwater around the plant water intake lagoon was damaged from the turbulence of the wave action. Repairs and modifications were made to the intake structure, including modifications to limit the amount of water that could flow into the auxiliary salt water system pump rooms. The safety-related equipment is now water tight to 48 feet above mean low level water.

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 Study 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.[270, 271] At the time, the second auxiliary transformer and a diesel generator were both in preventative maintenance servicing. A second generator automatically started but it 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

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

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

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.[272] 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. Historically, no plant has ever been in this situation greater than 21 hours and most average less than 90 minutes.[273]

Operator Error

During an earthquake, the likelihood of human error increases due to the unusualness of the event, possible confusion, and even panic. 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.[274, 275] 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.[276] 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 January 2008.[277] PG&E additionally implemented other physical and operational improvements, including installing debris interceptors and initiating a more aggressive containment clean-up

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

273 INEL, Nov '98 [38]

274 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.

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

276 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.

277 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.

program. PG&E will perform final mitigation measures when the new steam generators are installed in early 2008 and 2009.[278]

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.[279]

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.[280]

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]

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[278] 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.

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

[280] 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.

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.[281]

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.[282] 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.[283] 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 Diablo Canyon and SONGS, performed seismic PRAs. The NRC's review of those studies resulted in the following observations:

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[281] 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.

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

[283] 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.

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.[284]
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.[285]
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.[286] 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.[287] 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.[288]

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.[289, 290, 291, 292] The epicenter of the earthquake was 16 km from the

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[284] NUREG -1742, volume 1, p. xxi.

[285] NUREG -1742, volume 1, page xxi.

[286] NUREG-1742, volume 2, table 2.4, page 2-16.

[287] NUREG-1742, volume 2, table 2.4, page 2-13.

[288] NUREG-1742, volume 2, table 2.2, page 2-5.

[289] Presentations of the International Symposium on Seismic Safety of Nuclear Power Plants and Lessons Learned from the Niigataken 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_simpo_doc.html>.

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

[291] 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.

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.[293]

Over a year after this event, the KK NPP remains shut down. Investigations into its ability to operate safely were only recently completed.[294] 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.[295] 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."[296] (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, 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

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[292] 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.

[293] 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>

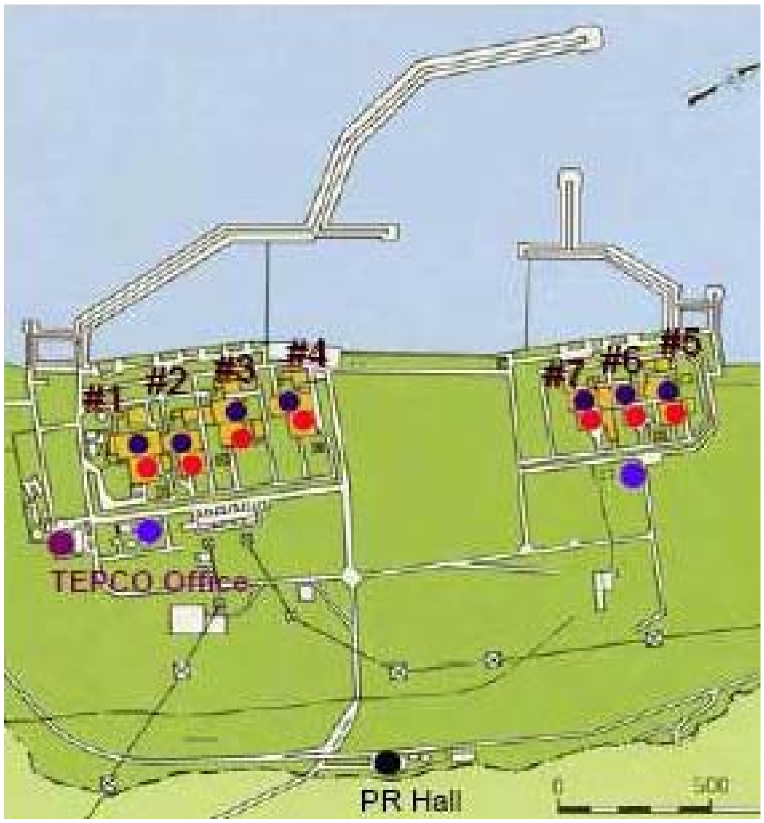
[294] Japan Atomic Industrial Forum, Inc. "External Inspections of All Kashiwazaki Kariwa NPS Units Soon to Finish: Seismic Reinforcement Work Commencing Successively." July 22, 2008.

[295] 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.

[296] International Atomic Energy Agency. August 6-10, 2007: 1

for such a strong earthquake."[297] (Figure 23 displays an image of damage discovered adjacent to the plant.)

Figure 22: Site Layout of Kashiwazaki-Kariwa Nuclear Power Plant[298]



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 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

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

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

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 Station[299]

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.

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

[299] 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>.

highest vertical accelerations in the same building were 0.416g versus the seismic design value of 0.240g.[300, 301] 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: [302]

> …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 conservatisms 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 would move simultaneously."[303] TEPCO concluded that a number of faults both offshore and

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300 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>.

301 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>.

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

303 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>.

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.[304] 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 as well as 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.

[304] 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 Earthquake[305]

Unit #	Status Before Earthquake	Reactor Type	Year Began Operations	East-West Acceleration At Reactor Building Base (gal: cm/s/s)		Significant Damage Events
				Observed	*Design Basis*	
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 *in an outage*	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.

[305] 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**
				Observed	*Design Basis*	
5	Shutdown *in an outage*	BWR	1990	442	254	A filtered water tank leaked; the leakage was not radioactive.
6	Shutdown *in an outage*	ABWR	1996	322	263	A minuscule amount of radioactivity was found on 3rd floor of the reactor building (0.6 liter) and mezzanine 3rd 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 safe-shutdown earthquakes of magnitude 7.2 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 in the event an earthquake 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 Study Team cannot assess the plants' true seismic vulnerabilities since seismic evaluations of the non-safety portions of the plants were not available to the Study Team.

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. 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.

The turbine building and tank areas might also be susceptible to damage. The turbine building at Diablo Canyon is large with an expansive open space inside. The turbine building's roof could collapse in an earthquake. At SONGS, the tank areas for the condensate storage tank and the refueling water storage tank are low-lying areas susceptible to water damage in the event of a tsunami that exceeds the design basis. Ground movement near the support pads for the tanks could cause underground pipes to burst and damage the tanks.

Diablo Canyon or SONGS could be shut down following an earthquake for as little as one week to as much as four 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. 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. A collaborative study involving the utilities, manufacturers, and researchers with the appropriate expertise could be beneficial to estimating power plant restart time.

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 appear to be the primary cause of the lengthy shut down, suggesting that repairing or replacing damaged components may not be the primary driver of how long a nuclear power plant is shut down following a major seismic event. Research and investigations into the earthquake and the root causes of damage at the nuclear power plant are ongoing; the Energy Commission and California's nuclear plant owners should stay informed as new information becomes available.

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.[306] PSHA can be summarized as the solution of the following expression of the total probability theorem:

$$\lambda[X \geq x] \approx \sum_{Sources\ i} \nu_i \int_{M_o}^{M_{Max}} \int_{R|M} P[X \geq x \mid M, R]\, f_M(m)\, f_{R|M}(r|m)\, dr\, dm \qquad (1)$$

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

$$P[X \geq x] = 1 - \exp(-t\lambda[X \geq x]) \qquad (2)$$

[306] 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

$$R_X(x) = \frac{1}{\lambda[X \geq x]} = \frac{-t}{\ln(1 - P[X \geq x])} \tag{3}$$

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:

$$R_X(x) = \frac{-50}{\ln(1 - 0.1)} = 475 \tag{4}$$

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.[307,308] 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

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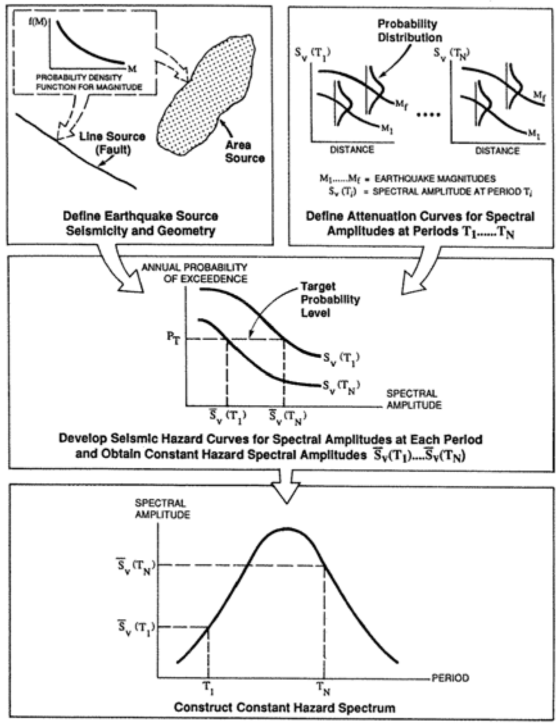
[307] McGuire, R.K. Seismic Hazard and Risk Analysis, EERI Monograph Series No. 10, 2004, page 221.

[308] 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.

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.

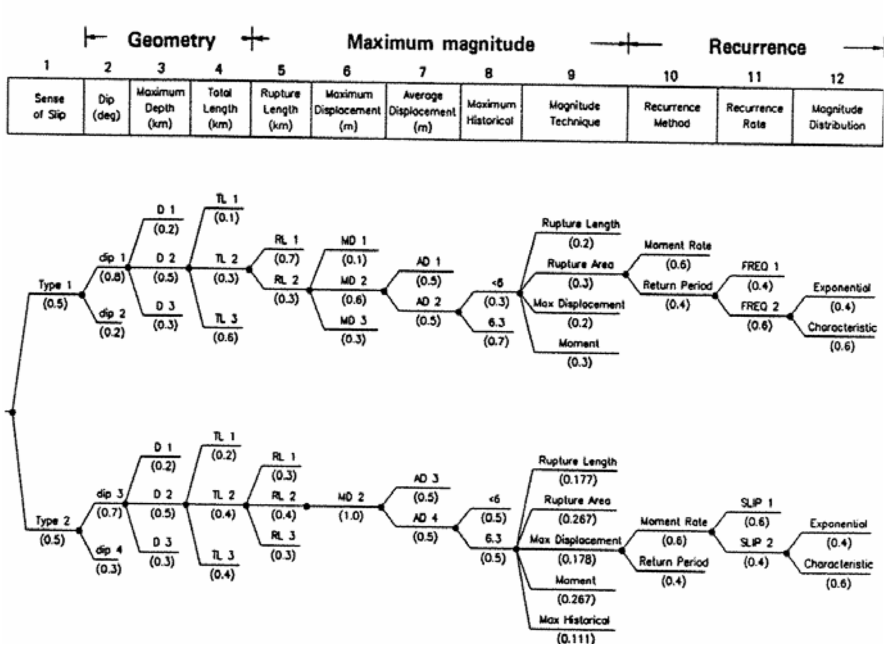
The result of PSHA is a suite of hazard curves for spectral amplitudes at each vibration period of interest. The hazard curves can then be sampled at various annual probabilities of exceedance to obtain constant, or uniform, hazard spectral amplitudes that are plotted together as a constant, or uniform, hazard spectrum.

Figure 24: PSHA Procedure[309]



309 Earthquake Engineering Research Institute (EERI) Committee on Seismic Risk. The Basics of Seismic Risk Analysis, *Earthquake Spectra*, Vol., 5, 1989, pages 675-702.

Figure 25: PSHA Logic Tree[310]



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310 PG&E. Diablo Canyon Long-Term Seismic Program, 1988.

Works Cited

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

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.

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

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.

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.

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.

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.

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

Energy Systems Research. <u>Electric System Seismic Safety and Reliability</u>. 2004.

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.

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.

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_simpo_doc.html>.

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.

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

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_simpo_doc.html>.

Matt, H. and Filiatrault, A. "Seismic Qualification Requirements for Transformer Bushings." April 2004. Final Project Summary found in Energy Systems Research, Electric System Seismic Safety and Reliability. 2004.

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_simpo_doc.html>.

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

Pacific Gas & Electric. "Diablo Canyon - San Simeon Earthquake Meeting." PG&E slide presentation to U.S. Nuclear Regulatory Commission. May 27, 2004.

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.

Pacific Gas & Electric. "Electric System Seismic Safety and Reliability." Report for the California Energy Commission CEC-500-2005-007. January 2005. <http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-007.html>.

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.

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

Pacific Gas and Electric. "Individual Plant Examination of External Events Report for Diablo Canyon Power Plant Units 1 and 2." June 1994.

Shukla, Girija S., U.S. Nuclear Regulatory Commission, Diablo Canyon Power Plant 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." Letter report and meeting summary. June 9, 2004.

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

Southern California Edison. "San Onofre Nuclear Generating Station Units 2 and 3 - Updated Final Safety Analysis Report." Docket # 50-xxx and 50-xxx. 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.

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

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_simpo_ doc.html>.

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>.

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>.

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.

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>.

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

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>.

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>.

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.

U.S. Nuclear Regulatory Commission. "Failure of Welded-Steel Moment-Resisting Frames During the Northridge Earthquake." Information Notice 97-22. April 25, 1997. <http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97022.html>.

U.S. Nuclear Regulatory Commission. "Generic Issues Program." <http://www.nrc.gov/about-nrc/regulatory/gen-issues.html>.

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

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>.

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.

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. "Seismic Design Classification." Regulatory Guide 1.29.

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>.

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>.

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

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

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

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>.

U.S. Nuclear Regulatory Commission. 10 CFR 100.

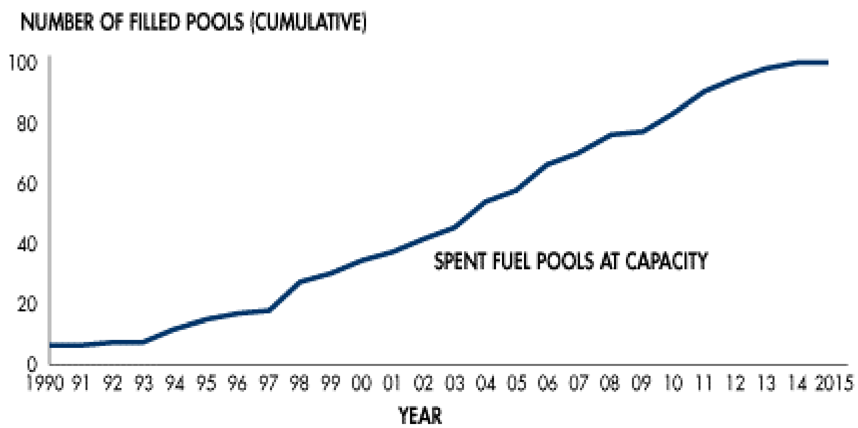
U.S. Nuclear Regulatory Commission. Information Notice 97-22.

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_simpo_doc.html>.

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 Plants[311]



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.

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[311] 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.[312] 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 ⅛-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 that the seismic criteria, spent fuel structures at nuclear power plants are able to withstand seismic loads substantially beyond those for which they were designed.[313]

Vulnerability to Seismic or Terrorist Events

The most severe accidents postulated for spent fuel pools are associated with the loss of cooling water from the pool. This could be precipitated by a large earthquake, a fuel cask dropping from an overhead crane during transfer operations, or a terrorist attack. Such an event would

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[312] 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.

[313] U.S. Nuclear Regulatory Commission. "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants." October 2000.

likely not lead to radiation release in a spent fuel pool that used open frame racks (i.e. 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 could lead to extensive radiation release and contamination.

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.[314, 315, 316]

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.[317] 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.[318] 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 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

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314 U.S. Nuclear Regulatory Commission. "Spent Fuel Storage Facility Design Basis." Regulatory Guide 1.13, March 2007.

315 U.S. Nuclear Regulatory Commission. "Seismic Design Classification." Regulatory Guide 1.29.

316 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).

317 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.

318 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>.

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."[146]

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 NCO earthquake in Japan. The earthquake rocked the spent fuel pools at all seven reactors at the KK NPP. The "sloshing" resulted in water being spilled onto the floors of all seven reactor buildings. The spilled water was successfully contained inside the control area of each reactor building except in Unit 6. Spilled, contaminated water in Unit 6 leaked into the Sea of Japan as a result of inadequate leak-tightness of penetrations in the reactor building's floor.[319]

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."[320] 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.[321] 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 reactor building.[322] 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."[323]

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[319] 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."

[320] IAEA, Volume I, page 53.

[321] PG&E Data Request Responses, 2008.

[322] PG&E Data Request Responses, 2008.

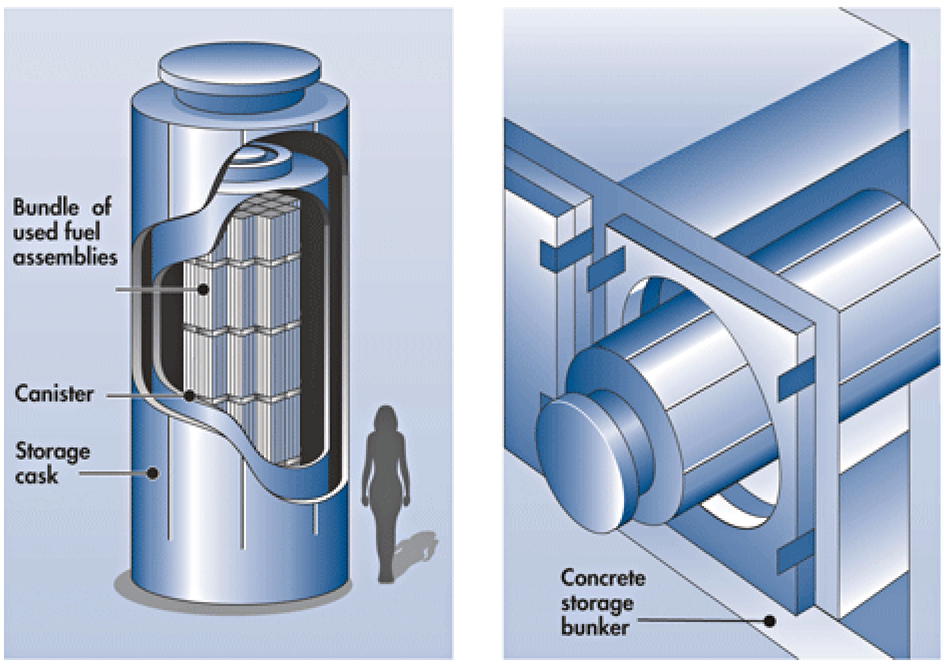
[323] SONGS Data Request Responses, 2008.

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. [324]

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 Storage[325]



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

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[324] 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.

[325] 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. [326] 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.

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[326] 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.[327] 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 on account of 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).[328] 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

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[327] U.S. Nuclear Regulatory Commission. "A Pilot Probabilistic Risk Assessment Of a Dry Cask Storage System At a Nuclear Power Plant." March 2007.

[328] Kazimi, Mujid S. and Neil E. Todreas. "Nuclear Power Economic Performance: Challenges and Opportunities." Annual Review of Energy and the Environment. 1999.

the following processes: mechanical dispersion of fuel particles or fragments and dispersion of 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).[329] This system is comprised of multipurpose canisters, storage overpacks, and HI-TRAC transfer casks located above ground.[330] 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.[331]

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[329] The Hi-Storm 100 system is also slated to be used at several other sites including Bryan, Braidwood, LaSalle, Dresden, Quad Cities and Fermi.

[330] Marine Research Specialists (MRS). "Diablo Canyon Independent Spent Fuel Storage Installation (ISFSI) Final Environmental Impact Report." SCH # 2002031155, January 2004.

[331] 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.

Figure 28: Photo of Loaded HI-Storm Casks at Plant Hatch[332]

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))

332 Holtec International. "Welcome to Holtec International." Accessed: June 3, 2008. <http://www.holtecinternational.com/>.

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.

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. To further strengthen the pad, rock anchors are installed in 2- to 3-inch diameter holes on 5-foot centers and drilled 30 feet deep from the cut-slope faces. Square concrete pads with steel top plates are cast over the holes to distribute anchor loads to the rock surface. High strength, corrosion-protected bar anchors are inserted into the holes, grouted, and pre-stressed.

At times the spent fuel pool work platform is relied on as a seismic restraint for the canister while in the pool. This does not appear to be a previously analyzed design condition for the work platform. As a result, it may be vulnerable to damage when used in this new design condition.

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 IFSFI 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.
- Fuel transfer operations must occur over a load-bearing wall. This may imply that the building floor is vulnerable to heavy loading and drops.
- There are provisions necessitating the reopening of 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. These new operations will similarly constitute an unanalyzed explosive force design condition for the spent fuel pool.
- 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. It should be verified whether these controls are effective, especially for truck drivers not directly involved in ISFSI operations.[333]

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.[334]

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.[335]

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333 U.S. Nuclear Regulatory Commission. "Reactor Oversight Process (ROP)." Accessed: June 1, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/index.html>.

334 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.

335 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.

> 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.[336]

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.)

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.[337] 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.[338] 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

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[336] Page 20 of the California Coastal Commission Report

[337] 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.

[338] U.S. Nuclear Regulatory Commission. "Reexamination of Spent Fuel Shipment Risk Estimates." NUREG/CR-6672, Washington, D.C. March 2000.

damage to the container occurred, there would be no release of radioactive material.[339] A draft of an updated NRC analysis concludes that the risk of radiation release is even lower.[340] 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.[341]

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 fuel and high-level radioactive waste in the United States.[342] 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.[343] 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

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339 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.

340 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)>.

341 U.S. Nuclear Regulatory Commission. "Public Meeting on Revision to Spent Fuel Cask Transportation Study." December 1999.

342 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).

343 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-Behaultern bei Transport un Lagerung." <http://www.bund.net/lab/reddot2/pdf/studie_castorterror.rtf>.

impact of respirable particles had not been fully considered.[344] Lyman and others have similarly criticized federal regulations pertaining to spent fuel transport security.[345]

A specific terrorist scenario has been postulated for the Diablo Canyon ISFSI.[346] 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.

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.[347] 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.[348]

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

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344 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.

345 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/>.

346 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.

347 California Department of Public Health. "Nuclear Emergency Response Program." Accessed: April 2008. <http://www.cdph.ca.gov/healthinfo/environhealth/Documents/NERP/NERP.pdf>.

348 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.

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 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.[349]

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 only accessible route to and from the site. During an emergency, this restricted access could result in traffic congestion and increase the

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[349] 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>.

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 one access road, there are unpaved 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. If the two-lane access road were blocked during an emergency, the only direct access into or out of the Diablo Canyon would be via the ocean-front landing of vessels or helicopter service landings.

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. If the traffic overwhelmed the highway system, it could bring all transportation to a halt and impede emergency response. This occurred in Texas and Louisiana ahead of the 2006 hurricanes.

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. The availability of roadway materials and equipment to make the necessary repairs should be considered in the mitigation solutions of any emergency planning plan.

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.[350] Notably, no transmission tower damage was reported from the Loma Prieta earthquake or from four other California

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350 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.

earthquakes examined in the FEMA study.[351] 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.[352] 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, 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.[353] High voltage equipment are most vulnerable, and blackouts are often associated with damage to high voltage substations.[354] 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.[355, 356]

Conclusion

The greatest risk with respect to spent fuel storage is the loss of water or the loss of active cooling in spent fuel pools. If not mitigated, such an event could lead to overheating of the stored spent fuel and the subsequent release of radioactive material. Loss of spent fuel pool

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351 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.

352 Union of Concerned Scientists. "Diablo Canyon Transformer Fire (Again)." Issue Brief. August 20, 2008.

353 Federal Emergency Management Agency. 1990: page 7.

354 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.

355 Federal Emergency Management Agency. 1990: page 7.

356 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.

water has occurred at plants outside California, but these events were recovered long before fuel heat-up occurred. Furthermore, the design of the spent fuel storage pools and associated systems reduces the possibility of draining of the pool below the stored fuel (which is what is necessary for overheating); nevertheless, loss of water is undesirable. The structures of the pools at Diablo Canyon and SONGS 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 pool is not expected to fail, even during a safe-shutdown earthquake.

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 loss-of-coolant event in a re-racked spent fuel pool could result in extensive radiation release and contamination.

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. Spilled water in one reactor building leaked into the Sea of Japan from leaks in the reactor building floor. Although the SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of sloshing, PG&E is investigating the water-tightness of conduits in its reactor buildings.

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. 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 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.

Although the primary focus of this report's vulnerability assessment of the spent fuel storage facilities was earthquake-related, the AB 1632 Study Team also reviewed published risk analyses for terrorist events or sabotage at dry cask storage facilities. Limited information is available on the vulnerability of dry cask storage to sabotage, which is consistent with the National Academies' finding when it conducted a study of spent fuel storage safety. 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. 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. If the traffic overwhelmed the highway system, it could halt highway access and impede emergency response. This occurred in Texas and Louisiana ahead of the 2006 hurricanes.

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.

Works Cited

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).

Blandford, R.K. D.K. Morton, T.E. Rahl, and S.D. Snow. "Preventing Failure in Spent Nuclear Fuel Canisters." PFANF8. (2003).

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. California Department of Public Health. "Nuclear Emergency Response Program." <http://www.cdph.ca.gov/healthinfo/environhealth/Documents/NERP/NERP.pdf>.

Chrisstoffels, Jan-Hein. "Earthquake Alarm – The Kashiwazaki nuclear incident and the consequences for Japan's nuclear policy." Clingerdael International Energy Programme, August 2007.

Diablo Canyon Independent Safety Committee. "Summary of Major DCISC Review Topics." 17th Annual Report. July 1, 2006 thru June 30, 2007. <http://www.dcisc.org/annual-report-17-2006-2007/volume1/4-07-emergency-preparedness.html>.

Electric Power Research Institute. "Probabilistic Risk Assessment of Bolted Storage Casks: Updated Quantification and Analysis Report." 1009691, December 2004.

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.

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/>.

Hirsch, H. and W. Neumann. "Verwundbarkeit von CASTOR-Behaultern bei Transport un Lagerung." <http://www.bund.net/lab/reddot2/pdf/studie_castorterror.rtf>.

Kazimi, Mujid S. and Neil E. Todreas. "Nuclear Power Economic Performance: Challenges and Opportunities." Annual Review of Energy and the Environment. 1999.

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.

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.

Marine Research Specialists (MRS). "Diablo Canyon Independent Spent Fuel Storage Installation (ISFSI) Final Environmental Impact Report." SCH # 2002031155, January 2004.

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.

San Luis Obispo Mothers for Peace. "Reply to NRC Staff and GG&E Subpart K." Presentations. June 16, 2008.

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

Southern California Edison. "San Onofre 2&3 FSAR (Updated)." San Onofre 2&3 UFSAR, 2.0 – Site Characteristics. 2005.

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."

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).

U.S. Geological Survey staff, USNRC, Office of Nuclear Reactor Regulation. "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'." NUREG-0675, Supplement No. 34, Appendix C. 1991.

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>.

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.

U.S. Nuclear Regulatory Commission. "Fact Sheet on NRC Review of Paper on Reducing Hazards from Stored Spent Nuclear Fuel." <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/reducing-hazards-spent-fuel.html>.

U.S. Nuclear Regulatory Commission. "Nuclear Fuel Pool Capacity." <http://www.nrc.gov/waste/spent-fuel-storage/nuc-fuel-pool.html>.

U.S. Nuclear Regulatory Commission. "Public Meeting on Revision to Spent Fuel Cask Transportation Study." December 1999.

U.S. Nuclear Regulatory Commission. "Reactor Oversight Process (ROP)." <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/index.html>.

U.S. Nuclear Regulatory Commission. "Reexamination of Spent Fuel Shipment Risk Estimates." NUREG/CR-6672, March 2000.

U.S. Nuclear Regulatory Commission. "Seismic Design Classification." Regulatory Guide 1.29.

U.S. Nuclear Regulatory Commission. "Spent Fuel Storage Facility Design Basis." Regulatory Guide 1.13, March 2007.

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).

U.S. Nuclear Regulatory Commission. "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants." October 2000.

U.S. Nuclear Regulatory Commission. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fig43.gif>.

Vuukov, V. S. and B. G. Ryazanov. "Problems and Experience in Guaranteeing the Nuclear Safety of the Storage of Spent Fuel from Nuclear Power Plants." *Atomic Energy*, Vol. 91, No. 4. (2001).

Chapter 5: Plant Aging Vulnerability Assessment

As a nuclear plant ages, there is an increased risk that one or more of its components could fail as a result of age-related degradation. 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."[357]

Age-related degradation can result in extended plant outages and impaired safety. Degradation can 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) can 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 can 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 San Onofre Nuclear Generating Station (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 Study 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. Changes in the capacity factor over time can provide an early indication of an impact of age-related degradation.

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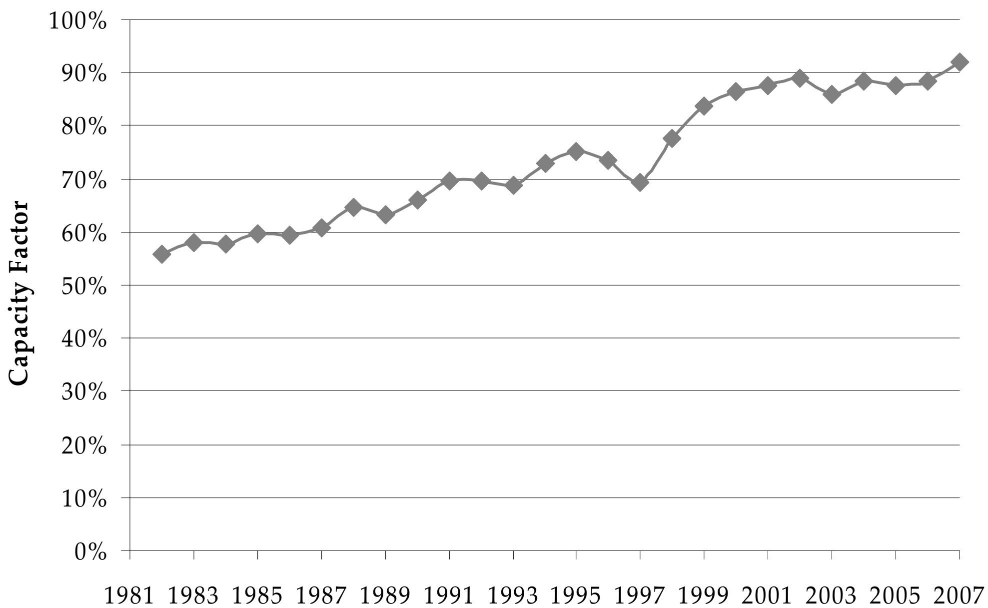
[357] U.S. Nuclear Regulatory Commission. "Nuclear Plant Aging Research (NPAR) Program Plan." NUREG-1144. Revision 2. June 1991.

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.[358] This indicates that age-related degradation of SSCs has not yet had any significant impact on overall nuclear plant performance. Indeed, plant performance has improved as plant operators have become more experienced and poor performing plants have been taken out of service.

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.[359]

Figure 29: Historical Capacity Factors of U. S. Nuclear Power Plants [360]



[358] 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.

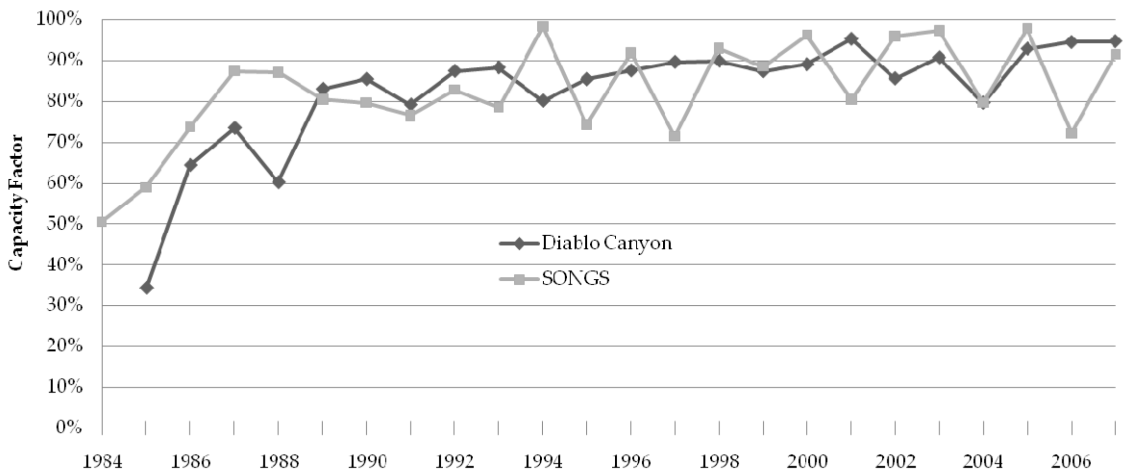
[359] The oldest operating commercial nuclear plants in the U.S. Oyster Creek and Nine Mile Point, will turn 40 in 2009. U.S. Energy Information Administration. "U.S. Nuclear Reactors." Accessed: May 14, 2008. <http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html>.

[360] 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. The year-to-year variations do not on their own indicate a lapse in performance. The 5-year average capacity factors at both plants are roughly 90 percent, indicating that there has been no apparent degradation in plant performance in recent years.

Figure 30: Diablo Canyon and SONGS Capacity Factors[361]



Degradation of Components

In assessing the impacts of aging 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 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.

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[361] Nuclear Energy Institute. "CEC-100-2007-005-F." 2008.

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.[362] 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.[363] 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.[364]
- 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.[365] 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 reactor coolant system failure occurred in August 2007 when a non-safety related portion of the Vermont Yankee cooling tower collapsed.[366] Immediately following the collapse, power output was reduced from 100 percent to 35 percent and remained between 35

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[362] 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.

[363] The NRC identified only the occurrence of degradation and not the severity of each occurrence.

[364] 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).

[365] The North American Electric Reliability Corporation (NERC) - Generating Availability Data System (GADS). "Cause Code Data." Appendix 5B. 2002-2006.

[366] U.S. Nuclear Regulatory Commission. "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report." 05000271/2007004. November 7, 2007.

percent and 65 percent for approximately 10 days.[367] The collapse was caused by structural degradation in the cooling tower from iron-salt and fungus that had weakened two wooden support beams.[368] 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)[369]

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
	Top 10 as percent of total	*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.[370] 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.[371]

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367 U.S. Nuclear Regulatory Commission, "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report," November 7, 2007.

368 U.S. Nuclear Regulatory Commission. "Vermont Yankee Nuclear Power Station – NRC Integrated Inspection Report," November 7, 2007.

369 North American Electric Reliability Corporation-GADS. "Cause Code Data." 2002-2006.

370 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.

371 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 had delayed the inspections past the NRC's deadline.[372, 373]

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

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[372] 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>.

[373] 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.[374]

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. [375]

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."[376]

The Union of Concerned Scientists also evaluated the NRC's role in the Davis-Bess 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.[377] 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.[378]

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

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374 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>.

375 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/docdblite/ details.php?rptno=GAO-04-415>.

376 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.

377 Union of Concerned Scientists. "Anatomy of a Flawed Decision: NRC Has a Brain, But No Spine." August 5, 2002, page 8.

378 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.[379] 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.[380, 381, 382]

As a result of steam generator tube leakage, the NRC developed a Steam Generator Action Plan in the early 1990s.[383] 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 NRC 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.[384, 385]

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379 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>.

380 California Public Utilities Commission. "Decision 05-12-040." Application 04-02-026. December 15, 2005.

381 California Public Utilities Commission. "Decision 05-11-026." Application 04-01-009. November 18, 2005.

382 The steam generator replacement projects at SONGS and Diablo Canyon are described in *Nuclear Power in California: 2007 Status Report*, beginning on page 128.

383 U.S. Nuclear Regulatory Commission. "Steam Generator Action Plan." June 1, 2007. <http://www.nrc.gov/reactors/operating/ops-experience/steam-generator-tube.html>.

384 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>.

385 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. [386, 387] 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.[388] 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.[389] Entergy submitted revised calculations in February 2008, [390] but Dr.

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[386] U.S. Nuclear Regulatory Commission. "Vermont Yankee License Renewal Proceeding,Proceeding." NRC Docket No. 50-271-LR.

[387] U.S. Nuclear Regulatory Commission. "Oyster Creek Generating Station License Renewal Proceeding." NRC Docket No. 50-219.

[388] 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.

[389] Hopenfeld declaration, Joram. "Vermont Yankee License Renewal Proceeding ." Declaration. NRC Docket No. 50-271-LR. April 15, 2008, paragraph 6.

[390] 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>..

Hopenfeld was not satisfied with the adequacy of these calculations.[391] 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.[392] Further, the NRC Staff found that Entergy demonstrated it can adequately manage the effects of aging for the specific components at issue.

In April 2004 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.[393] 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 re-licensing.[394]

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."[395]

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.

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391 Seventh Declaration of Dr. Hopenfeld, Joram Hopenfeld. "Vermont Yankee License Renewal Proceeding." Seventh Declaration. NRC Docket No. 50-271-LR. March 17, 2008.

392 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.

393 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 Regulatory Issue Summary 2008-10. April 11, 2008. <http://www.nirs.org/reactorwatch/licensing/ oclr04142008nrcrisfat.pdf>.

394 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>.

395 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.[396] 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.[397] 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.[398] At low concentrations (under 10,000 millirem), tritium poses little health risk.

Nuclear plant operators routinely dilute tritiated water for safe release. 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 many of these cases, tritium has been released into the environment slowly and has not caused a health risk; however, large leaks have also occurred, and tritium has been detected in well drinking water near some nuclear plants. 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.[399]

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 causes for inadvertent tritium releases: 1) leaking components, most often spent fuel pools,

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396 U.S. Nuclear Regulatory Commission. "Declaration of Dr. Richard T. Lahey, Jr. In the Matter Of Entergy Nuclear Operations, Inc." November 2007: 3, 9.

397 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>.

398 Lifetime cancer mortality risk is estimated at $4x10^{-14}$ per picoCurie; Argonne National Laboratory. "Tritium (Hydrogen-3)." August 2005.

399 U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006, page 11.

underground piping, and valves on effluent discharge lines; and 2) operator actions.[400] The largest leaks were caused by inadequate preventive maintenance and inadequate design configuration.[401]

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.

In January 2008, the Electric Power Research Institute (EPRI) released guidelines for a voluntary groundwater monitoring program at all U.S. nuclear plants.[402] 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.[403]

The main 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.[404] As there are no sources of potable groundwater at Diablo Canyon or SONGS, risk of drinking supply contamination from these plants is relatively low.[405]

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 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

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400 U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 3.

401 U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 24.

402 Electric Power Research Institute. "Groundwater Protection Guidelines for Nuclear Power Plants." Report 1016099, Public Edition. January 2008, page v.

403 Electric Power Research Institute. "Groundwater Protection Guidelines for Nuclear Power Plants." January 2008, Chapter 3.

404 U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006: 13.

405 See full discussion in Nuclear Power in California: 2007 Status Report, pages 176-177.

reactor vessel heads will be replaced between 2009 and 2012.[406] 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.[407]

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 in a timely manner 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).[408] 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.

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").[409] The Study Team does not have any information to suggest otherwise.

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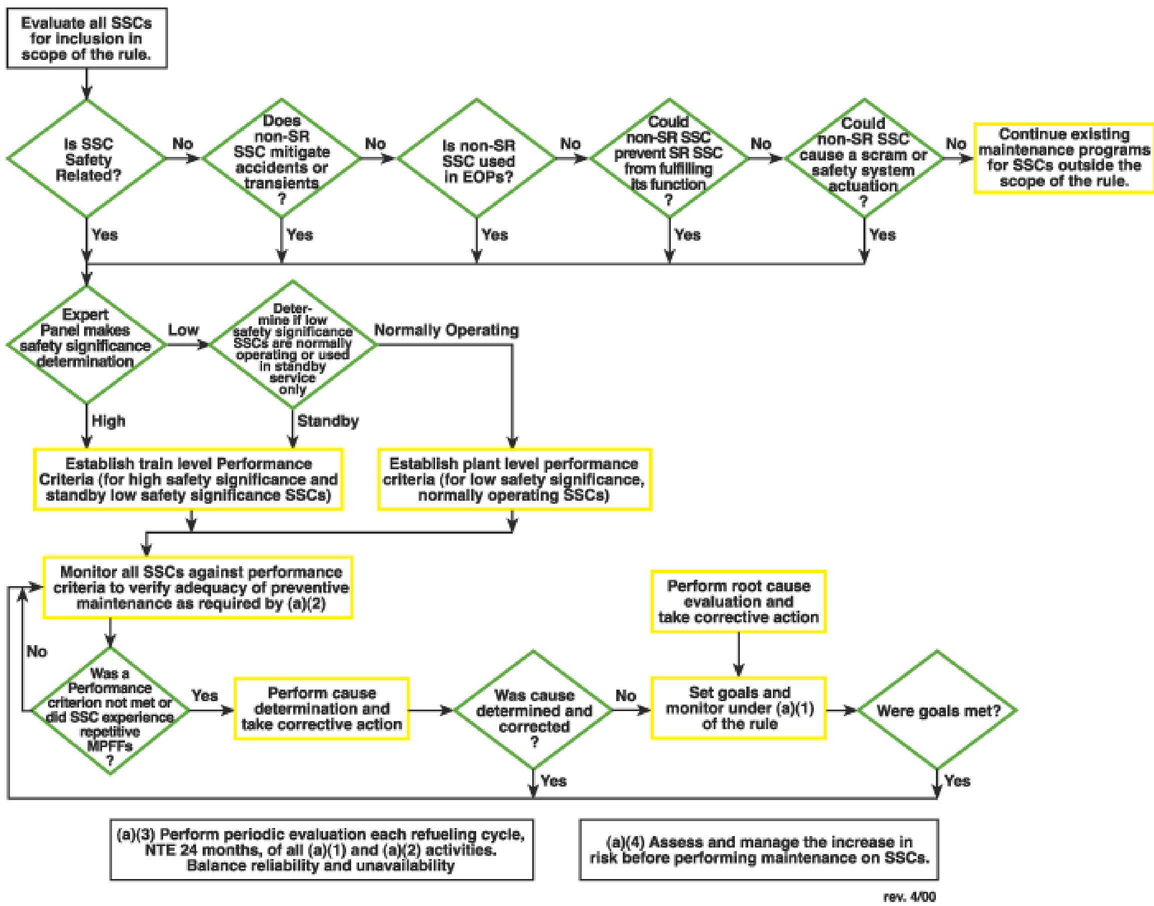
[406] PG&E Supplemental Response to Data Request L.4; SCE Data Request Response G1, CEC 2007 IEPR-SCE-02

[407] 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.

[408] 10 CFR 50.65, the "Maintenance Rule."

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.[410] (These programs, called Corrective Action Plans, are one element of the Maintenance Rule.) The report further recommended tighter NRC oversight concerning these 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."[411]

Figure 31: Simplified Maintenance Rule Flow Chart[412]



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[409] 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.

[410] Lochbaum, David. "Walking the Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages." *Union of Concerned Scientists*. Cambridge, MA. 2006.

[411] Lochbaum, David. "Walking the Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages." 2006.

[412] Nuclear Energy Institute. "Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants." NUMARC 93-01, Revision 2. April 1996.

The Mitigating Systems Performance Index

The Mitigating Systems Performance Index (MSPI) is the NRC's relatively new risk-informed performance index.[413] 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*.[414]

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."[415] 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.[416]

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.[417]

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.[418] The NRC indicates the MSPI value through the use of a color-coded system from green (best) to red (worst). All units at both Diablo Canyon and SONGS have been given "green" MSPI

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413 "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.

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

415 Nuclear Energy Institute. "New Performance Index Provides Closer Look At Nuclear Plant Safety Systems." Fact Sheet. Washington, DC. 2006.

416 See, for example, the August 23, 2003 letter from the *Union of Concerned Scientists* to John W. Thompson.

417 U.S. Nuclear Regulatory Commission. "Regulatory Issue Summary 2006-07: Changes to the Safety System Unavailability Performance Indicators." RIS 2006-07. June 12, 2006.

418 Data and information used in the MSPI calculation are derived from the at-power, Level 1 plant PRA.

performance indicators (the highest) since the second quarter of 2006, when MSPI was initiated.[419, 420]

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." [421] Important attributes of safety culture include practice of safety-over-production, procedural adherence, conservative decision-making, and willingness of employees to identify safety concerns.[422] The final attribute is also known as a safety-conscious work environment.

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419 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>.

420 Potentially excluding Security Performance Indicators, which are not publicly available.

421 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>.

422 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."[423] 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.[424] In the wake of the incident, the NRC modified the Reactor Oversight Program to better identify problems with safety culture.[425]

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.[426] 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."[427] Since that time, the technical issues have been resolved but the plant operator, Arizona Public Service, has not effectively remedied the safety culture issues.[428] 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.[429] If downgraded further, Palo Verde would be deemed unfit to continue operating.

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423 U.S. Nuclear Regulatory Commission. SECY-04-0111. July 1, 2004: 2.

424 U.S. Nuclear Regulatory Commission. SECY-04-0111. July 1, 2004: 3.

425 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/ secy2006-0122/2006-0122scy.pdf>.

426 MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007: 219.

427 U.S. Nuclear Regulatory Commission. "NRC Chairman Dale Klein Discusses Palo Verde Nuclear Plant." No. 07-026. February 23, 2007.

428 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>.

429 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.[430] 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.[431]

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.[432]

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.[433] 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.[434] 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.[435]

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

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[430] U.S. Nuclear Regulatory Commission. "Annual Assessment Letter –Palo Verde Nuclear Generating Station." March 3, 2008, page 2.

[431] 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.

[432] California Energy Commission. 'Transcript of CEC June 28, 2007 Workshop on Nuclear Power Issues." June 28, 2007, page 65.

[433] 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>.

[434] 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>.

[435] U.S. Nuclear Regulatory Commission. "Diablo Canyon 1 - 1Q/2008 Plant Inspection Findings," June 5, 2008.

investigation and result in enforcement action.[436] Between 2004 and 2007 only 2 of 13 allegations that were submitted regarding Diablo Canyon have been substantiated by the NRC and none have resulted in enforcement action.[437] There has, however, been a recent spike in allegations regarding Diablo Canyon—10 allegations were submitted between January and May 2008. At this point it is 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 on April 14, 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.[438] 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.[439] It is unclear whether the NRC has substantiated these allegations and to what extent they have responded to the MFP allegation due to the confidentiality of the review process.

In addition to NRC regulation, safety at Diablo Canyon is monitored by the Institute for Nuclear Power Operations (INPO) and by the Diablo Canyon Independent Safety Committee (DCISC) (see text box below). INPO is a private, industry-funded agency that uses peer pressure to encourage enhanced safety and reliability at U.S. nuclear power plants.[440] 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.[441] This represents a marked improvement over Diablo Canyon's 1996 rating of 64.9 and 2003 rating of 82.1.[442]

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

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436 U.S. Nuclear Regulatory Commission. "Reporting Safety Concerns to the NRC." NUREG/BR-0240, Rev. 3. April 2005.

437 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>.

438 Mothers for Peace. "Diablo Canyon Safety Allegations." April 14, 2008. Accessed: July 8, 2008. <http://mothersforpeace.org/issues/workers/allegations/04142008/>.

439 Mothers for Peace. "Diablo Canyon Safety Allegations." April 14, 2008.

440 For a more comprehensive discussion of the INPO and NRC regulatory frameworks, see "Nuclear Power in California: 2007 Status Report," pages 207-216.

441 Pacific Gas & Electric. Letter to the Energy Commission Re: 2007 Integrated Energy Policy Report. August 30, 2007.

442 Pacific Gas & Electric. Letter to the Energy Commission. August 30, 2007.

and that recent NRC licensed operator exams showed a high failure rate. The DCISC will continue to investigate these concerns.[443]

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.[444] 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.[445] 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.[446]

Between November 2006 and January 2008, SONGS received enforcement action for five willful violations.[447] Among the violations, SONGS workers failed to follow a Radiation Work Permit and failed to control work of unqualified technicians operating on safety-related equipment.[448] 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

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443 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>.

444 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>.

445 U.S. Nuclear Regulatory Commission. "Notice of Violation (NRC Inspection Report No. 050-00206/06-011)." EA-06-149. September 13, 2006.

446 U.S. Nuclear Regulatory Commission. "Notice of Violation (NRC Inspection Report No. 050-00206/06-011)." September 13, 2006.

447 U.S. Nuclear Regulatory Commission. "Confirmatory Order." EA-07-232. January 11, 2008, page 2.

448 U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 2.

had been completed when they had not been.[449] 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.[450] 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 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 undertake a series of tasks to improve SONGS' safety culture.[451] 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.[452]

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.[453] 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.[454] Concerned with the persistence of these problems, the NRC has requested that SCE address these issues at a public meeting with the NRC.[455]

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

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449 U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 2.

450 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>.

451 U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 4.

452 U.S. Nuclear Regulatory Commission. "Confirmatory Order." January 11, 2008: 4.

453 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>.

454 U.S. Nuclear Regulatory Commission. "Midcycle Performance Review and Inspection Plan – San Onofre Nuclear Generating Station." September 2, 2008.

455 U.S. Nuclear Regulatory Commission. September 2, 2008.

readiness of backup safety systems."[456] According to the report, INPO rated SONGS as a three on a five-point scale.[457]

There is no independent safety committee at SONGS analogous 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.[458] SONGS' management concluded that the results of these surveys are unsatisfactory and that improvement is needed.[459]

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.[460] In response the NRC conducted a special inspection beginning on August 4, 2008. A report on the findings is expected in mid-September 2008.[461]

Plant Staffing and Training

In order for nuclear plants to maintain a strong safety culture and a safety-conscious work environment, they must be properly 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 new plants.[462] The NRC forecasts that 90,000 new workers will be needed by 2011 to continue operating current plants.[463] A 2001 study by NEI estimated that demand for nuclear engineering graduates would be about 150 percent of supply by 2010.[464] Great need

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456 Los Angeles Times. "San Onofre Nuclear Power Plant Feeling Regulatory Pressure." Reported by Elizabeth Douglas. August 19, 2008.

457 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.

458 Southern California Edison. "SONGS' Safety Conscious Work Environment and Nuclear Safety Culture." Presentation to the NRC. May 2006, pages 8, 11.

459 Southern California Edison. "SONGS' Safety Conscious Work Environment and Nuclear Safety Culture." May 2006: 20.

460 U.S. Nuclear Regulatory Commission. "NRC Conducting Special Inspection at San Onofre Nuclear Plant." News Release No. IV-08-033, July 30, 2008.

461 U.S. Nuclear Regulatory Commission. July 30, 2008.

462 U.S. Nuclear Regulatory Commission. "Testimony by Dale E. Klein, Chairman." March 28, 2007.

463 U.S. Nuclear Regulatory Commission. "Maintaining a Competent and Dedicated Workforce." Speech by Peter B. Lyons, NRC Commissioner. May 1, 2008, page 3.

464 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>.

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.[465] 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.[466, 467]

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.[468] 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).[469] 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.[470]

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.[471] In its 2005 survey, 62 percent of respondents reported that the inability to find replacements with utility-specific skills was also a challenge.[472] Successful recruiting and effective training and knowledge transfer are critical for ensuring that the plants continue to operate safely and reliably.

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465 Nuclear Energy Institute, January 2007.

466 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/>.

467 Nuclear Energy Institute, January 2007.

468 Pacific Gas & Electric. "Testimony in 2007 General Rate Case." A.05-12-002. Exhibit 3, pages 4-14.

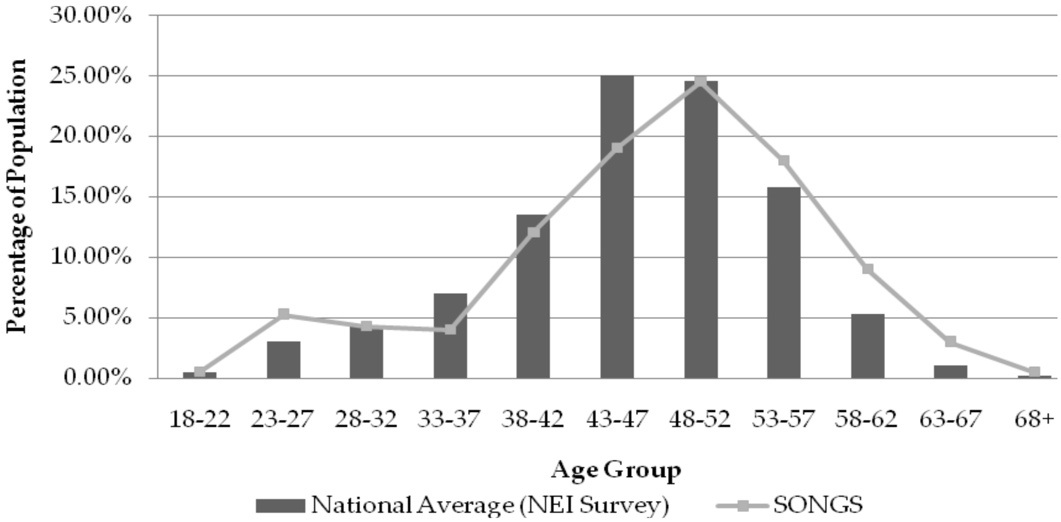
469 Southern California Edison. "2009 GRC Testimony Part 2." Volume 2. A.07-11-011, page 13.

470 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.

471 American Public Power Association. "Workforce Planning for Public Power Utilities: Ensuring Resources to Meet Projected Needs." 2005, page 6.

472 American Public Power Association, 2005: 6.

Figure 32: SONGS Workforce Demographics[473]



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.[474] 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.[475] SCE has supplemented its recruitment processes by offering sign-on bonuses, relocation benefits, enhanced housing allowances, and loan repayment plans.[476] 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 may degrade plant structures, systems, and components, which, in turn, can impair safety and result in extended outages. There is a clear correlation between the age of a plant and the number of degradation occurrences it experiences. A plant that is 30 years old experiences passive system degradation occurrences at a rate twice that of a 20-year old plant.

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 age-related degradation has not yet led to impaired performance. This does not necessarily indicate the absence of plant degradation, but it suggests

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473 Southern California Edison 2009 GRC Testimony Part 2 Volume 2, page 13.

474 Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Supplemental Data Requests." Docket No. 07-AB-1632. April 28, 2008, H1.

475 Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Supplemental Data Requests." April 28, 2008, H1.

476 Southern California Edison. "2009 GRC Testimony Part 2." Page 14.

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. In addition, EPRI's groundwater protection guidelines should be followed to prevent further inadvertent releases of tritium on account of degraded materials or operational failures.

Effective maintenance and oversight can forestall outages and prevent the safety hazards that could arise as a result of age-related 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 benefits from the oversight of the DCISC, which investigates concerns that do arise. There is no analogous independent safety committee that oversees SONGS.

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 are aware of the need to replace retiring workers and to pass on the institutional knowledge that they have, and they have instituted programs for this purpose. It is critical to the ongoing reliability and safety of the plant that they do so and that strong safety cultures are maintained throughout this shift in workforce.

Works Cited

American Public Power Association. “Workforce Planning for Public Power Utilities: Ensuring Resources to Meet Projected Needs.” 2005.

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>.

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.

Braverman, J.I. C.H. Hofmayer, R. J. Monante, S. Shteyngart and P. Belzer, Brookhaven National Laboratory. “Assessment of Age-Related Degradation of structures and Passive Components for U.S. Nuclear Plants.” NUREG/CR-6679. August 2000.

California Energy Commission. ‘T”Transcript of CEC June 28, 2007 Workshop on Nuclear Power Issues.” June 28, 2007.

California Public Utilities Commission. “Decision 05-11-026.” Application 04-01-009. November 18, 2005.

California Public Utilities Commission. “Decision 05-12-040.” Application 04-02-026. December 15, 2005.

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>.

Electric Power Research Institute. “Groundwater Protection Guidelines for Nuclear Power Plants.” Report 1016099, Public Edition. January 2008.

Hopenfeld, Joram. “Vermont Yankee License Renewal Proceeding.” Seventh Declaration. NRC Docket No. 50-271-LR. March 17, 2008.

Lochbaum, David. “Walking the Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages.” *Union of Concerned Scientists*s.: Cambridge, MA. 2006.

Mothers for Peace. “Diablo Canyon Safety Allegations.” April 14, 2008. <http://mothersforpeace.org/issues/workers/allegations/04142008/>.

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

North American Electric Reliability Corporation-GADS. “Cause Code Data.” Appendix 5B. 2002-2006.

Nuclear Energy Institute (NEI). “Nuclear Energy Industry Initiatives Target Looming Shortage of Skilled Workers.” January 2007. <http://www.nei.org/filefolder/ nuclear_energy_ industry_i initiatives_target_looming_shortage_of_ workers_ 0107.pdf>.

Nuclear Energy Institute. "Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants." NUMARC 93-01, Revision 2. April 1996.

Nuclear Energy Institute. “CEC-100-2007-005-F.” 2008.

Nuclear Energy Institute. "NERC-GADS 2007." 2008.

Nuclear Energy Institute. "New Performance Index Provides Closer Look At Nuclear Plant Safety Systems." Fact Sheet. Washington, DC. 2006.

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>.

Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Supplemental Data Requests." Docket No. 07-AB-1632. April 28, 2008.

Pacific Gas & Electric. "PG&E's Response to Data Requests AB 1632 Study Report." March 25, 2008.

Pacific Gas & Electric. "Testimony in 2007 General Rate Case." A.05-12-002. Exhibit 3.

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>.

Sisson, Paul. "More falsified documents investigated at San Onofre." *North County Times*. June 28, 2008. <http://www.nctimes.com/articles/2008/06/28/news/coastal/ oceanside/ z479b66a2869a9481882574750060d7e3.txt>.

Southern California Edison. "Data Request Set CEC 2007 IEPR-SCE-02." 2007 IEPR 06-IEP 1I. March 28, 2007.

Southern California Edison. "2009 GRC Testimony Part 2." Volume 2. A.07-11-011.

Southern California Edison. "SCE response to AB 1632 Nuclear Power Plant Assessment: Data Request for San Onofre Nuclear Generating Station (SONGS)."

Southern California Edison. "SONGS' Safety Conscious Work Environment and Nuclear Safety Culture." Presentation to the NRC. May 2006.

Stiles-Shell, Lisa, Nuclear Energy Institute. "2015: Do You Know Where Your Work Force Is?" Speech. May 19, 2006. <http://www.nei.org/newsandevents/ speechesandtestimony /2006/assemblystilesshellextended/>.

The North American Electric Reliability Corporation (NERC) Generating Availability Data System (GADS). "Cause Code Data." 2002-2006.

U. S. Nuclear Regulatory Commission. "Palo Verde 2: 1Q/2008 Plant Inspection Findings." June 5, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/ PALO2/palo2_ pim.html>.

U.S. Congress, Office of Technology Assessment. "Aging Nuclear Power Plants: Managing Plant Life and Decommissioning." OTA-E-575. September 1993. <http://www.princeton.edu/~ota/disk1/1993/9305/9305.PDF>.

U.S. Energy Information Administration. "U.S. Nuclear Reactors." <http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html>.

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/docdblite/details.php?rptno=GAO-04-415>.

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>.

U.S. Nuclear Regulatory Commission. "1Q/2008 ROP Action Matrix Summary." May 7, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/actionmatrix_ summary.html>.

U.S. Nuclear Regulatory Commission. "Annual Assessment Letter –Palo Verde Nuclear Generating Station." March 3, 2008.

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>.

U.S. Nuclear Regulatory Commission. "Confirmatory Order." EA-07-232. January 11, 2008.

U.S. Nuclear Regulatory Commission. "Davis-Besse Reactor Vessel Head Degradation Lessons-Learned." Task Force report. May 15, 2002. <http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/lessons-learned/lltf-report.html>.

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.

U.S. Nuclear Regulatory Commission. "Diablo Canyon 1 - 1Q/2008 Plant Inspection Findings." June 5, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/DIAB1/diab1_pim.html#IE1st>.

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. "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. "Escalated Enforcement Actions Issued to Reactor Licensees." January 14, 2008. <http://www.nrc.gov/reading-rm/doc-collections/enforcement/actions/reactors/s.html#SanOnofre>.

U.S. Nuclear Regulatory Commission. "Fatigue Analysis of Nuclear Power Plant Components." NRC Regulatory Issue Summary 2008-10. April 11, 2008. <http://www.nirs.org/reactorwatch/licensing/oclr04142008nrcrisfat.pdf>.

U.S. Nuclear Regulatory Commission. "Liquid Radioactive Release Lessons Learned Task Force Final Report." September 1, 2006.

U.S. Nuclear Regulatory Commission. "Maintaining a Competent and Dedicated Workforce." Speech by Peter B. Lyons, NRC Commissioner. May 1, 2008.

U.S. Nuclear Regulatory Commission. "Notice of Violation (NRC Inspection Report No. 050-00206/06-011)." EA-06-149. September 13, 2006.

U.S. Nuclear Regulatory Commission. "NRC Chairman Dale Klein Discusses Palo Verde Nuclear Plant." No. 07-026. February 23, 2007.

U.S. Nuclear Regulatory Commission. "NRC Conducting Special Inspection at San Onofre Nuclear Plant." News Release No. IV-08-033, July 30, 2008.

U.S. Nuclear Regulatory Commission. "Nuclear Plant Aging Research (NPAR) Program Plan." NUREG-1144. Revision 2. June 1991.

U.S. Nuclear Regulatory Commission. "Oyster Creek Generating Station License Renewal Proceeding." NRC Docket No. 50-219.

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. <http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2004/ secy2004-0111/2004-0111scy.pdf>.

U.S. Nuclear Regulatory Commission. "Regulatory Issue Summary 2006-07: Changes to the Safety System Unavailability Performance Indicators."RIS 2006-07. June 12, 2006.

U.S. Nuclear Regulatory Commission. "Reporting Safety Concerns to the NRC." NUREG/BR-0240, Rev. 3. April 2005.

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. <http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2006/secy2006-0122/2006-0122scy.pdf>.

U.S. Nuclear Regulatory Commission. "San Onofre 2 - 1Q/2008 Plant Inspection Findings." June 5, 2008. <http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/ SANO2/sano2_pim.html#IE1st>.

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. "Statistics on Allegations." June 17, 2008. <http://www.nrc.gov/about-nrc/regulatory/allegations/statistics.html>.

U.S. Nuclear Regulatory Commission. "Steam Generator Action Plan." June 1, 2007. <http://www.nrc.gov/reactors/operating/ops-experience/steam-generator-tube.html>.

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>.

U.S. Nuclear Regulatory Commission. "Testimony by Dale E. Klein, Chairman." March 28, 2007.

U.S. Nuclear Regulatory Commission. "Transcript of 549th Advisory Committee on Reactor Safeguards." Meeting on February 7, 2008 at 8-10. <http://adams websearch.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML081200041>.

U.S. Nuclear Regulatory Commission. "Vermont Yankee License Renewal Proceeding." NRC Docket No. 50-271-LR.

U.S. Nuclear Regulatory Commission. 10 CFR 50.65, the "Maintenance Rule."

U.S. Nuclear Regulatory Commission. " EA-96-123 - Diablo Canyon 1 & 2 (Pacific Gas & Electric Company)." June 7, 1996. <http://www.nrc.gov/reading-rm/doc-collections/enforcement/actions/reactors/ea96123.html>.

Union of Concerned Scientists. "Anatomy of a Flawed Decision: NRC Has a Brain, But No Spine." August 5, 2002.

Union of Concerned Scientists. "Davis-Besse: One Year Later." March 3, 2003.

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.[477] As discussed in Chapters 3 and 5, the plants 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.[478] 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

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, whereas a prolonged shutdown of SONGS could result in serious grid reliability shortfalls unless transmission infrastructure improvements are completed.

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477 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>.

478 Diablo Canyon is interconnected with the PG&E service area, and SONGS is interconnected to both the SCE and SDG&E service areas.

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.[479] The study focused on the impact of a full shutdown of Diablo Canyon on the CAISO transmission system.[480]

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:[481]

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.

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 generation 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 generation dropping in southern California.

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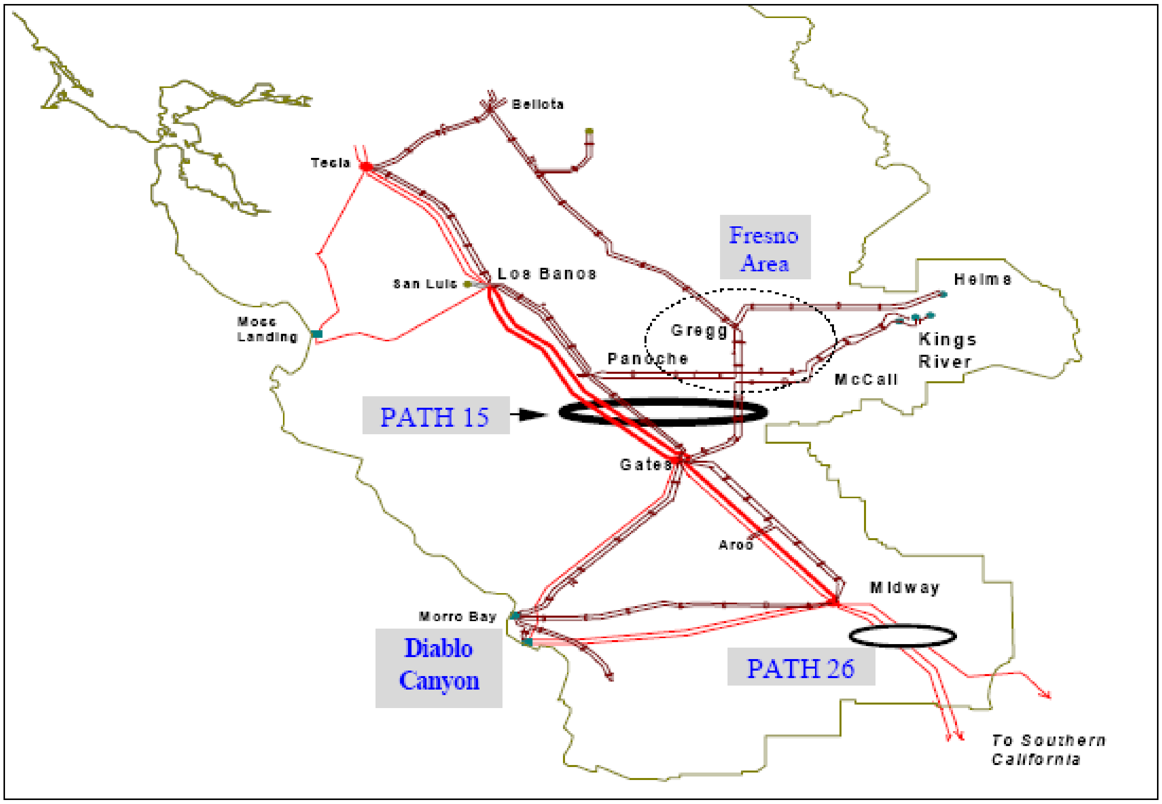
[479] Fluckiger, Kellan and Armando Perez. "CAISO Memorandum to CGRO Committee." April 19, 1999.

[480] Note that the study pre-dates the Path 15 upgrade, which was placed in service in December 2004.

[481] Pacific Gas & Electric. "Diablo Canyon Power Plant Operational Study." 2000, page 4.

Figure 33: Diablo Canyon Interconnections to CAISO Transmission System[482]



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 import capabilities, or dropping load.[483] 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

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482 Pacific Gas & Electric, 2000: 5.

483 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.

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.[484]

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.[485]

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.[486] SCE proposed three different transmission mitigation scenarios. One of these scenarios involved upgrades to the 230 kV

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[484] 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.

[485] Unlike the other scenarios, this mitigation option does not require the bypassing of the Southwest Power Link series capacitors.

[486] 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.

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.[487] SCE estimated that this upgrade would cost $287 million (in 2004 dollars) and could be completed in five years.[488] 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.[489] 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).[490]

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.[491] 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.

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-though cooling. Due to its harmful effects on marine organisms, the use of once-through cooling may be restricted in the future. A full discussion of the environmental impacts of once-though cooling and potential policy implications is included in Chapter 9. The State Water Resources Control Board commissioned a preliminary analysis of the reliability

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487 Static VAR Compensators provide reactive power compensation on high-voltage electricity transmission networks in order to regulate voltage.

488 The 2004 application stated that the upgrade could be completed by 2009.

489 SCE assumed that the Valley-Rainbow transmission line was unlikely to be built since this project has been rejected twice by the CPUC.

490 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.

491 California Public Utilities Commission. "Interim Opinion Adopting Methodology for 2005 Market Price Referent." D. 05-12-040. December 15, 2005, pages 26-27.

impacts of retrofitting, repowering, or retiring the power plants using once-through cooling.[492] (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.[493] However, if sufficient lead time is not provided, and all once-though cooling plants including the nuclear plants were retired, new generation capacity and transmission could cost ratepayers as much as $11 billion.[494]

A similar study is being conducted by the CAISO which will examine reliability implications of removing older thermal generating units and units with once-though cooling. [495] 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.[496] 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.[497] The full report is expected in the fourth quarter of 2008.[498]

Reliability Planning

A major disruption of operations at either Diablo Canyon or SONGS (or both) can cause transmission reliability issues as a result of 1) an inability to respond immediately to the loss of supply, such as a lack of spinning reserve capacity or other operational issue, or 2) a shortage of replacement generation needed to meet peak loads.[499] This section reviews current studies of the sufficiency of replacement generation in the event of a major disruption at Diablo Canyon or SONGS. The primary concern is whether the CAISO system has sufficient generating capacity to meet forecasts of peak demand without Diablo Canyon and/or SONGS.

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492 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>.

493 California Ocean Protection Council, 2008: 56.

494 California Ocean Protection Council, 2008: 3.

495 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>.

496 Ibid.

497 California Ocean Protection Council, 2008: 53.

498 California Independent System Operator. "Old Thermal Generation – Phase 1 Report." February 29, 2008. <http://www.caiso.com/1f80/1f80a4a5568f0.pdf>.

499 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)

The CPUC Resource Adequacy program specifically addresses the sufficiency of replacement supplies, requiring load-serving entities to plan to meet a 15 to 17 percent reserve margin[500] based on a 1-in-2 load forecast.[501]

The CAISO publication entitled "2008 Summer Loads and Resources Operations Preparedness Assessment" provides a detailed discussion of electricity transmission issues and replacement power supply plans.[502] Table 6 shows the supply and demand outlook for the summer of 2008, based on a 1-in-2 peak demand forecast. The import amounts are based on an Energy Commission assessment of the transmission system's physical capability to deliver into the CAISO control area.[503]

Table 6: CAISO Planning Reserve Forecast (1-in-2 peak demands)[504]

Summer 2008 Outlook - CEC Assumed Imports

Resource Adequacy Planning Conventions	CAISO	SP26	NP26
Existing Generation	47,716	22,376	25,349
Retirements (Known)	-122	-122	0
High Probability CA Additions	489	442	47
Net Interchange	10,350	10,100	250
Total Net Supply (MW)	58,432	32,796	25,646
Demand (1-in-2 Summer Temperature)	48,900	28,331	21,969
DR & Interruptible Programs (80% of CPUC 2008 estimates)	2,130	1,427	703
Planning Reserve[1]	**23.9%**	**20.8%**	**19.9%**

[1] Planning Reserve calculation (Total Net Supply + Demand Response + Interruptibles)/1-in-2 Demand)-1.

Table 6 shows that under normal conditions and given current loads and resources, there is a 23.9 percent planning reserve margin, which is well above the CPUC's required resource adequacy margin of 15 percent to 17 percent.[505] When the zones north of Path 26 (NP26) and south of Path 26 (SP26) are considered independently, the forecasted reserve margins are lower but still above required levels. The existing generation counted in this assessment includes the qualifying capacity of the California nuclear plants: 2,240 MW at Diablo Canyon and 2,246 MW

500 The reserve margin is the amount by which planned generation capacity exceeds the forecast of peak demand. A reserve margin prevents supply shortfalls in the event of a transmission line or generator outage, or unexpectedly high demand.

501 A 1-in-2 load forecast is based on the expectation that there is a 50 percent probability that actual peak demand will be higher than the forecast and a 50 percent probability that the peak demand will be lower than the forecast.

502 California Independent System Operator. "CAISO 2008 Summer Loads and Resources Operations Preparedness Assessment." Seasonal Assessments. April 28, 2008. <http://www.caiso.com/docs/2003/04/25/ 200304251132276595.html>.

503 The CAISO control area comprises California's investor owned utilities, which serve the majority of California's electric customers.

504 Ibid.

505 Note that the CAISO demand forecast for 2008 is 0.3 percent lower than the CEC forecast adopted in CEC-200-2007-015-SF2, November 2007. Using the CEC 2008 coincident peak demand forecast of 49,071 MW (1-in-2 Summer Temperature), the CAISO planning reserve margin would be 23.4 percent.

at SONGS.[506] If the total nuclear capacity of 4,486 MW were removed from the existing supply, the CAISO reserve margin would be reduced from 23.9 percent to 14.7 percent, which is just outside of the CPUC's resource adequacy planning level. Planning reserve margins for SP26 would be 12.9 percent without SONGS and the margin for NP26 without Diablo Canyon would be 9.7 percent. [507] These values are below the CPUC resource adequacy planning reserve requirements, suggesting that replacement capacity would need to be constructed in the event that either plant is completely shut down but that operating reserve requirements would not necessarily be violated. The amount of available imports is a key assumption that is subject to a high level of uncertainty. If actual imports at the time of plant outages were lower than the assumed amount, the loss of generating capacity at Diablo Canyon and SONGS would have a proportionately greater impact on operating reserve margins.

It is not clear from the CAISO analysis whether the assumed import levels could be maintained in the event that SONGS was off-line and was not contributing to the ability of the transmission system to support imports from the southwest. Furthermore, the CAISO did not address contingencies that occur in real-time, such as a loss of a significant amount of generation and/or transmission and limited ability to rely on imports from other control areas. Finally, loads and available resources change over time, and the availability of hydroelectric power varies from year to year. While the CAISO assessment shows marginally sufficient resources in 2008 and an improving situation in 2009, these findings may not hold over the duration of the Diablo Canyon and SONGS operating lives.

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 Study 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 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).[508]

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506 Qualifying Capacity is the maximum dependable capacity for the resource type.

507 Imports into SP26 assume approximately 3,000 MW of North to South transfers across Path 15, however Path 15 can also flow South to North. If the SP26 imports were reduced by 3,000 MW to reflect a scenario in which Path 15 imports were not available, the SP26 reserve margin without SONGS would drop to just 2 percent.

508 North American Electric Reliability Corporation. "GADS Services." <http://www.nerc.com/~gads/>.

Table 7: Outage Durations at Pressurized Water Reactors (> 1,000 MWe), days[509]

	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	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	6.5%	7.1%	6.6%	7.6%	7.8%	7.1%
Total Unavailability	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.[510] 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.[511] 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).[512] As a result, what was originally

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509 Ibid.

510 Lochbaum, David. "Walking a Nuclear Tightrope." *Union of Concerned Scientists*. September 2006.

511 Lochbaum, David. "Walking a Nuclear Tightrope." September 2006: 1.

512 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.[513]

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 year-long unplanned outage at one or both of the nuclear plants in 2012.

Production Simulation Model

For the replacement power analysis, the Study 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

[513] 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 MARKETSYM™, the Study 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.[514] 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 Study 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 Study Team started at current market conditions and gradually added capacity.[515]
- 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.

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[514] 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.

[515] 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 Study 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 Study 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 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 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
Total California Load	*312,000*	*312,000*	-	*312,000*	-

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). 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 Capacity[516]	76,841	74,593	74,609
Reserve Margin	***26%***	***23%***	***23%***

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.

516 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.

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.[517] 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.[518]

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.[519] 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.[520] Should capital improvements of this scale be required to repair Diablo Canyon or SONGS, these repair costs would likely be included in the plant's ratebase and recovered from ratepayers over the expected lifetime of the capital improvement. This would reduce the rate impact in any given year. For example, a $203 million capital improvement recovered over 10 years would cost

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517 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 form out-of-state must be purchased at market rates calculated internally within the MARKETSYM model.

518 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.

519 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; 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>.

520 All figures are in 2008 dollars.

ratepayers at most $46 million in one year, which would raise rates by roughly 0.05¢ per kWh.[521]

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 CO_2), 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 CO_2). 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 CO_2.

As shown in Table 10, emissions of NOx and SOx would also increase, albeit by a much smaller percentage than seen for CO_2.

Table 10: Emissions Changes from year-Long Plant Outage in 2012

	Base Case Emissions, Thousands of Tons	Change in emissions from Diablo Canyon Outage		Change in emissions from 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.

- 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

[521] This calculation presumes a 9 percent cost of capital and a 44 percent tax rate.

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.[522] This has resulted in the incremental emissions of 24 million tons of CO_2, representing two percent of Japan's emissions in FY 2007 and approximately three percent of Japan's emissions per year of outage going forward.[523]

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 over the summer of 2007 than over the summer of 2006.[524] 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.[525] However, the potential impacts of the shutdown could become more severe as fuel inventories are depleted.[526]

522 Institute of Energy Economics, Japan. "Impacts on International Energy Market of Unplanned Shutdown of Kashiwazaki-Kariwa Nuclear Power Station." April 2008, page 1.

523 Institute of Energy Economics, April 2008: 23.

524 Institute of Energy Economics, April 2008: 14, 18.

525 Institute of Energy Economics, April 2008: 16, 21.

526 Institute of Energy Economics, April 2008: 27.

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.[527] 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 on account of 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 finds that in the event of an extended outage at either nuclear plant in 2012, replacement power would be available, mostly from combined cycle natural gas-fired plants. The CAISO has also found that there are sufficient reserve margins to accommodate the loss of either or both nuclear plants. However, this assessment of replacement power options is not applicable beyond 2012 and does not account for local transmission constraints that could restrict the deliverability of replacement power to some areas. More complete studies will be needed periodically to reassess the availability of replacement power at a system and local level given updated supply and demand conditions and local transmission constraints.

Previous studies have shown that while Diablo Canyon represents a significant generation resource and supports power flows through Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. During a major disruption at Diablo Canyon replacement power can be supplied by existing and new resources, albeit at significant incremental cost (about $470 million per year) and with a greater impact on the environment (e.g. a 7.6 percent increase in CO_2 emissions).

[527] Institute of Energy Economics, April 2008: 12-13.

SONGS is a more integral part of the Southern California transmission system, and when it is shut down imported power flows are also restricted. Consequently, while replacement power for SONGS would be available (at similar costs and environmental impact as for Diablo Canyon), there would likely need to be modification to the transmission system in the event of a long-term or permanent plant shutdown. The extent of the transmission system changes would depend on the transmission configuration in place at the time of the SONGS shutdown.

Works Cited

California Energy Commission. “2007 Net System Power Report.” CEC-200-2008-002-CMF. April 2008. <http://www.energy.ca.gov/ 2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>.

California Independent System Operator. “CAISO 2008 Summer Loads and Resources Operations Preparedness Assessment (SLROPA).” Seasonal Assessments. April 28, 2008. <http://www.caiso.com/docs/2003/04/25/ 200304251132276595.html>.

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>.

California Independent System Operator. “Old Thermal Generation – Phase 1 Report.” February 29, 2008. <http://www.caiso.com/1f80/1f80a4a5568f0.pdf>.

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>.

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.

California Public Utilities Commission. “Interim Opinion Adopting Methodology for 2005 Market Price Referent.” Decision (D.) 05-12-040. December 15, 2005.

Fluckiger, Kellan and Armando Perez. “CAISO Memorandum to CGRO Committee.” April 19, 1999.

Institute of Energy Economics, Japan. "Impacts on International Energy Market of Unplanned Shutdown of Kashiwazaki-Kariwa Nuclear Power Station." April 2008.

Lochbaum, David. “Davis Besse.” *Union of Concerned Scientists*. September 2006. <http://www.ucsusa.org/assets/documents/clean_energy/Davis-Besse-II.pdf>.

Lochbaum, David. “Walking a Nuclear Tightrope.” *Union of Concerned Scientists*. September 2006.

North American Electric Reliability Corporation. “GADS Services.” <http://www.nerc.com/~gads/>.

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.

Pacific Gas & Electric. “Diablo Canyon Power Plant Operational Study.” 2000.

Southern California Edison. "Devers Palo Verde No. 2 (DPV2)." Presentation at the 2008 Biennial Transmission Assessment Workshop 1. May 22, 2008. <http://www.cc.state.az.us/Divisions/Utilities/Electric/Biennial/2008%20BTA/DPV2%20BTA%20Workshop_May%2022-23%202008.ppt>.

Union of Concerned Scientists. "Unlearned Lessons of Year-Plus Reactor Outages – Case Studies." September 26, 2006. <http://www.ucsusa.org/clean_energy/nuclear_safety/unlearned-lessons-from.html>.

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.[528] 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

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[528] 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.[529] Spent fuel is composed of uranium, plutonium, and fission byproducts that remain after the fuel has been used for electricity generation.[530] 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.[531]

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.[532] 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.[533] 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.[534] 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).[535] 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

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[529] 42 USC 10101, pages 1-4.

[530] 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.

[531] 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>.

[532] U.S. Nuclear Regulatory Commission. "High-Level Waste". February 13, 2007. Accessed: February 5, 2008. <http://www.nrc.gov/waste/high-level-waste.html>.

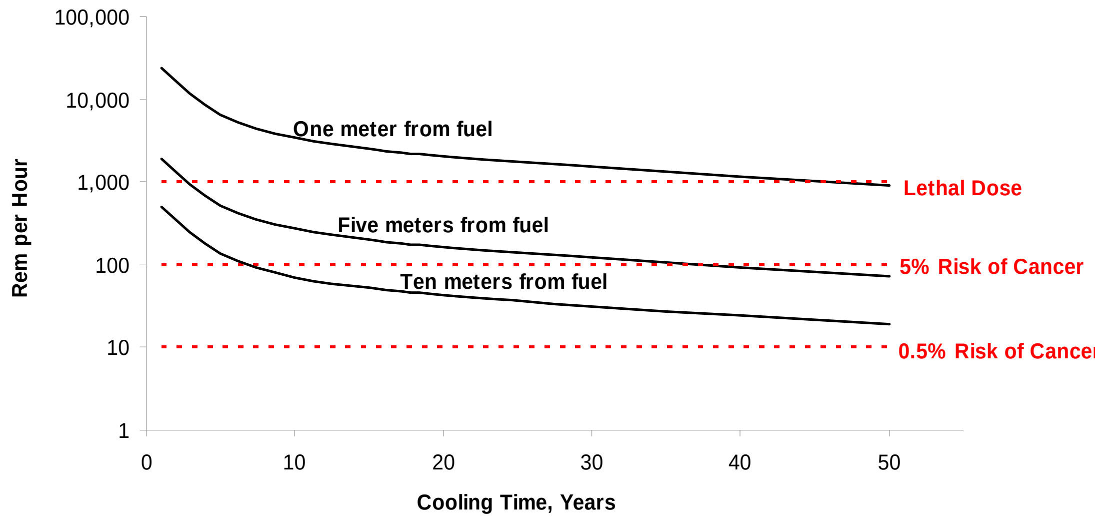
[533] U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." (NUREG/BR-0216, Rev. 2). May 2002. <http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0216/ r2/br0216r2.pdf>.

[534] U.S. Nuclear Regulatory Commission. "Radioactive Waste: Production, Storage, Disposal." May 2002.

[535] 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).[536]

Figure 34: Radiation Dose Rate from a Pressurized Water Reactor Spent Fuel Assembly[537]



[536] U.S. Nuclear Regulatory Commission, 10 CFR 61.7.

[537] Lloyd, Sheaffer, and Sutcliffer. "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.>

Table 11: Low-Level Waste Characteristics and Disposal Methods[538]

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

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.[539] 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.[540] 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.[541] 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.[542] There are no facilities currently licensed by the NRC for the disposal of GTCC low-level waste or spent fuel.

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538 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>.

539 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/>.

540 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.gtcceis.anl.gov/guide/gtccllw/ index.cfm>.

541 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.

542 42 USC 2021c

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 ft^3 of Class A low-level waste, and 1,700 ft^3 of Class B and C low-level waste.[543] 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.

[543] 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[544] (ft^3)**
Diablo Canyon[545]	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[546]	2,546	1,786	Unknown
	License Extension	2,112	908	17,480	2,680	1,880	Unknown
	Decommissioning	None	None	240,752[547]	23,308	1,148	866
	Total	**6,422**	**2,761**	**288,768**	**29,338**	**5,377**	
SONGS[548]	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.[549]			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.[550] The composition of Diablo Canyon's spent fuel is provided in Table 13.

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544 Disposal volume of GTCC waste is not determined until the waste shipment is prepared.

545 Pacific Gas & Electric. February 27, 2008: B1.

546 Includes 3,000 ft^3 for removal of first set of steam generators and 2,800 ft3 for two reactor heads removed in 2009 and 2010.

547 Includes 17,342 ft3 for both sets of steam generators.

548 Southern California Edison. March 21, 2008: B1.

549 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.

550 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 Fuel[551]

	Isotope	Diablo Canyon		SONGS	
		All extracted spent fuel (mass percent)[552]	Most recently extracted (mass percent)[553]	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.[554] 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.[555] 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

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551 Pacific Gas & Electric. February 27, 2008: B2.

552 SCE declined to provide information to the Energy Commission on the composition of SONGS spent fuel.

553 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.

554 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.

555 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.

also awaiting final ISFSI license approval, but challenges to this license will not delay use of the ISFSI (see "Mothers for Peace Challenge Diablo Canyon ISFSI License").[556]

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.

The ISFSIs that PG&E and SCE are building reflect two different on-site waste management strategies. PG&E plans to build an ISFSI that is large enough to store all of the spent fuel that will be generated during Diablo Canyon's current license period (Table 14). With this ISFSI, PG&E would have sufficient room in the spent fuel pool to continue operating the reactors for 25 years past their current operating licenses, even if no off-site storage space is available. PG&E would also be able to move all of Diablo Canyon's spent fuel to the ISFSI and fully decommission the spent fuel pools should the reactors' licenses not be extended. SCE plans to build an ISFSI with capacity for less than 40 percent of the spent fuel to be generated during SONGS' current license period, relying on the spent fuel pool to store the remaining spent fuel. This means that additional storage space would be required if SONGS were to continue operating past its current license or if SCE wished to decommission the SONGS spent fuel pools prior to the availability of off-site spent fuel storage.

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[556] Pacific Gas & Electric. February 27, 2008: C2.

Mothers for Peace Challenges Diablo Canyon ISFSI License

In 2005 San Luis Obispo Mothers for Peace (MFP) filed a lawsuit contending that the EIS for the Diablo Canyon ISFSI was incomplete because it did not address the environmental impacts of terrorist activity at the facility. In June 2006 the Ninth Circuit Court of Appeals ruled in favor of MFP. PG&E appealed that ruling to the Supreme Court in January 2007, but the Court declined to review the case. As a result, the NRC completed a supplemental analysis that considered the environmental impacts of a potential terrorist attack on the Diablo Canyon ISFSI. The NRC found 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.

In response to the supplemental environmental impact statement, MFP filed several contentions before the NRC Commissioners. 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. The Commissioners accepted the first two of these contentions. In response, NRC staff released further documentation, and in July 2008 the NRC Commissioners held a hearing regarding the second contention.

The NRC has not announced a date for a final 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>; 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.

Moreover, SCE may need to expand its storage capacity further during the current SONGS license period. Due to a change in SCE's plans for operating SONGS, the SONGS spent fuel pool and ISFSI are now expected to have sufficient combined storage capacity for only 98 percent of the spent fuel that will generated during this period (Table 14).[557] In order to accommodate the remaining spent fuel, SCE will need to secure offsite storage or develop additional capacity. SCE has not yet determined how it will manage the extra spent fuel.[558]

Table 14: On-Site Spent Fuel Storage Capacity (number of assemblies)[559]

	Diablo Canyon	SONGS Units 2 & 3
ISFSI Capacity	1,280[560]	312[561]
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**	**4,972**[562]

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.[563] If the spent fuel is not transported off-site within the design lives of the ISFSI components, the spent fuel may need to

557 The shortfall in storage capacity is due to a recent change in the projected SONGS fuel cycle. When the ISFSI capacity was planned, SONGS had been operating on a 21-month fuel cycle and projecting a 24-month fuel cycle for future operation. Since that time, SCE has determined that a 24-month fuel cycle is not optimal and plans instead to operate with an 18-month fuel cycle in the future. This means that the reactors will be refueled more often and will generate more spent fuel assemblies than originally expected; Southern California Edison. "SCE 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.

558 Southern California Edison. "SCE Letter to Energy Commission." May 9, 2008.

559 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.

560 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.

561 This includes the total current capacity (707 assemblies) less 395 assemblies from Unit 1 that are in the ISFSI.

562 SCE additionally has 270 assemblies of spent fuel from Unit 1 stored at a facility in Illinois. Southern California Edison. March 21, 2008: C1.

563 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>.

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.[564]

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 $160 million and $300 million (present value), respectively.[565] Notably, the planned SONGS ISFSI will be both smaller and more expensive than the Diablo Canyon ISFSI. On a per assembly basis, the SONGS ISFSI will cost more than three times the Diablo Canyon ISFSI (Table 15).

Table 15: ISFSI Construction and Loading Costs

Cost Component	**PG&E**	**SCE**[566]
Costs through 2007	$37 million[567]	$139 million[568]
Construction and Loading Costs (present value)	$160 million	$300 million
Construction and Loading Cost per assembly (present value)	$38,000	$140,000

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 its current operating license will be $180 million.[569] Delays in shipment to offsite storage of up to 25 years might incur $1.5 million (2008$) per year in operations, maintenance, and security costs.[570] Additional delays could require that the spent fuel be removed from the ISFSI and repackaged in new canisters on account of 50–year ISFSI design life.

[564] Southern California Edison. March 7, 2008: C3; Pacific Gas & Electric. February 27, 2008: C3.

[565] Pacific Gas & Electric. February 27, 2008: D1; Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

[566] Figures for SCE include costs for storage of waste from Unit 1.

[567] Pacific Gas & Electric. February 27, 2008: D1.

[568] Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

[569] MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007, page 46.

[570] Calculated based on Pacific Gas & Electric. February 27, 2008: D1.

Table 16: ISFSI Ongoing Costs[571]

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**	

The present value of the cost to construct and load the SONGS ISFSI to its current planned capacity is approximately $300 million exclusive of operation, maintenance, and security costs.[572] However, as described above, additional spent fuel storage capacity will be required to store all of the spent fuel that is expected to be generated by SONGS during the current licensing period (Table 14). In addition, delays in shipments could require that the spent fuel be removed from the ISFSI and repackaged in new canisters on account of the 40-year design life of the canisters.[573]

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.

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).[574] Including interest, California ratepayers have contributed over $1 billion to the Nuclear Waste Fund.[575] 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 and the plants continue to operate at these levels, ratepayers will pay an additional $636 million (Table 17).[576]

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571 Pacific Gas & Electric. February 27, 2008: D1; Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

572 Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

573 AREVA. "NUHOMS® 24PT1, 2, 4 Dry Shielded Canister" Accessed: April 7, 2008. <http://www.transnuclear.com/nuhoms-24pt124.htm>

574 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.

575 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>.

576 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.

Table 17: Nuclear Waste Fund Payments, millions (nominal dollars)[577]

	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.[578]

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.[579] 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 result of DOE's breach of contract.[580] 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.[581] 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

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577 These figures do not include interest on payments.

578 The status of a federal repository at Yucca Mountain is discussed in detail in Appendix 7A.

579 U.S. Court of Appeals for the Federal Circuit. "Indiana Michigan Power Company v. United States." 04-5122. September 9, 2005.

580 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.

581 U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

earlier schedule.[582] 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.[583] 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.[584]

SCE claimed $150 million in damages through 2005 (Table 18).[585] In its claim SCE contended that had DOE not breached its contract, SCE would not have needed to construct an ISFSI at SONGS.[586] 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 investments in the proposed Private Fuel Storage facility in Utah.[587] The standard discovery phase of the proceeding has ended, though SCE has indicated that additional discovery may be required.[588] No trial date has been set.

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 spent fuel would contain one to five casks per train or a single cask per overweight truck.[589] 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

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582 U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

583 U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

584 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.

585 Southern California Edison. March 28, 2007: D9.

586 Southern California Edison. March 28, 2007: Attachment D8, page 3.

587 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.

588 Southern California Edison. March 21, 2008: E1.

589 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.

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.[590]

Table 18: Nuclear Waste Fund Litigation[591]

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 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 plans to use 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

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[590] Calculated based on Southern California Edison. March 21, 2008: B1; Pacific Gas & Electric. February 27, 2008: B1.

[591] 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.

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)."[592] 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.

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.[593] 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.[594] 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.[595]

To date, DOE has specified only preliminary performance specifications for the proposed TAD system, and no TAD canisters have yet been developed.[596, 597] In the absence of final regulations,

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592 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>.

593 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>.

594 McCullum, Rod. "Transportation, Aging, and Disposal (TAD) Canisters." April 2008: 11.

595 McCullum, Rod. "Transportation, Aging, and Disposal (TAD) Canisters." April 2008: 9.

596 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.

597 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>.

the utilities have adopted their own canister systems. PG&E's spent fuel canister system is not compatible with DOE's proposed TAD system.[598] SCE states that at this point it is unclear whether its storage system will comply with DOE's final TAD requirements.[599]

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.[600] (These estimates do not include the cost to build transportation infrastructure from 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.[601]

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.[602] 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.[603] 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

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

598 Pacific Gas & Electric. February 27, 2008: E4.

599 Southern California Edison. March 21, 2008: E4.

600 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>.

601 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>.

602 Neither PG&E nor SCE has any current plans of pursing interim off-site storage. Pacific Gas & Electric. February 27, 2008: C3; Southern California Edison. March 21, 2008: C3.

603 Pacific Gas & Electric. February 27, 2008: B1; Southern California Edison. March 21, 2008: B1.

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.[604] Legislation passed in October 2007 extended this funding mechanism through 2019.[605]

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 as spent fuel remained on site.[606] 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.[607]

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.[608] 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.[609] 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.[610]

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

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604 California Emergency Services Act: Nuclear Planning Assessment Special Account. (AB 292, Blakeslee, Signed October 11, 2007).

605 AB 292, Blakeslee.

606 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>.

607 Personal Communication between Barbara Byron, California Energy Commission, and Ben Tong, California Office of Emergency Services. July 15, 2008.

608 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>.

609 Federal Register. Vol. 72, No. 140. Monday, July 23, 2007: 40139.

610 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>.

transportation plan for repository shipments.[611] 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.[612]

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 emergency response along shipment corridors in California.[613] 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.[614] He also characterized DOE's proposed funding levels as "seriously insufficient" for California.[615] 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.[616] 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."[617] 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.

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611 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 l. 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>.

612 Western Interstate Energy Board. January 17, 2008.

613 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 l. 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>.

614 Commissioner James Boyd, California Energy Commission. January 22, 2008.

615 Commissioner James Boyd, California Energy Commission. January 22, 2008: 8.

616 Commissioner James Boyd, California Energy Commission. January 22, 2008: 10.

617 Commissioner James Boyd, California Energy Commission. January 22, 2008: 19.

Table 19: DOE's Proposed Emergency Response Grant Program[618]

	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.[619]

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.[620] 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.[621] PG&E reports that it will review other options for the disposal of Class B and C low-level waste if they become available.[622] PG&E also plans to store large reactor components on-site until decommissioning in order to minimize low-level waste shipments and costs.[623] (This

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618 Federal Register. Vol. 72, No 140. Monday, July 23, 2007: 40139; Commissioner James Boyd, California Energy Commission. January 22, 2008.

619 The Atlantic Compact includes Connecticut, New Jersey and South Carolina.

620 Pacific Gas & Electric. April 5, 2007: B9.

621 Pacific Gas & Electric. February 27, 2008: E7.

622 Pacific Gas & Electric. February 27, 2008: E7.

623 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 2002-2007[624]

		Diablo Canyon	SONGS
Time Period	**Waste Class**	**Disposal Volume (ft^3)**	**Disposal Volume (ft^3)**
2002-2006	Class A	7,176	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.[625] SCE will continue to ship Class A waste to the Clive, UT 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.[626] However, the steam generators are large components and may be difficult to transport. In 2003 SCE attempted to ship the Unit 1 reactor vessel to Barnwell but was unable to find a suitable means of transportation given the size and weight of the vessel.[627]

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.[628] In addition, large quantities of low-level waste will be created when the oldest reactors running today begin decommissioning.[629] In October 2007 the NRC issued an assessment of its low-level waste regulatory program in order

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624 Pacific Gas & Electric. April 5, 2007: B9.

625 Southern California Edison. March 21, 2008, E7.

626 Southern California Edison. March 21, 2008: E6.

627 MRW & Associates, Inc. "Nuclear Power in California: Status Report." March 2006: 88.

628 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.

629 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.

to address upcoming challenges regarding low-level waste disposal.[630] 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 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.[631] The NRC expects to complete this task by the end of 2008.[632]

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.[633] 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.[634] 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 Costs[635]

	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

630 U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." SECY-07-0180. October 17, 2007.

631 U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." October 17, 2007: 5.

632 U.S. Nuclear Regulatory Commission. "Strategic Assessment of Low-Level Waste Regulatory Program." October 17, 2007: 13, C-8.

633 Pacific Gas & Electric. February 27, 2008: B1, E3.

634 Southern California Edison. "SCE Letter to Energy Commission." April 7, 2008.

635 Pacific Gas & Electric. February 27, 2008: E3.

per cubic foot and that costs were expected to exceed $1,000 per cubic foot in the future.[636] These cost increases will have the biggest impact when the plants are decommissioned. For example, PG&E estimated in 2006 that waste disposal costs during Diablo Canyon decommissioning would total $242 million (2004$).[637] However, these estimates were based on a waste disposal cost of $248 per cubic foot, well below the cost of Class A waste disposal today. Total waste disposal costs would increase to $438 million (2004$) at $450 per cubic foot, and $974 million (2004$) at $1,000 per cubic foot.[638]

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 in order to protect humans and the environment from exposure to radioactive materials. In the case of spent fuel, which is extremely radioactive, 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 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 PG&E to transfer and store 100 percent of the spent fuel produced during the period of the current operating license. This approach would allow PG&E to decommission its spent fuel pool at the end of the current license if needed. SCE has designed an ISFSI with a capacity to store 36 percent of the spent fuel generated during the current license period. SCE intends to rely on its spent fuel pool to store the remaining spent fuel. However, the total combined spent fuel pool and ISFSI storage capacity at SONGS is sufficient to contain just 98 percent of the total spent fuel expected to be produced. SCE has not yet determined how it will manage the additional spent fuel.

The costs for constructing and loading the ISFSIs are substantial. On a present value basis, the total cost is $160 million for Diablo Canyon and $300 million for SONGS. Since the ISFSI at

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636 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>.

637 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.

638 Disposal costs during decommissioning could be even higher if additional large components are replaced. These components are costly to transport and dispose of. See *Nuclear Power in California: 2007 Status Report,* page 132.

SONGS is just 40 percent the size of the Diablo Canyon facility and nearly twice as expensive, the SONGS ISFSI is three to four times as expensive per fuel assembly.

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. 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). DOE 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 the 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; 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 an alternate facility is available. 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 current estimates of disposal costs during decommissioning are based on outdated cost information. Costs could be substantially higher than estimated during the most recent California regulatory proceeding on decommissioning costs in 2005.

Works Cited

42 USC 10101.

42 USC 2021c.

Adams, J.P. M.L. Carboneau, and W.E. Allred. "National Low-Level Waste Management Program Radionuclide Report Series." Paper Presented at Waste Management '99 (Preprint). February 28 – March 4, 1999. <http://www.inl.gov/technicalpublications/Documents/3314426.pdf>.

AREVA. "NUHOMS® 24PT1, 2, 4 Dry Shielded Canister." <http://www.transnuclear.com/nuhoms-24pt124.htm>.

California Emergency Services Act: Nuclear Planning Assessment Special Account. (AB 292, Blakeslee, Signed October 11, 2007).

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. <http://www.ocrwm.doe.gov/ym_repository/seis/comments/RRR000108.pdf>.

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 l. 72, No. 1401. Monday, July 23, 2007/Notices). <http://www.ocrwm.doe.gov/transport/180c_comments/California_Comments_Final_1-22-08.pdf>.

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. <http://www.westchestergov.com/currentnews/2005pr/levitanreport.pdf>.

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. <http://www.westgov.org/wieb/meetings/hlwsprg2008/briefing/present/r_mccullum.pdf>.

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

MRW & Associates, Inc. "Nuclear Power in California: Status Report." Prepared for the 2005 Integrated Energy Policy Report. March 2006.

Nuclear Energy Institute. "Key Issues: Yucca Mountain." Accessed: September 12, 2008. <http://www.nei.org/keyissues/nuclearwastedisposal/yuccamountain/>

Nuclear Energy Institute. "Nuclear Waste Fund Payment Information by State." <http://www.nei.org/filefolder/nuclear_waste_fund_payment_information_by_state.xls>.

Oatley, David. "IEPR Committee Workshop on Issues Concerning Nuclear Power." Presentation to the California Energy Commission. August 15, 2005. <http://www.energy.ca.gov/2005_energypolicy/ documents/2005-08-15+16_workshop/presentations/panel-2/Oatley_David_PG&E.pdf>.

Pacific Gas & Electric. "PG&E's Response to Data Requests AB 1632 Study Report." Docket No. 07-AB-1632. February 27, 2008.

Pacific Gas & Electric. "PG&E's Responses to CEC's Nuclear Power Plant Data Requests." Docket No. 06-IEP-1N. April 5, 2007.

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). <http://www.supremecourtus.gov/docket/06-466.htm>.

Peterson, Per. "Annotated Draft Consultant's Report CEC-100-2007-005-D." June 28, 2007.

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. <http://www.state.nv.us/nucwaste/trans/pic2/2piccovr.htm>.

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." (U.S. Court of Appeals for the Ninth Circuit No. 03-74628. June 2, 2006). <http://www.ca9.uscourts.gov/ca9/newopinions.nsf/2BFBC6088AF13AA98825718000723C79/$file/0374628.pdf?openelement>.

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.

Southern California Edison. "Data Request Set CEC 2007 IEPR-PV-SCE-01." 2007 IEPR 06-IEP 1I. March 28, 2007.

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.

Southern California Edison. "SCE 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 (SONGS). May 9, 2008.

Southern California Edison. SCE Letter to Energy Commission re: AB 1632 Nuclear Power Plant Assessment, (Docket No. 07-AB-1632). April 7, 2008.

U.S. Court of Appeals for the Federal Circuit. "Indiana Michigan Power Company v. United States." 04-5122. September 9, 2005.

U.S. Court of Appeals for the Federal Circuit. "Pacific Gas and Electric Company v. United States." 2007-5046. August 7, 2008.

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.

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. <http://www.ocrwm.doe.gov/about/budget/pdf/tslccr1.pdf>.

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.

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>.

U.S. Department of Energy. "Integrated Data Base Report." DOE/RW-006, Rev 12. December 1996.

U.S. Department of Energy. "Yucca Mountain Repository License Application," December 2007. <http://www.ocrwm.doe.gov/ym_repository/license/index.shtml#skiptop>.

U.S. Government Accountability Office. "Low-Level Radioactive Waste: Disposal Availability Adequate in the Short Term, but Oversight Needed to Identify Any Future Shortfalls." GAO-04-604. 2004. <http://www.gao.gov/new.items/d04604.pdf>.

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.

U.S. Nuclear Regulatory Commission, 10 CFR 61.55.

U.S. Nuclear Regulatory Commission, 10 CFR 61.7.

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. "Backgrounder on Radioactive Waste." April 12, 2007. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/ radwaste.html>.

U.S. Nuclear Regulatory Commission. "High-Level Waste". February 13, 2007. <http://www.nrc.gov/waste/high-level-waste.html>.

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>.

U.S. Nuclear Regulatory Commission. “Strategic Assessment of Low-Level Waste Regulatory Program.” SECY-07-0180, October 17, 2007.

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.

U.S. Nuclear Regulatory Commission. Memorandum and Order. CLI-08-01. January 15, 2008.

United Press International. “Energy Dept. OKs waste storage contracts.” May 21, 2008. <http://www.upi.com>.

United States Court of Federal Claims. “PG&E v. United States.” Case No. 04-75C. Final Decision, October 13, 2006.

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 l. 72, No. 1401. Monday, July 23, 2007/Notices). <http://www.ocrwm.doe.gov/transport/180c_comments/Overview_dated_01-17-2008_w-Answer_Matrix.pdf>.

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 Study 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 Study 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 within 60 miles of Orange County and 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.[639] 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 Study 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.

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[639] 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.[640] 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.[641]

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.[642] 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.[643] 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.[644]

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.

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640 Pacific Gas & Electric. “ISFSI Environmental Report, Amendment 1.” October 2002, pages 2.2-4.

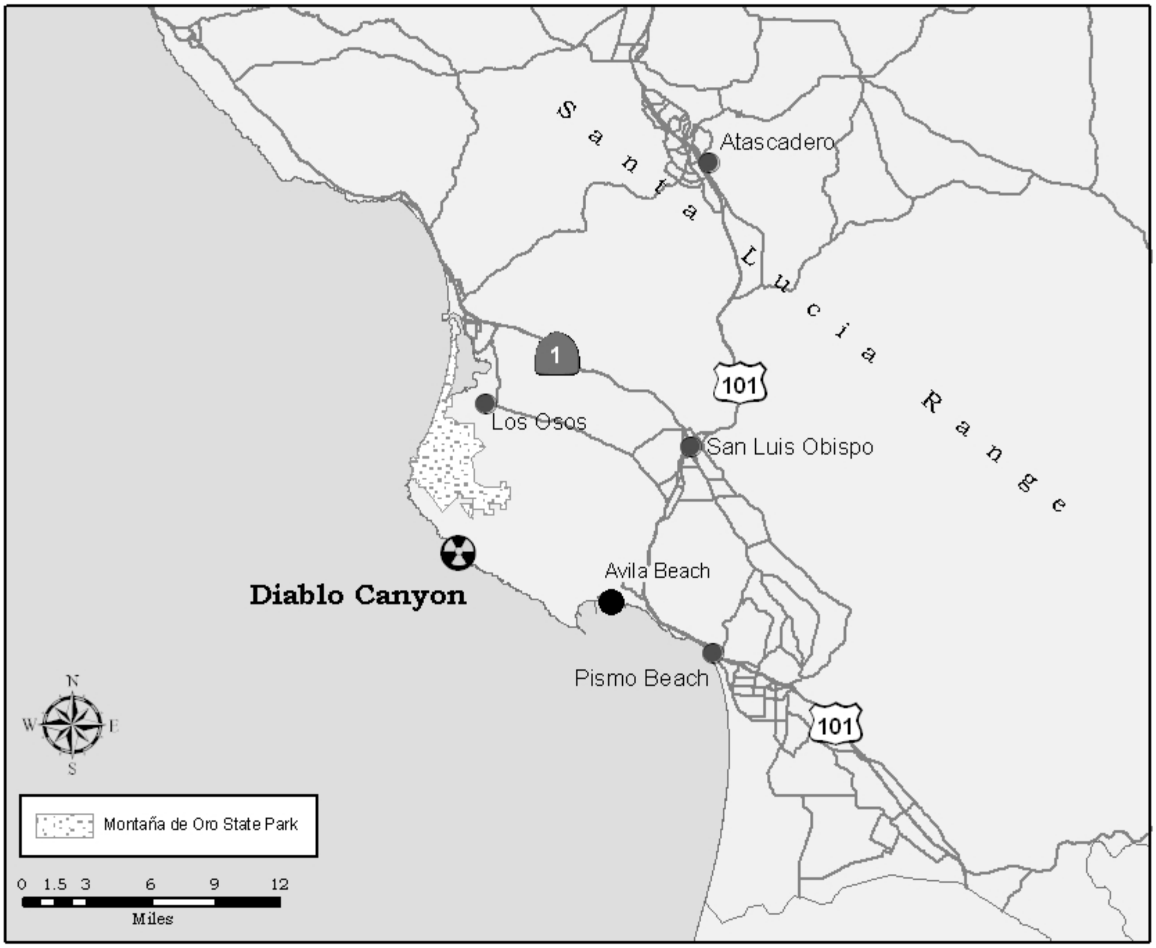
641 U.S. Census Bureau. “2006 data.” Accessed: March 26, 2008. <http://www.census.gov>.

642 Pacific Gas & Electric. “Steam Generator Replacement Project, Final Environmental Impact Report.” August 2005: ES-7.

643 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.

644 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.[645] Current real estate grants authorize SONGS to maintain a presence on Camp Pendleton until approximately 2024.[646]

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.[647] It is

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[645] The Marine Corps is an administrative unit under the Department of the Navy.

[646] Camp Pendleton. "Draft Integrated Natural Resource Management Plan." August 2005. Accessed: April 30, 2008. <http://www.pendleton.usmc.mil/base/environmental/inrmp.pdf>.

[647] 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.[648] The City of San Clemente, the nearest municipality, is located two miles north of SONGS and has a population of approximately 61,000.[649] The City of Oceanside, with a 2006 population of 165,803, lies outside Camp Pendleton approximately 20 miles south of SONGS.[650] There are also 900 housing units located approximately one mile northwest of SONGS in Camp Pendleton.[651]

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.[652] 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.[653] 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.[654] This has occurred at several decommissioned plants in the U.S. (see "Experiences with Land Use Following Decommissioning").

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648 City of San Diego. "Economic Development: Population." Accessed: June 16, 2008. <http://www.sandiego.gov/economic-development/glance/population.shtml>.

649 U.S. Census Bureau. "2006 data."

650 U.S. Census Bureau. "2006 data."

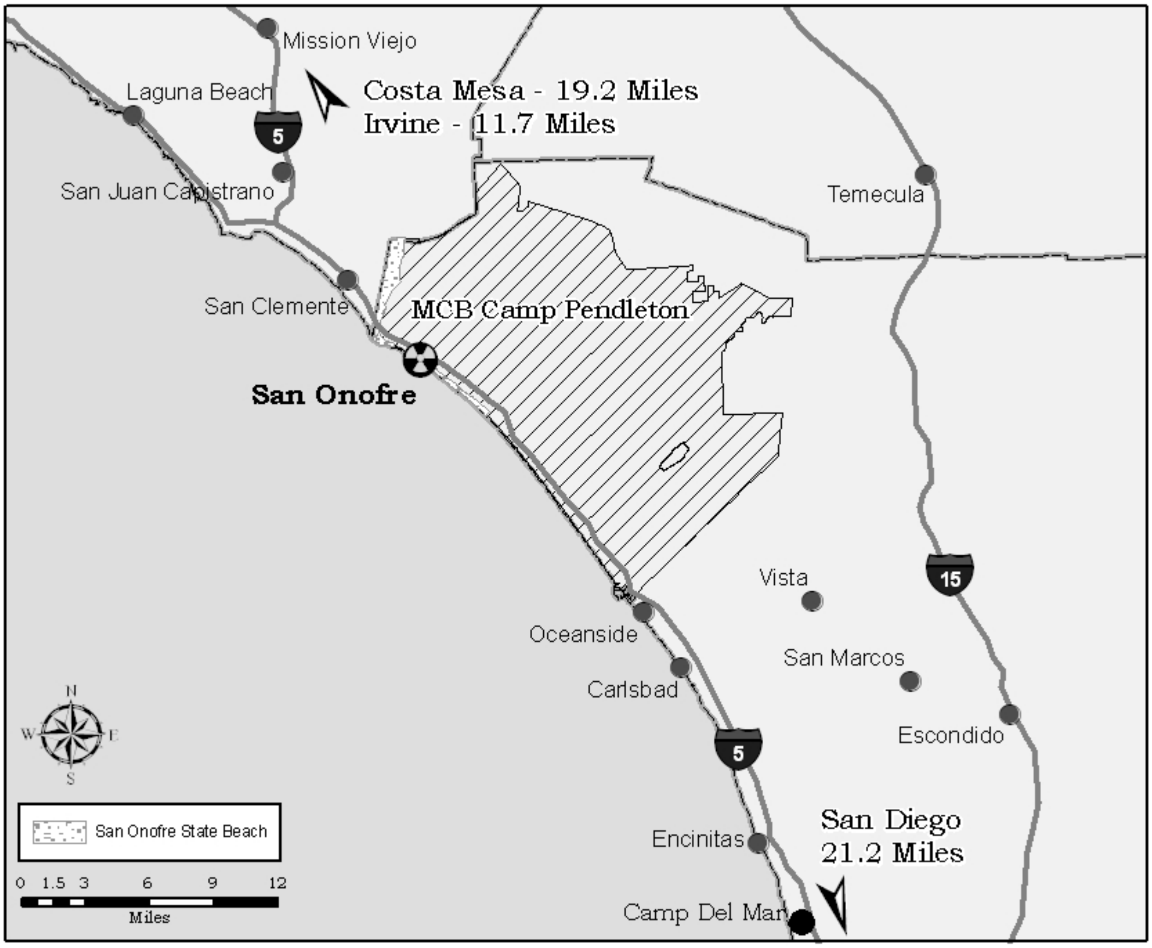
651 Camp Pendleton. "San Onofre Housing Community." Accessed: April 30, 2008. <http://www.cpp.usmc.mil/base/housing/san_onofre.asp>.

652 California Department of Parks and Recreation. "San Onofre State Beach Revised General Plan." June 1984.

653 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>.

654 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. In the case of SONGS, future land uses are less certain at this time.

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."[655]

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.[656] 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,[657] 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.[658] 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.[659] 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.[660] Camp Pendleton presumably would then have the option of leasing or selling the land to another party.

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[655] 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/>.

[656] 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.

[656] Pacific Gas & Electric, April 28, 2008: 4.1.

[657] U.S. Nuclear Regulatory Commission, 10 CFR 72.106.

[658] Pacific Gas & Electric, April 28, 2008: 4.1.

[659] California Department of Parks and Recreation. "San Onofre State Beach Revised General Plan." June 1984.

[660] 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:[661]

- 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.[662] 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.[663] 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.[664] The Transportation Corridor Agency has appealed the Coastal Commission's ruling to the U.S. Department of Commerce.[665] 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.

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[661] Camp Pendleton. "Draft Integrated Natural Resource Management Plan." August 2005. Accessed: April 30, 2008. <http://www.pendleton.usmc.mil/base/environmental/inrmp.pdf>.

[662] 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>.

[663] 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>.

[664] California Coastal Commission. October 2007.

[665] 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.[666] 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.[667] Clark and Allison found that within

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666 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.

667 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.

667 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."[668]

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."[669]

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.[670]

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.[671] 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 that nuclear power generation.[672] 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:

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668 Clark and Allison, 1999: 413.

669 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.

670 This issue is also discussed in Chapter 10.

671 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.

672 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."[673]

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."[674] The authors concluded that statistical analysis "provides a more conservative, statistically accurate estimation of property value loss."[675] 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.[676] 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.[677] 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.[678]

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

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673 Metz and Clark, 1997: 508-509.

674 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.

675 Simons and Saginor, 2006: 97.

676 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.

677 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.

678 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.[679] 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.[680] 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.[681] 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.[682] 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.[683] This would likely be the case if a transportation accident

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[679] U.S. Nuclear Regulatory Commission. "2007-2008 Information Digest." August 2007, page 121.

[680] Bassett Jr. 1996: 312.

[681] 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.

[682] Nevada Agency for Nuclear Project, 2002: 52.

[683] 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.[684]

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.[685] 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.[686]

In conclusion, the local economies in the areas surrounding Diablo Canyon and SONGS would be impacted if these areas were stigmatized or seen as riskier on account of 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.[687] 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.

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[684] Nevada Agency for Nuclear Project, 2002: 62.

[685] 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.

[686] 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.

[687] 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) *(percent of total)*	Travel Spending ($ Million) *(percent of total)*	Sales Tax Receipts ($ Million) *(percent of total)*
San Luis Obispo	16,610 *(10.6%)*	1,085 *(4%)*	29.7 *(11.8%)*
Orange	86,430 *(2.3%)*	8,307 *(4.7%)*	210.2 *(6.2%)*
San Diego	114,230 *(3.4%)*	10,556 *(5.2%)*	281.3 *(9.9%)*

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. In the case of Diablo Canyon, the plant site will likely be converted to primarily recreational use. In the case of SONGS, the plant site, which is located on military land, will presumably 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.

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 have the potential to overstate actual economic effects and are unreliable economic predictors, and 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.

Works Cited

Aspen Environmental Group. “Diablo Canyon Area Land Use Map.” April 2008.

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).

California Association of Governments. “San Orange County Transportation Infrastructure Improvement Project.” Environmental Impact Statement. December 2005.

California Coastal Commission. “2006 Updated Assessment and Strategy of the California Coastal Management Program.” January 2006. <http://www.coastal.ca.gov/fedcd/ccmp2006assessment.pdf>.

California Coastal Commission. “Staff Report and Recommendation on Consistency Certification.” <http://documents.coastal.ca.gov/reports/2007/10/Th19a-10-2007.pdf>.

California Coastal Conservancy. “Completing the California Coastal Trail.” January 2003.

California Coastal Conservancy. “Public Meeting Minutes.” January 17, 2008. <http://www.coastalconservancy.ca.gov/sccbb/0804bb/0804_January_Minutes.pdf>.

California Department of Parks and Recreation. “San Onofre State Beach Revised General Plan.” June 1984.

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>.

California Government Code. Section 11000-11019.9. <http://www.leginfo.ca.gov/cgi-bin/displaycode?section=gov&group=10001-11000&file=11000-11019.9>.

California Public Resources Code. Section 5096.400. <http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=05001-06000&file=5096.400>.

Camp Pendleton. “Camp Pendleton: In-Depth.” <http://www.pendleton.usmc.mil/impact/facilities.asp>.

Camp Pendleton. “Draft Integrated Natural Resource Management Plan.” August 2005. <http://www.pendleton.usmc.mil/base/environmental/inrmp.pdf>.

Camp Pendleton. “San Onofre Housing Community.” <http://www.cpp.usmc.mil/base/housing/san_onofre.asp>.

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).

Coastal Enterprises, Inc. “Maine Yankee Power Plant.” <http://www.ceimaine.org/content/view/12/24>.

Connecticut Yankee. "Haddam Neck Point, Haddam, Connecticut: Property Fact Sheet." <http://www.connyankee.com/_pdf/CY_Property_factsheet_F.pdf>.

Connecticut Yankee. "The Connecticut Yankee Atomic Power Plant." <http://www.connyankee.com/html/future_use.asp>.

County of San Luis Obispo. "San Luis Bay Area Plan (Coastal)." Revised, April 2007.

Electric Power Research Institute. "Maine Yankee Decommissioning Experience Report: Detailed Experiences." 1997-2004 , pages 1-2. Accessed: June 18, 2008.. <http://www.maineyankee.com/public/pdfs /epri/my%20epri%20report-2005.pdf>.

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.

Johnston, K. "A Push for More Access." *New Times San Luis Obispo*. <http://www.newtimesslo.com/index.php?p=showarticle&id=2574>.

King, P. "Economic Analysis of Beach Spending and the Recreational Benefits of Beaches in the City of San Clemente." <http://userwww.sfsu.edu/~pgking/ssanclemente%20final %20report.pdf>.

McKee, B. "The Future of Trestles." *Surfer Magazine*. <http://surfermag.com/features.oneworld/trestles/index.html>.

Metz, William C. and David Clark. "The Effect of Decisions About Spent Nuclear Fuel Storage on Residential Property Values." *Risk Analysis*. Volume 17, (1997).

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.

Nelsen, C. L. Pendleton and R. , L. Vaughn, R.. "A Socioeconomic Study of Surfers at Trestles Beach." <http://www.surfrider.org/surfecon/Trestles2007-WP1.pdf>.

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.

Pacific Gas & Electric. "PG&E's Response AB 1632 Study Report Supplemental Data Requests." Docket No. 07-AB-1632. April 28, 2008.

Pacific Gas & Electric. "PG&E's Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008.

Pacific Gas & Electric Company. "ISFSI Environmental Report, Amendment 1." October 2002.

Pacific Gas & Electric. Company, "Steam Generator Replacement Project, Final Environmental Impact Report." August 2005.

Sacramento Municipal Utility District. "Rancho Seco Nuclear Facility." <http://www.smud.org>.

San Luis Obispo County. "Advisory vote only on Diablo Canyon Lands -- San Luis Obispo County, Ballot Measure A." March 7, 2000. <http://www.smartvoter.org/2000/03/07/ca/slo/meas/>.

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.

Transportation Corridor Agencies . "The Toll Roads." <http://www.thetollroads.com/home/news_press_feb08.htm>.

Transportation Corridor Agencies. "TCA Response to Staff Report and Recommendation on Consistency Certification." Executive Summary. January 2008. <http://www.ftcsouth.com/home/pdf/Executive_Summary_TCA_Response_to_Coastal_Commission_staff_report.pdf>.

U.S. Census Bureau. "2006 data." <http://www.census.gov>.

U.S. Nuclear Regulatory Commission. "2007-2008 Information Digest." August 2007. <http://ww<w.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/v19/sr1350v19.pdf Accessed July 10http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/v19/sr1350v19.pdf Accessed July 10, 2008>.

U.S. Nuclear Regulatory Commission. "Code of Federal Regulations." 10 CFR 72.106.

U.S. Nuclear Regulatory Commission. "Code of Federal Regulations." Title 10, part 20 subpart E, and parts 50.75, 50.82, 51.53, and 51.95.

U.S. Nuclear Regulatory Commission. "Frequently Asked Questions About Reactor Decommissioning." April 17, 2007. <http://www.nrc.gov/about-nrc/regulatory/decommissioning/faq.html#1http://www.nrc.gov/about-nrc/regulatory/decommissioning/faq.html#1 Accessed July 10, 2008>.

CHAPTER 9: Power Generation Options

The California legislature, through Assembly Bill 32 (AB 32, Nunez, 2006), mandated greenhouse gas reductions statewide, 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."[688]

The primary ways to meet California's growing energy demand while lowering greenhouse gas emissions are energy efficiency, renewable resources, and distributed generation.[689] However, there are technical limits to the availability of renewable power sources, conservation, and energy efficiency, and all resources pose economic and environmental costs.

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 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 hazards from nuclear plant operation, 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

[688] California Energy Commission. "2007 Integrated Energy Policy Report." CEC-100-2007-008-CMF, page 35.

[689] 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.

distributed generation energy resources, including combined heat and power;[690] and third, with clean fossil-fueled generation resources and infrastructure improvement.[691] 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 (CO_2) than clean-burning natural gas plants emit.[692] 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.[693] The distinction between technical potential

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[690] 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.

[691] California Energy Commission. "2007 Integrated Energy Policy Report." Page 20.

[692] 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.

[693] 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.[694] 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.[695] 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, constrain the widespread replacement of fossil-fueled and nuclear plants with renewable power alternatives.[696]

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694 Demand-side resources are incentives, policies, and programs that reduce electricity demand.

695 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>.

696 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 Potential[697]

Resource	Technical Potential		Near-Term Economic Potential	
	MW	GWh	MW	GWh
Wind[698]	21,000-23,000[699]	61,000-66,0000	5,000	16,000
Solar Thermal[700]	1,000,000	2,700,000	450,000-800,000	1,000,000-2,000,000
Solar PV[701]	17,000,000	24,000,000	75,000	100,000
Geothermal[702]	3,000	17,000	1,500-2,500	10,000-15,000
Biomass[703]	2,000-5,000	15,000-35,000	N/A	N/A
Demand Side Resources – Energy Efficiency[704]	12,000-15,000	50,000-60,000	7,000-11,000	40,000-50,000
Demand Side Resources – Demand Response[705]	15,000	N/A	7,000	N/A
Demand Side Resources – Combined Heat and Power[706]	30,000	N/A	2,000-7,000	N/A

697 Also see Appendix 9A for a full discussion of the technical and economic potential of each resource.

698 California Energy Commission. "Strategic Value Analysis: Economics of Wind Energy in California." June 2005; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

699 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.

700 California Energy Commission. "California Solar Resources." April 2005; Black & Veatch. "RETI Phase 1A, Draft Report." March 2008

701 California Energy Commission. "California Solar Resources." April 2005.

702 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.

703 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.

704 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.

705 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. 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, PG&E ratepayers paid $34 per MWh for power from Diablo Canyon in 2007.[707]

The numbers presented below derive from a number of 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.[708, 709, 710] These values generally do not include the costs of transmission expansions that could be required to connect the plants to the transmission grid, and 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.

Electric generation technologies can be differentiated between capital intensive and fuel intensive resources.[711] 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.

Table 24 provides an illustrative example of this difference by showing the impact of capital cost and fuel price increases on the levelized cost of power from new nuclear plants, which are capital intensive, and from natural gas plants, which are fuel intensive. Doubling natural gas prices has roughly the same impact on natural gas power costs as doubling fixed capital costs has on new nuclear power costs––both experience a roughly 70 percent increase in levelized costs as a result.

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706 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.

707 Pacific Gas & Electric. "PG&E Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008, question F1.

708 California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007.

709 Weisser, Daniel. "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies." Energy 32. (2007), pages 1543–1559.

710 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.

711 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.

Table 23: Summary of New Power Costs by Technology (2007 dollars)

Resource	**Construction Cost, $/kW[712]**	**Levelized Cost, $/MWh[713]**
Biomass (cofired)[714]	$300 - $500	-$1 - $22
Natural Gas (Combined Cycle)[715]	$763 - $834	$36 - $97
Biomass (not cofired)[716]	$2,263 - $5,925	$51 - $150
Geothermal[717]	$2,988 - $5,000	$54 - $107
Wind (Class 5, onshore)[718]	$1,600 - $2,400	$49 - $128
Solar Thermal (several technologies)[719]	$3,600 - $6,446	$110 - $519

712 The construction cost estimates shown represent all-in costs, which include financing and interest costs.

713 The 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.

714 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008:5-9.

715 Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13. Accessed: June 14, 2008. <http://cbo.gov/ftpdocs/91xx/doc9133/05-02-Nuclear.pdf>; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 10, 18.

716 Energy Information Administration. "Biomass for Electricity Generation: Projections of Biomass Resource Availability at Different Price Levels, 2020." July 2002. Accessed: April 17, 2008. <http://www.eia.doe.gov/oiaf/analysispaper/biomass/pdf/tbl3.pdf>; 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.

717 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.

718 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.

719 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.

Resource	Construction Cost, $/kW[712]	Levelized Cost, $/MWh[713]
Solar PV[720]	$6,500 - $9,672	$201 - $705
Natural Gas (Small Simple Cycle)[721]	$846 - $1,053	$352 - $647

Table 24: Illustrative Example of Levelized Cost Impact from Doubling of Fuel Costs and Fixed Costs on Capital Intensive and Fuel Intensive Resources (2007$)[722]

	100% Increase in Fuel Costs	100% Increase in Fixed Costs
	Increase in Levelized Cost	
Advanced Nuclear (capital intensive)	11% - 25%	68% - 77%
Combined Cycle Gas (fuel intensive)	60% - 70%	21% - 35%

The cost of power from capital-intensive power sources, such as nuclear, 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. [723]

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

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720 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.

721 California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 10, 18.

722 Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13. Accessed: June 14, 2008. <http://cbo.gov/ftpdocs/91xx/doc9133/05-02-Nuclear.pdf>; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007, pages 7, 18.

723 Wiser, Ryan and Mark Bolinger. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007: 15.

improvements counterbalance the upward pressures of rising demand and supply cost increases.[724]

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.[725]

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.[726] Nuclear power and other capital-intensive technologies such as renewable energy are most competitive under a regime of low capital costs, high fuel costs, continued federal subsidies, and the presence of a greenhouse gas emissions cap.[727]

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724 Denholm, et al. January 2007: 96.

725 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.

726 Natural gas power plants have a significantly lower greenhouse gas emissions rate than coal plants, and are therefore less dependent on the outcome of potential greenhouse gas regulations.

727 Congressional Budget Office. May 2008: 13.

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 life cycles impacts of nuclear power and alternate power sources are discussed in Appendix B and summarized in Table 25.

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. The remainder of this section compares life cycle GHG emissions and land use impacts of various technologies. It then considers marine impacts from the use of once-through cooling at coastal power plants. Other impacts that are particular to just one or a few of the technologies are discussed in Appendix B.

Table 25: 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 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: Cadmiuim toxicity and carcinogenity 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 26.[728]

[728] Solar thermal emissions are not listed due to lack of life cycle data.

Table 26: Summary of CO_2 Emissions from Alternative Generation Technologies[729]

Generation Technology	Life cycle GHG Emissions ($g\ CO_2$-eq/kWh)	Major life cycle contributor of CO_2 emissions
Gas-fired[730]	400-600	Direct fuel combustion during operations (81% of total emissions)
Nuclear[731]	5-140 Likely range: 25-55	Uranium enrichment, plant construction, plant maintenance, and decommissioning
Wind[732]	10-150 Nationwide median: ~45 California median: ~65	Turbine production
Solar PV[733]	20-50	Panel production
Biomass[734] (non-cofiring)	45-120	Feedstock production and transportation, biomass burning
Geothermal[735]	0-40	Similar emissions throughout life cycle

729 Also see Appendix 9A for a full discussion of the carbon emission associated with each resource.

730 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>.

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

732 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>.

733 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.

734 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.[736] 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 27 provides a summary of direct land use impacts of the different technologies.[737]

Table 27: Direct Land Use Requirements for Alternative Generation Technologies[738]

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[739]	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

735 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>.

736 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>.

737 California Energy Commission. "2007 Environmental Performance Report." January 2008: 69.

738 California Energy Commission. "2007 Environmental Performance Report." January 2008.

739 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 27.[740] 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 27.

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.[741] 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 and larvae), fish, and in some cases larger marine animals, including 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.[742]

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.[743] 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 per year.[744]

Diablo Canyon and SONGS can withdraw up to 4.8 billion gallons of water per day. However, on account of differences in the plants' local marine environments, respective designs, and intake and discharge technologies, the impacts from the plants are quite different (Table 28).

The SWRCB estimates that Diablo Canyon entrains over 1.8 billion fish but impinges relatively few biological specimens (around 400 pounds, plus 1 large marine animal) on a yearly basis.[745] PG&E, in May 2008 comments to the SWRCB, questioned the validity of the impact assessments and expressed extreme doubt that the reported fish larval mortality would translate into any

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740 Gagnon, et al. 2000: 1267-1278.

741 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.

742 SWRCB, 3/2008; Tetra Tech, 2/2008; CEC-700-2005-013

743 CEC-700-2007-016SF

744 SWRCB, March 2008.

745 SWRCB, March 2008.

actual effects on adult fish populations.[746] 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 1.4 miles of shoreline intertidal and subtidal communities.[747]

The SWRCB estimates that SONGS annually entrains over 5.6 billion fish and impinges over 3.5 million fish (nearly 48,000 pounds).[748] The plant also impinges around 47 large marine animals per year. In fact, the SONGS once-through cooling system is responsible for 70 percent of California's total fish impingement and 82 percent of the tetrapod impingement.[749] 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.[750] Thermal impacts at SONGS are reportedly minor; however, turbidity (haziness caused by suspended solids) caused by the discharge has resulted in the loss of 179 acres of kelp forest.[751]

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.[752]

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).[753] 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 1 percent of statewide impingement and roughly 4 percent of statewide entrainment.[754] However, these impacts result in the loss of 10-30

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[746] California Energy Commission. "2005 Environmental Performance Report of California's Electrical System." June 2005 and Electric Power Research Institute. "Assessment of Once-Through Cooling System Impacts to California Coastal Fish and Fisheries." December 2007.

[747] 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..

[748] SWRCB, March 2008.

[749] SWRCB, March 2008: 16.

[750] 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>.

[751] 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.

[752] California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling." June 2005: 25.

[753] 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.

[754] SWRCB, March 2008: 15.

percent of larva for five near-shore species.[755] These impacts are discussed further in Appendix B and are summarized in Table 28.

Table 28: Water Intake and Once-through Cooling Impacts for California Coastal Power Plants

Power Plant	Seawater Intake[756]	Impingement/ Entrainment[757]	Habitat Impacts[758]
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	Alteration of rocky intertidal and shallow subtidal communities over 1.4 miles 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	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

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.[759] Similarly, the

[755] 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>.

[756] SWRCB, March 2008: 2-3.

[757] SWRCB, March 2008: 16.

[758] California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling and California's Coastal Power Plants." June 2005, page 25.

[759] EPRI, December 2007: 62.

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 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 (like Diablo Canyon) or near kelp forest (like SONGS) could also have significant impingement and entrainment impacts.[760]

In some cases, the nuclear plants and other plants have been required to mitigate impacts to coastal habitats.[761] 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.[762]

Entrainment losses can be partially mitigated by placing mesh screens over the intakes. Impingement losses can be mitigated by use of technologies that keep water intake velocities low enough for most fish to swim against the intake current. [763] 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.

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760 California Energy Commission. “2005 Environmental Performance Report.” June 2005, page 94.

761 California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling." June 2005: 25.

762 Southern California Edison. “Response to Scoping Document on Once-Through Cooling.” May 20, 2008.

763 Electric Power Research Institute (EPRI). “Assessment of Once-Through Cooling System Impacts to California Coastal Fish and Fisheries.” December 2007.

Table 29: Contribution of California Power Sources to their Local Economies[764]

Generation Technology		**Nuclear** [765]	**Oil/Gas**	**Wind**	**Solar Thermal**	**Geo-thermal**	**Biomass**
Percent of Projects Surveyed		*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[766]							
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*

Table 29 compares the economic benefits per unit capacity of power plants located in California to evaluate the socioeconomic benefits from different technologies.[767] 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

[764] 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.

[765] 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.

[766] 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.

[767] The information provided in Table 29 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.

capacity in terms of both installed and effective capacity.[768] 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.[769]

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. Table 30 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 30: Total Payments for 2,000 MW Effective Capacity (thousands of dollars)[770]

	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

Table 30 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.

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.

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768 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.

769 For example, 6,000 MW of wind capacity would need to be installed in order to obtain 2,000 MW of effective capacity.

770 California Energy Commission. "Socioeconomic survey of power plants in support of the Environmental Performance Report." 2005.

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.[771]

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 29, only 0.15 permanent jobs are created per megawatt of wind capacity.

On account of data limitations, Table 29 and Table 30 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 large-scale PV farms in San Luis Obispo County with a combined capacity of 800 MW.[772] 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.[773]

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[771] 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>.

[772] 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>.

[773] 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>.

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.[774] To begin to explore the possible economic and environmental impacts of this situation, the Study Team performed some preliminary production cost model simulations of the western electricity system in 2020, both with and without SONGS and Diablo Canyon.[775] For the simulations, the Study 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 Control Board in a study of the impact of regulating Once-Through-Cooling technology in California. [776, 777] 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.[778] For the case where the plants are removed, the lost nuclear capacity is replaced with renewable generation.[779] 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

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774 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.

775 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.

776 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>.

777 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>.

778 California Energy Commission. "Scenario Analyses Of California's Electricity System." June 2007: Case 1b aging plants retirement scenario for 2020.

779 California Energy Commission. "Scenario Analyses Of California's Electricity System." June 2007: Case 4a.

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.

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 underling 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. From a pure resource potential perspective, given adequate time California could license and build new renewable generation to replace the energy from Diablo Canyon and SONGS. However, since there are no large-scale renewable units with the same characteristics as baseload nuclear plants, current technologies would require support of some fossil fuel units to replace all the attributes of the nuclear plants. Operational and local transmission issues must be studied more carefully to identify which attributes of these plants would need to be replaced should the plants be shut down. In addition, the costs of renewable energy are uncertain, and a switch to renewable power resources away from nuclear power could result in an overall increase in the cost of electricity. Technological advances could ameliorate some or all of the potential cost and reliability concerns.

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 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 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 would 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 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.

Works Cited

Argonne National Laboratory. "Tritium (Hydrogen-3)." Human Health Fact Sheet, August 2005. <http://www.ead.anl.gov/pub/doc/tritium.pdf>.

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. < http://www.nrel.gov/pv/thin_film/docs/lce2006.pdf>.

Black & Veatch Corporation. "RETI Phase 1A Report." April 12, 2008. <http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-D.PDF>.

Borenstein, Severin. "The Market Value and Cost of Solar Photovoltaic Electricity." UC Energy Institute, January 2008.

Brattle Group. "Quantifying Demand Response Benefits in PJM." Report for PJM Interconnection, LLC and the Mid-Atlantic Distributed Resources Initiative. January 29, 2007. <http://www.energetics.com/madri/pdfs/BrattleGroupReport.pdf>.

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>.

California Biomass Collaborative. "California Biomass and Biofuels Production Potential." Prepared for the California Energy Commission. December 2007.

California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." CEC-700-2005-016. June 2005. <http://energy.ca.gov/2005publications/CEC-700-2005-016/CEC-700-2005-016.PDF>.

California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008. <http://energy.ca.gov/2007publications/CEC-700-2007-016/CEC-700-2007-016-SF.PDF>.

California Energy Commission. "2007 Integrated Energy Policy Report." CEC-100-2007-008-CMF.

California Energy Commission. "California Solar Resources." April 2005.

California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007.

California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling." June 2005.

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

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. <http://energy.ca.gov/2007_energypolicy/documents/index.html#06252807>.

California Energy Commission. "Strategic Value Analysis: Economics of Wind Energy in California." June 2005.

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. <http://www.energy.ca.gov/2007publications/CEC-500-2007-120/CEC-500-2007-120.PDF>.

California Senate Bill 1368.

Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008. <http://cbo.gov/ftpdocs/91xx/doc9133/05-02-Nuclear.pdf>.

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." American Solar Energy Society. January 2007.

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.

Electric Power Research Institute. "Assessment of Once-Through Cooling System Impacts to California Coastal Fish and Fisheries." December 2007.

Energy Information Administration. "Biomass for Electricity Generation: Projections of Biomass Resource Availability at Different Price Levels, 2020." July 2002. <http://www.eia.doe.gov/oiaf/analysispaper/biomass/pdf/tbl3.pdf>.

Gagnon, Luc, Camille Belanger, and Yohji Uchiyama. "Life-cycle assessment of electricity generation options: The status of research in year 2001." Energy Policy 30. (2002).

GeothermEx, Inc. "New Geothermal Site Identification and Qualification." Prepared for Public Interest Energy Research (PIER) Program, California Energy Commission. April 2004.

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. <http://www.swrcb.ca.gov/water_issues/programs/tmdl/docs/power_plant_cooling/reliability_study.pdf>.

Kagel, A. Bates, D. and Gawell, K. "A Guide to Geothermal Energy and the Environment." Geothermal Energy Association, Washington, D.C. April 2007. <www.geo-energy.org/publications/reports/ Environmental%20Guide.pdf>.

Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." Defense Technical Information Center, March 2003. <http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA415268&Location=U2&doc=GetTRDoc.pdf>.

Los Angeles Times. "San Onofre Nuclear Power Plant Feeling Regulatory Pressure." Reported by Elizabeth Douglas. August 19, 2008.

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. <http://fti.neep.wisc.edu/pdf/fdm1181.pdf>.

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.

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

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." 2006. <http://books.nap.edu/openbook.php?record_id=11666&page=1>.

Pacific Gas & Electric. "PG&E Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008.

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>.

Reed, Daniel C. et al. "Quantitative Assessment of Different Artificial Reef Designs in Mitigating Losses to Kelp Forest Fishes." *Bulletin of Marine Science*, 78(1):133, 2006. <http://www-rohan.sdsu.edu/~kelpbass/Reed_et_al_2006.pdf>.

Southern California Edison. "Response to Scoping Document on Once-Through Cooling." May 20, 2008.

State Water Resources Control Board, 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.

U.S. Nuclear Regulatory Commission. "Midcycle Performance Review and Inspection Plan – San Onofre Nuclear Generating Station." September 2, 2008.

Weisser, Daniel. "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies." Energy 32. (2007).

Western Governors' Association. "Clean and Diversified Energy Initiative: Geothermal Task Force Report." January 2006.

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.

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.[780] If granted, license renewals could keep Diablo Canyon and SONGS in operation until the early to mid 2040s (Table 31).

Table 31: 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[781]	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.[782] 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.[783] 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

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780 Current NRC regulations allow reactors licenses to be extended for one 20-year period. 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.

781 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.

782 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.

783 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.[784]

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).[785] 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

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784 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.

785 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.[786] 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).[787]

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.

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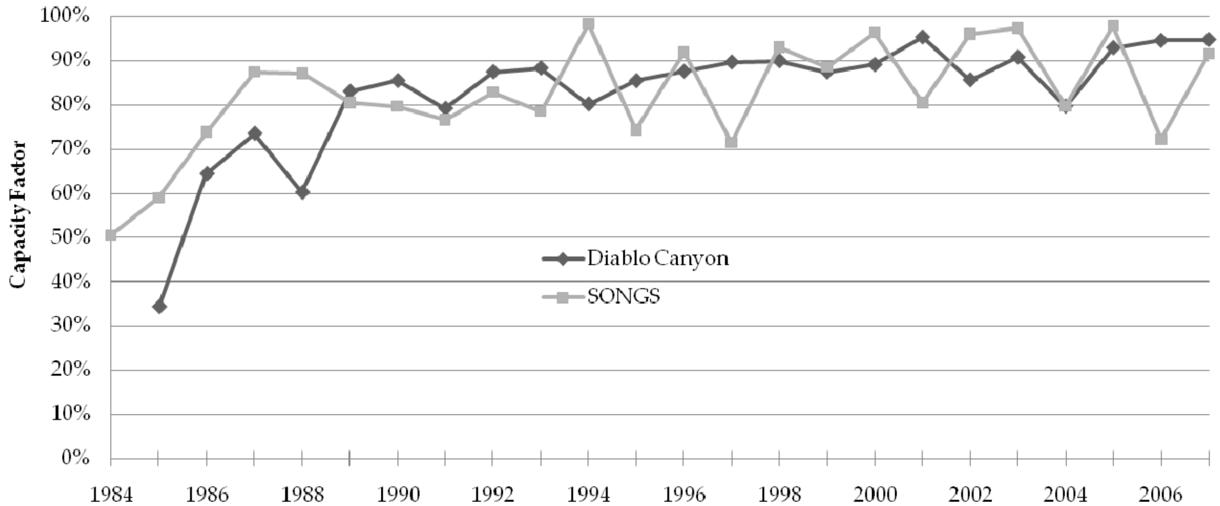
[786] The capacity factor is the amount of power produced as a percent of the total possible power production from the plant over a given time period.

[787] 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[788] (Table 32):

- **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.[789] 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.[790] To account for these outages, Scenario 2 shows a gradual decline in production beginning at the end of the initial operating license period.

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788 These scenarios were developed for illustrative purposes only. Actual future production may or may not be explained by the scenarios depicted.

789 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/nuclear04fnl.pdf>.

790 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 32: 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 33 below.

Figure 38: Estimated Electricity Production at Diablo Canyon

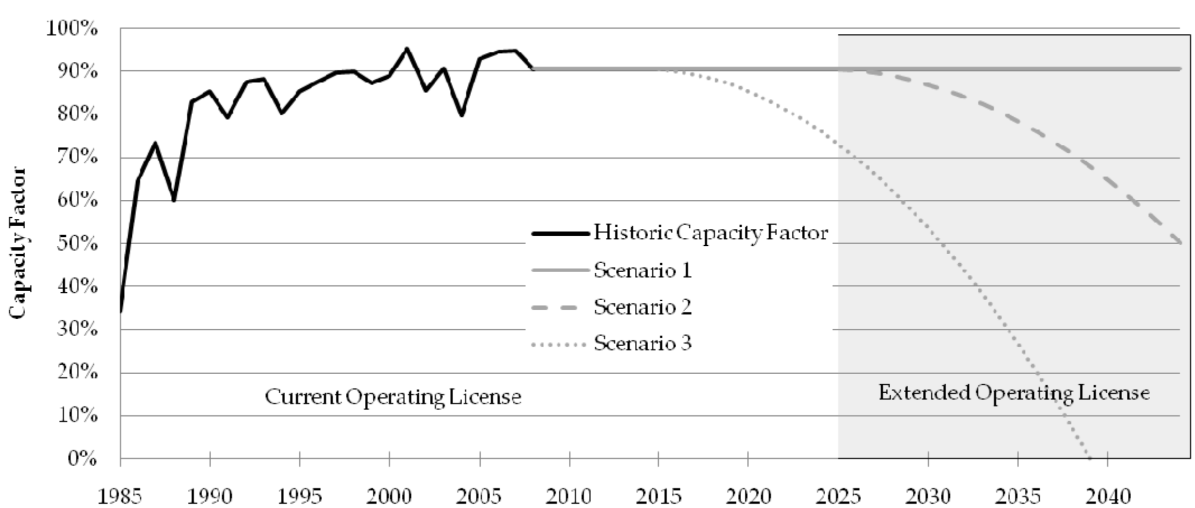

Figure 39: Estimated Electricity Production at SONGS

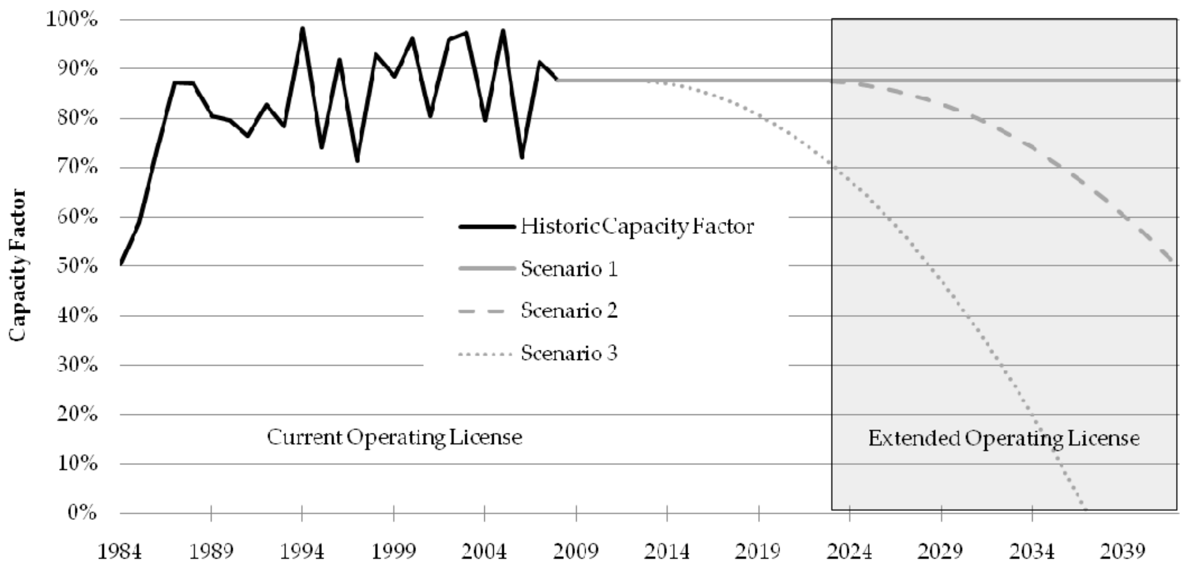

Table 33: Results of Scenario Analysis

		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.[791] 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.[792] 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.[793] 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.[794] Over the past 5 years these plants have produced between 20 and 35 percent California's power.[795] 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.[796] 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.[797]

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.

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[791] 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>.

[792] Further analysis is required to ensure that a replacement power portfolio would maintain local reliability throughout California.

[793] For a full discussion of this proposed legislation see "Once-through Cooling Retrofit Costs" below.

[794] California Independent System Operator. "Old Thermal Generation: Phase 1 Report." February 29, 2008. Accessed: May 16, 2008. <http://www.caiso.com/1f80/1f80a4a5568f0.pdf>.

[795] 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.

[796] SWRCB, March 2008: 4.

[797] 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.[798] 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, a comparable level of economic benefit would likely be transferred to the areas where replacement power was 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.[799] 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.[800]
- In 2006, SONGS paid $4.85 million in property taxes to San Diego County.[801] This accounts for just one-tenth of one percent of San Diego County's total property tax levy.[802]

Estimates of future property tax payments are shown in Table 34.

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[798] 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.

[799] Pacific Gas & Electric. February 27, 2008.

[800] NEI, 2004.

[801] 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.

[802] San Diego County Treasurer-Tax Collector. "Property Taxes." Accessed: April 10, 2008. <http://www.sdtreastax.com/pt_general.html>.

Table 34: Estimated Future Property Tax Payments[803]

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.[804] PG&E reported that 94 percent of the Diablo Canyon workforce resides in San Luis Obispo County.[805] 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.[806]

SONGS employed 2,043 people in 2007.[807] 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.[808,809,810,811] Unlike Diablo Canyon, SONGS is located in a broad urban area and has employees living in several counties. SCE did not provide information on its employees based on which county they live in, therefore, it is difficult to determine SONGS' contribution to employment and expenditures within each county.[812]

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

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803 Pacific Gas & Electric. February 27, 2008: K1.

804 Additional workers may be hired for refueling and maintenance outages.

805 Pacific Gas & Electric. February 27, 2008: K2.

806 Pacific Gas & Electric. February 27, 2008: K3.

807 Southern California Edison. March 21, 2008: K1.

808 Southern California Edison. March 21, 2008: K3.

809 San Diego County Treasurer-Tax Collector. "Property Taxes."

810 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>.

811 San Diego Housing Federation. "What is area median income." 2007. Accessed: April 30, 2008. <http://www.housingsandiego.org/about_definition.php>.

812 Southern California Edison. March 21, 2008: K3.

clear because the presence of a nuclear facility is associated with economic benefits, such as 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.[813] 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.[814] 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.[815] Their results also showed that the older the reactor, the larger the negative impact on property values.[816]

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.[817] 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.[818]

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

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813 Folland, Sherman and Robbin Hough. "Externalities of Nuclear Power Plants: Further Evidence." *Journal of Regional Science.* Volume 40 No. 4. 2000, pages 735-753.

814 Folland and Hough, 2000: 737.

815 Folland and Hough, 2000: 749.

816 Folland and Hough, 2000: 747.

817 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.

818 Clark and Nieves, 1994: 235-253.

with a nuclear facility may have changed. In addition, the relatively short time-period 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.[819] They found that within this distance, being closer to the plant is associated with an increase in property values.[820] 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.[821]

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.[822]

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819 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.

820 Clark, et al. 1997: 496-519.

821 Clark, et al. 1997: 509.

822 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.[823] 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. However, these adverse impacts may not materialize immediately upon plant closure but would more likely 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 even less certain.

Economic impacts would also depend on how the plant sites are used once the plants are decommissioned. As discussed in Chapter 8, according to current plans, the Diablo Canyon property will not be redeveloped as a commercial or industrial facility but will be used for habitat preservation, sustainable agriculture, and public use. These uses carry certain economic benefits that would need to be studied. It is unclear at the present time how the SONGS property will be used. If the SONGS site is developed into a facility with comparable employment, income, or other benefits, net economic impacts to the region from closing the plant could be neutral or even positive. 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. Therefore, in the short term, closure of either plant would likely have a negative impact on the local economy.

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.[824] 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

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[823] Clark and Nieves, 1994: 235-253.

[824] 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.

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, once the Diablo Canyon land is redeveloped for open space, agriculture, and public use, the county will accrue economic benefits associated with these activities 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.[825] 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).[826] (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.

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[825] 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>.

[826] 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.

Once-Through Cooling Retrofit Costs

Diablo Canyon and SONGS currently use once-through cooling to cool their reactors. 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 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.[827] 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.[828] 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.[829] The EPA subsequently suspended its regulations and 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 draft resolution requiring existing power plants to fully comply (or work toward full compliance) with federal and state water regulations, including EPA regulations, as a condition for receiving land lease

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[827] 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.

[828] 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>.

[829] See MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007.

extensions or amendments.[830] The draft 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. [831]

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.[832] 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.[833] 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.[834]

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

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[830] California State Lands Commission. "Resolution by the California State Lands Commission Regarding Once-through Cooling in California Power Plants." Adopted April 20, 2006.

[831] In response to a petition from the owners of coastal power plants including 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.

[832] SWRCB, March 2008.

[833] SWRCB, March 2008.

[834] 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.

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. 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.[835,836]

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."[837]

Electric Power Research Institute[838]

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,[839] water and wastewater discharge and/or disposal, increased noise, visual impacts from taller cooling towers, temporary construction-

835 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.

836 See MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

837 California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008.

838 Electric Power Research Institute (EPRI). "Issues Analysis of Retrofitting Once-Through Cooled Plants with Closed-Cycle Cooling: California Coastal Plants." October 2007.

839 Drift refers to liquid water droplets entrained in the tower exit plume and released to the atmosphere.

related impacts, intake losses,[840] solid waste from accumulation of suspended solids in cooling 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.[841]

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.[842] 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.[843] In addition, Tetra Tech found that retrofitting would require the relocation of several support facilities including maintenance facilities, warehouses, and employee parking.[844] Because both units share a common water intake structure, retrofit would require both units to be offline concurrently for eight months or more.[845]

At SONGS, the study recommended installation of two water cooling complexes each with six plume-abated towers.[846] Retrofitting SONGS' once-through cooling system would also require an eight month outage. However, the study found that the configuration of SONGS may enable

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840 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.

841 Tetra Tech. "California's Coastal Power Plants: Alternative Cooling System Analysis." Prepared for the California Ocean Protection Council. February 2008.

842 Tetra Tech, 2008: 7C-1.

843 Tetra Tech, 2008: 7C-11, 12.

844 Tetra Tech, 2008: 7C-1.

845 Tetra Tech, 2008: 7C-2.

846 Tetra Tech, 2008: 7N-1.

staggered retrofit, causing only one unit to be offline at a time.[847] The installation and operation 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.[848] 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.[849]

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.[850] 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.[851] 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. Additionally, the change in quantity and characteristics of effluent discharge could require amended NPDES permits (if required at all).

In comments regarding the Tetra Tech report, both PG&E and SCE responded that retrofit is not feasible.[852,853] 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.[854] 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

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847 Tetra Tech, 2008: 7N-1.

848 Tetra Tech, 2008: 7C-1, 7N-1.

849 Land area restrictions at Diablo Canyon are the main cause of the difference in cost between the two plants.

850 Tetra Tech, 2008: 7C-28, 7N-30.

851 Tetra Tech, 2008: 7C-26, 7N-31.

852 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>.

853 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>.

854 Pacific Gas & Electric. May 20, 2008: 44.

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.[855]

Others

PG&E commissioned a study 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.[856] 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."[857]

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).[858]

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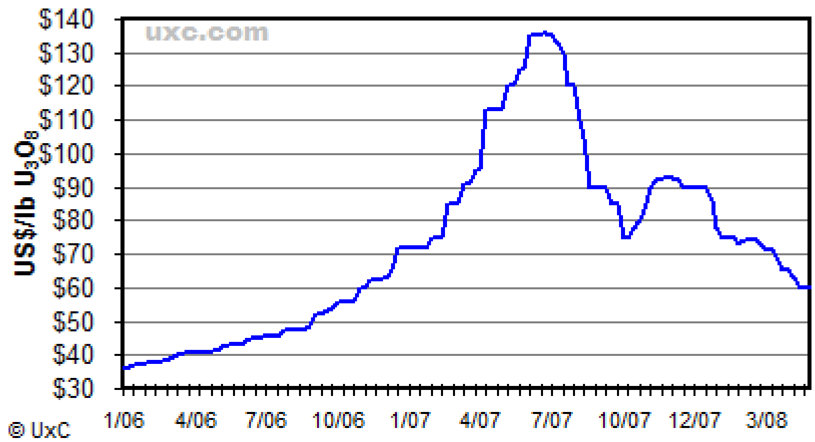
855 Pacific Gas & Electric. May 20, 2008: 55.

856 California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling and California's Coastal Power Plants." June 2005.

857 & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

858 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 2008[859]



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.[860] 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.[861] 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.[862] 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.[863]

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859 Ux Consulting Company, LLC. "Ux U3O8 Prices."

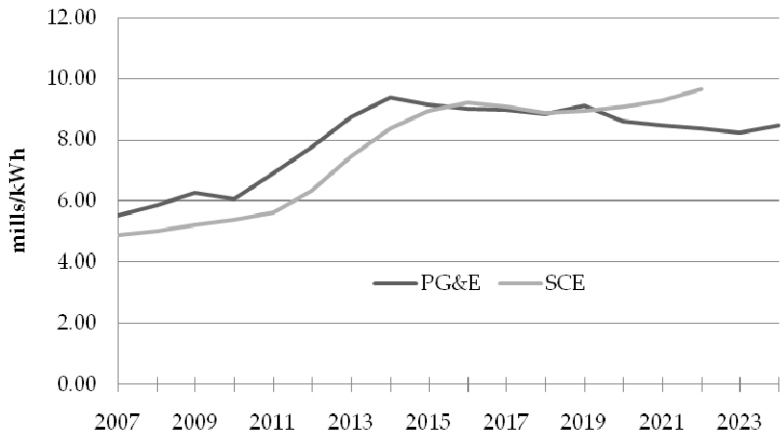
860 Worldwide, only 20 percent of uranium is traded through the spot market. World Nuclear Association. "Uranium Markets." March 2008. Accessed: May 12, 2008. <http://world-nuclear.org/info/inf22.html>.

861 Pacific Gas & Electric. February 27, 2008: F1; Southern California Edison. March 7, 2008: F1 and Attachment A.

862 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/>.

863 Pacific Gas & Electric. February 27, 2008: F1.

Figure 41: Utility Nuclear Fuel Price Predictions[864]



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.[865] The NRC also proposed a rulemaking to amend 10 CFR Part 73 requirements for physical protection of the nation's nuclear plants.[866]

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.[867] The NRC received 48 comments on the proposed rules during the comment period, which closed in March 2007.[868] Among them, several intervenors noted that the proposed requirements do not include any provisions addressing the threat of an air-based suicide

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864 Pacific Gas & Electric. "PG&E 2008 DR Responses." Question F1; Southern California Edison. "SCE 2008 DR Response." Attachment A.

865 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>.

866 Federal Register. "RIN 3150-AG63." Vol. 71, No. 207. October 26, 2006, pages 62666-62667. <www.gpoaccess.gov>.

867 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>.

868 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.[869] No date for the final ruling has been released, though the ruling is expected by the end of 2008.[870]

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.[871]

Given current and expected NRC security requirements, spending for security is likely to remain a small portion of overall nuclear power costs.[872] PG&E and SCE estimate that they will spend $28 million and $36.5 million, respectively, for security at the nuclear plants in 2008.[873] For PG&E this represents just 4 percent of the overall Diablo Canyon revenue requirement.[874]

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. Unfortunately, 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 any 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 the costs should remain comparable to current levels with relatively minor increases due to higher nuclear fuel costs and potentially stricter security requirements. However, degradation of major components or extended outages could result in

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869 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.

870 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.

871 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>.

872 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.

873 Pacific Gas & Electric. February 27, 2008: J1; Southern California Edison. March 21, 2008: J1.

874 Pacific Gas & Electric. February 27, 2008: F1, J1; Southern California Edison. March 21, 2008: F1, J1.

much higher costs. In addition, the plants may be required to retrofit their cooling systems prior to a license renewal. If feasible, this is expected to cost a minimum of $2.6 billion at SONGS and $3.0 billion at Diablo Canyon.

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. Given current economic conditions, 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 or all of the loss 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 by 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.

Works Cited

American Public Power Association. “Workforce Planning for Public Power Utilities: Ensuring Resources to Meet Projected Needs.” 2005.

California Energy Commission. "Issues and Environmental Impacts Associated with Once-Through Cooling and California’s Coastal Power Plants." June 2005.

California Energy Commission. “2007 Environmental Performance Report of California’s Electrical Generation System.” January 2008.

California Energy Commission. “2007 Net System Power Report.” CEC-200-2008-002-CMF. April 2008. <http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>.

California Energy Commission. “Comparative Cost of California Central Station Electricity.”

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

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.

California Independent System Operator. “Old Thermal Generation: Phase 1 Report.” February 29, 2008. <http://www.caiso.com/1f80/1f80a4a5568f0.pdf>.

California State Lands Commission. “Resolution by the California State Lands Commission Regarding Once-through Cooling in California Power Plants.” Adopted April 20, 2006.

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).

Clark, David, Lisa Michelbrink, Tim Allison, and William Metz. “Nuclear Power Plants and Residential Housing Prices.” *Growth and Change*, Volume 28. (Fall 1997).

Congressional Budget Office. “Nuclear Power’s Role in Generating Electricity.” May 2008. <http://cbo.gov/>.

Electric Power Research Institute. “Issues Analysis of Retrofitting Once-Through Cooled Plants with Closed-Cycle Cooling: California Coastal Plants.” October 2007.

Folland, Sherman and Robbin Hough. “Externalities of Nuclear Power Plants: Further Evidence.” *Journal of Regional Science*, Volume 40 No. 4. (2000).

Frieman, Jack and Barry Diskin. “Nuclear Waste Disposal: A Taxing Real Estate Issue.” *Real Estate Issues* Summer 2006.

Gamble, H.B. and R.H. Downing. “Effects of nuclear power plant on residential property values.” *Journal of Regional Science*, Vol 22.

Lochbaum, David. “U.S. Nuclear Plants in the 21st Century: The Risk of a Lifetime.” *Union of Concerned Scientists*. May 2004. <http://www.ucsusa.org/assets/documents/clean_energy /nuclear04fnl.pdf>.

Nelson, Jon P. “Three Mile Island and Residential Property Values: Empirical Analysis and Policy Implications.” Land Economics, Vol 57 No 3. August 1981.

Nuclear Energy Institute. “Economic Benefits of Diablo Canyon Power Station, An Economic Impact Study by the Nuclear Energy Institute.” 2004.

Nuclear Energy Institute. “Nuclear Energy Industry Initiatives Target Looming Shortage of Skilled Workers.” January 2007. <http://www.nei.org/filefolder/nuclear_energy_industry _initiatives_target_looming _shortage_of_workers_0107.pdf>.

Orange County. “2008 Orange County Community Indicators.” March 2008. <http://egov.ocgov.com/vgnfiles/ocgov/OCGOVPortal/docs/CIR2008.pdf>.

Pacific Gas & Electric. " PG&E Responses to CEC Nuclear Power Plant Data Requests." Docket No. 06-IEP-1N. April 5, 2007.

Pacific Gas & Electric. " PG&E Response to AB 1632 Study Report Data Requests." Docket No. 07-AB-1632. February 27, 2008.

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.sh tml>.

Pacific Gas & Electric. “Response to Scoping Document on Once-Through Cooling.” May 20, 2008. <http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316 _may08/comments/ mark_krause.pdf>.

Pacific Gas & Electric. “Testimony in 2007 General Rate Case.” A.05-12-002 Exhibit 3.

Pilgrim Watch. “RE: RIN 3150-AG63 - Power Reactor Security Requirements.” February 22, 2007.

San Diego County Treasurer-Tax Collector. “Property Taxes.” <http://www.sdtreastax.com/pt_general.html>.

San Diego Housing Federation. “Affordable Housing.” 2007. <http://www.housingsandiego.org/about_definition.php>.

Southern California Edison. " Data Request Set CEC 2007 IEPR-PV-SCE-01." 2007 IEPR 06-IEP 1I. March 28, 2007.

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.

Southern California Edison. "2009 GRC Testimony Part 2." Volume 2. A.07-11-011.

Southern California Edison. "Response to Scoping Document on Once-Through Cooling." May 20, 2008. <http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316_may08/comments/michael_hertel.pdf>.

State Water Resources Control Board, 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.

State Water Resources Control Board. "Scoping Document: Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling." March 2008.

Stiles-Shell, Lisa, Nuclear Energy Institute. "2015: Do You Know Where Your Work Force Is?" Speech, May 19, 2006. <http://www.nei.org/newsandevents/speechesandtestimony/2006/assemblystilesshellextended/>.

Tetra Tech. "California's Coastal Power Plants: Alternative Cooling System Analysis." Prepared for the California Ocean Protection Council. February 2008.

U.S. Energy Information Administration. "U.S. Nuclear Reactors." <http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html>.

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. <http://a257.g.akamaitech.net/7/257/2422/06jun20041800/edocket.access.gpo.gov/2004/pdf/04-4130.pdf>.

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.

U.S. Nuclear Regulatory Commission. "Maintaining a Competent and Dedicated Workforce." Speech by Peter B. Lyons, NRC Commissioner. May 1, 2008.

U.S. Nuclear Regulatory Commission. "NRC Approves Final Rule Amending Security Requirements." January 29, 2007. <http://www.nrc.gov/reading-rm/doc-collections/news/2007/07-012.html>.

U.S. Nuclear Regulatory Commission. "Physical Protection Rulemaking." January 2, 2008. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-spotlight/physical-protection.html>.

U.S. Nuclear Regulatory Commission. "Power Reactor Security Requirements Docket." NRC-2008-0019. <http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d =NRC-2006-0016>.

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.

U.S. Nuclear Regulatory Commission. "RIN 3150-AG63." *Federal Register.* Volume 71, No. 207. October 26, 2006. <http://www.gpoaccess.gov>.

U.S. Nuclear Regulatory Commission. "Security Spotlight." January 2, 2008. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-spotlight/index.html>.

U.S. Nuclear Regulatory Commission. "Testimony by Dale E. Klein, Chairman." March 28, 2007.

U.S. Nuclear Regulatory Commission, Office of the Inspector General. "Audit of NRC's License Renewal Program." OIG-07-A-15. September 6, 2007.

Ux Consulting Company, LLC. "Ux U3O8 Prices." <http://www.uxc.com>.

World Nuclear Association. "Uranium Markets." March 2008. <http://world-nuclear.org/info/inf22.html>.

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.