The Fukushima Daiichi accident and implications for policy and safety in the United States

Presentation to the California Energy Commission
July 26, 2011
Arjun Makhijani, Ph.D.
President, Institute for Energy and Environmental Research
www.ieer.org
arjun@ieer.org
301-270-5500

Overview

1. Fukushima should end complacency about safety: severe accidents are not as rare as assumed in theory.
2. 100 percent functional failure of Fukushima Mark I vent system.
3. Zirconium: a poor choice for fuel rod material from a safety viewpoint.
4. Spent fuel pool accident mechanisms more varied than NRC assumes.
5. Emergency management assumptions are hopelessly out of sync with Fukushima reality.
6. Fukushima raises grave decommissioning issues.
7. $12 billion liability limit is too low.
8. NRC is often reluctant to impose even reasonable costs for safety.
9. Federal government is not doing all that it reasonably should.
10. States should have the right to impose higher safety standards.

Fukushima Daiichi, Nov. 15, 2009

Satellite imagery courtesy of GeoEye/EyeQ

Vermont Yankee Nuclear Power Station

Courtesy of the U.S. Nuclear Regulatory Commission (http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1415/v19n1/sr1415v19n1.pdf, page 21)

Diablo Canyon Power Plant (NRC photo)

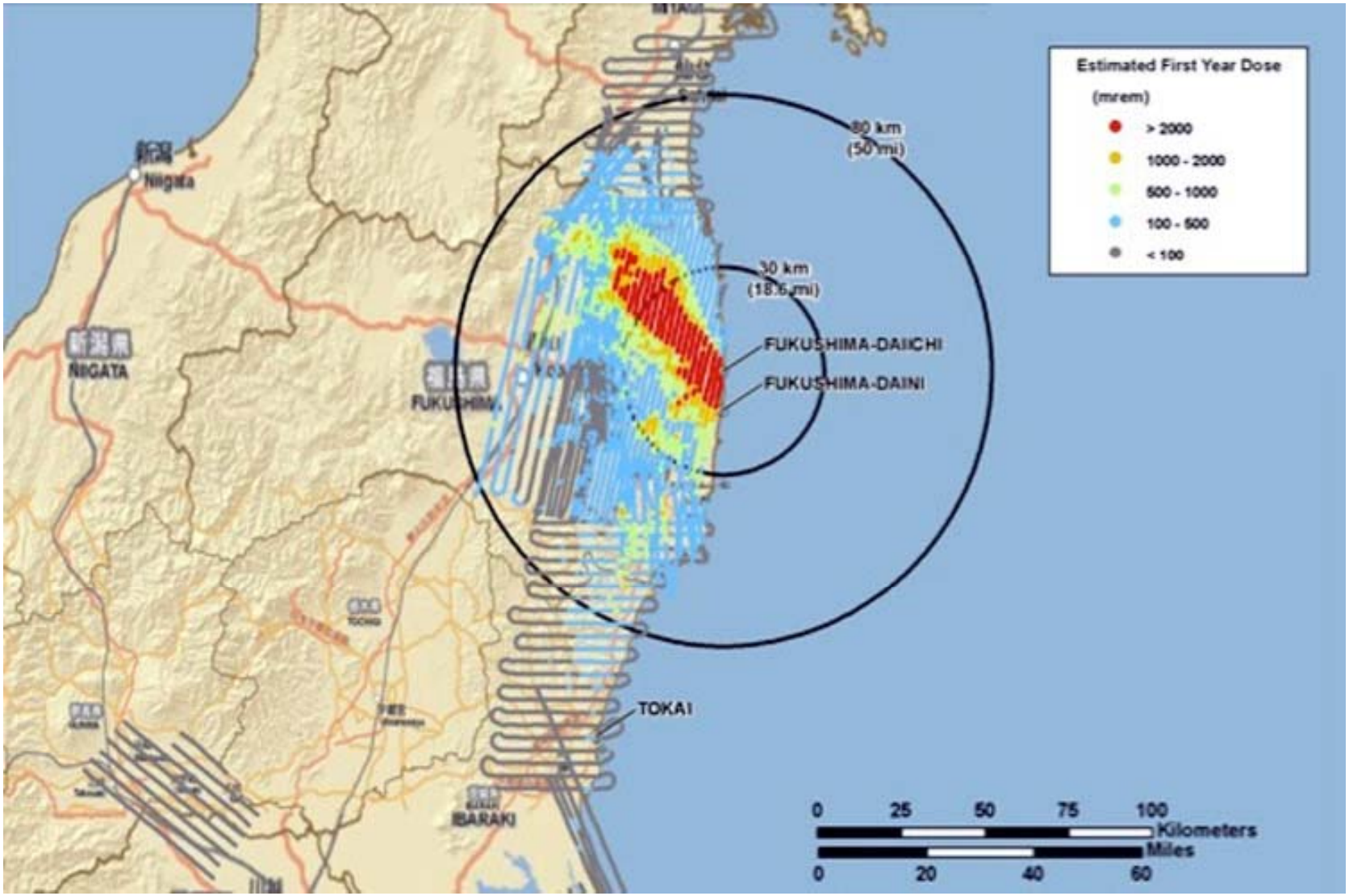
Fukushima Daiichi - March 18, 2011

Satellite imagery courtesy of GeoEye/EyeQ

The record

- Three Mile Island – partial core meltdown, but no severe offsite hot spots
- Chernobyl – severe 10-day fire, 1,000 square-mile exclusion zone, contaminated for generations. Attitude in the West – a poor design in a Soviet dictatorship.
- Fukushima: by mid-April, contaminated zone 1,000 km2 (> 1000 mrem dose in Year 1) to 3,000 km2 (>100 mrem dose in Year 1). Chernobyl exclusion zone: about 2,800 km2. Like Chernobyl, hot spots occur much farther.
- Fukushima: lofting of plume not so great, but ocean contamination severe in the vicinity.
- One in every 100 light water reactors has had a core meltdown (full or partial) before 40 years are up.
- Three reactors plus possibly (probably?) one spent fuel pool (Unit 4) have had serious releases
- Much more grave than in theory. One severe reactor accident with substantial releases and radiation doses every five to ten years for a few hundred operating reactors.

DOE Year 1 dose map (external plus re-suspension dose; ingestion dose excluded)



Fukushima fallout area and area needed for wind energy

Facility	Area	Comments
Wind land area per MW typical. For actual footprint.	0.6 hectares	Less on flat area, more in hilly areas. Footprint = roads, towers, electrical buildings. Wind farm area ~20x footprint but 95% of the land can be used.
Area of Fukushima fallout	1,000 km2 (>1,000 mrem in year 1) to 3,000 km2 (>100 mrem in year 1) or 100,000 to 300,000 hectares	Rough numbers from DOE map. Outdoors external and re-suspension inhalation dose; ingestion not included. Soil consumption by children is sometimes substantial (several hundred mg/day)
Wind footprint area to	~160,000 hectares	Nuclear capacity factor =

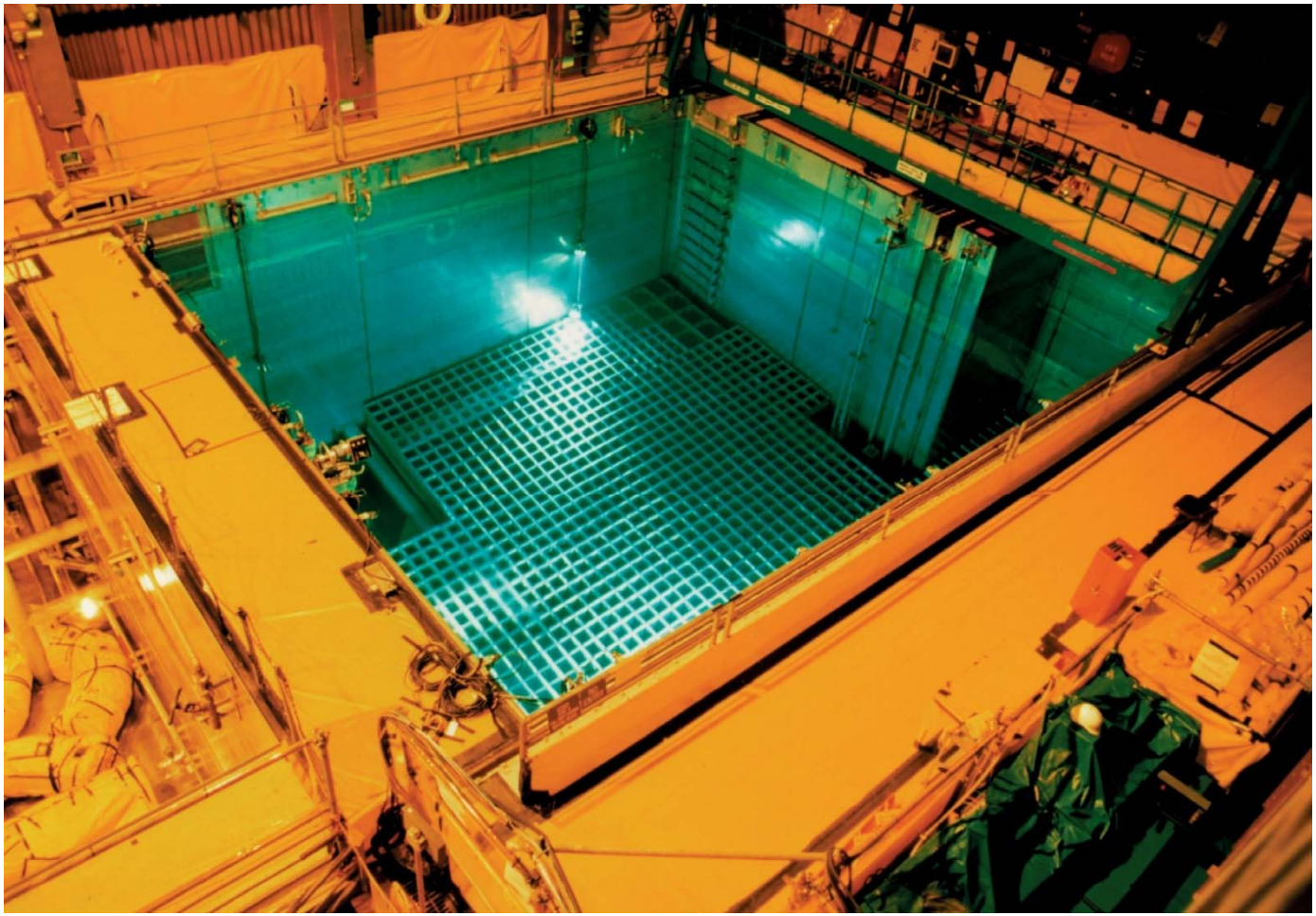
Hydrogen explosions

- Hardened vents were supposed to prevent accumulation of hydrogen.
- Fukushima: Japan installed vents similar to US design.
- Between prohibitively high radiation levels and lack of power (and some confusion apparently), there was a complete functional failure of the venting system – i.e., whether partial venting occurred or not, there were four hydrogen explosions out of four reactors/pools in crisis.
- Issue of the problem of valve requiring power and station black-out was raised at the time the backfitting was discussed.
- Task Force report did not discuss regulatory lessons from decision to use vulnerable design.
- Vent installation was voluntary! Mark I: all 23 installed. Mark II: only 3 out of 8 installed.

Zircaloy: A common vulnerability

- All four core meltdowns have involved exothermic steam reaction with zirconium, the main metal (>95%) in zircaloy fuel rods (TMI plus Units 1, 2, and 3 at Fukushima Daiichi).
- Ditto: All four hydrogen explosions.
- All LWRs have zircaloy fuel rods.
- Problem was known early on. In fact, one of Westinghouse's leading engineers, Earl Gulbransen pointed it out in 1975 (when at U of Pittsburgh); noted that there was no alternative material. Warning generated controversy but no serious action.
- None plan to replace it forthcoming after four hydrogen explosions (five, including contained TMI hydrogen explosion).

Spent fuel pool (NRC photo)



Spent fuel accident issues

- NUREG-1353: Fires only – assume instant loss of all water, hence no steam and no hydrogen explosion scenario.
- Fukushima: Four pools heated significantly; one or more lost coolant (via boiling?), and one may have had hydrogen generation sufficient to cause an explosion (Unit 4, reactor defueled, source of hydrogen not clear).
- Fukushima common wet pool separate from reactors for aged fuel (more than 19 months): apparently zero releases. U.S. reactors do not have comparable pools.
- Fukushima dry storage: apparently zero releases.
- U.S. allows dense storage: average 3,000 fuel assemblies. Fukushima total for all for pools: 2,724 assemblies (including the reactor core in Unit 4).
- NRC has ignored National Academies conclusion that dry storage of all aged spent fuel is safer in case of terrorist attack.
- Dry storage cost is very modest. 0.02 cents per kWh approximately. Maybe twice that for hardened dry storage.

PRA example: Containment failure self assessment (NUREG/CR-6906, 2006)

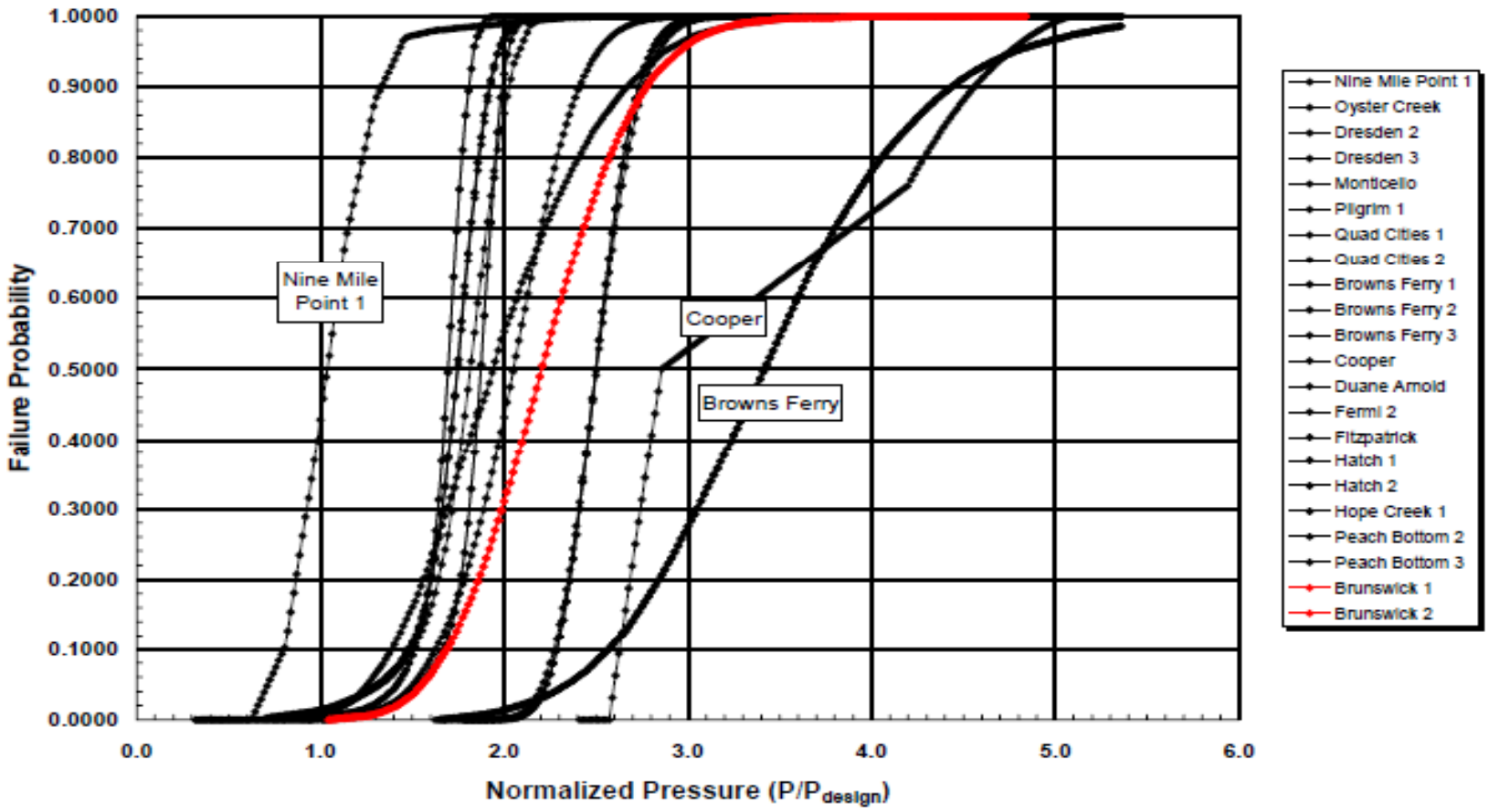


Figure 19 IPE Fragility Curves for BWR Mark I

Probability Risk Assessment (PRA) – containment failure example, cont'd.

- Large variability between evaluations for the similar design
- One reactor (Nine Mile Point 1) estimated failure at below design pressure (but still operating)!
- Causes: differences in design, but also: different definitions of failure, failure modes considered, calculation methods, and methods of incorporating uncertainty.
- PRA is a useful tool for frequent events where there are ample data and well understood models, but as a practical means to assess rare (hence data-poor), complex events with potentially catastrophic outcomes it is more a pacifier than a robust scientific tool in the service of public safety.

Emergency management

- Worldwide economic damage from Fukushima, including industrial disruption, tens of thousands cannot go home, hot spots to 85 miles, contaminated ocean, destroyed fisheries, farms, and businesses (from fallout).
- Release duration – months. A year? More? Not clear at the moment.
- Spent fuel handling cranes and other equipment destroyed in at least three reactors. Reality of irregular intense fallout as far as 40 kilometers and need for evacuation, long-term or permanent denial of return, contaminated schools, etc., not taken into account in the NRC Task Force Report (July 12, 2011).
- Fukushima questions: Remediate the site? How to decommission the reactors and their spent fuel pools? Will it be a high-level waste dump by the seashore in a seismic zone?
- Despite Fukushima school children radiation dose issue (up to 2 rem per year was proposed by Japanese government) the problem was not mentioned by NRC Task Force.
- Implicit idea that severe accidents will be like TMI – short duration of releases, no severe hot spots, and people can return to homes, farms and businesses underlies analysis – is incorrect in light of Fukushima.
- NRC Task Force recommendations for improving emergency management are grossly inadequate – possibly the most inadequate part of the NRC Task Force report (other than ignoring problem of self-assessment and zircaloy fuel rods).

The moral hazard of nuclear power in the economic sense of the term

1. Maximum industry liability about $12 billion per accident, so about $110 to $120 million liability per reactor in the worst case.
2. Brookhaven National Lab. 1997 (NUREG/CR-6451) worst case spent fuel accident damage about $540 billion (roughly $700 billion in 2010 dollars), densely populated area. Plus about 140,000 excess cancer fatalities.
3. Federal government (i.e., taxpayers) would cover the rest. Will it?
4. This is classic economic moral hazard: Individuals and private businesses can pass on the risks of economic failure to third parties at little or no cost to themselves, setting the stage for rash behavior. Like the bundling of low-grade mortgages and selling them after taking the commissions. Approach here is: socialize liabilities, privatize profits.
5. NRC allows self-assessment. Task Force did not recommend a change there.
6. Independent evaluation including field seismic capability is essential.
7. In an atmosphere where federal regulation is frowned upon politically and even the legitimacy of the federal government is questioned, one cannot expect a vigorous NRC. Initial divided reaction to Task Force's rather mild recommendations is rather predictable, if unfortunate.

State and federal issues – slide 1

- The consequences, at all levels for environment, health, and economy of Fukushima will be immense.
- 90-day Task Force has some very useful recommendations, but they do not go far enough.
- Self assessment still allowed as the primary means of analysis – e.g. in seismic assessment.
- Licensing and relicensing decisions continue, even though backfitting could result in high costs.
- Regulatory changes recommended by the NRC Task Force could result in much higher costs. Relicensing before costs are clear is arguably not in compliance with spirit of NEPA – alternatives cannot be reasonably evaluated without clear cost picture.
- For California, this is especially important due to the potentially high cost of seismic backfits, if needed, and of replacement power.

State and federal issues – slide 2

- New NEPA statements are needed for license extensions that reconsider costs and alternatives. If the NRC does not act in this regard, the state should do its own assessment.
- California needs to revisit emergency management at Diablo Canyon and San Onofre in light of Fukushima.
- Federal preemption needs to be revisited – states should be allowed to set tougher safety standards and insurance requirements.

My analysis of the July 12 NRC Task Force report is at

- http://foe.org/sites/default/files/Review%20of%20the%20July%2012%20NRC%20report%20on%20Fukushima%2019%20July%202011.pdf

Questions?