CALIFORNIA ENERGY COMMISSION

AN ASSESSMENT OF CALIFORNIA'S NUCLEAR POWER PLANTS:

AB 1632 COMMITTEE REPORT

COMMITTEE REPORT

OCTOBER 2008
CEC-100-2008-009-CTF

Arnold Schwarzenegger, *Governor*

CALIFORNIA ENERGY COMMISSION

ELECTRICITY AND NATURAL GAS COMMITTEE

Commissioner Jeffrey Byron
Presiding Member

Vice Chair James D. Boyd
Associate Member
California's State Liaison Officer to the U.S. Nuclear Regulatory Commission

Barbara Byron
Project Manager

Melissa Jones
Executive Director

DISCLAIMER

This report was prepared by the California Energy Commission's Electricity and Natural Gas Committee as part of the *2008 Integrated Energy Policy Report Update* proceeding. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal responsibility for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. The views and recommendations contained in this document are not official policy of the Energy Commission until the report is adopted.

ACKNOWLEDGEMENTS

This report would not have been possible without the expertise, dedication, analytic work ,and major contributions from MRW & Associates, Inc., in particular, Steve McClary, Heather Mehta, and Laura Norin. It draws heavily upon a consultant report which MRW prepared for the Energy Commission in collaboration with ABS Consulting, Aspen Environmental Group, Ventyx, and EllerStone D'Paul, Inc. We wish to thank them for their thorough assessments, commitment to accuracy and balance, and their well-written and well-documented report.

In addition, we wish to thank the senior technical staff from the California Geologic Survey, Seismic Safety Commission and the Coastal Commission, who participated on the Seismic Vulnerability Advisory Team. They provided valuable technical review and input to the seismic assessment for this report.

We also wish to thank the following California Energy Commission staff for their valuable technical additions and review of drafts of this report and the consultant report: Susan Brown, Bill Chamberlain, Karen Griffin, Mike Jaske, Eugenia Laychak, Matt Silverman, Bob Strand, Laurie ten Hope, and Chris Tooker. We also wish to thank Eugenia for her assistance in coordinating the Seismic Vulnerability Advisory Team and Susanne Garfield-Jones for her editorial support. Finally, we wish to thank Suzanne Korosec and Donna Parrow for their steadfast assistance and support throughout the AB 1632 assessment.

ABSTRACT

The report *An Assessment of California's Nuclear Power Plants: AB 1632 Committee Report* was prepared in response to Assembly Bill 1632 (Blakeslee, Chapter 722, Statutes of 2006). The bill directs the California Energy Commission to assess the potential vulnerability of California's largest baseload power plants, Diablo Canyon Power Plant and San Onofre Nuclear Generating Station, to a major disruption due to a seismic event or plant aging; to assess the impacts of such a disruption on system reliability, public safety, and the economy; to assess the costs and impacts from nuclear waste accumulating at these plants; and to evaluate other major issues related to the future role of these plants in the state's energy portfolio. The AB 1632 assessment will be included in the California Energy Commission's *2008 Integrated Energy Policy Report Update*, which is scheduled for adoption in November 2008.

The report provides findings and policy recommendations resulting from the AB 1632 assessment. It 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 these 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 power 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 these plants.

Key Words

Nuclear power plants, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Hosgri Fault, seismic, earthquake, tsunami, safe shutdown earthquake, design basis, Kashiwazaki-Kariwa, Nuclear Regulatory Commission, NRC, nuclear waste, nuclear waste storage, nuclear waste disposal, nuclear waste transport, Department of Energy, DOE, spent fuel, safety culture, transmission, production simulation, replacement power, low-level waste, renewable energy, once-through cooling, plant license renewal, relicensing, electricity, dry cask, greenhouse gas emissions, GHG emissions

Table of Contents

EXECUTIVE SUMMARY **1**

Study Approach **2**

Seismic Vulnerability **3**

Seismic Hazards at Diablo Canyon 3

Recommendations 6

Seismic Hazards at SONGS 7

Recommendations 9

Tsunami Hazards at Diablo Canyon and SONGS 9

Recommendation 10

Vulnerability of Power Plant Buildings and Structures 10

Recommendations 13

Vulnerability of Spent Fuel Storage Facilities to Seismic and Terrorist Events 13

Recommendations 15

Vulnerability of Roadways and Transmission Systems 16

Recommendation 16

Vulnerability to Plant Aging-Related Degradation **16**

Recommendations 19

Impacts of a Major Disruption **19**

West-Wide Resource Adequacy Scenario 20

Ad Hoc Planning Scenario 21

Current Capacity Planning Extended Forward Scenario 22

Evaluating Reliability Implications and Other Transmission Issues 23

Recommendations 24

Economic, Environmental, and Policy Issues **24**

Recommendation 25

Nuclear Waste Accumulation **25**

Recommendations 28

Land Use and Economic Implications of On-Site Waste Storage **28**

Power Generation Options **29**

Recommendation 31

Recommendation 34

Acronyms and Abbreviations **37**
Glossary of Technical Terms **41**

EXECUTIVE SUMMARY

Assembly Bill 1632 (Blakeslee, Chapter 722, Statutes of 2006) directs the California Energy Commission (Energy Commission) to assess the potential vulnerability of California's largest baseload power plants, which are California's two operating commercial nuclear power plants, to a major disruption due to seismic event or plant aging.[1] The Energy Commission is directed to adopt this assessment on or before November 1, 2008, and include it in the *2008 Integrated Energy Policy Report Update (2008 IEPR Update).* The legislation also directs the Energy Commission to assess the impacts that such a disruption would have on California's energy system reliability, public safety, and the economy; assess the costs and impacts from nuclear waste accumulating at these plants; and evaluate other major policy and planning issues affecting the future role of these plants in the state's energy portfolio. AB 1632 also requires updates of the seismic vulnerability assessment to be performed as part of future *Integrated Energy Policy Reports* and that these updates take into account new data or new understandings of seismic hazards for these plants.

The state's two operating commercial nuclear power 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.[2] Because California's operating nuclear power plants are important to the state's electricity supply, California needs a long-term plan to prevent or significantly reduce the chances of major disruptions and to be prepared should a disruption occur or should one or both of the plants be shut down, such as from regulatory actions following a major event at one plant that leads to a general plant shut down for an indefinite period. Both plants have achieved very high average annual capacity factors in recent years, making them reliable sources of power for the state. With California's current population exceeding 37 million and projected to grow to more than 44 million by 2020, California's electric supply infrastructure will be strained further to meet the state's increasing demand for electricity.

Recent tightening in the credit markets increases the uncertainty regarding the financial viability of new energy projects. 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. Without license renewals, the plants will be permanently retired at the conclusion of their current operating licenses in the early to mid 2020s.

---

[1] 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 excluded from the study.

[2] 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>.

The U.S. Nuclear Regulatory Commission (NRC) has regulatory authority over the radiological safety aspects of nuclear power, including plant licensing and license extensions. The State has much broader authority to set electricity generation priorities based on economic, electricity reliability, and environmental concerns. For example, the California Public Utilities Commission (CPUC) establishes the framework for considering the cost effectiveness of plant license renewal and authorizes funding for license renewal feasibility studies. The CPUC has established a clear link between the Energy Commission's AB 1632 assessment, findings and recommendations and PG&E's license renewal feasibility study. In 2007 the CPUC authorized $16.8 million for PG&E to conduct a Diablo Canyon license renewal feasibility study and required PG&E to: (1) defer its own license renewal feasibility study until after the Energy Commission issues its AB 1632 assessment, (2) incorporate the AB 1632 findings and recommendations into PG&E's own study, and (3) address in its study whether license renewal is cost effective and in the best interest of PG&E's ratepayers. This report, *An Assessment of California's Operating Nuclear Power Plants: AB 1632 Committee Report*, provides findings and recommendations to policymakers and stakeholders about Diablo Canyon and SONGS, as mentioned in the CPUC's 2007 General Rate Case Decision for PG&E, to assist energy policy planning. It is based on a consultant report prepared by MRW & Associates, Inc. for the Energy Commission entitled *AB 1632 Assessment of California's Operating Nuclear Plants* and reflects public comments on the draft consultant report as well as public comments on an earlier draft of this report.[3] A key element of the consultant report was 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 report draws heavily from a consultant report prepared for the California Energy Commission. The consultant report was developed by an interdisciplinary Study Team led by MRW & Associates. The Study Team reviewed materials that included 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; and data provided by the nuclear plant owners. To assist with the seismic vulnerability assessment, the Energy Commission formed a Seismic Vulnerability Advisory Team made up of senior staff from the California Seismic Safety Commission, the California Geological Survey, and the California Coastal Commission. The Advisory Team reviewed and commented on the seismic vulnerability assessment, in particular, the Request for Proposals for the AB 1632 seismic assessment, the proposed study plan, a list of the literature reviewed by the Study Team, and the Study Team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS.

Members of the public also contributed by identifying studies for review in the AB 1632 overall assessment and by providing comments on the draft study plan and on the draft consultant report. To maintain the independence of the assessment, the Energy Commission staff and

3 The final consultant report and public comments on the draft of this report can be obtained from the Energy Commission's website at: http://www.energy.ca.gov/ab1632/documents/index.html.

Study Team did not meet with the nuclear plant owners or other interested parties on the AB 1632 assessment. The plant owners, members of the public and interested stakeholders were provided the opportunity to submit written comments and participate in a public workshop on December 12, 2007, on the proposed study plan and submitted written comments and participated in a public workshop on September 25, 2008, on the Draft Consultant Report.[4] A second public workshop to receive comments on this Draft Committee Report was held October 20, 2008 and written comments on this report were received through October 22, 2008. This Final Committee Report is planned for release on October 30, 2008, and the Energy Commission will consider adopting the AB 1632 Committee Report as part of the *2008 Integrated Policy Report Update* at the Energy Commission's Business Meeting on November 19, 2008.

The Committee's major findings and recommendations from this analysis are provided below and are organized into the following major study areas: Seismic Vulnerability, Vulnerability to Plant –Aging Related Degradation,, Impacts of a Major Disruption, Economic, Environmental and Policy Issues, Nuclear Waste Accumulation, Land Use and Economic Implications of On-Site Waste Storage, Power Generation Options, and License Renewal Issues for State Policymakers.

SEISMIC VULNERABILITY

According to the California Seismic Safety Commission staff, there is a risk of a major earthquake in California on the order of 2 to 3 percent per year. According to the 2007 Working Group on Earthquake Probabilities, California faces a 99.7 percent chance of a magnitude 6.7 or larger earthquake during the next 30 years. The likelihood of an even more powerful quake of magnitude 7.5 or greater in the next 30 years is 46 percent.

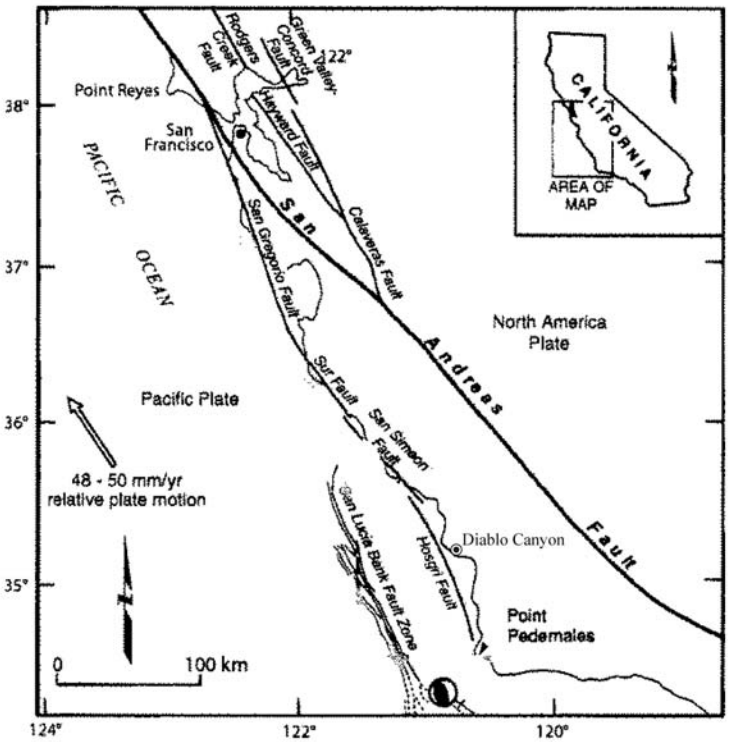
The seismic vulnerability assessment consists of three parts: 1) an assessment of the geology and seismic hazards in the vicinity of Diablo Canyon and SONGS, 2) an assessment of the seismic design of the power plants, and 3) an assessment of the seismic and other vulnerabilities of the spent fuel storage facilities located at the plants, and of the transmission systems leading to and from the plants, and the access roadways for the plants.

Seismic Hazards at Diablo Canyon

The offshore Hosgri Fault zone, 4.5 kilometers west of Diablo Canyon, creates the primary seismic hazard at the plant site (Figure 1). Over the years there has been uncertainty regarding the tectonic setting of this fault zone, and the characterization of the Hosgri Fault as either a lateral strike-slip fault or as a thrust fault (Figure 2). 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 from an earthquake could be greater.

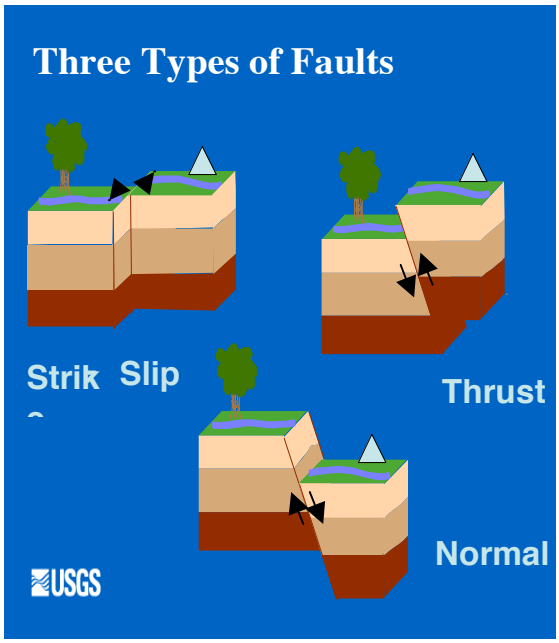
4 Copies of stakeholder comments may be viewed on the Energy Commission's web site at: http://www.energy.ca.gov/ab1632/index.html

Figure 1: Seismic Setting of Diablo Canyon



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 plate.

Figure 2: Three Types of Faults



Current published geologic and seismologic research literature, much of which has been developed through PG&E's Long-Term Seismic Program (LTSP),[5] supports the interpretation that the Hosgri Fault is predominantly characterized by strike-slip faulting. Experts with the U.S. Geological Survey (USGS), the California Geological Survey, and the Southern California Earthquake Center have accepted the strike-slip characterization for the Hosgri Fault. However, a minority of scientists disagrees with this characterization and believes that the Hosgri Fault is a thrust fault.

The implications of a thrust fault characterization for the seismic vulnerability of Diablo Canyon are uncertain. PG&E and the NRC separately evaluated the seismic hazard at Diablo Canyon from the Hosgri Fault assuming up to 33 percent thrust faulting. They found that there was sufficient safety margin in the plant design to accommodate the resulting ground motion from the Hosgri Fault under this assumption,, even though this motion was greater than had been anticipated when the plant was designed. PG&E has not published an analysis showing the implications of 100 percent thrust faulting on the safety of the plant, and such an interpretation is extreme in the context of the current professional consensus.

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

The Diablo Canyon seismic setting has been extensively studied, largely under PG&E's Long Term Seismic Program (LTSP), and PG&E continues to study it. Further study using advanced technology may help resolve remaining uncertainties. For example, high quality three-dimensional geophysical seismic reflection mapping could resolve questions about the characterization of the Hosgri Fault and might change estimates of the seismic hazard at the plant. Similarly, direct imaging of the subsurface structure at Diablo Canyon could determine if faults exist near the site that do not break to the surface and could also 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. A permanent global

[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.

positioning system (GPS) array, currently under development in the onshore region of the Diablo Canyon site, could refine models of tectonic block movements in the plant vicinity. Results of these surveys might alter fault parameters that are used in existing seismic hazard assessments.

Additional information on the seismic hazards at Diablo Canyon can be derived from the "Uniform California Rupture Forecast, Version 2 (UCERF-2)" database of faults and rupture probabilities in California, which was recently updated by the USGS, California Geological Survey, and the Southern California Earthquake Center. This database, used in conjunction with USGS models, would provide additional useful information regarding the seismic hazards at Diablo Canyon. To obtain accurate seismic hazard data, the USGS models must be modified to reflect site-specific conditions at the plants.

Finally, since Diablo Canyon was built, scientists have learned more about the ground motions that could result from an earthquake rupture. One important finding is that ground motion can be highly variable in the region near a rupture, with significant amplification of ground motion in some areas. This could be important at Diablo Canyon since the plant lies within five kilometers of the Hosgri Fault. PG&E is working collaboratively with the USGS to study earthquake hazards along the coastline in central and northern California, including the area surrounding Diablo Canyon.

Recommendations

- The Energy Commission acknowledges PG&E's ongoing efforts to understand the seismic hazards affecting the Diablo Canyon site through its Long Term Seismic Program (LTSP), and recommends that this work continue. As part of future IEPR assessments, beginning with the 2009 IEPR, PG&E should report to the Energy Commission on the overall status and results of its research efforts. As ground motion models are refined to account for a greater understanding of the motion near an earthquake rupture, it will be important for PG&E to consider whether the models indicate larger than expected seismic hazards at Diablo Canyon and, if so, whether the plant was built with sufficient design margins to continue operating reliably after experiencing these larger ground motions.

- The California Energy Commission, in cooperation with other appropriate state agencies and in coordination with PG&E, should evaluate the degree to which using three-dimensional geophysical seismic reflection mapping and other advanced techniques should be pursued, if warranted by a cost-benefit analysis. This action will supplement PG&E's Long Term Seismic Program and help resolve uncertainties surrounding the seismic hazard at Diablo Canyon. Given the potential for an extended plant shutdown following a major seismic event, the Energy Commission, in consultation with appropriate state agencies, should evaluate whether these studies should be required as part of the Diablo Canyon license renewal feasibility study for the CPUC.

- PG&E should assess the implications of a San Simeon-type earthquake beneath Diablo Canyon.[6] This assessment should include expected ground motions and vulnerability assessments for safety-related and non safety-related plant systems and components that might be sensitive to long-period motions in the near field of an earthquake rupture.
- The Energy Commission, in cooperation with other appropriate state agencies, should consider the relevance of the USGS National Seismic Hazard Mapping Project models and the UCERF-2 database in the context of studies required as part of the license renewal feasibility assessment at Diablo Canyon for the CPUC. Updated seismic hazard analyses incorporating these inputs would provide additional information for regulators and the public regarding the seismic hazard at the plant site.

Seismic Hazards at SONGS

Seismologic and geologic data that have become available since SONGS was built indicate that the SONGS site could experience larger and more frequent earthquakes than had been anticipated when the plant was designed. For example, underground ("blind thrust") faults in the vicinity of SONGS have been postulated since the plant was built, and the estimated frequency of a design basis ("safe shutdown") earthquake at the plant increased from 1 in 7,194 years in a 1995 study to 1 in 5,747 years in a 2001 study. 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."

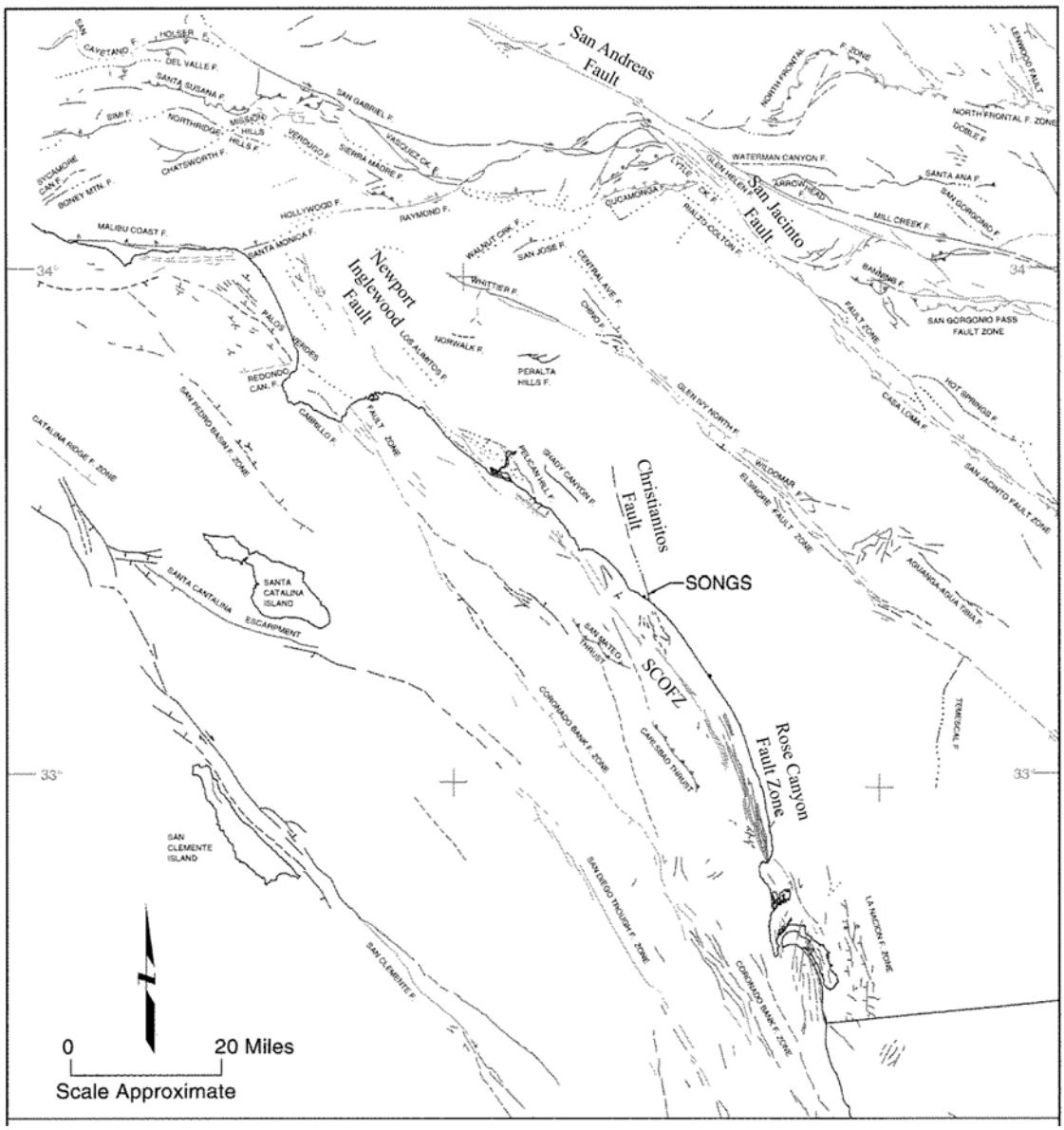
This new information does not necessarily imply that the facility is unsafe. Since the plant was engineered with a large margin of safety, it likely would withstand earthquakes of greater magnitude and frequency than originally expected. However, the possibility that the safety margin is shrinking suggests that further study is necessary to characterize the seismic hazard at the site, especially since much less is known about the seismic setting of SONGS than the seismic setting of Diablo Canyon. While SCE periodically evaluates the implications of new seismic data that become available, there is no ongoing program at SONGS similar to PG&E's Long-Term Seismic Program at Diablo Canyon.

The major uncertainties regarding the seismology of the SONGS site relate to the continuity, structure, and earthquake potential of a nearby offshore fault zone (the South Coast Offshore Fault Zone) and the faulting that connects faults in the Los Angeles and San Diego regions. There is also uncertainty regarding the potential for blind thrust faults near the plant. Well planned, high-quality three-dimensional seismic reflection data at strategically chosen locations

[6] PG&E has considered a San Simeon-type earthquake scenario within probabilistic seismic hazard assessments for Diablo Canyon. However, further studies that consider such an earthquake from a deterministic basis (i.e., using a probability of 1) are recommended to evaluate the full implications of this earthquake, particularly for non-safety related plant components and reliability.

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

Figure 3: Seismic Setting of SONGS[7]



Similar to Diablo Canyon, additional information on the seismic setting of SONGS is available through the UCERF-2 study. In addition, as SONGS is located within 10 kilometers of a fault, new research on ground motion near an earthquake rupture is also relevant to the seismic

[7] 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.

hazard of SONGS. When SCE incorporated some of these developments into the seismic hazard assessment for SONGS, SCE found that the safety margins at the plant are less than previously believed. SCE is currently assessing the applicability of updated ground motion modeling for the SONGS site.

Recommendations

- SCE should develop an active seismic hazards research program for SONGS similar to PG&E's LTSP to assess whether there are sufficient design margins at the nuclear plant to avoid major power disruptions. The research program should prioritize and include further investigations into the seismic setting at SONGS and should assess whether recent or current seismic, geologic, or ground motion research in the vicinity of SONGS has implications for the long-term seismic vulnerability of the plant. As part of the Energy Commission's future IEPR assessments, beginning with the 2009 IEPR, SCE should report to the Energy Commission on the results of its seismic research efforts.
- The Energy Commission, in cooperation with other appropriate state agencies and in coordination with SCE, should evaluate the degree to which new research programs should be pursued using three-dimensional seismic reflection mapping, other techniques, and a permanent GPS array for resolving seismic uncertainties for SONGS, if warranted by a cost-benefit analysis. Given the potential for an extended plant shutdown following a major seismic event, the Energy Commission, in consultation with appropriate state agencies, should evaluate whether these studies should be required as part of the SONGS license renewal feasibility assessments for the CPUC.
- The California Energy Commission, in cooperation with other appropriate state agencies, should consider the relevance of the USGS National Seismic Hazard Mapping Project models and the UCERF-2 database in the context of studies required as part of the license renewal assessments for SONGS for the CPUC. Updated seismic hazard analyses incorporating these inputs would provide additional information for regulators and the public regarding the seismic hazard at the plant site.

Tsunami Hazards at Diablo Canyon and SONGS

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, although a landslide could impair evacuation routes for plant workers and nearby communities, as well as access for emergency equipment and personnel.[8] 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 probabilistic hazard assessments, inundation modeling, and new data from the National Oceanic and Atmospheric Administration. Second-generation tsunami run-up maps being

[8] Multiple access routes are available for both plants.

prepared by the University of Southern California for evacuation planning purposes may also provide relevant information for tsunami hazard assessments at the plant sites.

SCE does not have plans to reassess the tsunami hazard at SONGS and has not reassessed this hazard since the plant was designed. Since then, scientists have learned that submarine landslides can generate large local tsunamis. The tsunami run-up maps that are being prepared by the University of Southern California will incorporate expected hazards from such near-to-shore landslides. These new maps may or may not result in significantly revised estimates of the tsunami hazard at SONGS. However, even a moderate increase in the estimated maximum tsunami run-up could raise significant concerns about the adequacy of the site's seawall.

PG&E is currently conducting a study to reassess the tsunami hazard at Diablo Canyon. This study is a probabilistic tsunami hazard analysis that considers tsunamis triggered by local and distant earthquakes and by local submarine landslide. PG&E expects to complete this study by December 2008. The most recent completed study, from the early 1990s, concluded that the plant was designed to sustain the largest tsunami that can be expected at the site.

Recommendation

- PG&E and SCE should review the tsunami hazard at their nuclear plants in light of recent research and improved scientific understanding of tsunamis. SCE should assess SONGS' tsunami vulnerability after new data from the National Oceanic and Atmospheric Administration for the SONGS site and adjacent coastal areas become available. SCE should also assess the relevance of the University of Southern California second-generation tsunami run-up maps for the tsunami hazards at their nuclear plant sites. PG&E and SCE should provide to the Energy Commission the results of the updated Diablo Canyon and SONGS tsunami hazard study as part of future IEPR assessments, beginning with the 2009 IEPR.

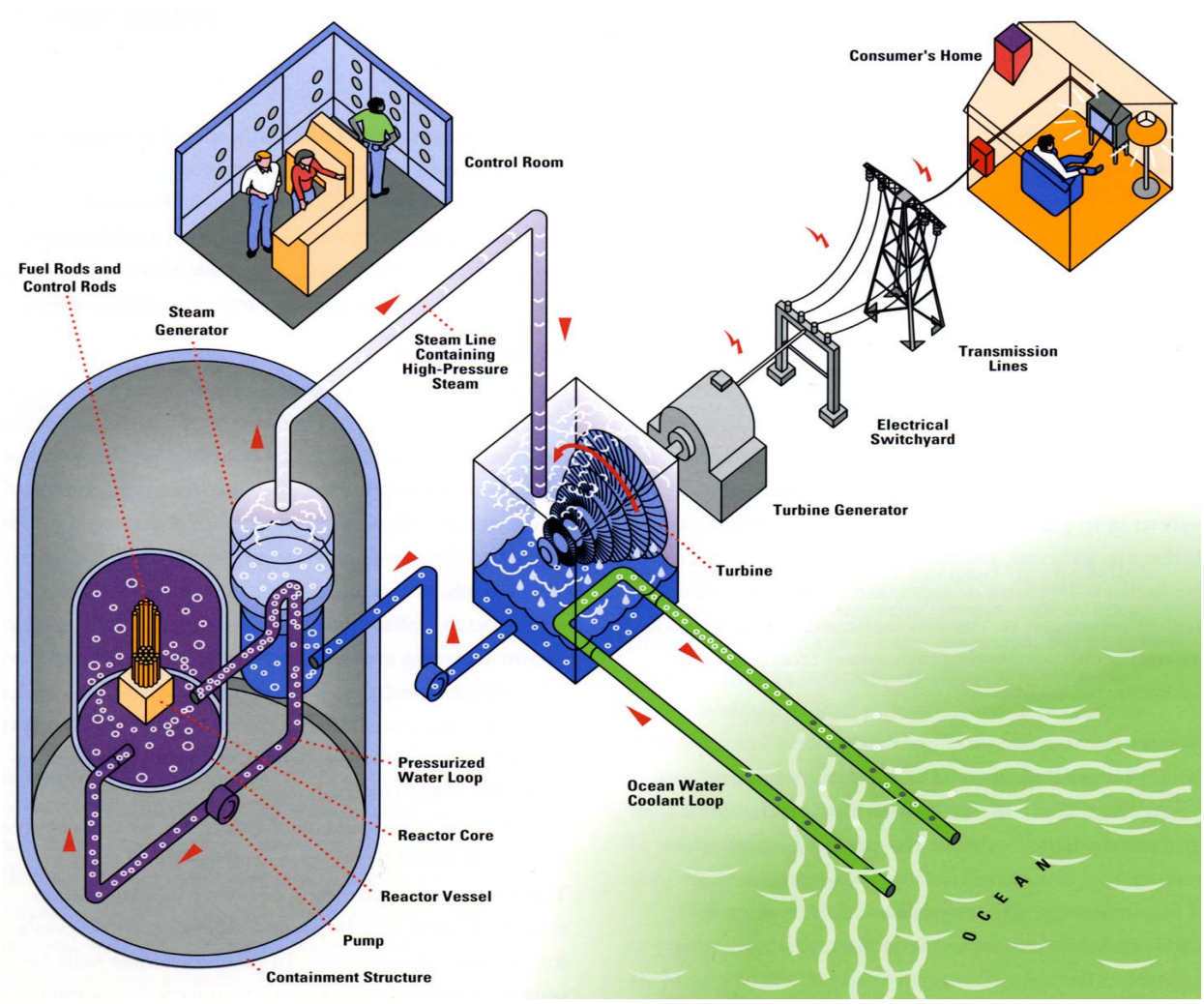
Vulnerability of Power Plant Buildings and Structures

The safety-related systems, structures, and components (SSCs) of Diablo Canyon and SONGS are designed to remain safe during earthquakes of magnitude 7.5 on the Hosgri Fault and 7.0 on the South Coast Offshore Fault Zone, respectively.[9] Earthquakes of these magnitudes are the plants' "safe-shutdown earthquakes," which are defined by the Nuclear Regulatory Commission as the maximum earthquake potential for the respective plant sites based on the regional and local geology and seismology and the local subsurface material. In other words, 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. Notably, the largest earthquakes experienced at SONGS and Diablo Canyon have been significantly less than the plants' safe-shutdown earthquakes.

[9] A safe-shutdown earthquake is defined by the Nuclear Regulatory Commission as the maximum earthquake potential for a specific site based on the regional and local geology and seismology and the local subsurface material.

Earthquakes with magnitudes equivalent to the safe-shutdown earthquakes would likely cause serious damage to Diablo Canyon or SONGS. However, 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 (Figure 4).

Figure 4: Nuclear Plant Layout[10]



The non-safety related systems, structures, and components (SSCs) of the plants are most vulnerable to damage from earthquakes. Damage to non-safety related SSCs is the greatest

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

source of seismic-related plant reliability risk for SONGS and Diablo Canyon. Damage to non-safety related SSCs could pose risks of injury and loss of life to plant workers and occupants but damage would not pose a direct safety hazard to the public; however, it could result in extended outages for repairs lasting weeks or months. The seismic-related reliability risk of non-safety related SSCs is not well understood in large part because the nuclear industry and the NRC historically have focused on safety-related SSCs. PG&E's representatives recognized this information gap at the Energy Commission's September 25, 2008 public workshop on the draft consultant report, and SCE confirmed in written comments to the Energy Commission that there are no studies that assess the seismic vulnerability of non-safety related SSCs at SONGS.

The electrical 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 and subsidence. For Diablo Canyon, the switchyard through which the plant's energy is transmitted out into the grid is located on deep fill and therefore is particularly vulnerable to damage. A separate switchyard transmits off-site power to the reactor units, and this switchyard has had some seismic upgrades to improve its robustness. In short, an earthquake could cause damage resulting in the failure of a switchyard that would cause a loss of power from the plants to the transmission grid, but the reactor units would continue to have a source of off-site power in addition to the onsite emergency diesel generators.

Seismic design standards of non-safety related SSCs have evolved significantly since Diablo Canyon and SONGS were designed and licensed. The construction permits for Diablo Canyon 1 and 2 were issued in 1968 and 1970, respectively, and the construction permits for SONGS 2 and 3 were issued in 1973. Given the evolution of seismic design standards since these reactors were designed in the 1970s and early 1980s, non-safety related SSCs at Diablo Canyon and SONGS may be less seismically robust than if those same SSCs were built to current standards. A full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of the evolution of seismic design standards since these plants were designed and built. Such an analysis would need to consider any retrofits to SSCs that PG&E and SCE may have completed.

Diablo Canyon or SONGS could be shut down following earthquakes for as little as one week or for a much longer period of time for repairs or component replacement. Estimates of time to repair or replace nuclear plant components are very uncertain since this information is not readily available. The determining factors most likely would be the extent and location of the damage, i.e., whether the repair is on the nuclear side or the non-nuclear side of the power plant, and. the availability of replacement parts. Other factors affecting the duration of a shutdown include the amount of time needed to investigate the plant for damage and the need for design and back fitting efforts. Public or regulatory concerns also could delay the restart of the power plant.

The experience in Japan of the Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP) in the wake of the 2007 Niigata Chuetsu-Oki earthquake may offer some lessons for California's nuclear

plant operators. The KK NPP is the largest nuclear plant in the world with the capacity to generate 8,200 megawatts of power when operating. The KK NPP experienced ground motions significantly higher than the design basis ground motion and yet suffered no significant damage to safety-related components. Nevertheless, more than a year after the earthquake, the KK NPP remains shut down. Extensive investigations and a re-evaluation of the seismic design standards for the plant appear to be the primary cause of the lengthy shut-down, suggesting that repairing or replacing damaged components may be just one factor in how long a nuclear power plant is shut down following a major seismic event. 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.

Recommendations

The Energy Commission recommends that PG&E and SCE do the following and report on their progress as part of future IEPR assessments, beginning with the 2009 IEPR:

- Investigate and report their findings on the extent to which their respective plants' non-safety-related systems, structures, and components (SSCs) comply with current building codes and seismic design standards for non-nuclear power plants.
- Evaluate the seismic vulnerability and reliability implications for the nuclear plants' non-safety related SSCs from changes to seismic design standards that have occurred since the plants were designed and built. Such an analysis should consider the IAEA (International Atomic Energy Agancy) Standards and Safety Reports and any retrofits that the plant owners may have undertaken and should focus on those plant systems or components whose failure could lead to extended outages.
- Describe plant component repair/replacement plans including initial estimates of time needed to repair or replace key plant systems or components that could cause a prolonged plant outage as a result of earthquake damage. This should consider the fragility of components both in their operating positions and when relocated for refueling or plant maintenance.
- As part of their license renewal feasibility analyses for the CPUC, PG&E and SCE should summarize the lessons learned from the Kashiwazaki-Kariwa plant experience in response to the 2007 earthquake and any implications for Diablo Canyon and SONGS, including whether any additional pre-planning or mitigation could minimize plant outage times following a major seismic event .

Vulnerability of Spent Fuel Storage Facilities to Seismic and Terrorist Events

After nuclear fuel has been used (spent), it must be stored safely prior to disposal. There are two types of storage for spent fuel: pool and dry cask storage. SCE uses both pools and dry cask storage facilities to store the spent fuel from SONGS. PG&E is currently using pools to store all

of the Diablo Canyon spent fuel and is constructing dry cask storage facilities for future use. 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.

The greatest risk to any nuclear spent fuel pool is the loss of water or the loss of active cooling. A loss of cooling event could be precipitated by earthquakes or a terrorist event. For example, in a 2005 study the National Academies' Committee on Safety and Security of Commercial Spent Nuclear Fuel investigated the vulnerability of commercial nuclear power plant spent fuel storage to a terrorist attack and concluded that spent fuel storage facilities cannot be ruled out as potential targets. They further concluded that a terrorist attack that partially or completely drained a spent fuel pool could lead to a propagating zirconium cladding fire and the release of large quantities of radioactive materials.[11] If not mitigated, a loss of water or the loss of active cooling in the spent fuel pool could result in overheating of the stored spent fuel, melting of the fuel cladding, and the subsequent release of radioactive material. Because of this risk, spent fuel storage pools are designed to reduce the possibility of drainage leading to water levels lower than the stored fuel. In the case of Diablo Canyon and SONGS, the spent fuel pools are designed to the highest safety classification and are supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis. The spent fuel pools are not expected to suffer a catastrophic loss of cooling as the result of earthquakes.

An earthquake could result in the spread of radioactivity if contaminated water spills from the pool, as occurred during the July 2007 Niigata Chuetsu-Oki earthquake in Japan at the KK NPP. The earthquake's ground motion caused water to slosh in the spent fuel pool and spill in one of the nuclear plant's reactor buildings; the contaminated water leaked into the Sea of Japan from leaks in conduits in the reactor building floor. The SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of sloshing in the event of an earthquake. However, in light of the leakage at the KK NPP, PG&E is investigating the water-tightness of conduits in Diablo Canyon's auxiliary building where the spent fuel pool is housed.

Because of the lack of a federal permanent spent fuel disposal facility (as discussed below), 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 (federal regulations permit re-racking of spent fuel pools). The more densely configured spent fuel pools are considered to have greater risk than a spent fuel pool that has a more open racking arrangement... For example, a loss-of-coolant event precipitated by a terrorist attack in a re-racked spent fuel pool could result in extensive radiation release and contamination. Reconfiguring the spent fuel in the pools to more evenly distribute decay heat loads appears to help reduce the vulnerability of spent fuel pools.

---

[11] National Academies, 2005, National Research Council Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, "Safety and Security of Commercial Spent Nuclear Fuel Storage", National Academies, Washington, D.C. 2005, pp. 35 and 37.

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

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

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

Limited information is available on the vulnerability of dry cask storage to sabotage or terrorist attack, which is consistent with the National Academies' findings in its 2006 study of commercial spent fuel storage safety and security. While terrorist scenarios have been postulated that could release large quantities of radioactive materials into the environment, an assessment of the likelihood of such scenarios occurring has not been publicly released. Such information is needed for state planning for emergency response and consequence mitigation. Returning spent fuel pools to their original spent fuel spacing configuration would reduce the overall risk associated with spent fuel storage at reactors and, therefore, would help maintain plant reliability.

Recommendations

- PG&E and SCE should return their spent fuel pools to open racking arrangements as soon as feasible, while maintaining compliance with NRC cask and pool spent fuel storage requirements, and report to the Energy Commission on their progress in doing so.

- The Energy Commission should continue to work with the Nuclear Regulatory Commission and the California Office of Homeland Security to obtain the necessary security clearances for selected California officials to review studies that assess the vulnerability of California's nuclear plants, spent fuel storage facilities, and spent fuel shipments to terrorist attacks or sabotage and the consequences of such attacks.

Vulnerability of Roadways and Transmission Systems

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

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

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

Recommendation

- As part of license renewal feasibility studies and to protect plant assets and equipment in an emergency, PG&E and SCE should reassess the adequacy of access roads to the plants and surrounding roadways for allowing emergency personnel to reach the plants and local communities and plant workers to evacuate. The assessments should consider changes to the local populations since the plants were constructed.

VULNERABILITY TO PLANT AGING-RELATED DEGRADATION

California's operating 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.

Diablo Canyon and SONGS are reliable sources of power, and continued vigilance is required to ensure that they remain so. More than a dozen commercial nuclear power reactors have permanently shut down in the United States prior to the end of their operating license periods.[12] In many cases, the shut-downs occurred unexpectedly. According to a study by the Union of

[12] Nuclear Regulatory Commission. "Locations of Power Reactor Sites Undergoing Decommissioning." September 26, 2008. Accessed: October 2, 2008. < http://www.nrc.gov/info-finder/decommissioning/power-reactor/>

Concerned Scientists, more than three dozen nuclear power reactors have experienced year-plus outages including reactors in California.[13]

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

Nuclear plants are baseload units and are planned to operate as much as possible. A standard measurement of nuclear plant performance is the capacity factor, which is calculated by dividing how much energy a plant actually generates by the total possible energy produced during a given period. Any increase in the amount of time a plant is unavailable or is forced to operate at less than full capacity is reflected in a reduced capacity factor.[14] Reductions in capacity factor over time may provide the first indication of an impact of aging-related degradation at a plant. 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.[15] Similar to any other large power facility, the plants' performance record is largely a function of the plant owners' efforts and expenditures to maintain and upgrade the plant and in the skills and care of the plant workers. This does not necessarily indicate the absence of plant degradation, but it suggests that, operational improvements and reductions in down time for plant maintenance and refueling have more than compensated for degradation-related operational losses.

Researchers generally agree that age-related degradation is of greater concern for passive rather than active components. In the 1990s, NRC-sponsored research found that piping, steam generators, and passive components of the reactor pressure vessel comprised over half of nearly 500 reported degradation occurrences at nuclear plants in the U.S. Problems with reactor coolant systems and reactor vessels/components 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 due to degraded materials or operational failures.

Plant component aging problems have surfaced at some U.S. nuclear plants outside of California. For example, Davis-Besse Ohio), Vermont Yankee (Vermont), Oyster Creek (New Jersey), and Indian Point (New York) have all received increased scrutiny by the NRC, government agencies, and/or watchdog groups concerned that different types of age-related degradation are eroding the safety of these plants. The implications for Diablo Canyon and

---

[13] Lochbaum, David. "Walking a Nuclear Tightrope: Unlearned Lessons of Year-Plus Reactor Outages." Union of Concerned Scientists. September 2006, pages 8-10.

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

[15] California Energy Commission, *Nuclear Power in California: Status Report 2007*, October 2007, http://www.energy.ca.gov/2007publications/CEC-100-2007-005/CEC-100-2007-005-F.PDF.

SONGS are twofold. First, the same unanticipated age-related degradation of some plant components or systems could be occurring at the California plants; age-related degradation has already occurred, for example, PG&E and SCE are replacing their plants' steam generators. Second, a 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.

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). 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 the Davis-Besse plant in Ohio.

The NRC recently raised concerns about the safety culture at SONGS and required SCE to create a plan to improve safety culture at the plant. In addition, Energy Commissioner James Boyd, State Liaison Officer to the U.S. Nuclear Regulatory Commission, expressed concern to Southern California Edison regarding reports of lapses in the safety culture at SONGS. These reports include SONGS' unsatisfactory response to the failure of an emergency diesel generator at the plant, as well as certain willful violations of procedures including an employee, who, over a five-year period, intentionally falsified records regarding required fire safety checks at SONGS.[16] The Institute for Nuclear Power Operations (INPO), an industry-funded oversight agency, has also identified safety concerns at SONGS, including an unusually high rate of employee injury.[17] Diablo Canyon, which has had no NRC violations since 1995, appears to have a relatively effective safety culture. Effective maintenance programs and safety cultures require well-trained workforces at the plants. The average age of the workforces at Diablo Canyon and SONGS is increasing, and large numbers of staff will soon retire. Both utilities have instituted programs for the retiring staff to pass on their institutional knowledge to newer staff. It is critical to the ongoing reliability and safety of the plants that adequate staffing levels are maintained, that programs to transfer knowledge from retiring workers to new workers are successful, and that strong safety cultures are maintained throughout this shift in the plants' workforces.

---

[16] Letter to Richard M. Rosenblum, Southern California Edison, from James D. Boyd, California Energy Commission, dated January 22, 2008.

[17] 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.)

Recommendations

- To support the long-term reliability of Diablo Canyon and SONGS as the plants age, effective safety culture and maintenance programs must be maintained at the plants in conjunction with enhanced oversight mechanisms, including:

    a. The Energy Commission should work with federal and state regulators, nuclear plant owners, and INPO (Institute for Nuclear Power Operations) to develop a means for usefully incorporating results of INPO reviews and ratings of reactor operations into a meaningful public process while maintaining the value of these reviews as confidential and candid assessments.

    b. The Energy Commission should continue to closely monitor NRC actions and reviews of Diablo Canyon's and SONGS' performance. In particular, the state should monitor the NRC's responses to safety culture lapses at SONGS and require SCE to provide evidence of achieving and maintaining a strong plant safety culture prior to SCE's submitting a license renewal application. SCE, as part of the IEPR reporting process, beginning with the 2009 IEPR, should report their progress on how they are addressing the SONGS safety culture issue.

- EPRI's groundwater protection guidelines should be followed to prevent inadvertent releases of tritium due to degraded materials or operational failures.

- The California Public Utilities Commission should continue to recognize the importance of PG&E's and SCE's plant worker training and recruiting programs and approve adequate funding for such programs. On a periodic basis, the state should assess the adequacy and success of PG&E and SCE recruiting and training programs for replacing retiring plant workers and ensuring that knowledge and strong safety cultures are instilled in new workers.

IMPACTS OF A MAJOR DISRUPTION

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 plant 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.

When any of California's nuclear reactors are not operating, the power they produce must be replaced with power from other sources. PG&E and SCE generally schedule refueling outages and other planned maintenance shutdowns to avoid periods of peak electricity demand and reduce the cost of replacement power. However, 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.

There are three scenarios which can be used to evaluate the consequences of an extended unplanned outage:

- Assume that California and the rest of the Western Interconnection develop and implement comprehensive long-term resource adequacy standards; [18]
- Assume that California utilities continue to use more ad hoc methods to estimate future capacity and energy requirements and continue to "muddle through" in procuring needed resources to cover likely conditions, and
- Assume that the California ISO and the CPUC implement reforms to current resource adequacy requirements to extend current resource capacity planning into the 4-6 year ahead time horizon;

Each of these alternative scenarios would lead to a different conclusion about the sudden disruption of output from one or both of the nuclear facilities.

West-Wide Resource Adequacy Scenario

This scenario assumes that policy makers continue the general trend of examining future resource needs from a reliability perspective that not only extends capacity requirements into the future, but also evaluates energy needs relative to the loss of resources, such as California's nuclear plants, which provide large amounts of energy. Such a framework is codified into planning and procurement standards, and utilities and other load serving entities (LSE) generally live up to such requirements.

Consultants to the Energy Commission using computer models simulated the operations of the electricity market for the year 2012 and beyond with and without one or both of the nuclear plants operational.[19] The simulations were conducted using a set of West-wide resource plans developed for the 2007 IEPR Scenarios Analysis that assumes supplies are always added to the system just in time to satisfy demand conditions and reserve requirements. Such studies typically assume that if today, for whatever reason, various regions have resources in excess of their demand and reserve requirements; they would only gradually trend down toward the minimum requirements established through the hypothetical resource adequacy standards.

Since much of the West and some California utilities currently have resources above those minimum requirements, as expected, the consultants found that no electricity supply shortages would occur as the result of either Diablo Canyon or SONGS being shut down for an extended

---

[18] The Western Interconnection is one of the two major power grids in North America. The other major interconnection is the Eastern Interconnection. The three minor interconnections are the Québec Interconnection, the Texas Interconnection, and the Alaska Interconnection.

[19] The simulations are described in more detail in the consultant report, *AB 1632 Assessment of California's Operating Nuclear Plants*.

period in 2012. In years beyond 2012, whether the energy lost from a year-long outage could be readily replaced from instate resources or imported from other parts of the West depends a great deal on whether WECC (Western Electricity Coordinating Council) and the NERC (Northern American Electric Reliability Corporation identify both energy and capacity risks in their assessments of system adequacy and whether these risks are fully mitigated by appropriate resource additions that have surplus energy generating potential that can substitute during the hypothetical outage.

The consultant's simulations found that in the event of an extended outage at either nuclear plant, replacement power 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.[20] 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 a year-long outage at either nuclear plant would increase in-state greenhouse gas emissions from power generation by seven to eight percent, or roughly 4.3 to 4.7 million tons of 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.

Ad Hoc Planning Scenario

The WECC collects electricity load (demand) and resource data from electrical system control areas (balancing authorities) and prepares an annual assessment of winter and summer peak conditions. In preparing its analysis, WECC counts resource additions only when they satisfy various criteria intended to screen out power plant proposals that are not considered committed. Because the purpose of the analysis is to reveal the extent to which peak planning needs are not satisfied by existing resources and committed resource additions, it is a very conservative view of what is actually expected to be in place in future years. Presumably by revealing deficits, it motivates independent generators to develop project proposals or move ahead toward contractual commitments with utilities and actually obtain needed permits and begin construction.

[20] 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.

The WECC draft 2008 *Power Supply Assessment* reports reserve margins through 2017 under adverse hydro conditions, restricted transfer capabilities, and 1-in-2 load conditions during the peak summer and winter months.[21] According to this assessment, reserve margins in both northern and southern California will decline over the next ten years if new plants are not built in addition to those currently undergoing regulatory review or already under construction. Under the adverse conditions described above, the WECC study shows that by 2012 generating resources will already be deficient to maintain the CPUC-mandated 15 percent reserve margin in Southern California assuming SONGS is available, and reserve margins would fall below acceptable levels to nearly 5 percent -- close to a Stage 2 Emergency – if SONGS were unavailable. Northern California is just in balance (including a 15 percent reserve margin) in 2012 with Diablo Canyon in service, but well below planning standards with it not available during summer peak electricity demand in California.

Actual reserve margins will depend on weather, economic conditions, and electrical resource development. For example, tightening credit markets could delay construction of plants that are currently under regulatory review or planned, resulting in lower reserve margins. On the other hand, tightening credit markets could reduce demand growth. Environmental constraints such as air quality requirements could limit new generation options, or once-through cooling restrictions could cause existing plants to retire more quickly than currently anticipated. Hotter than average peak weather would also worsen conditions. A planning reserve margin standard, such as the CPUC/California ISO requirement of 15 percent, would cover these contingencies. The WECC analysis indicates that increased reliability concerns if Diablo Canyon and SONGS were out of service in the (unlikely) environment that does not require utilities and other Load Serving Entities (LSEs)[22] to acquire resources to cover contingencies.

Extended Planning Time Horizon Scenario

Over the past two years, the CPUC and California ISO have been examining alternatives that would extend the current one-year-ahead time horizon for planning electricity resource adequacy to something more like 4-6 years ahead. The CPUC staff has recommended that this extended planning and commitment time horizon be adopted through bilateral markets or through a centralized capacity market mechanism administered by the California ISO. The CPUC is scheduled to make a decision by the end of 2008. If it does so, utilities and LSEs in the CPUC/California ISO jurisdiction would need to acquire resources to cover loads and reserve requirements 4-6 years into the future on a rolling basis.

---

[21] New resources included in the analysis are under (or have completed) regulatory review with a completed facility study, are in active negotiations for (or possess) an interconnection agreement, and are projected to be in-service prior to January 2014. Western Electricity Coordinating Council. "2008 Power Supply Assessment - Draft." September 29, 2008, page 11.

[22] LSEs are utilities and other electric service providers that directly deliver electric power to meet the demands (loads) of end use customers.

If this policy is adopted, an extended outage at Diablo Canyon or SONGS might be expected to have consequences somewhere in between the assessment of the two previous scenarios. It is possible that summer peak reliability could be assured, but that providing enough energy to replace Diablo Canyon or SONGS would greatly strain the system. There are ways to cover energy deficits, but most are not easily accomplished or inexpensive. For example, the old steam generating units targeted for retirement or repowering by existing Energy Commission policy could generate more energy, albeit at much higher cost and emissions than would normally be considered acceptable. Few other resources have any "upside" energy generating capabilities.

Evaluating Reliability Implications and Other Transmission Issues

In evaluating these alternative scenarios on the implications of unexpected, lengthy plant shutdowns, the Energy Commission must consider which one, if any, is most appropriate, and whether additional factors that were not modeled directly are important. In the current energy agency planning processes, there does not appear to be an overt consideration of lengthy shutdowns for the nuclear units on reliability or other implications for customers. Further, the July 2008 court decision invalidating South Coast Air Quality Management District's priority Reserve Rule 1309.1, absent some immediate remedy to restore the rule, threatens power plant additions in the Southern California region. This makes all existing units more critical and less easily replaced. The pessimistic WECC perspective, described above under the West-Wide Resource Adequacy Scenario, might be the most realistic, absent improvements to planning and regulatory processes.

Separate from the broad system perspective on resource adequacy are more detailed local assessments and procurement requirements that attempt to safeguard against outages in local load pockets. Such outages may require generation within the load pocket itself. These load pockets exist when the transmission system is inadequate to support all of the loads in an area.

None of the reliability assessments discussed above considered local transmission constraints that may restrict the deliverability of power to such areas. SONGS is within the Los Angeles Basin load pocket, but Diablo Canyon is not in any local load pocket. Simply based on this classification, SONGS is more critical to reliability for most of Southern California than Diablo Canyon is to Northern California. More complete studies will be needed periodically to reassess the need for 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 transmission Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. During a year-long outage at Diablo Canyon, if replacement power is available, then it can be supplied to end-user loads without a disruption of the overall transmission system. Of course, such replacement power may come 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, is a more integral part of the Southern California transmission system, and when it is shut down, imported power flows are also restricted. These restrictions affect Southern California by limiting inputs from the Southwest, and also affect San Diego which is interconnected with the Los Angeles portion of the California ISO through the SONGS units. The SCIT (Southern California Import Transmission) nomogram, which is a California ISO operating procedure to assure grid reliability, is one of the mechanisms that recognizes the need for generation internal to Southern California in assuring stability of the system. Assuming replacement power for SONGS would be available (at similar costs and environmental impacts as for Diablo Canyon), a prolonged shutdown at SONGS 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.

The Energy Commission believes that improvements in planning and reliability assessments are needed to fully understand reliability risks and other consequences of lengthy, unplanned outages of the nuclear units.

Recommendations

- The existing California ISO-organized Stakeholder Study of Aging Power Plants and Once-Through Cooling Mitigation should be completed as quickly as feasible using sound analytic techniques, and the results should be closely reviewed to determine whether further studies are needed to understand the issues resulting from unplanned outages of Diablo Canyon and SONGS. To the extent such supplemental studies are needed, they should be commissioned and completed in a timely manner.
- The Energy Commission, CPUC, and California ISO should further evaluate the unique uncertainties of losing the electricity provided by Diablo Canyon and SONGS over an extended period, identify how resources might be acquired that have an energy supply capability beyond that used in normal market conditions, and modify the long-term planning and procurement process at the CPUC to ensure that these resources are acquired in a timely manner.

ECONOMIC, ENVIRONMENTAL, AND POLICY ISSUES

In 2003, California's principal energy agencies adopted a "loading order" that sets the framework for adding new energy resources to meet electricity use demands in the state. The loading order places first priority on improved energy efficiency, second priority on renewable resources, third on distributed generation (electricity produced close to where it is used), and fourth on clean fossil fuel generation.

One of the challenges in replacing the nuclear plants with alternative energy resources would be the different impacts of this decision on communities and regions throughout California. If the new energy resources were built in California, the total economic benefit from employment

and taxes statewide could be comparable to the benefits currently provided by the nuclear plants.[23]

Replacing the nuclear plants with renewable generating facilities would involve a transfer of economic benefits from the coastal communities near Diablo Canyon and SONGS to communities in inland southern California and other areas of the state rich in renewable resources. Recent announcements of several planned large-scale solar facilities in San Luis Obispo County suggest that the transfer of benefits away from the County could potentially be mitigated or offset by renewable power development in the area. In addition, the local economy could see gains from alternate uses of the plant site, other commercial or industrial development elsewhere in the county, and/or a potential increase in property values as a result of the plant closure. Without such potential offsets, the loss of Diablo Canyon 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.

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.[24] 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.

Recommendation

- As part of the license renewal feasibility studies for Diablo Canyon and SONGS, the CPUC should require PG&E and SCE to conduct a detailed study of the local economic impacts of shutting down the nuclear plants compared with alternate uses of the site.

NUCLEAR WASTE ACCUMULATION

Diablo Canyon and SONGS produce significant quantities of radioactive waste in the form of spent fuel and other radioactively contaminated materials. These wastes must be carefully handled, stored, transported, and disposed of to protect humans and the environment from exposure to radioactive materials. Spent nuclear fuel, which is extremely radioactive and

---

[23] A California law (AB 1451) that temporarily exempts certain renewable energy facilities from property tax assessments will reduce the tax revenue generated from these facilities.

[24] Diablo Canyon and SONGS are currently among the least-cost generation resources in the state since the significant costs to construct the plants (roughly five billion dollars for each plant) have been depreciated or passed on to shareholders, and the cost of nuclear fuel is much lower than the cost of fuel for fossil-fueled plants. More information on the historic and current costs of Diablo Canyon and SONGS can be found in Chapter 6 of *Nuclear Power in California: 2007 Status Report*, available at http://www.energy.ca.gov/2007publications/CEC-100-2007-005/CEC-100-2007-005-F.PDF. Please also see *Comparative Costs of California Central Station Electricity Generation Technologies, Final Staff Report*, California Energy Commission, Dec. 2007, CEC-200-2007-011-SF.

remains radioactive for hundreds of thousands of years, must be stored at the nuclear power plant in a spent fuel pool for a minimum of five years following removal from the reactor core to shield plant workers against high levels of radiation.

The federal Nuclear Waste Policy Act (NWPA) of 1982 made the federal government responsible for the permanent disposal of spent nuclear fuel and high-level waste. The 1987 amendment to this act required the U.S. Department of Energy (DOE) to start taking possession of the spent fuel no later than January 31, 1998, and instituted a quarterly fee on spent fuel generators (of 0.1 cents per kWh of nuclear power that they generate) to finance a federally controlled Nuclear Waste Fund to support federal spent fuel transport and disposal efforts. DOE missed the 1998 deadline, and DOE has not yet begun to take possession of the utilities' spent fuel. Plant owners thus continue to be responsible for the safe storage of their spent fuel. They also continue to contribute to the Nuclear Waste Fund. As of September 2008, the fund contained $31.4 billion, with $1.4 billion from California.[25]

The federal spent fuel disposal program is focused on the construction of a deep, underground permanent repository at Yucca Mountain in Nevada. The most optimistic estimate for when Yucca Mountain might begin operation is 2020, and that date could slip even further pending developments in the repository licensing proceeding, licensing requirements, and the outcome of legal challenges to the proposed repository. In the absence of a repository, California must plan for continued accumulation and interim storage of high-level radioactive waste at existing reactor sites, even though none of the sites were originally designed for such long-term storage. As previously discussed, lacking a federal spent fuel disposal repository, 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 has designed and permitted a dry cask storage facility for Diablo Canyon that will allow the utility to transfer most of the spent fuel produced during the current operating license. SCE has designed and permitted and is constructing a dry cask storage facility for SONGS with capacity to store 36 percent of the spent fuel generated during the current license period (with additional storage available in the SONGS spent fuel pool). Both utilities may need to develop additional on-site storage or secure offsite storage to store all the spent fuel that will be produced over the plants' current operating licenses. Sufficient land area is available for the utilities to develop more storage capacity.

In June 2008 the U.S. Department of Energy (DOE) filed a license application with the NRC for a permanent geologic repository for spent fuel at Yucca Mountain, Nevada. If the license is granted, Yucca Mountain will begin operations most likely after 2020, more than 20 years after the January 1998 statutory and contractual deadline for the federal government to begin

[25] Nuclear Energy Institute. "Nuclear Waste Fund Payment Information by State through Q3 FY 2008." September 2008. Accessed: October 8, 2008. <http://nei.org/filefolder/Nuclear_Waste_Fund_Payment_Information_by_State.xls>

accepting spent fuel from utilities. PG&E and SCE have sued DOE for reimbursement of their dry cask storage costs, claiming that this delay represents a breach of contract. PG&E received a favorable judgment that provides for reimbursement of certain dry cask storage costs while denying other claims. PG&E is currently appealing the decision. A trial date to hear SCE's claim has not been set.

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

If a federal repository is established, spent fuel will need to be packaged for transport, aging, and disposal (TAD) at a repository. DOE has proposed designing and developing a new TAD canister packaging system, but has not yet established federal TAD packaging requirements, forcing PG&E and SCE to move forward with dry cask storage cask designs that may not be compatible with the federal TAD requirements. The costs for transport of spent fuel to off-site storage or disposal facilities will be substantial, including costs for security, accident prevention, and emergency preparedness. Policies are being developed to federally fund state and county emergency response preparation for shipments to the proposed repository; however, California has claimed that the proposed federal program may be insufficient, both in the planned timing of the grant program and the amount of the proposed grants for state planning and for training emergency response personnel to respond to potential accidents involving California's spent fuel shipments.

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

Low-level waste disposal costs are relatively modest during ongoing plant operations. However, a substantial quantity of low-level waste will need to be disposed of when the plants are decommissioned, and the cost to transport and dispose of this waste, presuming a disposal facility is available, is expected to be hundreds of millions of dollars or more. A 2004 GAO

report concluded that low-level waste disposal cost has increased from $1 to $400 per square foot over the last 20 years and could exceed $1,000 per square foot.[26] These disposal costs can reach hundreds of millions of dollars for utilities that are decommissioning their nuclear power plants. Ratepayers of PG&E, SCE, and SDG&E contribute to decommissioning funds that will be used to pay these and other decommissioning costs. Every three years (most recently in 2005), the CPUC reviews expected decommissioning costs and adjusts ratepayer decommissioning fees, as needed, to ensure that decommissioning funds will be adequate. Low-level waste disposal costs have been rising in recent years, and costs may be substantially higher than estimated during the last CPUC review. An increase in ratepayer fees may be needed to accommodate these higher costs.

Recommendations

- During the upcoming California Public Utilities Commission proceeding on decommissioning costs, PG&E and SCE should provide estimates of the amounts of low-level waste to be generated and ultimately disposed of during plant operation and decommissioning and the cost of this disposal based on current and projected market prices.
- As part of license renewal feasibility studies, PG&E and SCE should assess the costs of disposing of low-level waste that will be generated during a 20-year license extension. The assessments should include the cost to dispose of low-level waste that would be generated from major capital projects that might be required over this period. PG&E and SCE should also provide information on their plans for storage and disposal of low-level waste and spent fuel through plant decommissioning.

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.

[26] GAO, "Low-Level Radioactive Waste: Disposal Availability Adequate in the Short Term

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, if their proximity to major faults is not a consideration.

Residents of San Luis Obispo County expressed a strong preference that the Diablo Canyon plant site be converted to recreational use, but PG&E has not identified any priorities as to future plans for the plant site. The SONGS plant site, which is located on military land, will remain under the control of the U.S. Navy. The Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use. As long as spent fuel remains stored at the SONGS site, an NRC license will be required.

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, Nunez, Chapter 488, Statutes of 2006), has mandated greenhouse gas reductions statewide. The California Air Resources Board, the California Public Utilities Commission, and the Energy Commission are integrating this mandate into the state's energy policies. As the Energy Commission stated in the *2007 Integrated Energy Policy Report*, "AB 32 forces California to determine how to meet its electricity needs in a way that leaves an ever-shrinking *greenhouse gas* footprint."[27]

As mentioned, state policy sets the following "loading order" for meeting California's growing energy demand while lowering greenhouse gas emissions: energy efficiency, renewable resources, and distributed generation.[28] Substantial economic, environmental, and regulatory barriers to developing new nuclear power plants in California mean that new nuclear plants cannot be relied on, at least in the near term, to meet California's AB 32 greenhouse gas emissions reduction goals for 2020.[29]

---

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

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

[29] New nuclear power plant construction in California was suspended in 1976 pending a determination by the Energy Commission that a high-level federal nuclear waste disposal repository has been approved and built. In the 2005 IEPR, the Energy Commission reaffirmed its finding made in 1978 that a "high-level waste disposal technology has been neither demonstrated nor approved." The 2007 IEPR further discusses the status of the federal waste disposal

In the long term, renewable resources could be suitable replacement power options if either Diablo Canyon or SONGS were to be shut down, assuming the resolution of key operational and cost issues. However, current renewable energy technologies cannot replace the operational characteristics of baseload nuclear plants. If either nuclear plant is shut down, ancillary services and regulating capability will most likely need to be increased. 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, sufficient planning, siting, and construction time would be needed to develop these resources and any necessary transmission infrastructure. Moreover, the costs to develop renewable power resources and develop the transmission infrastructure needed to access them 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. The total life cycle or so-called "cradle-to-grave" environmental impacts of alternative power generation technologies should be considered when evaluating alternative energy resource options. These life cycle impacts include facility construction, operation and decommissioning, fuel, and waste disposal. 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 adverse impacts, including impacts from nuclear waste storage, transport, and disposal and from a potential major plant accident or terrorist event. On the other hand, replacing power from Diablo Canyon and SONGS primarily with power from current renewable technologies could result in certain other environmental 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.

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

Local economic impacts of generating facilities can also be important factors in policy decisions about resource options. Replacing the nuclear plants with an equal mixture of in-state wind, solar thermal, geothermal, and biomass power could result in roughly the same overall tax and employment benefits to the state as provided by the nuclear plants. However, these benefits

---

and commercial reprocessing program and its implications for the California nuclear laws, See *2007 IEPR* on pages 67-69.. .

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 long-term outages or permanently retiring Diablo Canyon and SONGS.

Recommendation

- As part of license renewal feasibility studies for Diablo Canyon and SONGS, the CPUC should require detailed studies of alternative power generation options to quantify the reliability, economic, and environmental impacts of replacement power options.

LICENSE RENEWAL ISSUES FOR STATE POLICYMAKERS

Diablo Canyon and SONGS have been operating for approximately half of their 40-year initial license periods, and PG&E and SCE are exploring the feasibility of seeking 20-year license renewals for the plants.[30] If granted, license renewals could keep Diablo Canyon and SONGS in operation until the early to mid 2040s (Table 1).

Table 1: 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[31]	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

[30] Current NRC regulations allow reactors licenses to be extended for 20-year periods. The NRC is investigating the feasibility of a second 20-year license renewal option. U.S. Nuclear Regulatory Commission; See 10 CFR 54.31d and Federal Register Volume 56, No. 240, December 13, 1991, pp. 64965-64964.. "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.

[31] 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.

The NRC has given approval to extend the operations of approximately half of the nation's 104 commercial nuclear reactors (49 reactors) for 20 years beyond their original 40-year operating licenses and is reviewing license extension applications for another 19 reactors. To date, the NRC has not denied any license extension applications. The NRC license renewal process consists of a safety review, environmental review, plant inspections, and a separate review by the Advisory Committee on Reactor Safeguards.[32] The safety review focuses on the plant hardware and equipment and 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. Other issues, including examination of seismic hazards, operational issues, plant security, emergency preparedness, environmental review of spent fuel storage, and analysis of spent fuel storage options, are considered by the NRC to be outside the scope of license renewal. The NRC Office of the Inspector General completed an audit of the license renewal process in September 2007 and concluded that improvements were needed in NRC staff's support for conclusions in license renewal reports and audits (OIG-07-A-15).[33]

The role of the state in the license renewal decision is limited by the NRC's regulatory authority over all radiological safety aspects of nuclear power. However, the State has 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 after PG&E sought approval for $16.8 million in ratepayer funding for a license renewal feasibility study.[34] The CPUC approved the requested funding and required that PG&E incorporate the Energy Commission's AB 1632 assessment in its feasibility study and submit the study along with an application to the CPUC on whether to pursue license renewal no later than June 30, 2011.[35] The CPUC Decision states:

> *"To avoid unnecessary duplication and overlap with the CEC's study, PG&E should defer to the extent feasible its work on its own study, and associated spending, until after the CEC issues its findings and conclusions. PG&E should incorporate the findings and recommendations of the CEC study in its own work."*

The CPUC noted that the decision on whether to forgo license renewal for Diablo Canyon should be made in a CPUC proceeding or other appropriate venue and that PG&E license renewal feasibility study should be submitted to the CPUC for review in the year 2011, which is approximately 13 years before Diablo Canyon's license expires.

---

[32] 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.

[33] http://www.nrc.gov/reading-rm/doc-collectionsinsp-gen/

[34] The license renewal feasibility study consists of the following components: (1) screening Diablo Canyon's structures, systems, and components to determine if they are within the scope of a renewed license, (2) performing an aging analysis of plant systems and components to determine the need for additional monitoring programs, and (3) preparing a draft environmental impact report.

[35] CPUC Decision 07-03-044

The CPUC specified that the application should address: (1) whether license renewal is cost effective and in the best interests of PG&E's ratepayers, (2) the AB 1632 assessment, and (3) any legislative framework that may be established for reviewing the costs and benefits of license renewal. The CPUC said that PG&E's 2011 General Rate case will result in a decision on whether PG&E should pursue a license renewal and that the results of the proceeding will be incorporated into the Energy Commission's 2013 IEPR and the CPUC's 2014 long-term procurement plan (LTPP). This timeframe is intended to provide the state and PG&E with sufficient time (approximately 12 years) to develop alternate resources should the decision be made to forego Diablo Canyon license renewal.[36] PG&E said at the Energy Commission's October 20, 2008 AB 1632 workshop and in written comments that PG&E does not interpret CPUC directives as requiring PG&E to include in their study issues that are outside the scope of NRC's license renewal proceeding.[37] In addition, PG&E stated that many of the items that this Report recommends including in the license renewal feasibility study are already being addressed in ongoing programs under the existing plant operating license and are subject to NRC review. However, the CPUC's GRC 2007 decision clearly directs PG&E not only to defer to the extent feasible its own license renewal study until after the Energy Commission issues its AB 1632 findings and conclusions, it requires PG&E to incorporate the Energy Commission's AB 1632 Report's assessment, findings and recommendations into their license renewal feasibility study.

SCE requested approval of $17 million for a similar feasibility study for SONGS. A decision on this funding is expected in the coming months as part of SCE's 2009 General Rate Case. It can be expected that the CPUC will require SCE to seek CPUC approval before proceeding with an NRC license renewal application and incorporate the AB 1632 assessment, findings and recommendations, as required for PG&E.

If the CPUC determines that license renewal is not cost-effective for either Diablo Canyon or SONGS, 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.

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

---

[36] California currently plans for long-term power procurement through the CPUC biennial adoption of a rolling 10-year long-term procurement plan (LTPP). The purpose of the LTPP is to identify resource needs a decade in advance to provide sufficient time to plan for, and procure, new capacity in an orderly and cost effective manner. .

[37] Letter dated October 22, 2008, to Barbara Byron, Energy Commission, from Mark Krause at http://www.energy.ca.gov/ab1632/documents/2008-10-20_workshop/comments/

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

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

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

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

Recommendation

- To help ensure plant reliability, the Energy Commission, working with the CPUC as part of the CPUC's authority to fund and oversee utilities' plant relicensing feasibility studies, should develop criteria and issues that the utilities will be asked to address in their license renewal feasibility studies to ensure that utilities fully evaluate the costs and benefits of nuclear plant license extensions. Further, such studies should address the following important considerations: the adequacy of the plants' maintenance programs and safety cultures; plans for waste storage, transport and disposal; seismic hazard and vulnerability assessments; the life cycle or "cradle-to-grave" environmental and economic impact evaluation of the nuclear plants compared with alternative generating and transmission resources; contingency plans in the event the state's nuclear power

plants have prolonged outages; implications for grid reliability if these plants shut down; and the overall economic and environmental costs and benefits of license extension. The utilities should report on the status and results of their license renewal feasibility studies as part of the IEPR process, beginning with the 2009 IEPR.

ACRONYMS AND ABBREVIATIONS

AB	Assembly Bill
California ISO	California Independent System Operator
CO_2	Carbon Dioxide
Coastal Commission	California Coastal Commission
CPUC	California Public Utilities 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
EPRI	Electric Power Research Institute
FY	Fiscal Year
GHG	Greenhouse Gas
GNEP	Global Nuclear Energy Partnership
GPS	Global Positioning System
IAEA	International Atomic Energy Agency
IEPR	Integrated Energy Policy Report
INPO	Institute for Nuclear Power Operation
KK NPP	Kashiwazaki-Kariwa Nuclear Power Plant
km	Kilometer
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
LTPP	Long-term Power Procurement Plan
LTSP	Long-Term Seismic Program
LSE	Load Serving Entity
MSPI	Mitigating Systems Performance Index

MTU	Metric Tons of Uranium
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
NP26	North of Path 26
NPDES	National Pollution Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
OBE	Operating Basis Earthquake
PGA	Peak Ground Acceleration
PG&E	Pacific Gas & Electric
PWR	Pressurized Water Reactor
RCFZ	Rose Canyon Fault Zone
SCE	Southern California Edison
SCOFZ	South Coast Offshore Fault Zone
SDG&E	San Diego Gas & Electric
SMUD	Sacramento Municipal Utility District
SOx	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.

High-level waste – Highly radioactive nuclear waste from the reprocessing of spent fuel. Spent nuclear fuel, which is also highly radioactive, is sometimes called high-level waste.

Integrated Energy Policy Report - Senate Bill 1389 (Bowen and Sher, Chapter 568, Statutes of 2002) requires the Energy Commission, every two years with updates in alternate years, to "conduct assessments and forecasts of all aspects of energy industry supply, production, transportation, delivery and distribution, demand and prices." The Energy Commission uses these assessments and forecasts to develop energy policies that conserve resources, protect the environment, ensure energy reliability, enhance the state's economy and protect public health and safety.

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 waste that is not classified as high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material. Low-level waste is categorized as Class A, B, or C and Greater-Than-Class-C waste. The latter classes are the most radioactive and require the most rigorous disposal specifications.

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 – Nuclear plant 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 – Process used to calculate the probability that design basis earthquakes may occur and to predict how effectively a plant would respond.

Reserve margin – An indicator of the amount of electricity 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.

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.

Spent fuel – Irradiated or "used" fuel that is removed from nuclear reactors.

Strike-slip fault – Vertical (or nearly vertical) fracture where the blocks have mostly moved horizontally.

Thrust fault – A reverse fault with a dip of 45° or less.