NUCLEAR POWER IN CALIFORNIA: 2007 STATUS REPORT

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Abstract

This consultant report examines how nuclear power issues have evolved since publication of the consultant report, *Nuclear Power in California: Status Report,* which was prepared for the 2005 IEPR. The report focuses on four broad subject areas: 1) nuclear waste issues, 2) costs of nuclear power, 3) environmental and societal impacts of nuclear power, and 4) nuclear power in the U.S. in the coming years. Nuclear waste issues include the status of a federal repository at Yucca Mountain, the proposed federal reprocessing program, and issues related to the transportation of nuclear waste. The costs of nuclear power are addressed from three angles: the costs of operating California's current nuclear power plants, the costs of building and operating new nuclear power plants, and the cost implications of a "nuclear renaissance." Environmental and societal impacts discussed include the environmental implications of nuclear power, the role of nuclear power in climate change policy, and the security implications of nuclear power generation. Finally, the future of nuclear power is addressed by considering the safety and reliability of the aging U.S. nuclear fleet, license extensions that could keep the current fleet operating for an additional 20 years, and the development of new nuclear power plants in the U.S. The report concludes by offering potential implications for California from these events.

Keywords

nuclear, nuclear power, nuclear waste, spent fuel, Yucca Mountain, interim spent fuel storage, reprocessing, Global Nuclear Energy Partnership, uranium, enrichment, greenhouse gas, once-through cooling, license renewal, relicensing, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Humboldt Bay, Rancho Seco, SMUD, NRC, Nuclear Regulatory Commission, U.S. Department of Energy, DOE, electricity, policy, California

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EXECUTIVE SUMMARY

In the *2005 Integrated Energy Policy Report*, the California Energy Commission (Energy Commission) reviewed the status of nuclear power as an energy resource for California. Through this review, which was supported by a comprehensive status report and a two-day workshop that brought together a wide range of industry experts, the Energy Commission found, as it had in 1978, that a demonstrated technology for the permanent disposal or reprocessing of high-level waste does not yet exist. Consequently, according to California law, the Energy Commission could not provide land use permits or certification for a new nuclear power plant in California at this time.

In the *2005 Integrated Energy Policy Report*, the Energy Commission additionally made the following findings and recommendations related to nuclear power:

- Reprocessing remains substantially more expensive than waste storage and disposal and has substantial adverse implications for the U.S. effort to halt the proliferation of nuclear weapons.

- Some portion of the funds paid by California ratepayers for a permanent national repository should be returned to the state to help defray the cost of long-term on-site spent fuel storage.

- California should evaluate the long-term implications of the continuing accumulation of spent fuel at California's nuclear power plants.

- California should evaluate the U.S. Department of Energy's increasing use of California routes to transport nuclear waste to and from Nevada.

- California should reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments.

- The California Legislature should develop a suitable framework for reviewing the costs and benefits of nuclear plant license extensions and clearly delineate agency responsibilities, scope of evaluation, and the criteria for assessment.

Since the release of the *2005 Integrated Energy Policy Report,* a renewed interest in nuclear power has emerged in the U.S., driven in part by concern over greenhouse gas emissions and by considerable subsidies offered by the federal government for new nuclear power plants.

Nuclear Power in California

Nuclear power plants generate a significant share of California's electricity and provide significant benefits to the state. Nuclear power plants also impose significant costs, risks and impacts. This is the essence of the "Faustian Bargain" described by nuclear pioneer Alvin Weinberg in 1970. Weinberg called on his colleagues to "weigh, and reweigh...the other side of the balances: the risks in our energy source" (Weinberg 1994, p.175). California's policy toward nuclear power reflects its conclusions from weighing this balance, as California relies upon the state's operating reactors for a significant portion of its electricity supply, while prohibiting the construction of new reactors in the state until the Energy Commission makes certain findings concerning spent fuel disposal.

California relies today on three nuclear power plants for approximately 15 percent of the state's overall electricity supply:

- Diablo Canyon Power Plant: Pacific Gas and Electric owns and operates Diablo Canyon, which has a total generating capacity of 2,220 megawatts in two units. The Diablo Canyon facility is located near San Luis Obispo, along the coast between San Francisco and Los Angeles.
- San Onofre Nuclear Generating Station: Southern California Edison, San Diego Gas and Electric, and the City of Riverside are co-owners of the San Onofre Nuclear Generating Station, which is operated by Southern California Edison. The two operating units have a total capacity of 2,254 megawatts. The San Onofre Nuclear Generating Station is located near the boundary between Southern California Edison's and San Diego Gas and Electric's service territories near San Clemente, in southern California.
- Palo Verde Nuclear Generating Station: Palo Verde is co-owned by Arizona Public Service Corporation, Southern California Edison, and five other utilities. Arizona Public Service Corporation operates the plant. Palo Verde's three units have an overall capacity of 3,810 megawatts. Palo Verde is located near Phoenix in Wintersburg, Arizona. California utilities own 27 percent of the plant.

These plants have been operating for roughly 20 years and are licensed to continue operating for roughly another 15 to 20 years. They provide significant benefits to California in the form of resource diversity, low operating costs, relatively low greenhouse gas emissions, and enhanced grid reliability. There are also three retired nuclear power plants in California: Humboldt Bay, Rancho Seco, and San Onofre Nuclear Generating Station Unit 1.

Many U.S. nuclear power plant operators are seeking approval from the U.S. Nuclear Regulatory Commission for license renewals. These extensions could keep the aging fleet of U.S. nuclear power plants operating for an additional 20 years, with uncertain economic, environmental, and reliability implications. Pacific Gas and Electric, which owns and operates the Diablo Canyon Power Plant, is beginning a license renewal feasibility study for that plant.

It is against this background that this report has been prepared. The report, which is an update to the Energy Commission consultant report, *Nuclear Power in California: Status Report*, examines how nuclear power issues have evolved since 2005. It focuses on four broad subject areas: 1) nuclear waste issues, 2) costs of nuclear power, 3) environmental and societal impacts of nuclear power, and 4) nuclear power in the U.S. in the coming years. Potential implications for California are also discussed.

Nuclear Waste Issues

Three categories of nuclear waste issues are discussed: storage and disposal of spent fuel, reprocessing of spent fuel, and nuclear waste transport.

Storage and Disposal of Spent Fuel

In *Nuclear Power in California: Status Report* and the workshops for the *2005 Integrated Energy Policy Report,* it became clear that progress in designing and developing the Yucca Mountain waste repository has been and continues to be problematic.

In 1982 Congress passed the Nuclear Waste Policy Act, which led to the creation of a comprehensive national program to permanently dispose of spent fuel and high-level radioactive waste from commercial nuclear facilities and national defense programs. Under the Nuclear Waste Policy Act, as amended in 1987 to focus on the Yucca Mountain site in Nevada, the U.S. Department of Energy is responsible for funding and developing a permanent, deep geologic repository for spent fuel and high-level radioactive waste.

The U.S. Department of Energy was to begin accepting spent fuel for the repository by January 31, 1998. However, nearly 10 years after this deadline, a repository at Yucca Mountain is still more than a decade away from being opened, and the opening date continues to slip. As recently as 2005, the U.S. Department of Energy had been targeting a 2012-2015 opening date. However, the U.S. Department of Energy announced in 2006 that the earliest possible opening date is March 2017 and that a more realistic opening date is September 2020. The U.S. Department of Energy announced in 2007 that the opening date is likely to slip an additional year. The U.S. Department of Energy does not anticipate submitting a repository license application to the Nuclear Regulatory Commission until mid-2008.

In the *2005 Integrated Energy Policy Report*, the Energy Commission noted that “the federal waste disposal program remains plagued with licensing delays, increasing costs, technical challenges, and managerial problems” (Energy Commission 2005b, p.85). Significant and persistent concerns over quality assurance and legal challenges have contributed to these delays. For instance, site characterization work was suspended between 1989 and 1992 due to concerns over quality assurance. Thirteen lawsuits filed by the State of Nevada and environmental organizations requesting review of various licensing requirements and procedures were pending before the U.S. Circuit Court of Appeals for the District of Columbia in 2004.

The Energy Commission also noted in 2005 that “Californians have contributed well over $1 billion to the federal waste disposal development effort.” The Energy Commission recommended that some portion of these funds “be returned to the state to help defray the cost of long-term on-site spent fuel storage” and that the state “evaluate the long-term implications of the continuing accumulation of spent nuclear fuel at California’s nuclear plants” (Energy Commission 2005b, p.85).

Spent fuel disposal also remains a major stumbling block for the U.S. nuclear power industry. John Rowe, Chief Executive Officer of Exelon, the largest nuclear power operator in the U.S., told shareholders in 2006 that he does not want to build a new nuclear power plant until the spent fuel disposal issue is solved: "We have to be able to look the public in the eye and say, 'If we build a plant, here's where the waste will go.' If we can't answer that question honestly to our neighbors, then we're playing politics too high for us to be playing" (Fortune Magazine 2006).

There has been limited progress over the last two years in addressing the waste disposal problem:

- The U.S. Department of Energy released a new schedule in 2006 for licensing and constructing the repository. The U.S. Department of Energy now acknowledges that Yucca Mountain is not likely to open before 2020.
- In lawsuits against the U.S. Department of Energy seeking restitution for interim storage costs, Pacific Gas and Electric and Sacramento Municipal Utility were awarded about $40 million each in compensation for dry cask spent fuel storage costs.

There have also been setbacks for Yucca Mountain and new reasons for concern:

- The U.S. Environmental Protection Agency has yet to release final air regulations for the Yucca Mountain repository to replace the regulations that were remanded by the U.S. Circuit Court of Appeals in 2004. In 2006, the U.S. Environmental Protection Agency claimed that these regulations would be released by the end of that year.
- With the change in control of Congress following the 2006 election, legislative action has focused on alternatives to the near-term completion of Yucca Mountain.
- A private off-site interim storage option, proposed to be built in Utah, was denied critical permits and will likely not be built.
- U.S. Department of Energy efforts to spur construction of new nuclear power plants and to commercialize a new generation of reprocessing technology have raised concerns that the Yucca Mountain effort might suffer from insufficient management and other resources.

Given the lack of progress toward opening a permanent repository, increased attention is being paid to interim storage options, including at Yucca Mountain. Some long-standing proponents of Yucca Mountain, including U.S. Nuclear Regulatory

Commission Commissioner McGaffigan, have suggested that it is time to re-examine the alternatives to Yucca Mountain. New interim spent fuel storage installations have been or are being constructed at all the reactor sites serving California. Regional storage proposals are under consideration, although these are generally opposed by state governments.

Reprocessing of Spent Fuel

Under existing law California's moratorium on building new nuclear power plants will continue until a technology for the permanent disposal or reprocessing of spent nuclear fuel has been demonstrated and approved for use in the U.S. In 1978 the Energy Commission found that high-level nuclear waste disposal technology had not been demonstrated nor approved by the authorized federal agency, that technology for the reprocessing of spent fuel does not yet exist, and that reprocessing of light-water reactor spent fuel is not necessary if the spent fuel can be stored at the reactor site. In 2005 the Energy Commission reaffirmed this finding. As we noted in *Nuclear Power in California: Status Report*, the National Academies, the National Commission on Energy Policy, the Harvard University Project on Managing the Atom, and the Massachusetts Institute of Technology Interdisciplinary Study, *The Future of Nuclear Power*, had all concluded that reprocessing is both uneconomic and burdened by substantial proliferation concerns. The Energy Commission also concluded that reprocessing is more expensive than waste storage and disposal and has "substantial adverse implications for the U.S. effort to halt the proliferation of nuclear weapons." (Energy Commission 2005b, p.85)

In early 2006 the Bush administration and the U.S. Department of Energy proposed the Global Nuclear Energy Partnership with the goal of establishing a proliferation-resistant nuclear fuel cycle based around a newly established domestic reprocessing capability. This initiative marks a significant departure from long-standing U.S. policy discouraging or neglecting domestic commercial reprocessing. Beginning in the late 1970s the U.S. opposed reprocessing on the grounds that the spread of the technology facilitates the proliferation of nuclear weapons. The Global Nuclear Energy Partnership seeks to re-introduce spent fuel reprocessing with new technologies that will discourage the spread of nuclear weapons technology.

The Global Nuclear Energy Partnership remains undefined in key respects, and it is far from certain that the proposal will be sustained over the next several years or, if it were, that it would ultimately be successful. There is substantial opposition to the proposal. According to John Deutch, Institute Professor at the Massachusetts Institute of Technology, the program would add to the cost of nuclear power and would likely not be fully deployed until about 2150, "a very, very, very, very, very long time in the future" (Greenwire 2007a). If the Global Nuclear Energy Partnership were successful, California's moratorium on new reactor permitting and certification could require reexamination.

Nuclear Waste Transport

Radioactive waste transport in the U.S. has been common for decades. For example, spent fuel is shipped from research reactors and naval vessels to storage sites, and low-level radioactive waste is shipped from reactor sites and other sources to low-level waste facilities. These shipments provide a framework of experience on which to build in designing the program to bring spent fuel from reactor sites across the country to Yucca Mountain. Nevertheless, all of this experience combined pales in comparison to the volume of shipments that will be required for the Yucca Mountain shipping endeavor.

Considerable uncertainty remains concerning when shipments to Yucca Mountain will begin; however, there is agreement that shipments will not begin in the near term. Based on the U.S. Department of Energy's estimate that Yucca Mountain will open around 2020, shipments are not expected to begin until close to the expiration of the Diablo Canyon and San Onofre Nuclear Generating Station operating licenses.

The U.S. Department of Energy continues to plan for shipments of spent fuel to Yucca Mountain. The U.S. Department of Energy has selected a "mostly-rail" transport option, has announced plans to use "dedicated trains" with certain restrictions on shipments, has released a design for transport casks, and has been investigating routes for the Nevada rail spur. Potential routes being considered could result in a large number of shipments from eastern states being routed through California.

According to the National Academies, spent fuel transport need not be a risky operation if it is managed well. However, social impacts could ensue along transportation routes if the public lacks confidence in the U.S. Department of Energy's ability to develop a transportation plan and safely manage the program. These impacts could include lower property values, a reduction in tourism, and increased public anxiety.

California could be strongly affected, since many spent fuel shipments could be routed through the state en-route to Yucca Mountain. The *Integrated Energy Policy Report* recommended that California evaluate the U.S. Department of Energy's proposed use of California routes to transport nuclear waste to and from Nevada, and reexamine the adequacy of the state's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments. California has repeatedly expressed concerns to the U.S. Department of Energy over route selection and has requested that additional public meetings be held in the state; however, the U.S. Department of Energy has for the most part not been responsive to these concerns.

Low-Level Waste Storage

Low-level radioactive waste will not be stored at Yucca Mountain and low-level waste disposal is the responsibility of the utilities and the states. In the 1980s and 1990s California selected Ward Valley in the Mojave Desert as a site for a low-level waste facility; however, the site is located on federal land and the state was unable to purchase the site from the federal government. Currently, California utilities dispose of their low-level waste in facilities in South Carolina and Utah. Beginning in mid-2008 only the Utah facility will be available and only for the least radioactive grade of wastes. In the near term, once the South Carolina facility closes to California waste, California utilities will be forced to keep their low-level waste on-site. According to California's compact with other western states, California is to be the host site of any commercial low-level waste facility to be opened in the compact states.

Costs of Nuclear Power

Three types of costs are discussed: the costs of California's operating nuclear power plants, the cost to build new nuclear power plants, and the potential implications of a "nuclear renaissance" on the cost of nuclear power.

Costs of California's Nuclear Power Plants

The California Public Utilities Commission has used a combination of traditional ratemaking and incentive-based ratemaking to determine cost recovery for nuclear power plants. In general, incentive-based ratemaking methods are intended to shield ratepayers from cost overruns and poor operating performance. Incentive mechanisms have had a secondary impact of making it more difficult to determine in retrospect the true costs of these plants.[1]

The cost to operate the current plants includes both historic ("sunk") costs and the plants' going-forward costs. Major going-forward costs include large capital investments to replace faulty or degraded reactor components, and operating costs for nuclear fuel procurement and disposal, security, and decommissioning. These costs were reviewed in substantial detail in *Nuclear Power in California: Status Report*.

In general, the cost of power from California's nuclear power plants over the upcoming years should be driven largely by the cost of the steam generator replacement projects and by the extent to which additional large capital projects will be required as the plants age. Unexpected long-term outages and additional U.S. Nuclear Regulatory Commission security requirements could also impact overall costs.

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[1] For example, while we know that Pacific Gas and Electric ratepayers paid $34.3 billion (2006 dollars) for power from Diablo Canyon from 1985 through 2006, averaging $99.76 per megawatt-hour, we do not know if these payments cover (or exceed) Pacific Gas and Electric's costs.

New Plants: Range of Potential Costs

In the 1950s it was expected that nuclear power would be "too cheap to meter." In the 1980s nuclear power proved in many cases to be a significant financial burden. Today, with the high cost of natural gas, impending limitations on greenhouse gas emissions, and significant federal subsidies in the Energy Policy Act of 2005, some utilities are considering making another round of commitments to nuclear power. One of the fundamental but as yet unanswered questions is: what will be the cost of these new nuclear commitments?

Historic development costs for nuclear power plants were very uncertain and, for most of the plants that began operating after the Three-Mile Island nuclear accident, development was extremely expensive. Development costs for new power plants are even more highly uncertain, since there has been very little reactor development in the U.S. for the past 20 years. Reactor development projects require large capital investments and very long lead times, and they may be subject to considerable swings in public opinion. These factors all contribute to the risk involved in nuclear power plant development.

Estimates for the costs of new nuclear power plants are wide-ranging. On the one hand, there is concern that new reactor developers could face extreme cost overruns comparable to those experienced in the 1980s and 1990s, especially since no reactors have been built in the U.S. since that time. On the other hand, there is optimism that new technologies, federal subsidies, standardized reactor designs, and revised U.S. Nuclear Regulatory Commission licensing procedures will keep developers' costs down, especially given that the financial climate today is much better for large investments than the period of 14 percent inflation and 21 percent interest rates during which most of the current fleet of reactors was constructed.

Given these uncertainties, Dr. Paul L. Joskow, Director of the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research, has expressed guarded optimism about the future of nuclear power.[2] He concluded a December 2006 paper by noting that the "future for investment in new nuclear plants in the U.S. is brighter than it has been for many years;" however, "investment in new nuclear plants is likely to proceed more slowly than may be implied by the recent euphoria in the industry" (CEEPR 2006, p.19).

Companies considering nuclear power development are likewise remaining cautious, and they are focusing on risk mitigation strategies to contain their costs. Strategies include forming partnerships, entering into risk-sharing contracts with vendors and contractors, and obtaining cost-recovery assurance from regulators. Most regulators that have faced requests in recent years for nuclear power development cost-recovery assurance have provided only limited assurance.

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[2] Dr. Joskow is also Elizabeth and James Killian Professor of Economics and Management at the Massachusetts Institute of Technology.

Cost Implications of a "Nuclear Renaissance"

Revival of interest in nuclear generation is sometimes referred to as a "nuclear renaissance." Such a "renaissance" may pose cost implications for utilities that own nuclear power plants even if they do not build new reactors.

Prices for nuclear fuel have already risen sharply in anticipation of a large worldwide increase in demand. There are concerns over temporary fuel shortages should demand increase rapidly, as uranium supplies and enrichment capability have not been developed to meet the demands of a rapidly growing nuclear industry. In addition, the location of both uranium ore and existing enrichment capacity raises questions of availability to U.S. nuclear operators.

Shortages of key reactor materials could also develop. Globally, little production capacity remains for some of the highly specialized reactor components. An increase in demand could lead to shortages that could also impact owners of currently operating nuclear power plants that need to replace reactor components.

New reactor development could also increase the demand for skilled labor beyond the available supply. According to Tom Christopher of AREVA, the nuclear industry is an aging industry and will require 10,000 to 20,000 new people over the next four to five years (EIR 2006).

Environmental and Societal Impacts of Nuclear Power

In addition to explicit costs to developers and ratepayers, nuclear power also poses costs to society. Some of these costs arise from the environmental impacts and security risks associated with nuclear power.

Nuclear Power and the Environment

The past few years have seen a resurgence of interest in nuclear power as part of a response to concerns over greenhouse gas emissions and global warming. However, designating nuclear power as "clean" because of the low emissions directly associated with electricity generation is controversial. Nuclear power generation poses direct environmental risks, including aquatic impacts from once-through cooling; risk of groundwater contamination with tritium; radiation hazards associated with disposal of radioactive waste; and risks of radioactive releases triggered by earthquakes, tsunamis, accidents, or sabotage. Additional environmental impacts are associated with the full nuclear lifecycle, which starts with uranium mining and extends through reactor construction and operation to spent fuel storage/disposal or reprocessing and finally, decommissioning.

Nuclear power is seen by some as an important tool for reducing greenhouse gas emissions. Others argue that nuclear power should not have a role in greenhouse gas emissions reduction strategies; yet others take a cautious, middle-of-the-road approach and neither rule out nuclear power nor embrace it whole-heartedly.

Supporters and opponents of nuclear power both emphasize the importance of using a number of different technologies to combat global warming. Supporters argue that the urgent need to address climate change precludes closing off any major option, including nuclear power. Opponents argue that nuclear power development could slow down greenhouse gas emissions reductions by shifting investments away from low-greenhouse gas power alternatives, such as renewable energy and energy efficiency, which could be deployed more quickly and more cheaply than new nuclear reactors.

Ultimately, this debate over whether nuclear power should be part of a greenhouse gas reduction strategy is constrained by our limited knowledge of what other resources will be available. Consequently, the best path right now may to pursue all options and defer decisions until more is known, as stated by Harvard University Professor Dr. John P. Holdren:[3]

> [Society] might decide that the combination of improved energy efficiency, advanced fossil fuel technologies and renewable energy technologies of a variety of kinds can meet this [climate change] challenge without nuclear energy. My position is agnostic on this, we don't know yet what the best mix is, we should be trying to fix the problems of fission to see if we want it to be a part of this mix and at the same time we should be pursuing with tremendous vigor the possibilities available to us in improving energy efficiency in renewable energy options and in advanced fossil fuel technologies (ABC Radio 2002).

Security for Reactors and Spent Fuel

The protection of nuclear power plants and spent fuel storage facilities from land-based assaults, attacks by commercial aircraft, and other terrorist attacks has received considerable attention in the wake of the terrorist attacks of September 11, 2001. This heightened concern over security has been reinforced by the many extensions of operating reactors' licenses, a surge in interest in building new nuclear power plants, and growing stockpiles of spent fuel.

In 2004 the National Commission on Energy Policy made the following observation about nuclear safety and security:

> Nuclear power reactors of contemporary design have compiled an excellent safety record. If the number of nuclear reactors in the United States is to double or triple over the next 30 to 50 years, however, and the number worldwide is to grow ten-fold…one would want the probability of a major release of radioactivity, measured per reactor per year, to fall a further ten-

[3] Dr. Holdren is Teresa and John Heinz Professor of Environmental Policy and Director of the Program on Science, Technology, and Public Policy at the Kennedy School, as well as Professor of Environmental Science and Public Policy in the Department of Earth and Planetary Sciences at Harvard University.

> fold or more. This means improved defenses against terrorist attack as well as against malfunction and human error…License extensions for existing plants and the issuance of licenses for new plants should be contingent on the [the U.S. Nuclear Regulatory Commission's] affirmative judgment that that the plants…[are] adequately resistant to terrorist attack (NCEP 2004, pp.58, 60).

Over the past five years, the U.S. Nuclear Regulatory Commission has instituted a number of measures to improve the security of U.S. reactors. The agency struggles to balance the concerns of plant operators that additional security requirements are excessive and too costly with critics' concerns that the same requirements are inadequate. In addition, the U.S. Nuclear Regulatory Commission's process for determining which concerns need to be addressed and how they should be addressed has not always been transparent, even to governmental or quasi-governmental organizations such as the U.S. Government Accountability Office and the National Academies.

For example, the U.S. Nuclear Regulatory Commission has not explained why it rejected some of its staff's proposals for requiring reactors to be secured against certain types of attacks. Similarly, the U.S. Nuclear Regulatory Commission has not explained why the agency is confident that the current fleet of U.S. reactors would stand up to aircraft attacks with a very low probability of radiation release, while some professional studies appear to have come to very different conclusions. For instance, a 1982 report by Argonne National Lab concluded that aircraft crashes might subject nuclear power plants to numerous multiple failures that could lead to "total meltdown" even without damaging the containment structure. U.S. Representative Bart Gordon noted that while this report did not address plant design changes, it clearly showed that design changes could help mitigate the potential impact of aircraft hazards at nuclear power plants (Gordon 2006).

This secrecy, particularly with regard to the U.S. Government Accountability Office and the National Academies, has made it difficult for the U.S. Nuclear Regulatory Commission to develop public confidence in its actions regarding plant security. Indeed, critics and members of the public continue to question the adequacy of the U.S. Nuclear Regulatory Commission's security regulations.

Nuclear Power in the Coming Years

The continued use of nuclear power in the U.S. depends largely on three factors: the reliability of the current fleet of reactors, how many of these reactors continue to operate past their initial operating license periods, and whether new reactors are built.

Reliability of U.S. Nuclear Power Plants

The aging of the U.S. fleet of nuclear power reactors presents challenges in terms of the reliability, safety and performance of nuclear power plants. In recent years, U.S.

nuclear power plants have proven to be reliable generation sources, with an average availability rate of 90 percent in 2006. However, some plants have experienced significant difficulties and poor availability. In all, of the 130 power reactors ever licensed in the U.S., 41 have had at least one outage lasting a year or more.

In addition, industry critics argue that the current reactor oversight process is ineffective at spotting and preventing problems before they require expensive repairs and extended shutdowns. If their concerns are correct, reliability levels at a plant could plummet with little warning at any time, as they did at Davis Bessie in 2002 and at Palo Verde beginning in 2003.

The Future of Nuclear Power in the U.S.

Commercial nuclear power is riding a wave of renewed interest and support in several arenas. Many owners of nuclear power plants are pursuing license renewals, which will allow their plants to continue operating for an additional 20 years. In addition, a number of Bush administration policy initiatives and the financial incentives included in the Energy Policy Act of 2005 have resulted in consideration by U.S. utilities for building new nuclear power plants.

The U.S. Nuclear Regulatory Commission license renewal process focuses on ensuring that the aging of plant components will not degrade reactor safety and that significant environmental impacts will not ensue from the license renewal. Cooling water impacts are among the environmental impacts considered by the U.S. Nuclear Regulatory Commission. However, some other issues of concern to the State of California, such as seismic safety and terrorist risks, are not considered, and the State has only a limited role within the proceeding. The State can have a role in determining whether or not a utility applies for or uses an extended operating license. For example, the California Public Utilities Commission has ruled that Pacific Gas and Electric, which has begun a license renewal feasibility study, must apply to the California Public Utilities Commission for permission before applying for a license renewal.

Alongside these activities, the first new U.S. reactors in 30 years are being planned, and research is underway to improve the economics, performance, and safety of the next generation of nuclear reactors. If instead no new reactors are built, the last units in the U.S. nuclear fleet will cease operating by 2056, even if all currently operating reactors receive 20-year license renewals.

Implications for California

Following are some preliminary assessments for consideration by the Integrated Energy Policy Report Committee of how the state may be impacted by the events described in this report and how the state and the Energy Commission might respond. These preliminary assessments are intended to provide starting points for consideration by the public and Commissioners. All parties are encouraged to submit comments on this draft report and their own proposed assessments to the Integrated Energy Policy Report Committee.

New and Existing Nuclear Power Plants in California

The legislature should develop a suitable framework for reviewing the costs and benefits of nuclear power plant license extensions and clearly delineate agency responsibilities, scope of evaluation, and the criteria for assessment.

The Energy Commission is not likely to receive a license application from Pacific Gas and Electric or Southern California Edison or from a third party group for the construction of a new nuclear power plant in California in the next two years. In light of California's moratorium on nuclear power development, until progress is made in disposing of or reprocessing spent fuel, the Energy Commission could not provide land use permits or certification for such a power plant at this time. It is unlikely that the Energy Commission will be able to provide land use permits or certification for a new nuclear power plant in California in the near future.

Spent Fuel Reprocessing and Implications for California

At this time the Energy Commission can conclude that reprocessing is still substantially more expensive than waste storage and disposal and that is still has substantial implications for U.S. efforts to halt the proliferation of nuclear weapons material.

The Energy Commission should continue to monitor the federal reprocessing initiative.

Waste Storage and Disposal and Implications for California

At this time the Energy Commission cannot conclude that the U.S. Department of Energy will ever succeed in opening the permanent repository at Yucca Mountain. Until a permanent repository at Yucca Mountain or at an alternative location either begins operation or can be credibly expected to begin operation using a demonstrated disposal technology, the Commission cannot find that the federal government has approved and that there exists a demonstrated technology for the permanent disposal of spent fuel from these facilities. The U.S. Department of Energy's failure to license and operate a permanent repository has imposed substantial costs on California's consumers who have paid over a billion dollars to the federal government for this service and have had to incur the costs of building and operating interim fuel storage facilities.

The Energy Commission should continue to monitor the federal high-level waste disposal and spent fuel storage and management programs with regard to their implications for California and the moratorium on new nuclear power permitting and certification in the state.

California has limited options for the storage and disposal of low-level nuclear wastes. California utilities may need to permanently store low-level nuclear wastes at the coastal sites of their nuclear power plants.

Consequences of Failure to Develop Yucca Mountain

The State should encourage the utilities to continue to seek damages from the U.S. Department of Energy to recover all costs related to interim waste storage.

The State should monitor the developments at the Diablo Canyon interim spent fuel storage facility and the likelihood that the facility operation will be delayed for an extended period.

The State should consider the implications of disputes regarding the vulnerability of spent fuel pools and interim spent fuel storage facilities to terrorist attack, and encourage the U.S. Nuclear Regulatory Commission to work with the National Academies' panel of experts to resolve these concerns. The State should also consider other means to ensure that a study of the implications of terrorism is performed, such as a request to the Department of Homeland Security or the U.S. Government Accountability Office.

Spent Fuel Transportation

The State should evaluate the U.S. Department of Energy's increasing use of California routes to transport nuclear waste to and from Nevada.

The Energy Commission should continue its participation in collaborative processes at the national and regional level regarding spent fuel transportation to ensure that the State's interests are represented. The Energy Commission should also continue to coordinate the California Interagency Transport Working Group to plan, prepare, and initiate state needs assessments for spent fuel and other large radioactive shipments in California.

The Energy Commission should continue to participate in the U.S. Department of Energy's route selection and transportation planning proceedings.

As recommended in 2005, the State should reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments.

The State should continue to work with other states to ensure that the U.S. Department of Energy provides states with the support that they need to prepare for shipments and establishes flexible procedures.

Environmental Impacts of Nuclear Power Plants

As part of the state policy reducing greenhouse gas emissions, the Energy Commission should examine the policy implications of lifecycle greenhouse gas assessments for energy technologies, including nuclear power. The State, in conjunction with other western states, should also decide what role imported or in-state nuclear power can play in a low-greenhouse gas emissions portfolio.

The Energy Commission should continue to assess the reliability implications of federal and state once-through cooling regulations.

Reliability of California's Nuclear Power Plants

California utilities should be directed to develop power supply contingency plans in the event that performance degradation at the state's nuclear power plants leads to prolonged plant outages.

Potential Expansion of Nuclear Power

The State should continue to monitor the status of the U.S. Department of Energy's programs that support new nuclear power development and the cost and progress of new reactor development in the U.S. When more information is available, the State should seek to determine the fuel cycle costs and performance of advanced nuclear reactors.

CHAPTER 1: INTRODUCTION

Over the last few years, a renewed interest in nuclear power has emerged in the U.S. This interest has been driven by volatility and overall increases in natural gas prices, concern over greenhouse gas (GHG) emissions, and increased subsidies offered by the federal government for new nuclear power plants. Many operating nuclear power plants are nearing the ends of their licenses and have received or are seeking approval from the U.S. Nuclear Regulatory Commission (NRC) for license renewals. If approved, these extensions will keep the aging fleet of U.S. nuclear power plants operating for an additional 20 years.

In the 1970s utilities in California, as in the rest of the country, embarked on an ambitious program of nuclear development. Against a backdrop of rapid increases in electricity demand, utilities projected a near-term need for over 50 new nuclear power plants in the state. However, safety and reliability concerns, concern over the disposal of radioactive waste that could harm future generations, and the financial burden of substantial construction cost overruns for building nuclear power plants contributed to an erosion of support for nuclear power development (Wellock 1998, pp.148-149). In 1976 California passed legislation that prohibits land use permits and certification for any new nuclear power plants in California until the California Energy Commission (Energy Commission) finds that the federal government has demonstrated, that the U.S. authorized agency has approved, and that there exists a technology for the permanent disposal or reprocessing of spent fuel from these facilities (PRC 25524). After extensive public hearings, the Energy Commission determined in 1978 that neither spent fuel disposal nor reprocessing technologies met the required standard, effectively placing a moratorium on the construction of nuclear power plants in California (Energy Commission 1978). The Energy Commission reevaluated the state of these technologies in 2005 and reaffirmed its 1978 finding (Energy Commission 2005b, p.E-4).

Background

The Energy Commission has the responsibility to prepare and adopt a biennial *Integrated Energy Policy Report* (IEPR) that contains "an overview of major energy trends and issues facing the state, including, but not limited to, supply, demand, pricing, reliability, efficiency, and impacts on public health and safety, the economy, resources, and the environment" and that presents "policy recommendations based on an in-depth and integrated analysis of the most current and pressing energy issues facing the state" (PRC 25524; SB 1389 2002).

As part of the development of the 2005 IEPR, the IEPR Committee began a comprehensive assessment of the status of currently operating nuclear power plants in California; the status of federal spent fuel storage, disposal, and reprocessing programs; and the potential role of nuclear power in California's energy future. The Committee issued a consultant's report, *Nuclear Power in California: Status Report* (*2005 Status Report*), and held two days of public workshops to receive input from a broad range of experts on nuclear power (Energy Commission 2006e).[4] Based upon this information, the Committee made the following findings (Energy Commission 2005b, pp.84-86):

- A demonstrated technology for the permanent disposal or reprocessing of spent nuclear fuel does not yet exist. Consequently, the Energy Commission could not provide land use permits or certification for a new nuclear power plant in California at this time.

- Reprocessing is more expensive than waste storage and disposal and continues to have implications for U.S. nonproliferation efforts.

- California needs a comprehensive assessment of the implications of indefinitely relying on at-reactor interim spent fuel storage and should evaluate the viability of centralized interim fuel storage proposals.

- California should evaluate whether the fees it charges for the transport of spent fuel through the state are sufficient to cover its costs, and the state should continue to participate in collaborative processes at the national and regional level to ensure that the state's interests are adequately represented.

- The California utilities should coordinate their plant outages to assure adequate resource availability during the replacement of the nuclear power plants' steam generators.

- California should continue to monitor the status of U.S. Department of Energy (DOE) programs for the development of advanced nuclear technologies.

Since the publication of the 2005 IEPR, market, regulatory, and legal developments have taken place that will continue to affect the cost, safety and reliability of nuclear power plants. For example, the Energy Policy Act of 2005 (EPAct) established subsidies for new nuclear power plants, and several U.S. utilities and consortia are now pursuing such plants. In California, replacement of the steam generators at the San Onofre Nuclear Generating Station (SONGS) and Diablo Canyon has been approved, and construction of an Independent Spent Fuel Storage Installation at Diablo Canyon has begun. In Arizona, the Palo Verde Nuclear Generating Station has been plagued by operational problems (ACC 2006b, p.9; NRC 2007s). While the federal government continues to struggle to develop and license a geological repository for high-level nuclear waste at Yucca Mountain, DOE has initiated a major new program to develop "proliferation-resistant" spent fuel reprocessing technologies.

In addition, many U.S. nuclear power plant operators are seeking approval from the NRC for license renewals. These extensions could keep the aging fleet of U.S. nuclear power plants operating for an additional 20 years, with uncertain economic

[4] The 2005 IEPR and the *2005 Status Report* are available at the Energy Commission's Web site: http://www.energy.ca.gov.

and reliability implications. Pacific Gas and Electric (PG&E), which owns and operates the Diablo Canyon Power Plant, is beginning a license renewal feasibility study for that plant.

It is against this background that this update to the *2005 Status Report* has been prepared. The report examines how nuclear power issues have evolved since 2005, focusing on four broad subject areas: 1) nuclear waste issues, 2) costs of nuclear power, 3) environmental and societal impacts of nuclear power, and 4) nuclear power in the U.S. in the coming years. Potential implications for California are also discussed.

Methods

The information presented in this draft report was drawn from the research and studies of many other individuals, organizations, government agencies, and universities. Much of the California-specific information was drawn from regulatory filings, regulatory agency reports, the 2005 IEPR workshop on nuclear issues, and responses to the Energy Commission's data requests to nuclear power plant operators on nuclear issues. In addition, interested parties are invited to submit written comments on this draft report, and workshops will be held at the Energy Commission in June 2007 to elicit the perspectives of experts on nuclear issues. Information gathered in the workshops and written comments received by 5 p.m. on July 13, 2007 will be considered in the development of the final report.

Report Structure

The report is structured as follows:

- Background
    - Chapter 1 provides an introduction to the report.
    - Chapter 2 provides an overview of the benefits and risks of California's nuclear power plants and the regulatory structures overseeing these plants.
- Nuclear Waste Issues
    - Chapter 3 reviews the status of proposals for the storage and disposal of spent fuel and high-level waste.
    - Chapter 4 examines the context for the federal government's reprocessing-related research activities and the implications of a domestic reprocessing program.
    - Chapter 5 examines issues related to the transport of spent fuel and low-level radioactive waste from reactor sites.
- Costs of Nuclear Power
    - Chapter 6 reviews the costs of California's operating nuclear power plants.

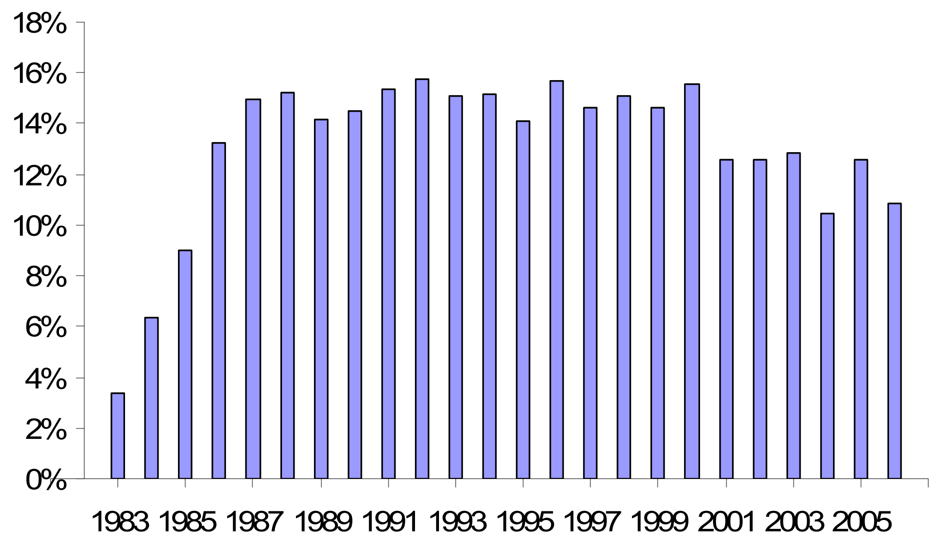
- Chapter 7 investigates the costs to construct and operate new nuclear power plants and strategies to mitigate the risks associated with these costs.
- Chapter 8 evaluates the implications of a possible nuclear renaissance on the costs to construct and operate nuclear power plants.

- Environmental and Societal Impacts of Nuclear Power
  - Chapter 9 examines the environmental impacts of nuclear power.
  - Chapter 10 evaluates the security of nuclear power plants.
- Nuclear Power in the U.S. in the Coming Years
  - Chapter 11 investigates safety, reliability, and performance issues related to aging nuclear power plants.
  - Chapter 12 assesses the future of nuclear power in California and the U.S., including efforts to extend the operating licenses of existing nuclear power plants and to construct new nuclear power plants.
- Implications for California
  - Chapter 13 suggests possible implications for California from the events discussed in this report.

CHAPTER 2: NUCLEAR POWER IN CALIFORNIA

Nuclear power plants generate a significant share of California's electricity (see Figure 1) and provide significant benefits to the state. Nuclear power plants also impose significant costs, risks, and impacts. This is the essence of the "Faustian Bargain" described by nuclear pioneer Alvin Weinberg in 1970. Weinberg called on his colleagues to "weigh, and reweigh…the other side of the balances: the risks in our energy source" (Weinberg 1994). California's policy toward nuclear power reflects its conclusions from weighing this balance, as California relies upon the state's operating reactors for a significant portion of its electricity supply, while prohibiting the construction of new reactors in the state until the Energy Commission makes certain findings concerning spent fuel disposal.[5]

Figure 1: Share of California Power Generated by Diablo Canyon and SONGS[6]



Source: (Energy Commission 2003a; Energy Commission 2007c)

This chapter provides an overview of the status of nuclear power in California. It begins with an introduction to California's nuclear power plants and then discusses the benefits that these plants provide and the costs, risks and impacts that they

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[5] The full title of the 2005 IEPR is *2005 Integrated Energy Policy Report*. The full title of the *2005 Status Report* is *Nuclear Power in California: Status Report*. Both reports are available at the Energy Commission's Web site: http://www.energy.ca.gov.

[6] Imported nuclear power contributed an additional 2 percent to California's gross system power in each of 2004, 2005, and 2006 (Energy Commission 2007b).

impose. Finally, it provides a summary of the federal and state agencies that are responsible for overseeing the safety and reliability of these plants.

More information about the issues addressed in this chapter may be found in the *2005 Status Report*.[7]

California's Nuclear Power Plants

California relies on three nuclear power plants for approximately 15 percent of the state's overall electricity supply (Energy Commission 2007c).

- Diablo Canyon Power Plant: PG&E owns and operates Diablo Canyon, which has a total generating capacity of 2,220 megawatts (MW) in two units. The Diablo Canyon facility is located near San Luis Obispo, along the coast between San Francisco and Los Angeles.
- San Onofre Nuclear Generating Station (SONGS): Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), and the City of Riverside are co-owners of SONGS, which is operated by SCE. (SCE acquired the City of Anaheim's 3.16 percent ownership share effective December 29, 2006.) (SCE 2006a) The two operating units (Units 2 and 3) have a total capacity of 2,254 MW. SONGS is located near the boundary between SCE's and SDG&E's service territories near San Clemente, in southern California.
- Palo Verde Nuclear Generating Station: Palo Verde is co-owned by Arizona Public Service Corporation (APS), SCE, and five other utilities. APS operates the plant. Palo Verde's three units have an overall capacity of 3,810 MW, which makes Palo Verde the largest power plant in the U.S. (APS 2007b). Palo Verde is located near Phoenix in Wintersburg, Arizona. California utilities own 27 percent of the plant.

These plants have been operating for roughly 20 years and are licensed to continue operating for roughly another 15 to 20 years. (See Table 1.) They provide significant benefits to California in the form of resource diversity, low operating costs, and enhanced grid reliability. In addition, there are three retired nuclear power plants in California: Humboldt Bay, Rancho Seco, and SONGS Unit 1.

[7] The final consultant's report is published on the Energy Commission's Web site: http://energy.ca.gov/2006publications/CEC-150-2006-001/CEC-150-2006-001-F.PDF.

Table 1: Operating Nuclear Power Plants that Serve California

Plant	Unit	Size	California Ownership	Date Commercial Operation Began	Expiration of Current License
Diablo Canyon	Unit 1	1087 MW	PG&E	May 7, 1985	Nov. 2, 2024[8]
	Unit 2	1087 MW		Mar. 15, 1986	Aug. 26, 2025
SONGS	Unit 2	1070 MW	SCE (78.2 percent), SDG&E (20 percent), City of Riverside (1.8 percent)	Aug. 8, 1983	Feb. 16, 2022
	Unit 3	1080 MW		Apr. 1, 1984	Nov. 15, 2022
Palo Verde	Unit 1	1243 MW	SCE (15.8 percent), SCPPA (5.9 percent), LADWP (5.7 percent)	Jan. 28, 1986	Dec. 31, 2024
	Unit 2	1243 MW		Sep. 19, 1986	Dec. 9, 2025
	Unit 3	1247 MW		Jan. 8, 1988	Mar. 25, 2027

Source: (PNM 2005; EIA 2005)

Benefits of Nuclear Power

Nuclear power provides significant benefits to the state of California, such as the following:

- Nuclear power plants provide approximately 15 percent of the state's electricity (Energy Commission 2007b).
- The operating costs of nuclear power plants are lower than the operating costs of natural gas fired plants (MIT 2003, p.136).
- The directly emitted greenhouse gases (GHG) from nuclear power plants are negligible.
- Using nuclear power enhances the state's fuel diversity and reduces demand for natural gas.
- The SONGS units enhance the reliability of the state's transmission grid.

An overview of these benefits is provided below. This overview is based on the discussion provided in the *2005 Status Report*.

Contribution to Electricity Supply

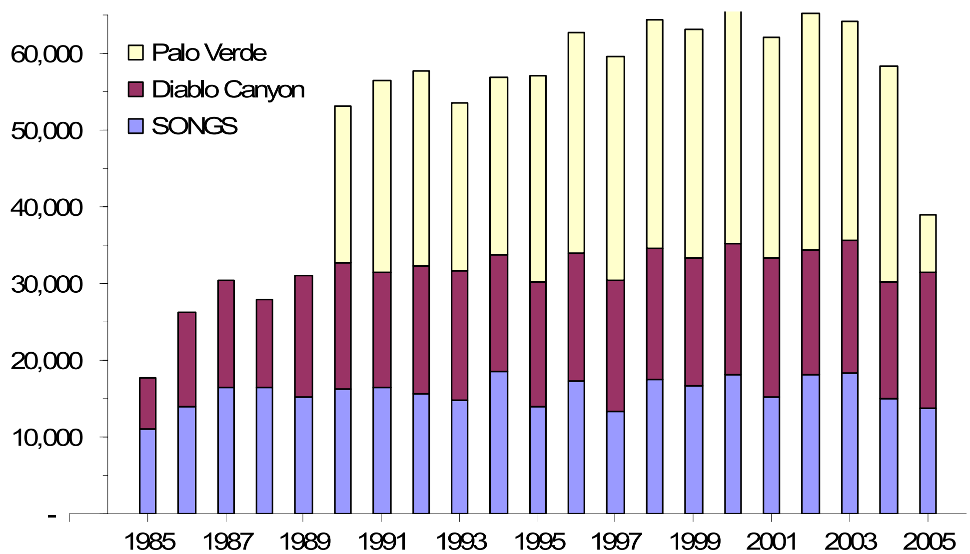
Nuclear power's contribution to the state's electricity supply comes from both the energy generated and the capacity added to the system. In terms of energy, nuclear

[8] On July 17, 2006 the NRC extended the operating licenses of the Diablo Canyon units by the amount of time that had been spent on low-power testing prior to the units' initial startup (license recapture) (NRC 2006b).

power provided over 36,000 gigawatt-hours (GWh) of power to Californians in 2005 (Energy Commission 2007b). The value of this energy can be estimated based on the cost to replace it when the plants are shut down. PG&E estimates that it spent over $675 million in replacement power costs between 2001 and 2006 during the 9,687 hours that one or both of the Diablo Canyon units were not operating, or an average of $66 per megawatt-hour (MWh). This amount is close to double the $35 per MWh rate that PG&E customers paid for Diablo Canyon power during this period (PG&E 2007b, M1, I1, I2).

Figure 2: Electricity Generation by Nuclear Power Plants Serving California

(Millions of kilowatt-hours (kWh), exclusive of plant use)



Source: (APS 2005b; NEI 2005; PG&E 1985-2004; SCE 1985-2004)

PG&E and SCE estimated the costs of replacement power for their respective plants as part of recent regulatory proceedings to approve steam generator replacement projects. PG&E estimated that permanently shutting down the two Diablo Canyon units in 2013 and 2014 would cause it to incur about $3.1 billion (2003 dollars) of replacement power costs through 2025. SCE estimated that permanently shutting down the two SONGS units in 2009 would cause it to incur about $5.2 billion (2004 dollars) in replacement power costs through 2022 (PG&E 2004b, p. 6-2; SCE 2004, p.34). Some interveners argued that the utilities exaggerated these figures. Based upon the evidence presented in these proceedings, the California Public Utilities Commission (CPUC) found the net present value of an $815 million steam generator replacement project at Diablo Canyon to be between $47 million and $678 million, and the net present value of a $748 million steam generator replacement project at

SONGS to be between $(11.2) million and $166.6 million.[9] Most of this value arises from the avoidance of replacement power costs (PG&E 2004b, p. 6-2).

The value of California's nuclear power could increase over the upcoming decade, as demand for electricity is projected to increase during this period. For example, the Energy Commission found in the 2005 IEPR that overall demand in California is expected to increase between 1.2 percent and 1.5 percent annually through 2016, with peak demand increasing between 1.4 percent and 1.75 percent annually (Energy Commission 2005b, pp.47-48). In addition, the U.S. Energy Information Administration (EIA) forecasted in February 2007 that in the Pacific region, which includes California, Oregon, Washington, Alaska, and Hawaii, electricity consumption will increase by over 46 percent between 2005 and 2030 (EIA 2007, table 74). If California's operating nuclear power plants are shut down, additional capacity will need to be developed to replace the lost capacity from the plants and to meet increasing demands for electricity.

Grid Reliability

In 1999 and 2000, the California Independent System Operator (CA ISO) investigated the role that Diablo Canyon and SONGS play in maintaining grid reliability. The CA ISO found that SONGS provides substantial grid reliability benefits as a result of its location between SCE's and SDG&E's service territories. Moreover, significant transmission reinforcements would be needed if SONGS were shut down. The CA ISO found that Diablo Canyon, on the other hand, does not provide a similar grid reliability benefit (CA ISO 1999; CA ISO 2000).

The grid reliability benefits of SONGS and Diablo Canyon will be reevaluated by the Energy Commission in a report to be prepared pursuant to California Assembly Bill 1632, signed by Governor Schwarzenegger in September 2006. This bill requires that the Energy Commission compile and assess existing scientific studies "to determine the potential vulnerability, to a major disruption due to aging or a major seismic event, of large baseload generation facilities, of 1,700 megawatts or greater…[including] an analysis of the impact of a major disruption on system reliability, public safety, and the economy" (AB 1632 2006).

Greenhouse Gas Benefits

Fossil-fueled power plants emit carbon dioxide and other pollutants as a byproduct of combustion. Other emissions from fossil fuel combustion, such as nitrogen oxides and particulates, cause environmental degradation, health problems, and other damage to society. In contrast, nuclear power plants emit very few GHGs or other pollutants while generating power. Thus, nuclear generation results in a net reduction of air emissions compared to a scenario in which existing nuclear

[9] The CPUC also found that the GHG benefits of nuclear power would add an additional net present value benefit of between $257 million and $308 million to the SONGS project. This benefit is not included in the figures presented in the text (CPUC 2005a, p.11; CPUC 2006c, p.8).

generation is replaced by either existing or new fossil-fired generation. The combined annual value of the GHG emissions reductions arising from Diablo Canyon's and SONGS' operation is estimated to be approximately $148 million in 2009; the value would rise to approximately $254 million in 2020.[10]

However, although nuclear power does not emit GHGs during plant operation, the overall nuclear fuel cycle does result in GHG emissions. These emissions are less (per unit of power output) than the emissions produced by gas, oil, and coal-fired generation, but they are greater than the emissions produced by some renewable technologies and energy efficiency. Nuclear power's lifecycle GHG emissions are discussed further in Chapter 9.

Fuel Diversity

Nuclear power provides a fuel diversity benefit that counterbalances over-reliance on any single fuel source. Natural gas-fired plants currently provide more than 40 percent of California's power in a typical year, and recent generation additions in the state have been predominately natural gas-fired plants (see Figure 3) (Energy Commission 2007b). California Senate Bill 1368, passed in 2006, could perpetuate this trend because it restricts the development of power plants that emit more GHG than a combined cycle natural gas-fired plant. The objective of the legislation is to encourage the development of energy efficiency, renewable energy, and demand response.[11] However, by using gas-fired power plants as the benchmark, it leaves the door open to further development of gas-fired power. Given the growing reliance on natural gas-fired power in California, nuclear power can provide a significant fuel diversity benefit to customers as a hedge against natural gas price increases. It can also reduce the cost of natural gas by reducing demand for the product.

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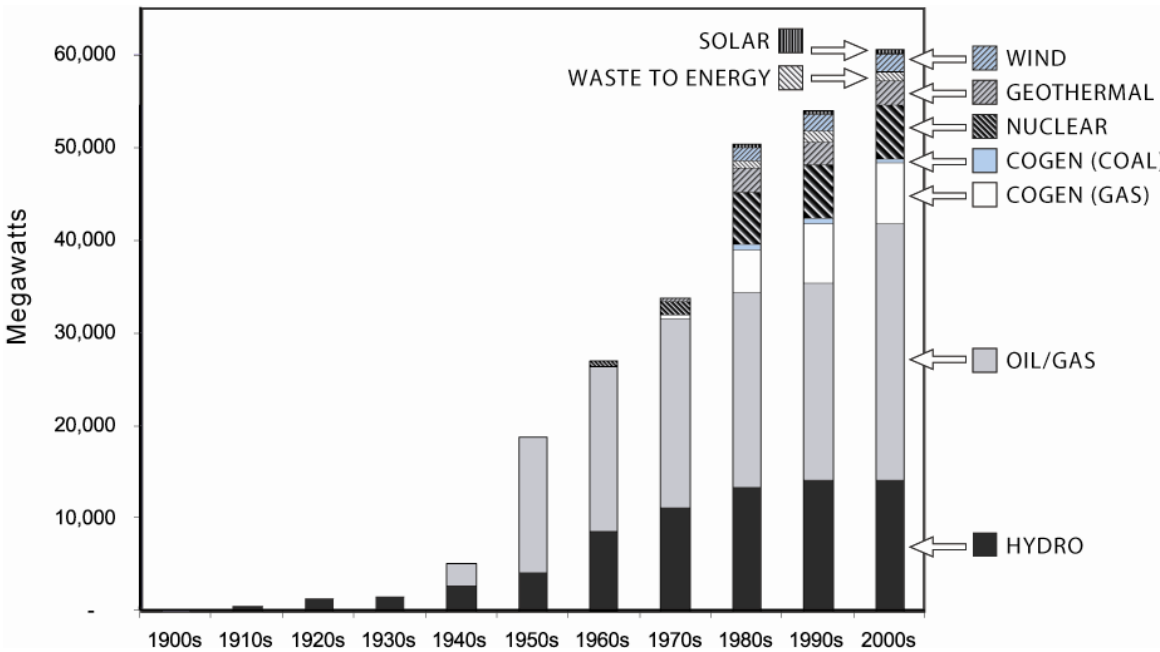
[10] In D.05-04-024 the CPUC adopted the GHG adders found in an October 2004 report prepared by Energy and Environmental Economics Consulting Group (EEECG 2004) which increase from $10.21 per ton of CO_2 in 2009 to $19.25 per ton of CO_2 in 2022. These rates were also used in D.06-11-024. The calculation of the emissions benefits of Diablo Canyon and SONGS is based on the assumption that power from these plants would be replaced completely by gas-fired combined cycle generation with an average emissions rate of 53 grams per thousand BTU and an average heat rate of 7,500 BTU per kWh (CPUC 2006c, pp.3-4; EPA 2007c, pp.3-12).

[11] Energy efficiency, renewable energy, and demand response are high in the loading order adopted by the state's energy agencies as part of the Energy Action Plan (Energy Commission 2005c).

Figure 3: Cumulative Generating Capacity in California by Fuel Type



Source: (Energy Commission 2005a, p.27)

Costs, Risks, and Impacts of Nuclear Power

Reliance on nuclear power also presents significant costs and risks. Costs and risks arise from the radioactive waste that is generated from nuclear power plant operation, the large upfront capital investments that are required for plant construction, the limited global experience with aging reactors, and the safety, security, and environmental impacts associated with the nuclear fuel cycle and the plant's operation. The National Commission on Energy Policy (NCEP) found that managing the most significant of the risks of nuclear power would be a prerequisite to any substantial expansion of nuclear power use in the U.S.[12] These risks are introduced below and are discussed in greater depth throughout the remainder of this report.

Nuclear Waste

Nuclear waste is a radiological hazard that poses health and safety risks to society. Spent fuel from nuclear reactors is highly radioactive, and the federal government is ultimately responsible for disposing of this material. The government has been investigating Yucca Mountain in Nevada as a possible disposal site.[13] However, it seems unlikely at this time that a facility will open prior to 2021. Indeed, given

[12] The National Commission on Energy Policy focused on the challenges associated with cost, terrorist attacks or accidents, radioactive waste disposal, and proliferation risks (NCEP 2007, p.21).

[13] For more information on these topics, see Chapters 3, 4 and 5.

significant political opposition and a history of delays, there is some uncertainty as to whether a facility will ever be opened (LVRJ 2006b; DOE 2007c, p.3). In the interim, the nuclear power plant-owning utilities are responsible for temporarily storing the spent fuel that their reactors generate.

The continued storage of spent fuel at reactor sites imposes additional radiological risks on the utilities and, in California, keeps coastal lands adjacent to spent fuel storage facilities inaccessible to the public (Energy Commission 2005f, p.37). In addition, for owners of non-operational plants, on-site fuel storage presents a barrier to full decommissioning of the plant and site clean-up. For these reasons, NCEP found that "a new generation of nuclear reactors is unlikely to be built in the United States unless and until nuclear power plant owners (largely electric utilities) and the public are persuaded that the government is able to meet its obligation, under existing law, to take possession of and adequately sequester the highly radioactive spent fuel from reactor operations" (NCEP 2007, p.58).

Low-level radioactive waste is also a by-product of nuclear power generation.[14] The disposal of low-level waste is a state, not a federal, responsibility (NRC 2007l). Currently, there is only one facility that will accept all but the least radioactive of nuclear waste from California. This facility, located in South Carolina, will be closed to California and most other states beginning July 1, 2008, after which time the utilities will need to store this waste on-site (NRC 2007l).

Financial Costs

The costs of nuclear power include construction and start-up costs, operating and maintenance costs, fuel costs, major capital projects, security, waste management, and decommissioning.[15] In addition, the nuclear insurance industry is set up using mutual insurance, which makes all owners of nuclear power plants liable to contribute funds in the event of an accident at any U.S. plant. Thus, the financial risks of nuclear power include contributions for clean-up costs in other regions.

Uncertainty over future fuel prices, regulatory requirements, capital costs, repair needs, responsibilities under the mutual insurance provisions, and the availability of fuel and skilled labor creates wide variations in the estimated levels of the costs of nuclear power. Moreover, the nuclear industry has a history of substantial cost over-runs and unexpected capital repairs, including the costly replacement of steam generators at Diablo Canyon, SONGS, and Palo Verde that were supposed to have lasted the entire lifetime of the reactors.

An important issue for regulators is to determine how these risks are shared between shareholders and ratepayers. For example, ratepayers will be responsible

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[14] Low-level waste includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. The radioactivity can range from just above background levels found in nature to very highly radioactive (NRC 2007l).

[15] For more information on these topics, see Chapter 7.

for $706 million to replace the steam generators at Diablo Canyon and $680 million to replace the steam generators at SONGS (CPUC 2005a, pp.2-3; CPUC 2005b, pp.2-3). The CPUC has shielded ratepayers from significant cost over-runs by capping ratepayers' share of expenses at the project costs that have been estimated by the reactor owners.

Performance Issues

As mentioned above, California's operating nuclear reactors make up a significant share of the state's baseload capacity, which is relied upon for satisfying the daily power demands of residents and businesses. Their reliability is important for the availability of power, though they have limited ability to vary their level of operation to follow load.[16]

There is reason for concern that these plants may become less reliable as they age. A 2004 study by the Union of Concerned Scientists (UCS) described the risk profile over a reactor's life with a bathtub-shaped curve—high risk during the initial break-in phase, lower risk during the middle life phase, and higher risk during the wear-out phase (UCS 2004, pp.1-2). As shown in Table 2, in recent years the reliability of Diablo Canyon, SONGS, and Palo Verde has been uneven. Palo Verde's performance in particular has degraded significantly since 2002, when it had a 94 percent capacity factor.[17] In fact, during 2006, Palo Verde Unit 1 had a capacity factor of just 42 percent (NEI 2007d). In addition, as mentioned above, the steam generators at many light water reactors, including Diablo Canyon and SONGS, have degraded prematurely, and the plants will require extended outages so that replacements can be installed.

Table 2: Capacity Factors of Nuclear Power Plants that Serve California

	Diablo Canyon	SONGS	Palo Verde
2002	86%	96%	94%
2003	91%	97%	87%
2004	80%	80%	84%
2005	93%	98%	77%
2006	97%	72%	81%
5-year average	*89%*	*89%*	*85%*

Source: (NEI 2007d; PG&E 1989-2004; SCE 1995-2004)

Moreover, events at other reactors may impact the operations of California's nuclear power plants. A major accident at a reactor could create political pressure to shut

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[16] Reliability issues are discussed further in Chapter 11.

[17] Capacity factor is a measure of the availability of the reactor. It is calculated as the megawatt-hours of generation divided by the product of the rated capacity (in megawatts) and the number of hours in the period.

down California's plants, and, if damage is found at any nuclear reactor, the NRC could require California's reactors to undergo additional inspections and possible modifications. This occurred in March 2002 when a large cavity was found by chance in the reactor pressure vessel head at the Ohio Davis-Besse Nuclear Power Station. As a result of this discovery, 29 reactors, including the California reactors, had to have their reactor vessel heads replaced at an estimated cost of $25 million each (NEI 2003).

Societal Impacts

There are a number of health and environmental impacts to society from nuclear power production, such as:

- Nuclear power production in California relies on once-through cooling, which has been found to have significant impacts on the local marine environment (Energy Commission 2005a, p.93).
- The nuclear fuel cycle results in radioactive releases and the emissions of greenhouse gases and other pollutants.
- Mining and milling uranium can have significant impacts on the local environment, miners and local inhabitants.
- Sabotage or a terrorist attack against a nuclear power plant or spent fuel pool poses risks of widespread radiation contamination. Accidents, large earthquakes, and tsunamis may pose similar risks.
- Nuclear proliferation continues to be a concern associated with nuclear technology. Uranium enrichment facilities, needed to produce uranium fuel, can also be used to enrich uranium for nuclear weapons development, while plutonium in spent fuel can be extracted for use in a nuclear weapon.

The environmental impacts of nuclear power are discussed further in Chapter 9, and the security risks associated with nuclear power are discussed further in Chapter 10.

Federal vs. State Jurisdictional Roles

Oversight of nuclear power plants is provided by a number of federal and state agencies. The NRC has sole jurisdiction over all radiological aspects of nuclear power production; however, state governments retain jurisdiction over other aspects of nuclear power production. The Supreme Court explained the federal and state jurisdictional responsibilities as follows: The "federal government maintains complete control of the safety and 'nuclear' aspect of energy generation; the states exercise their traditional authority over the need for additional generating capacity, the type of generating facilities to be licensed, land use, ratemaking, and the like" (PG&E v. Energy Commission 1983).

Within California, several state agencies participate in the licensing or regulation of different aspects of nuclear power:

- The Energy Commission is responsible for the non-radiological aspects of siting new plants of 50 megawatt (MW) or larger, including economic and non-radiological safety concerns (PRC 25524); also, as discussed above, no new nuclear power plant in California will be permitted land use or be certified by the Energy Commission until the Energy Commission makes certain findings about the availability of a means for the permanent disposal of high-level nuclear waste.
- Regional Water Quality Control Boards administer the National Pollution Discharge Elimination System (NPDES) permits. These permits address impacts associated with the discharge of pollutants and impacts due to the use of once-through cooling.
- The California Coastal Commission (CCC) has jurisdiction over all development in a coastal zone, except for thermal power plants under the Energy Commission's jurisdiction. With respect to those power plants, the CCC provides the Energy Commission with specific provisions to meet the objectives of the state's Coastal Management Act. The Energy Commission includes these provisions in its final decision on an application unless it finds that adopting the provisions would result in greater environmental harm or that the provisions would not be feasible.
- Once a plant has been built by one of the state's investor-owned utilities, the California Public Utilities Commission (CPUC) determines the appropriate level of revenue requirement, approves major capital expenditures, and determines how these revenue requirements and any operational risks should be allocated among ratepayers and shareholders. The CPUC also determines revenue requirements for decommissioning activities. For existing nuclear facilities (licensed by the CPUC before the Energy Commission's creation), the CPUC is the lead agency for environmental reviews of major capital projects to be conducted at the reactors, unless the result is an increase of 50 megawatts or more in generating capacity. In that case, the Energy Commission would have jurisdiction.

The oversight provided by these agencies aims to limit the costs to ratepayers and to society of California's nuclear power plants, while enabling the state to continue to benefit from these plants. A number of aspects of this oversight are discussed below: the adequacy of NRC oversight is discussed in Chapters 10 and 11, efforts by the CPUC to limit economic risk to ratepayers are discussed in Chapter 6, and efforts by Regional Water Quality Control Boards to limit or mitigate impacts of the plants on nearby marine environments are discussed in Chapter 9.

CHAPTER 3: STORAGE AND DISPOSAL OF SPENT FUEL

In the *2005 Status Report* and the 2005 IEPR workshops it became clear that progress in designing and developing the Yucca Mountain waste repository had been and continues to be problematic. In 1982 Congress passed the Nuclear Waste Policy Act (NWPA), which led to the creation of a comprehensive national program to permanently dispose of spent fuel and high-level radioactive waste from commercial nuclear facilities and national defense programs.[18] This law is based upon the principle that the generation benefiting from nuclear power is responsible for the safe disposal of the nuclear waste that it creates (DOE 2007d). Under the NWPA, as amended in 1987 to focus on the Yucca Mountain site in Nevada, the DOE is responsible for funding and developing a permanent, deep geologic repository for spent fuel and high-level radioactive waste. DOE was to begin accepting spent fuel for the repository by January 31, 1998 (42 USC 10101). However, nearly 10 years after this deadline, a repository at Yucca Mountain is still more than a decade away from being opened. Moreover, the repository opening date slipped by roughly five years over the past two years, and it continues to slip. DOE does not anticipate submitting a repository license application to the NRC until mid-2008 (DOE 2006h).

In the 2005 IEPR, the Energy Commission noted that "the federal waste disposal program remains plagued with licensing delays, increasing costs, technical challenges, and managerial problems" (Energy Commission 2005b, p.85). Significant and persistent concerns over quality assurance and legal challenges have contributed to these delays. For instance, site characterization work was suspended between 1989 and 1992 due to concerns over quality assurance. Thirteen lawsuits filed by the state of Nevada and environmental organizations requesting review of various licensing requirements and procedures were pending before the U.S. Circuit Court of Appeals for the District of Columbia in 2004 (NEI v. EPA 2004; GAO 1988, pp.204; GAO 2004b).

The Energy Commission also noted in 2005 that "Californians have contributed well over $1 billion to the federal waste disposal development effort" (Energy Commission 2005b, p.85). The Energy Commission recommended that some portion of these funds "be returned to the state to help defray the cost of long-term on-site spent fuel storage" and that the state "evaluate the long-term implications of the continuing accumulation of spent nuclear fuel at California's nuclear plants" (Energy Commission 2005b, p.85).

The delay in opening the federal repository remains a major stumbling block for the U.S. nuclear power industry. John Rowe, CEO of Exelon, the largest nuclear power operator in the U.S., told shareholders in 2006 that he does not want to build a new

[18] The NWPA definitions of high-level waste and spent nuclear fuel are presented in Figure 4.

nuclear power plant until the spent fuel disposal issue is solved: "We have to be able to look the public in the eye and say, 'If we build a plant, here's where the waste will go.' If we can't answer that question honestly to our neighbors, then we're playing politics too high for us to be playing" (Fortune Magazine 2006).

However, there has been limited progress over the last two years in addressing the waste disposal problem:

- In 2006 DOE released a new schedule for licensing and constructing the repository. DOE now acknowledges that Yucca Mountain is not likely to open before 2020.
- A number of bills aimed at facilitating progress on the repository were discussed in Congress in 2006.
- In lawsuits against DOE seeking restitution for interim storage costs, PG&E and the Sacramento Municipal Utility District (SMUD) were awarded about $40 million each in compensation for dry cask spent fuel storage costs.

There have also been setbacks for Yucca Mountain and new reasons for concern:

- The U.S. Environmental Protection Agency (EPA) has yet to release final air regulations for the Yucca Mountain repository to replace the regulations that were remanded by the U.S. Circuit Court of Appeals in 2004. In 2006, it was claimed these regulations would be released by the end of that year.
- With the change in control of Congress following the 2006 election, legislative action has focused on alternatives to the near-term completion of Yucca Mountain.
- A private off-site interim storage option, proposed to be built in Utah, was denied critical permits and now will likely not be built.
- Increasingly, proposals related to Yucca Mountain include provisions for interim storage. Several of these proposals would require interim storage facilities in California. Focus on interim storage could remove political impetus from the Yucca Mountain effort and further delay the development of a permanent repository.
- DOE efforts to spur construction of new nuclear power plants and to commercialize a new generation of reprocessing technology have raised concerns that the Yucca Mountain effort might suffer from insufficient management and other resources.

This chapter begins by discussing regulatory, legal, and legislative developments relating to the Yucca Mountain repository and the implications for California of the repository. It then discusses the status of interim spent fuel storage construction at the California reactors and the suits filed against DOE seeking restitution for interim storage costs. Finally, it discusses proposals for centralized interim storage and responses to these proposals.

Figure 4: NWPA Definitions Related to Radioactive Waste

High-level radioactive waste: The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Commission determines requires permanent isolation.

Low-level radioactive waste: Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material.

Spent nuclear fuel: Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Repository: Any system licensed by the Commission that is intended to be used for, or may be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel, whether or not such system is designed to permit the recovery, for a limited period during initial operation, of any materials placed in such system. Such term includes both surface and subsurface areas at which high-level radioactive waste and spent nuclear fuel handling activities are conducted.

Source: (42 USC 10101, pp.1-4)

Status of the Proposed Federal Repository at Yucca Mountain

Over the last few years, the Yucca Mountain repository project has had a mixture of encouraging news and setbacks. In July 2004, the U.S. Circuit Court of Appeals upheld nearly all of DOE's requirements and procedures that had been under question in the 13 repository-related lawsuits that it heard (NEI v. EPA 2004). However, the Court remanded the EPA's radiation protection standards, and, as discussed below, the EPA has not yet released its revised standards. In addition, in March 2005 a series of e-mails written by U.S. Geological Survey (USGS) scientists working on the Yucca Mountain project raised new questions about DOE's quality assurance program (LVRJ 2005). DOE investigators concluded that there had been deficits in quality assurance reporting but found that the USGS scientists' results were reproducible and that their conclusions were sound.

During the first half of 2006 prospects for developing a repository at Yucca Mountain seemed to be improving. First, Edward Sproat was confirmed in May as director of DOE's Office of Civilian Radioactive Waste Management (OCRWM), which oversees the Yucca Mountain project (DOE 2006m). Referring to Sproat and his colleagues, outgoing NRC Commissioner McGaffigan said that "DOE has the best people they have ever had running this program" (Energy Daily 2007a). Then in July, DOE announced a new schedule for Yucca Mountain that called for DOE's submission to NRC of a license application for the repository by June 30, 2008, with a targeted opening of the repository on March 31, 2017 (DOE 2006h). Finally, several legislative proposals to support the development of Yucca Mountain, including one proposed by DOE, were debated by Congress during the first nine months of 2006. However, as discussed below, the repository opening date has continued to slip, and none of these legislative proposals were called for a vote.

The political climate for Yucca Mountain changed after the November 2006 midterm elections, which installed long-time Yucca Mountain opponent Senator Harry Reid of Nevada as Senate Majority Leader. While it remains to be seen whether Reid and the Nevada congressional delegation can “significantly slow, if not completely kill, Yucca Mountain,” as Reid proclaimed, debate on Yucca Mountain has shifted since November 2006 (Reid 2007). Recent legislative and policy proposals have included interim storage and other waste management options that could be used along with or in place of Yucca Mountain. (See Figure 5 and the section *Offsite Interim Spent Fuel Storage Proposals* below.

Figure 5: National Commission on Energy Policy Recommendations

NCEP’s most recent recommendations on nuclear power focus on ways to break through the current impasse on nuclear waste disposal while continuing to make progress on the siting and development of one or more secure geologic disposal facilities. In particular, NCEP recommended that the NWPA be amended to meet the following objectives:

- Align its requirements with human engineering and scientific capabilities, while adequately protecting public health and safety and the environment.
- Require DOE to site and operate consolidated national or regional interim storage options.
- Require that research and development be undertaken to explore technological alternatives to the direct geologic disposal of waste that 1) meet commercial requirements and non-proliferation objectives, 2) reduce the challenge of waste disposal, 3) ensure adequate protection of public health and safety, and 4) extend fuel supply.
- Codify that interim storage and federal responsibility for disposal of nuclear waste is sufficient to satisfy the NRC’s waste confidence requirement.
- Require the Secretary of Energy to take possession of and/or remove fuel from reactor sites that have been, or are in the process of being fully decommissioned.

Source: (NCEP 2007)

DOE's Expected Timeline

There are three critical milestones for the proposed Yucca Mountain repository: the regulatory review and licensing of the repository, the construction of the repository, and finally the period during which spent fuel is moved to the repository from nuclear power plants. Delays in achieving the first milestone ripple through the overall timeline and affect the second and third milestones.

DOE plans to submit a Yucca Mountain license application to the NRC by June 30, 2008, which is two years later than had been planned in 2005. (See Table 3.) (Energy Commission 2006e, p.100) DOE also plans during 2008 to complete the Supplemental Environmental Impact Statement (EIS) for Yucca Mountain, design the canisters to be used to ship spent fuel to the repository, issue the final EIS for the Nevada Rail Line, and deliver a report to Congress on the need for a second repository (DOE 2007c, pp.1-2). In addition, DOE plans to certify its collection of licensing support documents. As of June 2007, DOE has already released 3.4 million support documents to the public, more than seven months before the required date.[19] This early disclosure is reportedly a response to a threatened lawsuit by the State of Nevada, which had been concerned that disclosure of these documents in December would not have provided Nevada officials with sufficient time to adequately review the documents (E&E 2007).

Table 3: Yucca Mountain Repository Licensing Schedule

Design for License Application Complete	30 November 2007
Licensing Support Network Certification	21 December 2007
Supplemental EIS Issued	30 May 2008
Final License Application Verifications Complete	30 May 2008
Final Rail Alignment EIS Issued	30 June 2008
License Application Submittal	30 June 2008
License Application Docketed by NRC	30 September 2008

Source: (DOE 2006f)

As recently as 2005, DOE had been targeting a 2012-2015 opening date for the Yucca Mountain repository (Energy Commission 2006e, p.100). However, DOE announced in 2006 that the best-achievable schedule now calls for the repository to open by March 2017 (See Table 4). This schedule assumes that legislation is passed that would streamline regulatory requirements and ensure financing for the repository (discussed below) and that there will be no further delays due to litigation or legislative processes. DOE's Edward Sproat recently reported to Congress that a "one year slip is likely" in the best-achievable schedule due to lower than requested FY 2007 funding for the project (DOE 2007c, p.3). In late 2006 Sproat told a nuclear

[19] DOE is required to release its support documents and certify the document collection six months prior to submitting a repository license application. The deadline for document release according to the proposed application date of June 30, 2008 would be on December 21, 2007 (DOE 2007f).

studies panel of the National Academies of Science that because of anticipated lawsuits a more realistic opening date for the repository is September 2020 (LVRJ 2006b).

Table 4: Best-Achievable Repository Construction Schedule

Start Nevada Rail Construction	5 October 2009
Construction Authorization from NRC	30 September 2011
"Receive and Possess" License Application Submittal to NRC	29 March 2013
Rail Access In-Service	30 June 2014
Construction Complete for Initial Operations	30 March 2016
Start up and Pre-Op Testing Complete	31 December 2016
Begin Receipt (Best-Achievable Schedule)	31 March 2017
Begin Receipt (More Likely Schedule)	September 2020

Source: (LVRJ 2006b; DOE 2006f)

The most recent schedule given by DOE as to when it would accept spent fuel from commercial nuclear power plants was published in July 2004 and assumed that spent fuel shipments would begin in 2010 (OCRWM 2004, p.2). This schedule is clearly out of date, and it is unclear at this time whether DOE still plans to follow the sequence and rate of acceptance shown in the 2004 schedule. If DOE follows the 2004 schedule but with shipments beginning in 2020 instead of 2010, DOE will begin to accept spent fuel from California nuclear power plants between 2020 and 2027. (See Table 5.)

Table 5: Yucca Mountain Spent Fuel Acceptance Schedule

Adjusted for 10-Year Delay

Spent Fuel Source	First Shipment	Final Shipment
Humboldt Bay	2020	2022
SONGS Unit 1	2020	post-2029
General Atomics	2020	2029
Rancho Seco	2023	2028
SONGS Units 2 & 3	2027	post-2029
Diablo Canyon	2027	post-2029

Source: (OCRWM 2004)

However, shipments of spent fuel could be delayed until the early 2030s. DOE officials outlined before Congress in 2006 “a three-step repository strategy where, with the legislation enacted, the repository would first receive high-level waste from the naval reactor program; second, spent fuel from decommissioned sites; and, third, spent fuel from operating facilities. The last step was projected in the late 2020s” (Energy Daily 2007c). According to this schedule, if the repository opening is delayed until September 2020, spent fuel from operating reactors will not begin to be accepted into Yucca Mountain until the early 2030s. Completion of all shipments is expected to take at least 24 years (OCRWM 2002, p.5).

Legal and Regulatory Developments

Over the past two years, there have also been several legal and regulatory developments related to Yucca Mountain. These developments represent both progress and setbacks for the Yucca Mountain project. In fact, the delay in the EPA's publication of air regulations for Yucca Mountain could impact the repository licensing schedule. Below are discussions of four major developments.

EPA Air Quality Regulations

Under the NWPA, the EPA is charged with establishing standards for allowable releases of radioactive materials from Yucca Mountain (42 USC 10101). In June 2001 the EPA released its standards limiting exposure. Per the regulation, for 10,000 years after the repository's closure, the maximally exposed individual outside of the repository could receive up to 15 millirem (mrem) per year (U.S. Senate 2006b, p.20). In 2004 the U.S. Circuit Court of Appeals for the District of Columbia remanded that standard, ruling that the 10,000-year compliance period is not "based upon and consistent with" the findings and recommendations of the National Academies and that it therefore violates Section 801 of the Energy Policy Act (NEI v. EPA 2004). The EPA proposed a revised rule in 2005 that would limit radiation doses to the maximally exposed individual to 15 mrem per year for the first 10,000 years and 350 mrem per year after that out to one million years (U.S. Senate 2006b, p.21). The EPA held hearings and received public comments on the proposed standard and continues to consider these public comments. (See Figure 6.) The final EPA standards have not yet been released (EPA 2007d).

USGS Data Falsification

As noted in the *2005 Status Report,* (Energy Commission 2006e, p.17) there have been reported problems with data integrity related to scientific studies on water infiltration rates through geologic formations at Yucca Mountain. DOE recently released the report of a root cause analysis team that investigated whether scientists falsified Yucca Mountain water infiltration quality assurance data (DOE 2007m). The team reviewed over 900,000 e-mails and 7,000 documents from a 24-year period, as well as modeling software, model reports, and scientific notebooks. The team found that while some quality assurance data did not meet traceability and transparency requirements, there was no evidence of falsification. Moreover, DOE was able to reproduce all of the infiltration model results (DOE 2007m, p.v). The team concluded that the e-mails suggesting that data was being falsified were written by "a small group of USGS employees" and that they appear "to represent frustration with work pressures" (DOE 2007m, p.vi). It also found that DOE "was not completely effective in managing the application of quality assurance requirements" and that this "contributed to poor work practices and indicated weaknesses in the implementation of quality assurance by the USGS infiltration group" (DOE 2007m, p.vi).

Figure 6: Senate Hearing on the EPA's Proposed Standard

In March 2006, the Senate held a hearing on the EPA's proposed rules. A significant point of contention at this hearing was the adequacy of the 350 mrem standard for the period between 10,000 and one million years after closure. Senator Barbara Boxer of California cited an analysis done by Thomas Cochran of the NRDC that shows that the 350 mrem standard would create a one in five risk of increased fatal cancer for the general population and a one in four risk for women. David Moeller, former president of the Health Physics Society, questioned this figure. According to his estimates the 350 mrem standard would increase the probability of cancer by about half of 1%. Bill Wehrum of the EPA noted that the 350 mrem standard represents less radiation than present naturally in other parts of the country.

There was also some contention at the hearing over the validity of having different standards for different time periods. Paul Golan of DOE supported this approach, stating that a "rule with two compliance periods recognizes the limitations of bounding analyses, the greater uncertainties at the time of peak risk, as well as the lessened precision and calculated results as time and uncertainties increase." However, John Ensign of Nevada was skeptical:

> This rule, on its face, I believe doesn't make sense, and the closer one looks, the worse it appears. The EPA found itself in a very difficult position. The original EPA Yucca rule had been thrown out by a Federal Court, which found its 10,000 year compliance period was not consistent with the recommendations of the National Academy of Sciences. The EPA could have simply modified its rule by extending it to cover the time of peak radiation exposure as required by the Court. We know why the EPA did not do this. It didn't do this because Yucca Mountain could not be engineered to meet [the] standard. Yucca Mountain could not be built if that was the case. So, instead of putting forth a common sense solution, the EPA proposed the weakest peak dose standard in the world, a proposal opposed by the National Council of Radiation Protection. Again, when it comes to Yucca Mountain, sound science has been rejected.

At the time of the Senate hearing the EPA had planned to release its final standards by the end of 2006; however, as of May 1, 2007, the EPA's final standards were undergoing interagency review and had not been released.

Source: (U.S. Senate 2006b)

State of Nevada Legal and Regulatory Challenges

The State of Nevada has mounted both legal and regulatory challenges to various aspects of the Yucca Mountain repository.

In 2004 the State of Nevada petitioned the U.S. Court of Appeals to review the final EIS for the transportation of waste to Yucca Mountain. The State argued that DOE had exceeded its "authority in selecting the Caliente Corridor and that its conditional decision to ship waste in legal-weight truck casks, should the repository at Yucca be operational before completion of a branch rail line, was arbitrary and capricious" (Nevada v. DOE 2006, p.7). The U.S. Court of Appeals ordered that it was premature to review these claims. The first claim could become subject to review should DOE determine to operate the branch line as a common carrier, and the second claim could become subject to review should DOE formulate a plan to ship waste by truck. The Court also rejected five claims regarding the Yucca Mountain EIS. The State does not plan to appeal the ruling (LVRJ 2006a).

The State of Nevada petitioned the NRC in December 2006 for a rulemaking to address DOE's plans for aging up to 21,000 metric tons of heavy metal (MTHM) of spent fuel at the surface of Yucca Mountain prior to repository emplacement. Under the NWPA, surface storage is permissible to the extent that it is "integral to waste handling and disposal at the proposed repository," including activities pursuant to the repository's thermal-loading strategy. The State of Nevada alleged that "it is absurd to suppose that storage in capacities approaching anywhere near 21,000 MTHM of spent fuel on the Site could be justified" as part of a thermal loading strategy, noted that spent fuel can be more easily aged at its current locations, and requested that the NRC advise DOE that its plans for such a large aging facility "are manifestly unlawful" (NRC 2006o). As of May 2007 no NRC action has been taken.

New Transportation Corridor

In 2006 DOE began investigating the Mina rail corridor as an alternative to the Caliente corridor to transport spent fuel through Nevada to Yucca Mountain. (The Mina rail corridor is a northern route through Nevada to the proposed repository.) At the present time, consideration of the Mina corridor has been withdrawn. This is discussed further below and in Chapter 5.

Proposed Yucca Mountain Legislation

Several legislative and industry proposals in support of Yucca Mountain were introduced in 2006. None of the bills was voted on by either house of Congress, and it is not yet clear whether any of them will be considered by the 110th Congress in 2007 or 2008. The major provisions of these proposals are compared in Table 6, and each proposal is discussed further below.

Table 6: Comparison of 2006 Yucca Mountain Legislative Proposals

Provision	Details	H.R. 5360/ S. 2589 (DOE)	The Nuclear Energy Institute (NEI)	S. 3962 (Domenici)
Land Withdrawal	For the repository	√	√	√
	For the railroad			√
Repository License Application	To contain information only on surface facilities required for the initial operation	√	√	
	To include provisions for continued repository monitoring		√	
	To be reviewed under informal hearing procedures		√	
Other Repository-Related Applications (including application for receipt and acceptance of spent fuel)	To be considered using expedited, informal procedures	√	√	
	Decision on spent fuel acceptance to be issued within one year of application receipt	√	√	
	All governments to expedite review of repository-related applications and to consider repository activities as beneficial to the public and to interstate commerce	√	√	
Infrastructure Activities	May begin before the construction license is issued (includes rail construction)	√	√	√
	At most, a limited EIS would be required to satisfy all National Environmental Policy Act (NEPA) requirements	√	√	Complete EIS required
	May be funded by the Nuclear Waste Fund			√
Capacity Limit	70,000 metric tons of uranium (MTU) limit removed	√	√	√
Nuclear Waste Fund	Allocations removed from regular budgetary process	√	√	√
Restrictions to State and Local Environmental Regulations	Designates the EPA as the permitting agency for any air quality permits required for the repository	√	√	
	Prohibits state and local governments from enforcing air quality requirements for repository-related activities at Yucca Mtn.	√	√	
Exemptions from Federal, State, and Local Regulatory Requirements	Exempts DOE-owned material from regulatory requirements under the Solid Waste Disposal Act	√	√	
	Allows DOE to preempt any state or tribal requirements related to the transport of spent fuel to the repository	√	√	
Water Rights	Allocated to DOE; possibility for state interference removed	√	√	
Waste Confidence	Determination of waste confidence	√	√	√
Modified Spent Fuel Contract	DOE deadline for removing spent fuel from new reactors (from plant operation date)		15 years	25 years

Source: (Congress 2006b; NEI 2006c; S.3962 2006)

H.R. 5360/S. 2589

The Nuclear Fuel Management and Disposal Act (NFMDA) includes a number of provisions to streamline the Yucca Mountain licensing process, limit environmental requirements, and provide DOE with the authority and funding that it says it needs to construct the repository.[20] DOE considers the passage of the NFMDA essential for the Yucca Mountain license approval, as it would give DOE certain authorities that DOE considers critical (Congress 2006c, pp.14-16):

- The legislation would provide DOE with control of lands near Yucca Mountain, which are presently public lands. This control is necessary in order for DOE to obtain NRC approval for the repository.
- The State of Nevada has declared Yucca Mountain "not in the public interest," which prevents DOE from applying to the state water engineer for water permits. The proposed legislation would declare Yucca Mountain "in the public interest," thereby allowing DOE to apply to the State water engineer for permits. Permitting would proceed under the normal Nevada regulatory process, which considers whether there is unappopriated water at the source, whether the water use would conflict with existing rights, and whether the water use would adversely impact domestic wells (Nevada 2007b).
- The legislation would provide DOE approval to begin work on the Nevada railroad spur to Yucca Mountain prior to the permitting of Yucca Mountain construction. According to DOE, this is necessary in order to maintain the current construction schedule,
- The 70,000 metric ton limit on Yucca Mountain capacity is an "administrative limit, not a safety limit." With this limit in place, a second repository will be required. The legislation calls for this limit to be lifted and the technical capacity of the repository to be reexamined.
- The legislation would reclassify nuclear fund receipts as discretionary offsetting collections rather than mandatory receipts. This would enable appropriations committees to allocate funds to Yucca Mountain without impacting their budgetary limits and would provide budget certainty to DOE.
- The legislation would transfer authority over air quality permits from the State of Nevada to the EPA and also give the EPA authority over environmental impact reports. According to DOE, it would eliminate "duplicative" environmental reviews by federal, state, and local agencies by designating the EPA as the appropriate agency to issue and enforce the air quality permits required for Yucca Mountain. It would also give DOE the authority to use the Department of

[20] NFMDA was developed by DOE and sponsored by Senator Domenici and Representative Barton as S. 2589 and H.R. 5360. These bills were introduced in April 2006 and were not voted on before the end of the legislative session in November. A substantively identical proposal was made by DOE on March 6, 2007, but it has not been sponsored by a legislator as of May 1, 2007. A related bill, S. 2610, was proposed by Senator Inhofe in April 2006. It comprises the provisions of the NFMDA that fall under the jurisdiction of the Senate Committee on Environment and Public Works. It also was not voted on in 2006 (S.2610 2006; DOE 2007b).

Transportation preemption process to work around any “obstructions” caused by local or tribal governments in transporting waste to Yucca Mountain.

- The waste confidence language in the bill clarifies that the NRC need not consider waste disposal when permitting new nuclear facilities.

Several legislators have expressed their disapproval of this legislative proposal, and, according to NRC Commissioner McGaffigan, the proposal “has no chance of enactment” (Energy Daily 2007c). (See Figure 7.) In an August 2006 Senate Committee on Energy and Natural Resources hearing, Senator Reid of Nevada said that the changes proposed by DOE in the NFMDA would not be required if Yucca Mountain was safe. Robert Loux, executive director of the Nevada Agency for Nuclear Projects, agreed with Senator Reid and noted that the legislation exempts nuclear waste transport and storage from hazardous waste rules, curtails the rights of parties to review the Yucca Mountain application, and allows DOE to use as much water as it desires without considering Nevada’s other needs (U.S. Senate 2006a).

According to DOE, passage or defeat of the NFMDA will not impact the June 2008 submittal date of the license application. Annual Nuclear Waste Fund (NWF) receipts, which are about $750 million, will be sufficient to fund DOE’s efforts through the Yucca Mountain application period.[21] During construction, however, DOE will likely need to tap into the $19 billion in accumulated NWF funds. Based on DOE’s plans for a 2017 repository opening, the peak annual funding requirement will be in 2012 or 2013 (Congress 2006c, pp.25-26).

NEI Proposal

A proposal put forward by the Nuclear Energy Institute (NEI) includes all of the provisions of the NFMDA, plus several other provisions that would simultaneously advance four solutions to the nuclear waste problem: Yucca Mountain, centralized interim storage, reprocessing, and DOE taking title to spent fuel at reactor sites. Key provisions of NEI’s proposal are as follows (NEI 2006c):

- The proposal would require DOE to submit the repository application by the end of 2007, and it would require the NRC to review the application under informal hearing procedures and to approve it or reject it within three years.
- It would limit the repository environmental compliance period to 10,000 years.
- It would require that the repository be operating by March 30, 2016 and that spent fuel be retrievable for at least 300 years.
- It would encourage the co-location of temporary storage and reprocessing facilities.

[21] The NWF collects receipts from nuclear power plant owners to pay for the permanent disposal of spent fuel.

- It would expedite the construction of at least one interim storage facility and would allow for additional interim storage sites at locations suggested by host states.
- It would require DOE to take title to spent fuel at the request of an owner (not using NWF resources).

This proposal was not sponsored by a legislator, and NEI ultimately endorsed S. 3962 (see below) (NEI 2006d).

S. 3962[22]

S. 3962 includes many of the provisions of the NFMDA and the NEI proposal, but excludes or moderates the more controversial elements. For example, it does not provide for a streamlining of the repository licensing process, and it does not impose limits on environmental requirements for the repository. Furthermore, it includes provisions for just one interim storage facility located at Yucca Mountain, and it restricts transporting commercial waste to the facility until the Yucca Mountain license has been granted. (It allows defense waste to be transported to the facility as soon as the interim storage facility license is approved.) S. 3962 also adds provisions to expedite the construction of a railroad to Yucca Mountain, and it extends the deadline by which DOE must accept spent fuel from a new reactor until 25 years after the reactor has begun to operate.

Issues for California and Other Western States

The planned operation of a repository at Yucca Mountain could have environmental implications for California and other western states. For example, transport of shipments to the repository could create logistical problems and safety hazards and could adversely impact groundwater and wildlife in California and Nevada (California 2006, pp.4-5; DOE 2002b).

Groundwater and Wildlife

The State of California has expressed concerns to DOE that contamination from the repository and spent fuel shipments could impact California's surface water channels and groundwater. For example, the State is concerned that radionuclides from the repository could contaminate California groundwater and impact Death Valley National Park wildlife (DOE 2002b). DOE has largely disputed these claims, arguing that natural and engineered barriers will keep the release of radioactive materials well below legal limits and that contaminants from the repository cannot reach any part of California (DOE 2002b).

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[22] S. 3962 was introduced on September 27, 2006 by Senator Domenici and titled, "A bill to enhance the management and disposal of spent nuclear fuel and high-level radioactive waste, to assure protection of public health and safety, to ensure the territorial integrity and security of the repository at Yucca Mountain, and for other purposes." It was not voted on during that legislative session, and it was reintroduced on May 23, 2007 as S. 37, the Nuclear Waste Access to Yucca Act (NU-WAY).

Figure 7: An NRC Commissioner Speaks Out

In 2007 departing NRC Commissioner McGaffigan declared: "As I prepare to depart the commission later this year, the opening of the repository is if anything more distant than when I arrived [in 1996] and it is absolutely dependent on the passage of legislation that currently has no chance of enactment." McGaffigan classified this as a political failure stemming from the site-selection process rather than a technical failure. He proposed that a bipartisan expert panel be commissioned to come up with a new solution. The panel should consider the lessons of the operating Waste Isolation Pilot Plant in New Mexico and the Finnish and Swedish repositories under development, all of which avoided the delays that plague Yucca Mountain by first seeking approval of affected communities. The panel should also consider transferring responsibility for the repository to a government-chartered corporation with a bipartisan board serving long terms, and should reconsider the repository safety standard. According to McGaffigan, "calculations to 1 million years are nonsensical." McGaffigan concluded: "There is no easy path for a restructuring of our high-level waste program and for fixing a quarter century of bad law, leading to bad regulations, bad personnel policy, bad budget policy and bad science advice. But the effort can no longer be postponed."

Duke Energy executive Henry "Brew" Barron agrees that the singular focus on Yucca Mountain is a mistake; in fact, he considers it "the single greatest flaw" in U.S. nuclear waste policy. He advocates reprocessing spent fuel and disposing of the remaining high-level waste in a different repository. (Reprocessing is discussed in Chapter 4.) In an April 2007 speech Barron said, "The U.S. mindset is that all roads lead to Yucca Mountain. They do not all lead to Yucca Mountain; and they should not all lead to Yucca Mountain."

Former principal deputy director of OCRWM (1993-2002) Lake Barrett supports McGaffigan's call to form a high-level commission to examine the Yucca Mountain project. Barrett, however, recommends that the commission look for ways to improve the project: "A fundamental rewrite and do-over would not be helpful," he said. Barrett recommended not abandoning the Yucca Mountain site, since it is a suitable repository site and it is currently the only option on the table.

Source: (Energy Daily 2007b; Energy Daily 2007c; LVRJ 2007b)

Waste Handling

Continuing changes in the design of the Yucca Mountain repository could impact waste handling procedures in California. The spent fuel canisters currently used in California may not be authorized for shipment to Yucca Mountain if DOE's proposal to develop and implement a Transport, Aging and Disposal canister is adopted.[23] If

[23] Indeed, in a letter to SMUD in 2003 DOE noted that the multi-purpose transport and storage containers in use at Rancho Seco were "not presently an acceptable waste form" (DOE 2003b).

this is the case, repackaging of the spent fuel could be required. This would be costly and risky, and it would create logistical problems at sites such as Rancho Seco that no longer have spent fuel pools or waste handling facilities. However, as discussed in Chapter 5, DOE's current plans include provisions for some spent fuel shipments to be made using alternate canisters.

Transportation through California

As discussed in Chapter 5*,* DOE's proposed new Mina rail route to Yucca Mountain, announced in October 2006, could result by one estimate in as many as half or more of the rail shipments of spent fuel from eastern reactors, as well as the high-level radioactive waste shipments from federal facilities in Washington State, being routed through California. This would entail "exponentially more shipments in California (as much as half of the [nationwide] shipments or more) than previously estimated" (California 2006, p.4).

Furthermore, some of these routes may be hazardous. As described by the State of California in comments to DOE (California 2006, p.4-5):

> California rail routes include dangerous sections that have a history of major derailments, hazardous spills, and hazardous materials incidents. These include the major derailment and toxic spill near Dunsmuir Loop in 1991 in which an entire 40-mile section of the Upper Sacramento River, one of two primary water resources for Californians, was poisoned. Several areas in the state, particularly in southern California, have had major railroad accidents, including the derailment near Cajon in 1996 involving hazardous materials and fire, derailments in Barstow, and the recent derailment earlier this month involving fire and hazardous materials along the Union Pacific Line over Donner Summit…
>
> California's heavily populated and congested Sacramento, Central Valley, and Los Angeles regions (Los Angeles is the second largest metropolitan region in the country), the steep terrain and heavily weather-impacted rail and truck routes over the Donner Summit to Reno, Nevada, as well as corridors through southeastern California, including Barstow, California, could be heavily impacted by these shipments.

As of May 2007, the Mina route was no longer being investigated, since DOE had been unable to obtain a right of way through tribal land that the route traversed. DOE is focusing once again on the Caliente rail route, which could also impact California, as it is expected that some of the shipments from eastern states will be routed through southern California to the Yucca Mountain site if the Caliente route is used.

Moreover, regardless of the transportation route, the NFMDA, if passed, could increase the transportation risk to California and other western states. In August

2006 the Western Governors' Association wrote a letter to the Chairmen of the Senate Energy Committee opposing portions of the NFMDA because of concerns that portions of the bill related to transportation could "seriously undermine shipment safety and public confidence, key to successful repository operations." Of particular concern are provisions of the bill that would preempt Yucca Mountain shipments from existing Federal regulations (the Hazardous Materials Transportation Authorization Act and the Resource Conservation and Recovery Act) and provisions that would preempt state laws. These provisions would eliminate the state's ability to take reasonable measures to ensure the safety of these shipments, such as carrier and shipment inspections, routing restrictions to avoid high-risk areas. They would also run counter to recommendations by a recent National Academy of Sciences study that spent fuel shipments can be done safely "when conducted in strict adherence to existing regulations" (WGA 2006).

Waste Storage at California's Reactors

Most of the spent fuel from California's operating reactors is stored in spent fuel pools at the reactor sites. At the time the spent fuel pools were constructed, it was assumed there would be a solution for spent fuel. Starting in 1982 it was expected that DOE would begin to collect the spent fuel by January 31, 1998, for shipment to a federal repository, as required by contracts between DOE and the nuclear power plants. However, DOE has not yet begun spent fuel shipments, and the pools are approaching capacity. In recent years, the utilities have begun to construct interim dry cask storage facilities for their older fuel in order to free up space in their spent fuel pools for newer assemblies. They have sued DOE for the costs of their interim storage.

Amount and Composition of Accumulated Waste

As of the end of 2006 there were about 56,330 metric tons of uranium (MTU) of commercial spent fuel and 13,308 MTU of defense-related high-level waste in the U.S. Of the commercial spent fuel, approximately 2,437 MTU were in California and approximately 1,541 MTU were in Arizona (from Palo Verde) (OCRWM 2007). In addition, 270 spent fuel assemblies from SONGS Unit 1 are currently stored at General Electric's Morris facility in Illinois (Planning Information Co. 1996).

As of March 2007, each unit at Diablo Canyon had generated approximately 524 MTU of spent fuel, with a total of 1,048 MTU from both units. Of this, 890 MTU are stored in the spent fuel pool and temporary cask pit racks, with the remainder contained in the reactor cores (until the next refueling) (PG&E 2007b, B4, C1). Fuel in the spent fuel pool that has cooled for less than one year is surrounded on four sides by cold assemblies in order to facilitate heat dissipation (PG&E 2007b, C2).

The main component by mass of spent fuel from Diablo Canyon is uranium-238, which accounts for 97 percent of the mass of the spent fuel. The spent fuel also contains other uranium isotopes, transuranic elements such as plutonium and neptunium and fission products, such as cesium-137. (See Table 7.)

The permanently shut-down Humboldt Bay power plant in northern California generated 49.34 MTU of spent fuel during its operations. Of this, 28.22 MTU are stored in the Humboldt Bay spent fuel pool and 21.12 MTU were shipped offsite to a now-defunct reprocessing plant prior to 1976 (PG&E 2007b, B5). The spent fuel in the Humboldt Bay spent fuel pool consists of 98 percent (by mass) uranium-238, 1 percent uranium-235, 0.3 percent plutonium-239, and 0.2 percent other uranium isotopes (PG&E 2007b, B7). Construction of dry cask storage facilities at Humboldt Bay has begun and Pacific Gas & Electric Co. plans to transfer all of the spent fuel into dry cask storage.

Table 7: Composition of Diablo Canyon Spent Fuel[24]

	Isotope	**mass percent**
Uranium	U-238	97 percent
	U-235	1 percent
	Other uranium isotopes	1 percent
Transuranic Elements	Pu-239	1 percent
	Pu-240	0.2 percent
	Pu-241	0.1 percent
	Other transuranic isotopes	0.3 percent
Fission Products	Nd-144	0.2 percent
	Ce-142	0.1 percent
	Cs-137	0.1 percent
	Other fission products	0.4 percent

Source: (PG&E 2007b, B7)

The permanently shut-down Rancho Seco power plant generated 228.6 MTU of spent fuel, which is stored in 493 spent fuel assemblies in an on-site dry cask storage facility. (Rancho Seco no longer has a spent fuel pool) (SMUD 2007, B5, C4). Spent fuel from Rancho Seco consists of 96 percent uranium (by mass) and 1 percent plutonium. Cesium-137 is the predominant fission product (SMUD 2007, B7).

SCE and APS classify information related to SONGS and Palo Verde spent fuel as security-sensitive and declined to provide this information to the Energy Commission.

Status of DOE Spent Fuel Litigation

As discussed above, DOE is responsible for developing a permanent waste repository for the nation's spent fuel and high-level waste and was obligated to have begun receiving spent fuel for the repository by January 31, 1998. DOE entered into

[24] Quantities sum to greater than 100 percent due to rounding.

fuel receipt contracts with generators of nuclear power based on this deadline.[25] However, DOE missed the deadline, and the opening of a repository remains at least ten years away. Over 60 utilities, including PG&E, SCE, SMUD, and APS, have filed breach of contract suits before the U.S. Court of Federal Claims seeking damages for the spent fuel storage costs that they have incurred due to DOE's delay in disposing of their spent fuel (National Law Journal 2006). DOE estimates that the current potential liability for this delay is $7.0 billion (DOE 2007c).

The suits filed by the California utilities are ongoing. Initial damage claims account only for damages already incurred. Subsequent damages may be collected at a future date.[26] The current status of these suits is as follows:

- PG&E claimed $92.1 million in damages through 2004 for costs related to its interim fuel storage facilities (PG&E 2007b, D9). The Court awarded PG&E $42.8 million in damages for putting Humboldt Bay into SAFSTOR status, for constructing dry cask storage units at Humboldt Bay, and for constructing larger dry cask storage units at Diablo Canyon than would have been required had DOE not breached its contract. The court did not allow PG&E to recover the full cost of the Diablo Canyon dry cask storage units, because it found that dry cask storage would have been required even had DOE opened a repository on schedule, since Diablo Canyon fuel would not have been retrieved by the end of 2007. The Court also disallowed PG&E's costs to evaluate off-site storage options, construct temporary spent fuel pool storage racks at Diablo Canyon, and remove a ventilation stack at Humboldt Bay, as it found that these costs were not the direct result of DOE's breach of contract (PG&E v. U.S. 2006). PG&E appealed the Court's disallowance of Diablo Canyon dry cask storage costs and requested that its award be increased. The U.S. government filed a notice of appeal, and the first appellate briefs were due to be filed in April 2007 (PG&E 2007b, D7).
- SMUD claimed $79 million in damages from January 1992 through December 2003, subject to several offsets. In 2006 the Court ruled that SMUD could recover only those costs incurred after May 14, 1997, ruling that prior expenditures were "made for business reasons" and that DOE's subsequent breach of contract was "not a substantial causal factor in those decisions" (SMUD v. U.S. 2006, p.48). The Court also disallowed incremental costs associated with the use of dual-purpose transportable casks and costs

[25] The contracts require owners and generators of nuclear waste to pay 0.10 cents per kWh of nuclear power generated in return for DOE's taking title to the waste and arranging for its permanent disposal.

[26] In 2005 the U.S. Court of Appeals for the Federal Circuit ruled that a utility that sues DOE for a partial breach of contract is entitled to claim damages only for costs that it has already incurred (IMPC v. U.S. 2005). If the utility instead claims a total breach of contract, it can claim both accrued and projected damages; however, doing so would release DOE of its contractual obligation to accept the spent fuel. The Court clarified that only accrued damages can be collected under a partial breach claim, since it is as yet unknown when DOE will fulfill its contractual duties and how much will be accrued in damages by that time.

associated with storing low-level nuclear waste, ruling that these costs were not directly related to DOE's breach of contract (SMUD v. U.S. 2006, pp.60-61). The Court ultimately awarded SMUD $40 million in damages (SMUD v. U.S. 2006, p.12). In February 2007 DOE filed a notice of appeal to the Federal Circuit, and SMUD filed a notice of cross appeal (SMUD 2007, D7).

- SCE claimed $150 million in damages through 2005 (SCE 2007a, D9). Discovery in this case will continue through August 2007, and a Joint Status Report is due in September 2007 (SCE 2007a, D7). A trial date has not yet been set (SCE 2006b, p.22).
- APS claimed $94 million in damages for Palo Verde through 2006. A trial date has not yet been set.

Four spent fuel breach of contract suits have settled out of court, and it is possible that the SCE and APS cases will settle prior to or during a trial (Inside Energy 2007). In a recent settlement DOE agreed to pay Duke Energy $56 million to cover storage costs incurred through July 31, 2005 at its three nuclear power plants, with additional amounts to be reimbursed annually for future storage costs (Duke Energy 2007). Since the settlement includes annual reimbursements, Duke Energy will not be required to return to court to collect future damages.

Status of Dry Cask Storage Facilities

Independent Spent Fuel Storage Installations (ISFSIs), also known as dry cask storage facilities, are operational or under construction at all of California's nuclear power plants and at Palo Verde. (See Table 8.) These facilities can be used to store spent fuel that has been cooled for at least five years in a spent fuel pool.

Storage in an ISFSI is generally regarded as a safe method of storage for partially-cooled spent fuel (Harvard 2001, p.11). However, ISFSI storage does present security concerns, as a terrorist attack could potentially puncture an ISFSI and release radiation to the public (Thompson 2003, p.66). In response to these concerns, the NRC has imposed additional security measures at ISFSIs since September 11, 2001 (NRC 2006e). These requirements are not publicly available.

Notwithstanding the NRC's security measures, concerns remain as to the security of ISFSI facilities. In the licensing proceeding for the Diablo Canyon ISFSI, the San Luis Obispo Mothers for Peace requested that the environmental impacts of terrorism be considered as part of the EIS. (See Chapter 10.) The NRC declined this request, and Mothers for Peace filed a suit with the Ninth Circuit Court of Appeals, arguing that the EIS for Diablo Canyon's ISFSI is incomplete on this account (MFP v. NRC 2006, p.6096). In June 2006, the Court ruled in favor of Mothers for Peace, and in January 2007 the Supreme Court declined to review PG&E's appeal of this

Table 8: ISFSI Status Summaries

Facility	ISFSI Status	Location of Spent Fuel Targeted for ISFSI	ISFSI Capacity[27]
Diablo Canyon	Under construction; initial phase targeted for completion by 3rd quarter of 2007	Stored in spent fuel pool and on temporary storage racks in spent fuel pool; transfer of fuel to the ISFSI may be delayed due to legal challenge (see text)	Initial phase will have the capacity for 1,280 fuel assemblies, which will be sufficient through nearly the end of the operating license; subsequent phases could add capacity for an additional 3,136 fuel assemblies
SONGS	Operational	Unit 1: Transferred to ISFSI Unit 2: Transfers underway Unit 3: To be transferred as necessary	Has sufficient capacity through 2008; will add additional modules as needed
Palo Verde	Operational since 2003	To be transferred as necessary	Has capacity for all spent fuel that will be generated through the end of operating license
Humboldt Bay	Under construction	Cask loading to begin as early as Spring 2008; plan to move all spent fuel into the ISFSI by 2008 is being evaluated	Will have capacity for all spent fuel at the site
Rancho Seco	Operational	Transferred to ISFSI completed in August 2002	Has capacity for all spent fuel at the site

Source: (PG&E 2007a, pp.18, 29; PG&E 2007b; SCE 2005b; SCE 2007a; NRC 2006d)

decision.[28] (PG&E v. MFP 2006) In response, the NRC conducted a supplemental environmental analysis to consider the impact of a terrorist attack on the Diablo Canyon ISFSI. The NRC concluded that the probability of a successful terrorist attack on an ISFSI is very low and that, in the event of a successful attack, the radiation dose to members of the public near the facility would be below the dose limit for workers in the nuclear industry (NRC 2007u). The NRC is scheduled to make a decision reaffirming, revoking, or conditioning the ISFSI license by February 26, 2008 (NRC 2007o). (See Chapter 10.)

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[27] The ISFSIs are sized to allow for sufficient space in the spent fuel pools at all time for the storage of all of the fuel that is in the reactor core. This is referred to as “full core off-load capability” and is a safety requirement.

[28] As discussed in Chapter 12, subsequent to the Ninth Circuit’s ruling, the attorney generals of Massachusetts and California filed petitions for rulemaking with the NRC requesting that the impact of terrorism on spent fuel pools be considered in all licensing applications.

Offsite Interim Spent Fuel Storage Proposals

There have been several legislative proposals one recent commercial venture for constructing offsite interim waste storage facilities. The commercial facility received its NRC license early in 2006 and then encountered regulatory roadblocks that appear to have halted the project. The legislative proposals, which would require DOE to develop interim storage facilities, have encountered opposition from DOE and some members of Congress.

Status of Private Fuel Storage Facility

In 1997 Private Fuel Storage, L.L.C (PFS), a consortium of SCE and seven other utilities that own nuclear reactors, applied to the NRC for a license to construct a temporary nuclear waste storage facility on the Goshute Reservation in Utah to be used by owners of spent fuel nationwide.[29] In addition to an NRC license, the project required approvals by three other federal agencies in order to proceed: approval from the Bureau of Indian Affairs of a business lease, authorization from the Bureau of Land Management for the right-of-way for a new rail spur or intermodal transfer facility, and approval from the Surface Transportation Board for the proposed rail spur (DOI 2006b, pp.6-7).

PFS was granted an NRC license in 2006 to receive, possess, store and transfer up to 40,000 metric tons of spent fuel on the reservation (PFS 2006). At the time, PFS appeared to be on track to build the waste storage facility. However, the State of Utah appealed the NRC license decision on the grounds that "federal regulators miscalculated the risk of a military aircraft crash, the need for stronger protections against terrorists, and the certainty that the federal government will eventually take the waste from the site and store it at Yucca Mountain" (Greenwire 2007c). It has not yet been announced whether this appeal will be heard.

Other roadblocks emerged—subsequent to the NRC's license approval—that now appear to have stalled the project. First, the National Defense Authorization Act for fiscal year (FY) 2006 designated certain lands in Utah through which the railroad spur was to be built as the Cedar Mountain Wilderness Area, withdrawing these lands from "entry, appropriation or disposal" (NDA Act 2006). The wilderness designation precluded the Surface Transportation Board and the Bureau of Land Management from approving the railroad spur. The Bureau of Land Management issued a decision that the railroad spur would be "inconsistent with the purpose for which the Bureau of Land Management manages the public lands" and inconsistent with the Wilderness Area designation (DOI 2006a, p.16). Furthermore, the Bureau of Land Management determined that the intermodal transfer facility would be contrary to the public interest, because it would impact local traffic, increase radiation to workers, and raise the possibility of short-term spent fuel storage at the intermodal transfer facility on public lands (DOI 2006a, p.12).

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[29] Also see discussion in *Nuclear Power in California: Status Report* (Energy Commission 2006e, p.120).

Second, the Bureau of Indian Affairs rejected the proposed lease of tribal trust land (DOI 2006b, pp. 6-7, 10-11). The Bureau of Indian Affairs cited several reasons for its decision (DOI 2006b, pp. 20-22, 24-25, 29, 41, 43):

- All studied transportation options had been rejected for the site.
- The EIS does not adequately analyze the impacts on the wilderness area of the cumulative truck traffic for the PFS facility and for the solid waste facility that is now on the tribal land.
- The EIS does not adequately address the impacts of transporting spent fuel away from the PFS facility.
- The EIS does not adequately consider the effects of a terrorist attack, as required by the Ninth Circuit decision in the San Luis Obispo Mothers For Peace vs. NRC case.
- The Bureau of Indian Affairs does not have the resources to provide adequate law enforcement for the proposed facility or to monitor PFS' activities.
- The Bureau of Indian Affairs would be unable to compel the removal of spent fuel once it is deposited on site, and there is significant uncertainty as to whether and when a permanent repository might be available for this spent fuel.

PFS will have the opportunity to appeal the Bureau of Indian Affairs and Bureau of Land Management decisions. According to news reports, PFS continues to explore this option (Deseret News 2007). Meanwhile, the State of Utah reportedly continues to pursue its appeal of the NRC license.

PFS' options may be limited due to loss of financial support. At least three of the eight original PFS backers have indicated that after the facility is licensed they will withhold future investment as long as adequate progress is being made at Yucca Mountain (Xcel Energy 2005). In addition, three of the original backers have already withdrawn their support from PFS (Southern Company 2005; FPL 2005; Entergy 2005).

Federal Interim Waste Storage Proposals

The concept of developing interim storage facilities on a state or regional basis has been discussed in Congress recently as delays to the Yucca Mountain repository continue to push the operating date out further and further. State governments have come out in opposition to the concept.

In addition to the interim storage proposals that were included in the NEI and Domenici proposals (discussed above in the section *Status of the Proposed Federal*

Repository at Yucca Mountain), there have been two additional legislative interim waste storage proposals in 2006 and 2007.[30] (See Table 9.)

Table 9: Comparison of Federal Bills for Interim Spent Fuel Storage

	H.R. 5427 **Energy and Water Appropriations**	**NEI Proposal**	**S. 37** (S. 3962) **Domenici Proposal**	**S.784** **Reid Proposal**
Location	Sites to be identified in **all** states that house nuclear reactors	At Yucca Mountain and other sites if proposed by host states	At Yucca Mountain only	At each reactor
Constructed with NWF funds	Yes	No	Yes	Yes
Application submission date	Within 9 months of legislation	Within 12 months of legislation	Along with repository application	Each operator would submit application and construct ISFSI (not DOE)
Bill Status	Not voted on during 2006 legislative session; not active	Not sponsored by a legislator (not active)	In committee	In committee

Source: (S.784 2007; NEI 2006c; DOE 2006k; S.3962 2006)

The FY 2007 Energy and Water Appropriations bill, as amended in the Senate, included funding for DOE to find sites for "consolidation and preparation" of spent fuel awaiting disposal or reprocessing (i.e., interim storage facility sites) (Congress 2006a).[31] Other key provisions of the legislation were as follows:

- The Secretary of Energy would have been required to appoint a Director of Consolidation and Preparation, who would recommend a site for interim fuel storage in each state that contains a civilian nuclear reactor. The Secretary would have six months to recommend sites and an additional 90 days to work with governors of impacted states to finalize facility locations.
- Regional facilities would be designated in states that did not contain a state facility. Any site owned by the federal government or that can be purchased from a willing seller would be eligible to house a regional facility, except for sites within Nevada or other states containing commercial, away-from-reactor dry cask storage or sites within national parks, wildlife refuges, or wilderness areas.

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[30] The NEI Proposal and S. 37 (Domenici Proposal) were discussed in the section *Status of the Proposed Federal Repository at Yucca Mountain*. (S. 37 was referred to as S. 3962 in the 2006 legislative session.)

[31] This bill was not approved by the 109th Congress before Congress adjourned on December 8, 2006 (Congress 2006d). Congress instead passed continuing resolutions to fund DOE and other impacted agencies through the end of the federal FY 2007 (September 30, 2007) (Congress 2007b). As a result, consideration of this interim storage proposal was deferred.

- Interim storage facilities would be licensed for one non-renewable 25-year term.
- The Secretary of Energy would be required to take title to spent fuel at the site of a shut down reactor at the request of the reactor owner.
- NWF funds would be made available for the siting, construction and operation of these facilities.
- The provisions of this section would provide sufficient grounds for finding that spent fuel will be disposed of safely (waste confidence).

The Attorneys General of California and nine other states expressed their deep concern over the interim storage proposal in H.R. 5427 in a letter to key congressional leaders. The primary concerns of the Attorneys General were as follows:

- The proposed DOE authority would override all relevant state and local siting laws, as it would enable DOE to purchase any parcel offered by a wiling seller even if "zoning laws, environmental laws (e.g., state endangered species or wetlands programs), or environmental justice siting provisions otherwise precluded such use" (Attorneys General 2006).
- The time-table provided in the proposal (i.e., nine months to select sites and 3.5 years for facility licensing) is insufficient to evaluate all the relevant safety, environmental, and transportation issues.
- The proposal does not contain measures to address the relevant transportation safety issues.
- The proposal limits a National Environmental Policy Act (NEPA) review to consider only the environmental impacts that will occur during the 25-year license period.[32] This overlooks the possibility that the "non-renewable" license period might be extended.
- Since the proposal is being advanced through the appropriations process, states have no formal opportunity to provide input.

Governors of 17 states similarly expressed their opposition to the H.R. 5427 interim storage proposal.[33] In addition to the issues raised by the Attorneys General, the governors expressed concern that the temporary facilities could become de facto permanent storage sites for nuclear waste. They also objected to the use of the Nuclear Waste Fund for interim storage solutions (Baldacci 2006). These same

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[32] "Such environmental impact statement shall not consider the environmental impacts of the storage of spent nuclear fuel and high-level radioactive waste at the consolidation and preparation facility beyond the term of the license" (DOE 2006k).

[33] The letter was signed by the governors of New Jersey, Connecticut, Michigan, Florida, Arizona, Illinois, Kansas, Maine, Minnesota, Mississippi, New Hampshire, New York, North Carolina, Oklahoma, Oregon, South Carolina, and Wyoming.

concerns were raised in an August letter to Senator Domenici from the Coalition of Northeastern Governors (CNG 2006).

Federal officials have also raised concerns about the interim storage proposal. DOE has objected to it out of concern that it will consume resources that should be used for Yucca Mountain. The NRC has reported that the need to review license applications for up to 31 interim sites would require an additional 200-300 full time employees and $15 million per site (Congress 2006c).

The American Physical Society conducted an assessment of consolidated interim storage and found no compelling reason to pursue or to reject the concept (APS 2007a). The study found that spent fuel can continue to be safely stored at operating reactors and that moving the fuel to consolidated sites would not provide cost savings to the federal government, nor would it provide safety or security benefits. However, interim storage could have other limited benefits. It could facilitate the decommissioning of reactor sites, it would establish a process for transferring title of the spent fuel to the federal government (though, as the report noted, the transfer of title could also take place at reactor sites without consolidated storage), and, by carrying out the necessary thermal mixing of fuels, it could reduce the size of buffer storage needed at a Yucca Mountain surface facility (APS 2007a, p.12).

In March 2007 Senator Reid proposed as S. 784 an alternate approach to interim storage based on continued at-reactor storage. S. 784 would amend the NWPA to require operators to transfer spent fuel from spent fuel pools to dry cask storage within six years of removal from the reactor. It would also require that the Nuclear Waste Fund be used for the licensing and construction of at-reactor dry cask storage facilities, fabrication of the casks, transfer of the spent fuel, and implementation of safety and security improvements. It would require DOE to take title to the dry casks and their contents at the reactor site and would confer on DOE "full responsibility (including safety, security, and financial responsibility) for the subsequent possession, stewardship, maintenance, monitoring, and ultimate disposition of all spent fuel transferred" (S.784 2007). As written, the bill appears to obviate the need for a federal repository.

However, dry cask interim storage is not a permanent option. ISFSIs are designed for an operating life of about 40-50 years, and their initial operating licenses extend only 20 years (Energy Commission 2005e, pp.242, 250; NRC 2007ac). The American Physical Society thus cautioned that consolidated storage cannot replace a repository and, if pursued, should not interfere with the establishment of a permanent repository (APS 2007a).

Conclusion

Over the last few years, limited progress has been made toward developing a permanent repository for spent nuclear fuel. Increased attention is now being paid to interim storage options, including at Yucca Mountain. Some long-standing proponents of Yucca Mountain, including NRC Commissioner McGaffigan, have suggested that it is time to re-examine the alternatives to Yucca Mountain. New interim spent fuel storage facilities have been or are being constructed at all the reactor sites serving California. Regional storage proposals are under consideration, though these are generally opposed by state governments.

CHAPTER 4: REPROCESSING AND THE GLOBAL NUCLEAR ENERGY PARTNERSHIP

Under existing law, California's moratorium on building new nuclear power plants will continue until a technology for the permanent disposal or reprocessing of spent fuel has been demonstrated and approved for use in the U.S. In 1978 the Energy Commission found that high-level nuclear waste disposal technology had not been demonstrated nor approved by the authorized federal agency and that reprocessing of spent fuel does not yet exist. In 2005 the Energy Commission reaffirmed this finding. As we noted in the *2005 Status Report*, the National Academies, the National Commission on Energy Policy (NCEP), the Harvard University Project on Managing the Atom, and the Massachusetts Institute of Technology (MIT) Interdisciplinary Study, *The Future of Nuclear Power*, had all concluded that reprocessing is both uneconomic and burdened by substantial proliferation concerns. The Energy Commission also concluded that reprocessing is more expensive than waste storage and disposal and has "substantial adverse implications for the U.S. effort to halt the proliferation of nuclear weapons" (Energy Commission 2005b, p.85).

In early 2006 the Bush administration and DOE proposed the Global Nuclear Energy Partnership (GNEP) with the goal of establishing a proliferation-resistant nuclear fuel cycle based around a newly established domestic reprocessing capability. President Bush described the GNEP initiative:

> We will develop and deploy innovative, advanced reactors and new methods to recycle [reprocess] spent nuclear fuel. This will allow us to produce more energy, while dramatically reducing the amount of nuclear waste and eliminating the nuclear byproducts that unstable regimes or terrorists could use to make weapons (Bush 2006).

The Bush administration's push to develop domestic reprocessing capability marks a significant departure from long-standing U.S. policy discouraging or neglecting domestic commercial reprocessing. Beginning in the late 1970s the U.S. opposed reprocessing on the grounds that the spread of the technology facilitates the proliferation of nuclear weapons. In fact, the first reprocessing programs were created to support the military's nuclear weapons programs in the U.S. and other countries during and immediately after World War II. The GNEP program seeks to re-introduce spent fuel reprocessing with new technologies that will discourage the spread of nuclear weapons technology.

This chapter discusses the goals and implementation plans of GNEP and the role of reprocessing within these plans. To provide the appropriate context, the chapter first presents an overview of current reprocessing technology, the international experience with reprocessing, and a historical review of U.S. policy on reprocessing. The chapter then outlines the GNEP vision and the new technologies that would be required under GNEP. The chapter then discusses key concerns with reprocessing in general and with GNEP in particular.

Overview of Reprocessing

Reprocessing refers to the mechanical and chemical separation of spent fuel into reusable materials and waste. (The components of spent fuel are summarized in Table 10.) Absent reprocessing, nuclear fuel can be used in reactor only once, a method referred to as a “once-through” fuel cycle. Reprocessing provides the potential to “close” the fuel cycle by recycling the reusable components of spent fuel for use in another reactor.[34]

Table 10: Spent Fuel Components

Component	**Volume percent** (approx.)	**Can be recycled into fuel?**	**Repository Implications**	**Proliferation Implications**
Uranium (depleted)	94 percent	Yes	Accounts for most of the needed repository volume	Usable in a nuclear weapon if re-enriched
Plutonium and other transuranic elements[35]	1 percent	Yes	Account for most of the radioactivity in the repository after a thousand years	Plutonium can be used in a nuclear weapon
Short-lived fission products (cesium and strontium)	<5 percent	No	Account for most of the radioactivity in the repository during the first hundreds of years	None
Long-lived fission products[36] (technetium and iodine)	<5 percent	No	Contribute to long-term radioactivity and peak dose in the repository	None

Source: (DOE 2005a, pp.3, 12; NRC 2007h)

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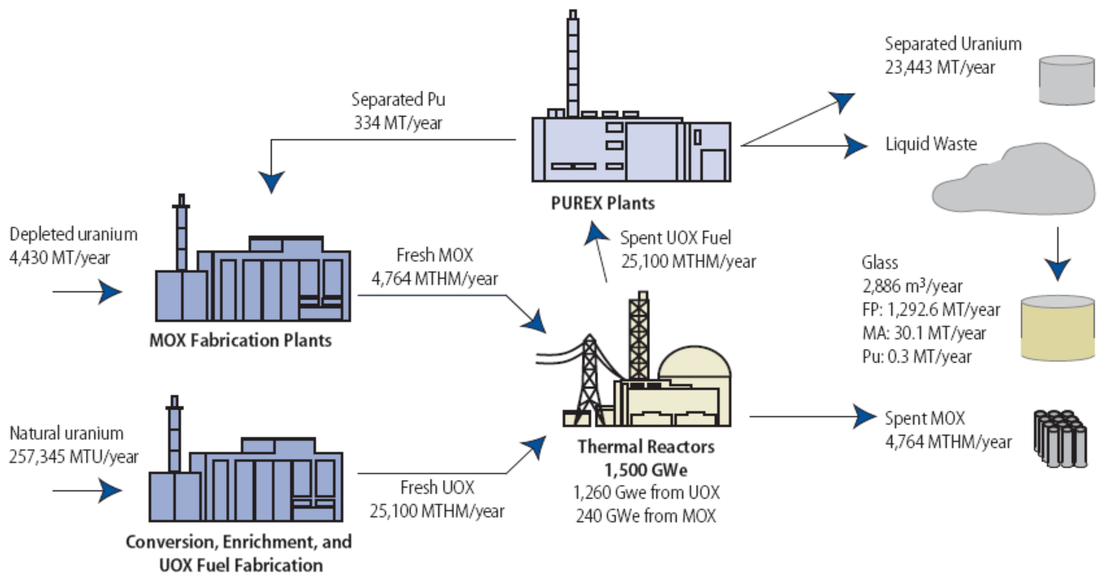
[34] Some classify as closed cycles only those cycles that include repeated reprocessing stages (i.e., where the fuel formed from the reprocessed spent fuel is used in a reactor and then again reprocessed). The PUREX fuel cycle shown in Figure 8 would not be considered a closed fuel cycle under this classification, since the spent MOX fuel is not recycled.

[35] Transuranic elements are elements in the periodic table with atomic numbers greater than uranium. The transuranic elements in spent fuel include plutonium, neptunium, americium, and curium. The transuranic elements other than plutonium are also called minor actinides.

[36] Fission products are waste products from the nuclear reaction.

With the current reprocessing technology, known as Plutonium-Uranium Extraction (PUREX), plutonium is extracted from the spent fuel. It is then combined with depleted uranium and recycled into mixed oxide (MOX) fuel; alternatively, it can be used in nuclear weapons. MOX fuel can be used to fuel certain reactors, after which it must be stored for final disposal in a geological repository. Other waste products also must be disposed of in a high-level waste repository. (See Figure 8.)

Figure 8: PUREX Fuel Cycle[37]



Source: (MIT 2003, p.30)

The number of times spent fuel can be recycled for use in currently operating light water reactors (LWR) is limited by the need to avoid an undesirable build up of transuranic elements, which are generated from each reactor cycle.[38] (DOE 2006l, p.8) Advanced reprocessing technologies are currently being researched and developed that would enable the repeated reprocessing and recycling of spent fuel.

Historical Context: Reprocessing in the U.S.

In the early years of the development of nuclear energy, the goals for reprocessing spent fuel were twofold: to recover plutonium for use in nuclear weapons and to extract more energy from natural uranium resources.[39] The U.S. government pursued the first goal beginning in World War II, when it developed an extensive

[37] The abbreviations used in this figure refer to the following: fission products (FP), minor actinides (MA), mixed oxide (MOX), metric tons (MT), metric tons of heavy metal (MTHM), metric tons of uranium (MTU), plutonium (Pu), and uranium oxide (UOX)

[38] All operating nuclear power plants in the U.S. are light water reactors.

[39] The report *Nuclear Power in California: Status Report*, published by the Energy Commission in March 2006, provides a lengthier review of the historical context for reprocessing in the U.S.

reprocessing capability at the Hanford Site in eastern Washington as part of the Manhattan Project (DOE 2002a, p.1.5). The second goal was pursued by private companies after the war, as commercial nuclear power was being developed. (See Figure 9.) Three commercial reprocessing facilities were built for the purpose of obtaining a closed fuel cycle, in which plutonium recovered from spent fuel would be used in breeder reactors, which would produce additional fuel for power production.[40] In theory, using plutonium to start up a breeder reactor could "extract one hundred times more energy than current generation reactors from a ton of natural uranium" (Von Hippel 2007, p.2).

Figure 9: U.S. Experience with Commercial Reprocessing

West Valley, NY
In 1963 Nuclear Fuel Services received a permit to construct a fuel reprocessing plant in West Valley, New York, 35 miles south of Buffalo. The plant became the first and only private fuel reprocessing plant ever to operate in the United States. It operated from 1966 to 1972 and had a capacity for reprocessing 300 MTU of spent fuel per year. In 1972 the facility suspended operations in order to increase plant capacity and to retrofit the plant to comply with new regulatory and environmental requirements. However, the project proved too costly, and the facility never resumed reprocessing operations. The site is now being decommissioned by DOE.

Morris, Illinois
The General Electric fuel reprocessing plant in Morris, Illinois was built in the early 1970s and also had a capacity of 300 MTU/year. The facility employed a different process than the West Valley facility. After construction it was determined that due to a series of technical problems the reprocessing facility would never be able to operate. The facility has since become a major site for spent fuel storage.

Barnwell, South Carolina
Allied General Nuclear Services began construction of a fuel reprocessing facility in Barnwell, South Carolina in 1970. The plant would have been capable of reprocessing 1,500 MTU/year. Operation had originally been scheduled to begin in 1974 but was delayed due to issues with construction and authorization. In 1977 the facility was in the final stages of licensing when President Carter cancelled the project due to nuclear proliferation concerns. Barnwell has also become a major site for spent fuel storage.

Source: (National Academies 1996, pp.165-167; DOE 1996)

This vision for a closed fuel cycle[41] never materialized in the U.S. because the development of reprocessing technologies encountered technical challenges, uranium supplies were sufficient, and the costs of reprocessing turned out to be higher than had been expected. However, other countries continued to pursue reprocessing and there is currently worldwide capacity to reprocess spent fuel from about 285 reactors each year (MIT 2003, p.120). (See Figure 10.)

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[40] Breeder reactors are nuclear reactors that produce more nuclear fuel than they consume.

[41] A closed fuel cycle is a cycle whereby fissile material would be recovered from spent fuel and reused in a reactor.

Figure 10: Worldwide Reprocessing Capacity

Two facilities account for over 85% of worldwide reprocessing capacity: the UK's Sellafield facility, which has the capacity to reprocess 2,400 MT per year of spent fuel, and France's La Hague facility, which has the capacity to reprocess 1,700 MT per year of spent nuclear fuel. Japan's first reprocessing facility is currently under construction.

The Sellafield facility comprises two plants, B205 and THORP (Thermal Oxide Reprocessing Plant). B205 was built in 1964 to process fuel from UK-designed Magnox reactors. As of March 2002 the unit had processed more than 40,000 MT of Magnox fuel from the UK, Italy and Japan. THORP began operating in 1994, and as of March 2002 the unit had processed 3,800 MT of spent fuel. During the first 10 years of contracts, approximately two-thirds of Thorp's capacity was devoted to foreign fuel reprocessing, mostly from Japan.

France's La Hague facility is operated by Cogema, a government-owned company. Facilities at La Hague include two reprocessing plants, UP2 and UP3. UP2 was originally constructed in 1966 to reprocess Magnox fuel. In 1976 it was retrofitted to process spent fuel from LWRs. UP3 came on line in 1996. More than half of the spent LWR fuel that La Hague has processed has been from Germany, Japan, Switzerland, the Netherlands and Belgium. Since 1990 UP2 has been processing French fuel almost exclusively. UP3 was financed entirely by foreign clients and was contracted to spend its first 10 years of operation reprocessing only foreign fuel; reprocessing of French fuel was scheduled to begin in 2006. Between 1990 and 2005, La Hague's units reprocessed approximately 20,000 metric tons of fuel.

Japan is currently building a new reprocessing plant that will have an annual capacity of 800 MT per year. This plant is expected to begin operating in 2007.

Source: (AREVA 2005; IAEA 2005; Energy & Security 1997)

In 1974 India used plutonium recovered through a U.S.-assisted reprocessing program to detonate a nuclear device. This event reinforced concerns that the spread of reprocessing technologies and experience would promote the proliferation of nuclear weapons. In response, President Ford suspended plans for U.S. commercial reprocessing, and President Carter deferred these plans indefinitely and removed federal funding for the Barnwell, South Carolina reprocessing facility (CRS 2006, pp.3-4). Although the moratorium on licensing U.S. reprocessing facilities was later reversed by the Reagan administration, by that time the high costs associated with commercial reprocessing and the decline of the commercial nuclear power plant market had eroded commercial interest in reprocessing.

In 1993 the Clinton administration reinstated U.S. opposition to reprocessing. This policy remained in place until 2001 when President Bush included in his National Energy Policy a recommendation that the U.S. should consider developing reprocessing and fuel treatment technologies that would be “cleaner, more efficient, less waste intensive, and more proliferation resistant” (NEPDG 2001). In February 2006 the Bush administration and DOE proposed the GNEP program with the establishment of domestic reprocessing capabilities as the centerpiece of the program.

The Global Nuclear Energy Partnership

GNEP is a federal research and development program headed by DOE that is designed to “effectively address two of the great concerns that have historically been associated with nuclear power” and which have limited the growth of nuclear power: disposal of spent fuel and nuclear weapons proliferation (DOE 2006a). The vision for GNEP is that both of these challenges would be addressed by the development of “proliferation-resistant” nuclear fuel reprocessing technologies that will minimize nuclear waste streams (DOE 2006j, p.61). In addition, the U.S. and other members of the global partnership would launch a fuel leasing program to allow countries to access nuclear power without developing their own uranium enrichment and reprocessing facilities. As described by DOE, the key objectives of GNEP are as follows (GNEP 2007):

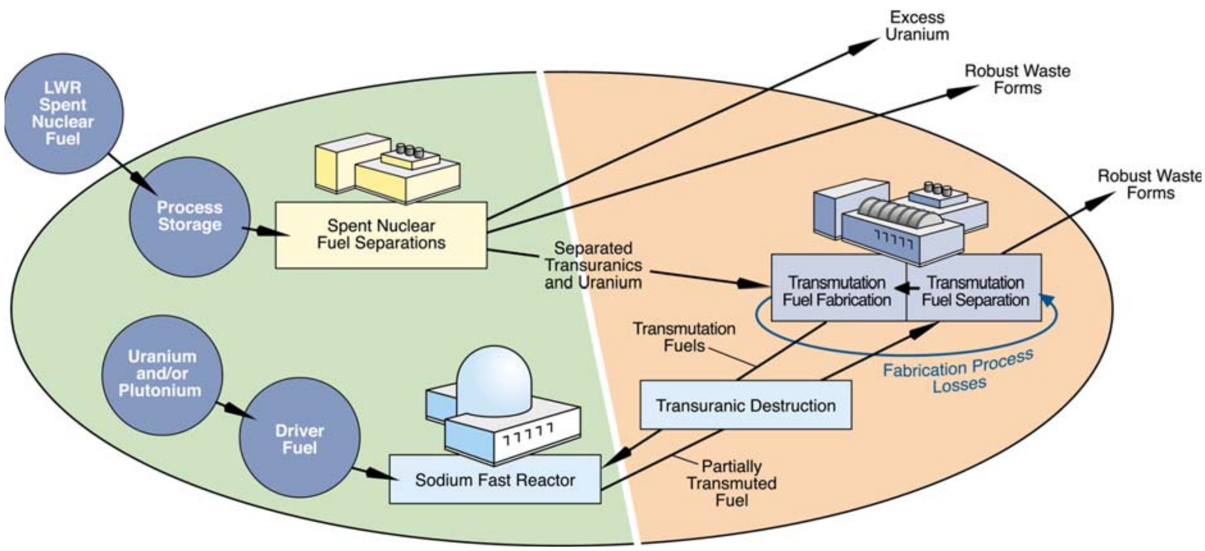
- Recycle nuclear fuel using new proliferation-resistant technologies to recover more energy and reduce waste
- Apply advanced technologies to the nuclear fuel cycle in order to reduce the risk of nuclear proliferation worldwide
- Encourage global economic prosperity and sustainable development by developing and promoting reliable, environmentally friendly energy supplies
- Reduce the use of fossil fuels

Achieving these goals will require a significant effort both domestically and internationally. The domestic components of GNEP will be initiated first, with the international components introduced only after the success of GNEP’s domestic reprocessing vision has been proven.

Domestic Components of GNEP

The domestic goal of GNEP is to move from the once-through fuel cycle currently used throughout the U.S. to a closed fuel cycle that incorporates repeated reprocessing of spent fuel. According to the GNEP plan, spent fuel from current reactors would be sent to a reprocessing and recycling facility, where the uranium and plutonium would be separated out. These components would then be sent to a fuel fabrication facility, where they would be recycled into fuel for a new type of reactor, called an advanced burner reactor or a fast reactor. The fast reactor would be used to generate electricity and to convert (transmute) long-lived transuranic elements in the spent fuel into less radioactive elements, thereby reducing the need for disposal at an underground geological repository.[42] Spent fuel from the fast reactor would be reprocessed and recycled into additional fast reactor fuel, which would then be reprocessed and recycled into additional fast reactor fuel. Unlike the reprocessing currently being done in Europe, under the GNEP plan spent fuel would be repeatedly recycled until nearly all the transuranic elements are destroyed (DOE 2006l, p.8). (See Figure 11.)

Figure 11: Domestic Components of GNEP



Source: (DOE 2007h, p.23)

The GNEP program plans to develop new reprocessing technologies instead of relying on the PUREX technology already available and in use in Europe. The primary reason for not using the existing PUREX technology is that it is seen as a potential proliferation threat. New technologies that DOE is exploring may provide some measure of proliferation resistance. They may also provide other benefits, such as the easing of fuel repository requirements and the facilitation of advanced reactor fuel reprocessing. DOE's preferred technologies are shown in Table 11. The reprocessing technologies are further described in Figure 12 and Figure 13 and in Appendix A.

[42] DOE has expressed preference for the sodium-cooled fast reactor, and a pre-conceptual design has been completed for a 250 MW test reactor.

Table 11: New Technologies Required for GNEP

Technology Needed	Preferred Candidate
Proliferation-resistant technology to reprocess spent fuel from LWR reactors	UREX+; COEX also being considered (See Figure 12.)
Advanced burner reactor	Sodium cooled fast reactor
Fuel for the advanced burner reactor (transmutation fuel)	Initially, metal or oxide fuels
Technology to reprocess spent fuel from the advanced burner reactor	Pyrochemical processing ("pyroprocessing"—see Figure 13)

Source: (DOE 2006d, p.10; DOE 2007h. p.28)

DOE has moved forward with planning for these new technologies on two parallel fronts: 1) identifying potential locations to host a fuel reprocessing center and/or an advanced reactor facility, and 2) soliciting early input from industry, government laboratories, and research centers on how best to develop the needed technologies to make GNEP possible. Table 12 identifies 13 locations that have expressed an interest in hosting one or more of the facilities planned under GNEP.

Table 12: Possible Locations for GNEP Facilities

DOE Sites	Non-DOE Sites
Argonne National Laboratory (IL)	Atomic City, ID
Hanford (WA)	Barnwell, SC
Idaho National Laboratory (ID)	Hobbs, NM
Oak Ridge National Laboratory (TN)	Roswell, NM
Paducah Gaseous Diffusion Plant (KY)	Morris, IL
Portsmouth Gaseous Diffusion Plant (OH)	
Savannah River National Laboratory (SC)	
Los Alamos National Lab (N.M.)	

Source: (DOE 2007h, p.39)

DOE is currently in the process of developing a programmatic environmental impact statement for the domestic component of GNEP; a final environmental impact statement may be released in late spring 2008.

Figure 12: PUREX, UREX+, and COEX

The PUREX process is currently the only commercially viable method for reprocessing. The process separates spent fuel into uranium, plutonium, and a nitric acid waste solution containing highly radioactive fission products and other isotopes. A variety of low-level and intermediate-level wastes also result from the process.

The UREX+ (Uranium Extraction plus) reprocessing method is similar to the PUREX process in that it extracts explicit elements from the spent fuel rods via chemical reactions in an aqueous solution. UREX+ differs from PUREX in that more radiotoxic materials are extracted and plutonium is kept mixed with transuranic elements and is not extracted in a pure form. Also, UREX+ reprocessing can be used in conjunction with a fast reactor to allow for repeated reprocessing cycles.

One benefit of the UREX+ process relative to the PUREX process is the extraction of cesium and strontium from the waste stream. Cesium and strontium are initially highly radioactive, and their presence in the waste stream increases the volume requirements for a waste repository. Separating these elements from the waste stream would thus allow for the storage of a much larger volume of spent fuel in a repository. As cesium and strontium lose their radioactivity relatively quickly (after about 300 years), they could theoretically be stored aboveground in a monitored facility until they no longer presented a health concern.

Another benefit of the UREX+ method is that it is more proliferation-resistant than the PUREX method, since plutonium is never isolated. However, as discussed below in the section *GNEP and Nuclear Weapons Proliferation*, there is debate over the proliferation-resistance of UREX+. Some fear that the combination of plutonium and transuranic elements that would be extracted using UREX+ would not be sufficiently radioactive to prevent handling and transport, while it would remain sufficiently radioactive to fuel a nuclear bomb. (UCS 2007a)

The UREX+ process has been demonstrated only in a laboratory environment at Argonne National Laboratory. Preparations for a “scale-up demonstration” are reported to be underway. (ANL 2007b) DOE estimates that the technology could be fully developed as early as 2012 and commercialized in the 2012-2025 timeframe. (DOE 2005a, p.24) NEI is less optimistic, estimating that commercialization could require at least 50 years. (NEI 2006a)

The COEX process is currently under development by AREVA, and it is an intermediate step between PUREX and UREX+. The COEX process co-extracts equal amounts of uranium and plutonium. This adds a measure of proliferation resistance, since pure plutonium is not extracted. However, it does not provide as much proliferation resistance as UREX+. (DOE 2006d, p.8; DOE 2005a) (See further discussion below in the section *GNEP and Nuclear Weapons Proliferation*.)

Figure 13: Pyroprocessing

Pyrochemical processing, also known as pyroprocessing, is an alternative to aqueous processing such as PUREX and UREX+. (The prefix "pyro" indicates that the process happens at relatively high temperatures of around 500^{o}C; there is no flame and no combustion occurs.) The process is primarily being developed to reprocess spent fuel from Generation IV reactors. These reactors, as discussed in Chapter 12, are advanced reactors that are in early stages of research and development. It is currently expected that they will not be LWRs and that their fuel will not be compatible with conventional aqueous processing (DOE 2005a).

A simplified version of pyroprocessing has been demonstrated at Argonne National Laboratory to treat wastes from its experimental breeder reactor (UIC 2005). However, critics question the success of the demonstration. According to Edwin Lyman of the Nuclear Control Institute, "DOE was only able to claim that the demonstration program met or exceeded all key performance criteria by changing the original criteria, in other words, it was only by moving the goal posts that [DOE] was able claim success" (NCI 2000).

Pyroprocessing technology has also been demonstrated in laboratories in Europe and Japan (Venneri 1999). However, the IAEA states that pyroprocessing is "still very much at the R&D stage" and that it would require on the order of 10 to 15 years of additional development before it would be ready for a full pilot-scale demonstration (IAEA 2004, p.109). Other experts estimate that advanced reprocessing technologies, such as pyroprocessing, will not be available for 50 to 60 years (DOE 2006a; Washington Post 2006; DOS 2006).

The IAEA notes that a key non-proliferation feature of pyroprocessing is that it results in impure plutonium, containing a highly radioactive mix of uranium, transuranic elements, and some fission product contamination (IAEA 2004, p.32). However, critics respond that the high radioactivity of the separated product is relatively short lived (on the order of years), after which it loses its nonproliferation benefit (SGS 2005). Another drawback to pyroprocessing is that it does not extract cesium and strontium from the waste stream, which UREX+ does (DOE 2003a).

Global Components of GNEP

A key goal of GNEP is to create an international framework that will allow developing countries and other countries without nuclear infrastructure to harness nuclear power while minimizing proliferation concerns. There are two parts to this framework: an international partnership whereby supplier nations would lease nuclear fuel to countries that agree not to pursue enrichment or reprocessing capabilities, and the deployment of nuclear reactors appropriately sized for the electricity grids and industrial needs of smaller, more rural, and less industrialized regions.

Under the fuel-leasing program, fuel-supplier states would provide fuel enrichment and reprocessing services to fuel recipient countries. Supplier countries would have three primary responsibilities:

1. To offer fuel services at competitive rates in order to provide incentives for fuel recipient countries to lease fuel rather than invest in nuclear infrastructure.
2. To accept spent fuel from fuel recipient countries and reprocess or otherwise dispose of it. This may require facing domestic concerns that land is being used as a nuclear waste dump for other countries' energy production.[43]
3. To continue diplomacy with countries that have been excluded from the partnership and that wish to develop enrichment and reprocessing technologies.

The U.S., the United Kingdom, France, Russia, China, and Japan comprise the initial set of global fuel supplier partners (DOE 2006a).

The goal of the GNEP small-scale reactor research program is to deploy nuclear reactors of 50-350 MW capacities with simple operations, fully passive safety systems, capabilities for remote monitoring by the International Atomic Energy Agency (IAEA), and long-life fuel loads, possibly not requiring any refueling over the reactor's lifetime. The U.S. has done only minimal research on reactors that would have these features, but other countries have been actively researching and developing such technologies. The IAEA leads an International Project on Innovative Nuclear Reactors and Fuel Cycles, which supports development of small-scale reactors for developing countries.[44] (IAEA 2003, p.2) The U.S. role, as currently envisioned under GNEP, is to help form international partnerships to accelerate the commercialization of these technologies (DOE 2007j).

GNEP Timeline

In the near term, DOE is focusing on compiling information and gathering public and industry input to support a decision by the Energy Secretary as to whether to move forward with GNEP. This decision, which may also determine where to locate these facilities, and which technologies to use, is expected to be made in June 2008 (DOE 2007h, p.40). If the Energy Secretary supports moving forward with GNEP, DOE would "build and operate [the] nuclear fuel recycling center and advanced recycling reactor facilities using the latest commercial technology available" as soon as

[43] Current U.S. policy is not to repatriate foreign spent fuel that originated in the U.S. This foreign spent fuel is termed U.S.-obligated, meaning that the countries in possession of the fuel are obligated to follow regulations that the U.S. has imposed with regard to fuel handling. For instance, countries must seek U.S. approval before reprocessing this fuel or transferring it to another country, and the U.S. does retain the right to repatriate it.

[44] Members of the IAEA project include the European Commission, Argentina, Pakistan, Russia, and a dozen other entities. The U.S. has not joined this project.

possible (DOE 2007i, pp.9-10). At the same time, DOE would move forward with an R&D program into advanced reprocessing and transmutation technologies.

If DOE follows this phased approach, using the latest commercial technologies as they become available, limited reprocessing in a LWR could begin before transmutation fuels are available. In addition, reprocessing could begin with the COEX process, rather than the preferred UREX+ process. Indeed, members of academia and industry estimate that achieving the complete domestic GNEP goal could take 50 to 60 years, whereas DOE's goal is to commercialize an advanced reprocessing system and a fast reactor in the U.S. by 2025.[45] The implications of using transitional reprocessing technologies in the near term are discussed below in the sections *GNEP and Spent Fuel Disposal* and *GNEP and Nuclear Weapons Proliferation*.

The global components of GNEP are considered late-stage components. That is, they will only be feasible once a reprocessing technology has been proven that is both proliferation-resistant and effective at minimizing the spent fuel waste problem. Moreover, according to John Deutch, Institute Professor at MIT, the key to GNEP is large-scale global deployment of nuclear power, which he does not anticipate in the near-term. Deutch expects that GNEP will not be fully deployed until about 2150, "a very, very, very, very, very long time in the future" (Greenwire 2007a).

Marvin Fertel, NEI senior vice president and chief nuclear officer, also sees a linkage between GNEP and new reactor deployment. Fertel recommended that key decisions on GNEP wait until 2020 or 2030, at which point industry will have a better idea of the extent of new reactor construction in the U.S. and abroad. By 2020, he said, "we'll have a reasonable idea of deployment" of new reactors, which will indicate whether there will be a market for GNEP's international fuel services portion and whether a tight uranium supply will require the use of reprocessed fuel (Greenwire 2007b).

GNEP and Spent Fuel Disposal

As discussed above, a primary objective of GNEP is to address some of the problems of disposing of nuclear waste in a geologic repository by introducing reprocessing into the fuel cycle. In fact, DOE has predicted that "[technological] advancements through GNEP could reduce the volume, thermal output, and radiotoxicity of waste requiring permanent disposal at the Yucca Mountain geologic repository" (DOE 2007k). These goals and the advancements that will be required to meet them are discussed in this section.

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[45] For example, according to a DOE advisory group, it will likely be necessary to fuel a fast reactor initially with a uranium-plutonium fuel (such as MOX fuel or COEX fuel), rather than with fuel that contains transuranic elements, such UREX+ fuel (DOE 2006d, p.2).

Volume

The technologies proposed for the GNEP program are not intended to replace the planned geologic repository for Yucca Mountain. However, GNEP is attempting to address the looming conflict between the statutory limits on the volume of spent fuel that can stored at Yucca Mountain and the actual and projected volumes of spent fuel accumulating around the country at nuclear power plants.

The Nuclear Waste Policy Act (NWPA) of 1982 limits the amount of spent fuel that can be stored at Yucca Mountain to 70,000 MTHM.[46] Of that amount, 63,000 MTHM is reserved for spent fuel from or commercial reactors. As of the end of 2005, the United States had accumulated about 53,000 metric tons (MT) of waste from civilian reactors, with an additional 2,100 MT accruing each year (DOE 2006l, p.7). At this rate of accumulation, the statutory limits of Yucca Mountain will be met by 2010. With the licenses of many of the country's nuclear reactors being renewed for up to another 20 years, spent fuel stockpiles could reach a total of 120,000-130,000 MTHM by around 2040 (APS 2005c, p.17). (License renewal is discussed in Chapter 12.)

Reprocessing spent fuel can reduce the volume of high-level wastes, but it also produces a greater amount of intermediate-level waste and low-level waste.[47] The operators of the British and French reprocessing facilities have reported that, using current technology, reprocessing spent fuel results in four times less volume of high level wastes than the volume of the original spent fuel (Harvard 2003, p.61).[48] But intermediate-level wastes may require storage in a geologic repository just like high-level waste does. If high- and intermediate-level wastes are combined, current reprocessing does not yield a smaller volume of waste when compared to a once-through fuel cycle (Harvard 2003, p.62).

DOE studied the role of different fuel cycle strategies for several different nuclear growth scenarios and considered the implications of these different strategies and growth scenarios on the need for *additional* geological repositories. DOE found that if all existing nuclear power plants are retired at the end of their original 40-year licenses and the fuel cycle does not include reprocessing, then an additional repository will be required simply to store the fuel from current nuclear power plants. Under DOE's highest growth scenario, where nuclear power accounts for a greater share of the electricity supply and reprocessing is not used, the U.S. could need as many as 20 repositories by 2100. However, under the three highest nuclear growth

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[46] Federal legislation has been introduced that would reexamine the capacity limit on the repository planned for Yucca Mountain. (See Chapter 3.) The theoretical maximum capacity is estimated by DOE to be about 120,000 MTHM (DOE 2003c, pp.1-3).

[47] Intermediate-level waste from reprocessing typically needs to be disposed of in geologic repositories along with high-level waste. In the U.S., this waste is referred to as transuranic waste (Harvard 2003, p.61). Low-level and high-level wastes are defined in Chapter 3.

[48] Note that this figure does not include the waste container that would encapsulate the high-level waste.

scenarios, the number of repositories could be cut in half by reprocessing and recycling fuel in current reactors. Additionally, using the new transmutation technologies envisioned under the full GNEP plan, a single repository would be sufficient even in DOE's highest growth scenario (DOE 2007e, p.13). Under all scenarios there would remain a need for long-term geological disposal of radioactive isotopes, and in the reprocessing scenarios there would be significant additional need for low- and intermediate-level radioactive waste disposal (AIADA).

Heat Output

Many of the technical standards established for the proposed repository at Yucca Mountain take the form of temperature limits applied to the overall repository as well as to individual waste packages. By reducing the heat output of nuclear waste, the capacity of a geological repository such as Yucca Mountain could be increased.

In theory, a fast reactor-based fuel cycle would reduce the long-term heat load of a repository by 20 percent 10 years after discharge and by 99 percent 300 years after discharge when compared to storage of spent fuel from a once-through cycle (National Academies 1996, pp.31-34, 100). However, reprocessing spent fuel and using the recycled plutonium in a LWR rather than a fast reactor, as might be done during early phases of GNEP, would actually yield a greater total heat output from the waste than if the same amount of electricity was generated using a once-through fuel cycle. In other words, the GNEP goal of limiting the needed capacity in a geologic repository can only be achieved if "the [reprocessing] soon switches [from limited recycling] to fast-neutron reactors or more complete separation and transmutation of the wastes" (Harvard 2003, p.39).

Radiotoxicity

Another important goal of GNEP is to reduce the duration of radiotoxicity of spent fuel from about 300,000 years to several hundred years, greatly easing the licensing requirements for a geologic repository.[49] DOE investigated the impact of four different fuel cycles on the radiotoxicity of spent fuel: the current once through cycle; a limited recycle scenario, in which enriched uranium and recycled plutonium are used as fuel for existing LWRs and, after a few cycles, the spent fuel is disposed; a transitional recycle scenario, in which spent fuel is recycled continuously using fast reactors until transuranic components are essentially eliminated; and a sustained recycle scenario, in which depleted and recycled uranium are converted into fuel and spent fuel is recycled through fast reactors (DOE 2005a, pp.8-11).

DOE found that limited recycling has no impact on the duration of spent fuel's radiotoxicity, because the long-term radiotoxicity of spent fuel is derived almost

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[49] Radiotoxicity is a measure of the hazard inherent in the waste. Different indices can be used to measure radiotoxicity, for instance: activity per volume, total activity, number of annual limits of intake contained in the material, etc. The duration of radiotoxicity is defined as the amount of time during which the spent fuel radiotoxicity exceeds the radiotoxicity of the source material (uranium ore) (IAEA 1994, p.25 ; DOE 2005a, p.13).

exclusively from the transuranic elements in the waste, and limited recycling leaves these elements intact. However, transitional and sustained recycling in fast reactors would transmute the transuranic elements into shorter-lived or less radiotoxic elements.

GNEP and Nuclear Weapons Proliferation

The U.S. ended efforts to develop commercial reprocessing capabilities in the 1970s when it became evident that reprocessing, if developed by countries or organizations with non-peaceful intentions, could lead to the proliferation of nuclear weapons. GNEP is a reversal of that long-standing U.S. policy against reprocessing. However, GNEP seeks to build in safeguards against weapons proliferation by developing proliferation-resistant fuel cycles and creating a fuel-leasing program that keeps reprocessing facilities in a limited number of countries.

Plutonium extracted from spent fuel via reprocessing can currently be used in one of two ways: as MOX fuel for a nuclear reactor or as fuel for a nuclear weapon. Globally, little of the plutonium that has already been extracted through reprocessing has been made into MOX fuel, and most of the plutonium remains stockpiled. As of the end of 2003, there was approximately 265 MT of plutonium in global military stockpiles and 240 MT of separated plutonium in civil stockpiles. There was an additional 1,300 MT of plutonium within civil stocks of (non-reprocessed) spent fuel (See Table 13.) (ISIS 2005, Tables 1, 3; ISIS 2007). Just 2 to 4 kg of weapons-grade plutonium or about 5 kg of reactor-grade plutonium can produce a 10 to 20 kiloton explosion, similar to the scale of the Hiroshima and Nagasaki bombs (CFR 1998; Greenpeace 2007).

GNEP would eliminate over time these stockpiles of separated plutonium by converting the plutonium into reactor fuel. In addition, the reprocessing technology envisioned under GNEP will be “proliferation-resistant,” meaning that it “would make more difficult, time-consuming, and transparent the diversion by states or sub-national groups of civilian nuclear fuel cycles to weapons purposes” (FAS 2001).

The initial idea under GNEP for achieving a proliferation-resistant fuel cycle was to mix plutonium with other transuranic elements, as is done with the UREX+ process that is under development. According to DOE, “as long as the fissile materials [i.e., plutonium and uranium] remain combined with sufficient quantities of non-fissile materials the product is not directly useable as a nuclear weapon.” However, the UREX+ technology is not expected to be commercially available until after 2020, and it is now expected that DOE would use an alternate process, called the COEX process, at least until UREX+ is available (DOE 2006d, p.8; DOE 2005a). The COEX process keeps plutonium mixed with an equal amount of uranium, but not with other transuranic elements. (See Figure 12.)

Table 13: Worldwide Stockpiles of Plutonium in 2003

Country of Origin	Military Stocks metric tons	Civil Stocks in spent fuel metric tons	Civil Stocks separated metric tons
Belgium		23.1	.4-1.4
China	4.8	5.1	
France	5	183	48.1
Germany		67-70	26
India	.38	12.5-13	1-1.5
Israel	.58		
Italy		4.0	2.5
Japan		111-113	40.6
Netherlands		1-1.4	2-2.5
North Korea	.015-.04		
Pakistan	.04		
Russia	145	88	38.2
Spain		26.6	0.3
Sweden		41	.83
Switzerland		16-17	1.5-3
United Kingdom	7.6	18.5-24.6	74.6
United States	99.5	403	
Other		324-327	2-6
Total	263	1,327-1,337	242

Source: (ISIS 2005, Tables 1, 3; ISIS 2007)

Many experts are concerned that the UREX+ process would not be proliferation resistant. For example, Jungmin Kang and Frank von Hippel investigated whether mixing plutonium with transuranic elements (as done in UREX+) would yield greater proliferation resistance than pure plutonium. They found insufficient improvements in four key areas (SGS 2005):

- A plutonium-transuranic mix would have a higher neutron emission rate than reactor-grade plutonium alone, leading some observers to "conclude that these materials are unusable in nuclear weapons." Kang and von Hippel countered that although a high-neutron emission rate reduces the expected "yield" from a Nagasaki-type weapon from about 20 kilotons to as low as 1 kiloton, the plutonium-transuranic mix could still be used in a weapon since even a 1 kiloton explosion would be devastating.[50]
- Most explosives become unstable at temperatures above 200° C. For this reason, nuclear warheads, which use heat-emitting plutonium, may require a

[50] A plutonium-transuranic mix has a neutron emission rate about twice as fast as the emission rate from reactor-grade plutonium, which is about 10 times as fast as the emission rate from weapons-grade plutonium. Thus, the plutonium-transuranic mix would be less desirable than pure plutonium as a weapons material.

cooling system of some kind. Although reactor-grade plutonium has a rate of heat release significantly higher than weapon-grade plutonium, the IAEA and weapons experts believe that it is possible to use reactor-grade plutonium in combination with a cooling system to make a nuclear warhead. Kang and von Hippel estimated that a plutonium-transuranic mix would have a rate of heat emission only about twice that of reactor-grade plutonium. Thus, if the appropriate cooling system were employed, a weapon could be made using a plutonium-transuranic mix.

- The amount of material required to initiate a chain reaction is greater for the plutonium-transuranic mix (17.9 kg) than for reactor-grade (14.4 kg) or weapons-grade (10.7 kg) plutonium. However, these differences are not significant to prohibit weapons construction.
- The radiation dose for a pure transuranic mix is more than three orders of magnitude lower than the threshold for self-protection.[51] Advanced reprocessing as envisioned under GNEP would increase the radiation dose above the threshold for self-protection by mixing cerium together with the transuranic elements. However, this cerium protection is short-lived. Since the half-life of cerium is less than a year, the radiation dose would remain above the threshold for just over two years.

There are similar (and even stronger) concerns over the proliferation-resistance of the plutonium-uranium mixture from the COEX process. In testimony to Congress, Matthew Bunn of Harvard noted that it would not be difficult to separate out the plutonium from the plutonium-uranium mixture.[52] Moreover, it would not be necessary to do so, since nuclear explosives could be made directly from this mixture. Furthermore, the NRC reviewed this approach 30 years ago and found it to be not significantly more proliferation resistant than pure plutonium.

A Massachusetts Institute of Technology (MIT) study determined that the once-through fuel cycle “defines the baseline for adequate proliferation-resistance,” while advanced closed fuel cycles that mix plutonium with other transuranic elements “need strong process safeguards against misuse or diversion” (MIT 2003, p.67). Moreover, “the development and eventual deployment of closed fuel cycles in non-nuclear weapons states is a particular risk both from the viewpoint of detecting misuse of fuel cycle facilities, and spreading practical know-how in actinide science and engineering” (MIT 2003, p.67). Indeed, a Harvard study questioned the need for reprocessing when there is minimal legitimate demand for plutonium and concluded that “the burden of proof clearly rests on those in favor of investing in reprocessing in

[51] The threshold for self-protection is the radiation dose (100 rads per hour at one meter) above which even short exposures to the material would be very hazardous to human health.

[52] However, the quantity of material that would be required to make a bomb out of the uranium-plutonium mixture is significantly greater than what would be required to make a bomb out of pure plutonium (Bunn 2006).

the near term," due in part to proliferation concerns with respect to separated plutonium (Harvard 2003).

It is debatable whether a plutonium-transuranic mix would be attractive to terrorists seeking to make a nuclear weapon. According to many weapons-design experts, "there is no proliferation-proof nuclear power cycle" because most of the transuranic elements and their oxides are explosive fissionable material (LLNL 1999, p.14). Moreover, as "nuclear weapons design and engineering expertise combined with sufficient technical capability become more common in the world, it becomes possible to make nuclear weapons out of an increasing number of technically challenging explosive fissionable materials" (LLNL 1999, p.14).

Concerns over these reprocessing technologies were echoed by representatives of arms control, consumer, environmental, and public health organizations who wrote in a letter to Congress in January 2006 that the "'proliferation-resistant' reprocessing technologies currently being researched by DOE are not sufficient to prevent theft by terrorists, while the plutonium mix that results from these technologies could be used to make a nuclear weapon" (ANA 2006). However, Dr. Per Peterson of the University of California, Berkeley believes this concern is misplaced. He argues that a plutonium-transuranic mix would not be attractive to terrorists since it is more difficult to develop weapons materials out of reprocessed fuel than out of virgin uranium (NY Times 2006).

The National Commission on Energy Policy (NCEP) reviewed U.S. policy on reprocessing in 2004 and found that reprocessing continues to pose a proliferation risk. It recommended that "the United States do everything it can to minimize access to uranium-enrichment and fuel-reprocessing technologies by countries other than the five de jure nuclear-weapon states" and "that it defer—at least for the next few decades—plutonium separation in its own commercial nuclear-energy operations" (NCEP 2004, p.59). NCEP made this recommendation based on its finding that weapons proliferation concerns were a substantial barrier to the expansion of nuclear energy in the U.S. (NCEP 2004, p.61).

GNEP and Reprocessing: Issues to Consider

If GNEP is pursued, it will substantially change the way that nuclear power is produced and consumed. It will also have a number of other local and national impacts. This section discusses the economic, environmental, and safety implications of the domestic reprocessing component of GNEP, as well as the implications that a large federal reprocessing program could have on competing federal energy programs. The implications of the global component of GNEP are not considered, as this is considered to be a late-stage component and too speculative at this time.

Economics of the Reprocessing Fuel Cycle

There are three major cost categories to the reprocessing fuel cycle: transportation of spent fuel from the reactor to the reprocessing facility, reprocessing, and final disposal of reprocessing waste by-products. A number of studies have compared the cost of the reprocessing fuel cycle using commercially available reprocessing technologies with the cost of the once-through fuel cycle currently in use in the U.S.

- The OECD compared the costs of nuclear power generated with a once-through fuel cycle to the costs of a fuel cycle that includes reprocessing and a one-time recycling of recovered plutonium into MOX fuel for a pressurized water reactor. The study found the reprocessing fuel cycle to be 14 percent more expensive than the once-through fuel cycle (OECD 1994, pp.40, 53, 115).
- A 2003 study by Harvard University found that the cost of reprocessing using the PUREX technology would be between $1,350 and $3,100 per kgHM.[53] They also found that even if the cost of reprocessing was reduced to $1,000 per kgHM, nuclear power-generated electricity costs would increase by at least 0.13 cents per kWh (Harvard 2003, p.28).
- Researchers at MIT concluded that reprocessing would increase the cost of electricity by 0.28 cents per kWh compared with electricity costs in a once-through fuel cycle scenario (MIT 2003, p.148).
- A study by the National Academies concluded that the cost of reprocessing the 63,000 MTHM of civilian spent fuel intended for Yucca Mountain using existing technologies would be about $2,100 per kilogram of heavy metal (kgHM) in 1992 dollars, which is equivalent to a total cost of $180 billion in 2006 dollars (National Academies 1996, p.7).
- In a study for AREVA, the Boston Consulting Group concluded that "the overall cost of recycling used fuel is in the order of $520 per kg, comparable to the cost of a once-through strategy," which is estimated to be around $500 per kg of spent fuel (BCG 2006, p.12).

The cost of the reprocessing fuel cycle using advanced reprocessing technologies remains highly uncertain at this time. DOE expects that UREX+ will be less costly to implement than PUREX because the amount of liquid waste requiring solidification is less and the scale of processing equipment that must be included in the plant design is smaller (DOE 2005a). DOE estimates that a plant capable of reprocessing 2,000 MT of spent fuel per year using UREX+ technology could cost $6 billion to construct with an annual operating cost of $280 per kilogram of material treated (DOE 2003a). However, the National Academies found that the cost to reprocess and transmute

[53] The variation in estimated cost is due to financing costs for a reprocessing facility. A government-owned reprocessing facility would be able to access very low-cost financing whereas a private entity would face higher financing costs. (The reprocessing facilities built in France, Great Britain, and Japan all relied on some level of government funding.)

the spent fuel sufficiently to affect the need for a second repository would cost about $500 billion (in 1992 dollars) over 150 years (National Academies 1996, p.82).

Opportunity Costs of GNEP

President Bush's 2008 budget proposal requested $405 million in funding for GNEP, an increase of $155 million above the 2007 budget request[54] (DOE 2007a).[55] DOE anticipates that $2 billion will be spent on the program through FY 2009, at which point a determination will be made on whether or not to proceed with the program (E&ETV 2006). If the program is pursued, its lifetime federal funding is projected to total $20-$100 billion. This level of funding raises three concerns:

1. Other DOE programs that support renewable energy, energy efficiency, and demand side management may receive less funding if the "pie" remains the same size overall.
2. DOE may be underestimating the true cost of the complete GNEP program over its expected lifetime.
3. If funding is focused on GNEP, the efforts to license and operate a geologic repository at Yucca Mountain may suffer.

The first concern raises the issue of whether the concentration of energy funds on advanced fuel cycle technologies may result in fewer funds for energy efficiency, renewable technology, demand side management, and other competing programs that may more directly benefit California and the nation as a whole. This type of fund shifting may be seen in DOE's FY 2008 budget request for energy supply and conservation R&D: DOE counterbalances requested funding increases of 10 percent or more for hydrogen and nuclear technologies with requested funding decreases for all other renewable energy and energy efficiency technologies (AAAS 2007).

The second concern reflects criticisms of GNEP cost estimates. For example, Thomas Cochran and Christopher Paine of the Natural Resources Defense Council (NRDC) have pointed out that GNEP cost estimates do not include the cost to build the new fast reactors that are a critical component of the GNEP closed fuel cycle vision. They have estimated that building enough new fast reactors to transmute the fuel discharged from existing U.S. power reactors could cost between $80 and $100 billion (NRDC 2006, p.6). In testimony before Congress, Matthew Bunn of Harvard University urged legislators to consider whether DOE projects of comparable scale and complexity have remained within initial cost estimates (Bunn 2006). Finally,

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[54] The House Appropriations Committee's fiscal year 2008 Appropriations Bill, released June 6, 2007, allocates just $120 million to GNEP. The committee explained: "It is unnecessary to rush into a plan that continues to raise concerns among scientists and has only weak support from industry given that there are reasonable options available for short term storage of nuclear waste and that this project will cost tens of billions of dollars and last for decades." This bill had not been voted on by the full House of Representatives as of the release of this draft report (Congress 2007c).

[55] It should be noted that legislators failed to complete an appropriations bill for DOE's 2007 budget. GNEP funding for 2007 was $167.5 million under a continuing resolution.

John Deutch of MIT said that while he believes it is essential to make nuclear power as affordable as possible, "all these fancy closed-cycle systems will add to the cost of nuclear power. It's not a cost-saver" (Greenwire 2007a). Japan's experience with developing reprocessing capacity may add to these concerns. (See Figure 14.)

Figure 14: Japan's Experience Developing Reprocessing Infrastructure

In the 1980s, Japan embarked on a project to develop domestic reprocessing capabilities. Japan planned to construct its first large-scale reprocessing plant by the mid-1990s, with an additional reprocessing plant to be completed in 2010. It also planned on developing breeder reactors that would be able to burn plutonium recovered from spent nuclear fuel. However, lengthy delays and massive cost overruns ensued. The first plant, called Rokkashomura, is now expected to become commercially available in November 2007 at a cost of $17-$25 billion, and a decision on whether or not to construct the second plant will not be made until 2010. The plans to build breeder reactors have been all but abandoned in favor of a program to develop MOX fuel that will fuel LWRs.

The delays in developing a large-scale reprocessing plant and breeder reactors have led to large and growing stockpiles of spent nuclear fuel in Japan. Stockpiles of recovered plutonium (from Japanese spent fuel that was reprocessed in Europe) are also growing. The accumulation of spent nuclear fuel and recovered plutonium has led to concerns over domestic nuclear safety as well as concerns that Japan may use stockpiled plutonium in a nuclear weapons program. China in particular has expressed concerns about Japan's accumulation of plutonium stockpiles. In 1987 the government addressed the spent nuclear fuel stockpiles with a "partial reprocessing" policy that recognized that interim storage facilities would be needed due to delays in constructing a reprocessing facility. Interim storage of spent nuclear fuel will add to the lifecycle cost of nuclear power.

Meanwhile, public confidence in nuclear power has eroded over the past two decades due to a series of accidents and cover-ups at other Japanese nuclear facilities. One notable accident occurred at a site with a reprocessing plant but did not directly involve the reprocessing plant. The erosion of public confidence has created difficulties for the government in licensing storage and waste facilities and even shipping routes, and it may influence the government's future decisions on nuclear infrastructure research and development.

Japan's vision of a closed fuel cycle was similar to, but much less ambitious than, the vision put forth in GNEP. Twenty years into the process, they have scaled back their near-term plans to one reprocessing facility, which will cost as much as the lower estimates for the entire GNEP plan. While the Japanese government remains committed to reprocessing, given its difficulties with the Rokkashomura plant and growing public dissent, it is unlikely to endeavor on large nuclear infrastructure projects in the near future. The U.S. cannot rely on Japan to be an early adopter of advanced reactor designs or reprocessing technologies.

Source: (Harvard 2001; FEPC Japan 2003; FEPC Japan 2006; Global Security 2005; Japan METI 2007, p.11; Japan NCDI 2001; AIADA 2006; UIC 2006)

The third concern reflects the fear that the GNEP program will divert resources from the continuing effort to develop and license Yucca Mountain to an effort to develop reprocessing technologies that are unlikely to be available for several decades (Washington Post 2006). For example, Representative Boucher said in a September 2006 hearing that he is ”somewhat skeptical about the ability of DOE simultaneously to fund and staff [GNEP and centralized interim storage projects] while continuing to meet the new schedule for opening Yucca Mountain” (Congress 2006c, p.4).Initial reactions to the GNEP proposal from some members of Congress support this concern. Senator Burr of North Carolina called for a “pause” on spending on Yucca Mountain in order to explore whether reprocessing may be a better route. Senator Pete Domenici of New Mexico suggested that the $20 billion Yucca Mountain fund be partially redirected for research on reprocessing (LVRJ 2006c).

Reliability and Safety Issues

Because reprocessing spent fuel involves handling highly radioactive wastes, the safety of any reprocessing facility is of critical importance.[56] Unfortunately, the safety record of reprocessing facilities is not stellar. A recent MIT study noted that “the historical accident frequency [i.e., accidents per year] of reprocessing plants is much larger than reactors… Furthermore, the number of reprocessing plant-years of operation is many fewer than in the case of reactors. Therefore the accident frequency [i.e., accidents per plant] of reprocessing plants is much higher” (MIT 2003, p.51).

The higher accident rate at reprocessing facilities than at reactors may in part be due to the difference in safety measures at these facilities. At a reprocessing facility, “fissile materials and waste are handled, processed, treated and stored in easily dispersible forms…using chemicals which can be toxic, corrosive or combustible” (IAEA 2005, p.9).As a result, human intervention and administrative policies, which are prone to human error, play a significant role in safety. At a nuclear power plant, on the other hand, active and passive engineered controls provide most of the safety support.

A recent safety violation at a modern reprocessing facility occurred in January 2005, when about 20 MTHM of uranium and plutonium dissolved in concentrated nitric acid internally leaked at the Sellafield facility in Great Britain. The leak occurred in a contained area, and no radiation was released into the atmosphere. However, the leak continued for three months before being discovered. Repairing the pipes and recovering the spilled liquids is expected to take months and may need special

[56] Although a country’s government has ultimate jurisdiction and control of safety regulations for a reprocessing facility located within its borders, international safety standards are under development. In 1997 a number of countries agreed to a Joint Convention related to safety standards at reprocessing facilities. The Joint Convention, which went into force in 2001 and which currently has 42 signatories, is legally binding under international law. The U.S. ratified the Joint Convention in 2003.

robots, which will have to be built. Other significant safety events at commercial reprocessing facilities are described in Table 14.[57]

Table 14: Significant Safety Events at Commercial Reprocessing Facilities

Location and Year	Description of Event
Chelyabinsk, Former Soviet Union, 1957	Chemical explosion in concrete waste storage tank; 20 million curies[58] of radioactivity were released[59]
Tokai, Japan, 1999*	Uncontrolled chain reaction during fuel fabrication causing the deaths of two workers

* The criticality event that occurred in 1999 at the Tokai complex in Japan, in which worker error caused an uncontrolled chain reaction in a solution containing enriched uranium, was not associated with the reprocessing facility. Rather, it was associated with the experimental fast reactor also located on the site (UIC 2000).
Source: (NWMO 2003, p.35)

In addition to process-based safety concerns, a reprocessing program would necessitate a significant high-level waste transportation program, which could have a variety of security and environmental impacts. The GNEP program would require an international high-level waste transportation program as well. In a letter to DOE, the Western Interstate Energy Board (WIEB) raised concerns about the impacts on these shipments of potential malevolent acts or transportation accidents involving long-duration high temperature fires. WIEB also outlined a series of transportation-related impacts warranting investigation (WIEB 2007). For example, WIEB called for an assessment of the number and type of shipments that would be expected both domestically and internationally and an examination of origin and destination points and estimated shipment routes.

Another safety issue raised by GNEP is the potential need for longer interim storage of spent fuel. The GNEP facility would have a planned capacity of 2,500 to 3,000 MT per year and handle all the spent fuel from commercial nuclear power plants. With such a facility, it would require 30 to 40 years to reprocess the 63,000-105,000 MT of spent fuel from current reactors. Since this reprocessing is not expected to begin until at least the 2020s, some of the spent fuel would not be reprocessed for another half century or more. This spent fuel would likely remain in interim storage, which could be located at reactor sites, at several regional locations, or at the reprocessing

[57] Additional safety events have occurred at defense reprocessing plants in the U.S.

[58] The original unit for measuring the amount of radioactivity was the curie (Ci), first defined to correspond to one gram of radium-226 and more recently defined as: 1 curie = 3.7×10^{10} radioactive decays per second (LBL 2000).

[59] By comparison, the Chernobyl reactor accident released about 50 million curies of radioactive matter.

site. Alternatively, the spent fuel could be buried in a repository in a manner that allows it to be retrieved for reprocessing.

Environmental Impacts

The environmental impacts of reprocessing are much greater than the impacts of spent fuel storage. Reprocessing creates multiple waste streams and releases radioactive isotopes, such as carbon-14, krypton-85, iodine-129, tritium, and technetium-99, from spent fuel into the atmosphere (Schneider 2001, p.23). In a conventional PUREX reprocessing plant, these elements are released to the atmosphere.[60] The proposed UREX+ process would capture some of the radioactive off-gases for disposal (IPS 2007).

Historically, these radioactive releases have been significant. DOE found that the radiation dose within 50 miles of the Savannah River military reprocessing site in South Carolina is "four to five million times greater from reprocessing than from interim storage" (IEER 1996; DOE 1995b).The Institute for Policy Studies found that radionuclides stored at the Hanford reprocessing facility "pose potentially significant risks to health and natural resources for 300 to more than 200,000 years" (IPS 2007, p.10).

Significant releases of radioactivity have also been identified from European reprocessing facilities. In a report to the European Parliament, Mycle Schneider of World Information Service on Energy -Paris noted that "reprocessing operations release considerably larger volumes of radioactivity than other nuclear activities, typically by factors of several 1,000 compared with nuclear reactors," with radioactive discharges from the Sellafield and LaHague reprocessing facilities ranking "among the largest anthropogenic sources of radioactivity to the world" (Schneider 2001, pp.2-3).Impacts of the Sellafield discharges include "significant concentrations of radionuclides in foodstuffs, sediments and biota" in the Irish Sea, "very large" volumes of contaminated lands, significant contamination of groundwater, tritium levels in drinking waters exceeding World Health Organization limits, and contaminated sediments for hundreds of kilometers along the Irish Sea coast (NDA 2007; Schneider 2001, pp.5-6). Local residents and opponents of Sellafield suspect that these discharges are responsible for the increased incidence of cancer along the eastern coast of Ireland and the western coast of England (TED 2007).

Reprocessing waste also contaminated the waters in the vicinity of some U.S. reprocessing facilities. Waste disposal practices at the Savannah River military reprocessing site led to severe contamination of portions of the surface and groundwater. Operation of the West Valley commercial reprocessing facility led to a plume of groundwater contamination beneath the reprocessing building, as well as extensive infrastructure contamination (GAO 2001, p.7). Many of the tanks storing

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[60] Scrubbers capture about 90 percent of the iodine-129 that is produced, but none of the other gases.

high-level radioactive waste at the Hanford military reprocessing facility have been found to leak (IEER 2004, p.8; DOE 1995a).

Cleanup efforts at these sites have been difficult. Cleanups of the Savannah River and Hanford sites have been bogged down for decades by technical and management issues and have not yet been completed. Cleanup has been similarly difficult at West Valley, which generated over 600,000 gallons of liquid high-level waste during just six years of operation. Cleanup was originally expected to be completed by 1990; however, there have been numerous delays, and significant cleanup efforts remain to be completed (GAO 2001, p.1; NRC 2007ai).

Conclusions

The advanced reprocessing fuel cycle envisioned under GNEP would prevent the need for a second repository for the foreseeable future, even if the use of nuclear power significantly increases. However, many are skeptical about whether this goal is achievable over the coming decades and are concerned that a limited reprocessing fuel cycle using readily available technologies could be instituted instead. Depending on the technologies used, such a fuel cycle could result in an increase in combined high- and intermediate-level nuclear waste, an increase in the risk of nuclear weapons proliferation, and an increase in the cost of nuclear power.

Even with the advanced GNEP technologies, environmental and safety impacts of a reprocessing fuel cycle could be significant. Reprocessing releases radioactive emissions during routine operations, has a higher accident rate than spent fuel storage does, and in some cases has generated significant contamination. A reprocessing fuel cycle also could require the long-term interim storage of large amounts of spent fuel at reprocessing facilities. These concentrated interim storage sites could present security hazards.

Accordingly, there is substantial opposition to the GNEP program. However, the program remains undefined in key respects, and it is far from certain that the proposal will be sustained over the next several years or, if it were, that it would ultimately be successful.

CHAPTER 5: NUCLEAR WASTE TRANSPORT

Radioactive waste transport in the U.S. has been common for decades. For example, spent fuel is shipped from research reactors and naval vessels to storage sites, and low-level waste is shipped from reactor sites and other sources to low-level waste facilities (National Academies 2006, p.50). These shipments provide a framework of experience on which to build in designing the program to bring spent fuel from reactor sites across the country to Yucca Mountain. Nevertheless, all of this experience combined pales in comparison to the volume of shipments that will be required for the Yucca Mountain shipping endeavor.

Considerable uncertainty remains as to when shipments to Yucca Mountain will begin; however, there is agreement that shipments will not begin in the near term. Based on DOE’s estimate that Yucca Mountain will open around 2020, shipments are not expected to begin until close to the expiration of the Diablo Canyon and SONGS operating licenses. PG&E described its understanding of DOE’s schedule for shipping spent fuel from utilities as follows (PG&E 2007b, D1):

> Last Summer [*sic*], the DOE published a "best achievable" schedule for the Yucca Mountain project with 2017 as being the year of initial receipt of spent fuel from utilities. More recently, the Director of the Office of Civilian Radioactive Waste Management was quoted as clarifying during a presentation to the National Academy of Sciences that "best achievable" did not mean most likely, and that the 2017 date did not reflect anticipated litigation. The director offered 2020 as a more likely date for DOE's initial receipt of spent fuel from utilities. Most recently, in Congressional testimony concerning DOE's FY 2008 budget, the director acknowledged that DOE's schedule had slipped since publication of the 2017 date due to limited FY 2007 appropriations. He estimated the slippage at one year. Thus, it appears that DOE is estimating 2021 as the most likely date for the commencement of spent fuel pickup from utilities. DOE has not recently updated its projections of how quickly it will accept spent fuel from utilities once it starts performance. Assuming that prior projections are still valid, DOE can be expected to ramp up to an industry-wide acceptance rate of 3000 MTU per year within 5 years of commencing acceptance. . . It is uncertain whether DOE will use the sequencing provisions provided for in the Standard Contract or how those provisions will operate once DOE begins acceptance from utilities.

Despite the significant uncertainty surrounding the schedule, DOE continues to plan for shipments of spent fuel to Yucca Mountain. DOE has selected a “mostly-rail” transport option, has announced plans to use “dedicated trains” with certain restrictions on shipments, has released a design for transport casks, and has been investigating routes for the Nevada rail spur. Potential routes being considered could result in a large number of shipments from eastern states being routed through California. According to a 2006 National Academies study, these shipments are unlikely to result in a release of radiation as long as regulations are followed with care. However, the study also found that economic and other social impacts of spent fuel transport can be significant. The study, due to restrictions on releasing classified information, did not evaluate the possible impacts of a terrorist attack on a spent fuel shipment.

Low-level waste will not be stored at Yucca Mountain, and low-level waste disposal is the responsibility of the utilities and the states. In the 1980s and 1990s California selected Ward Valley in the Mohave Desert as a site for a low-level waste facility; however, the site is located on federal land and the state was unable to purchase the site from the federal government. Currently, California utilities dispose of their low-level waste in facilities in South Carolina and Utah. Beginning in mid-2008 only the Utah facility will be available and only for the least radioactive grade of waste. In the near term, once the South Carolina facility closes to California waste, California utilities will be forced to keep their low-level waste on-site.

This chapter discusses ongoing and anticipated nuclear waste shipments and the factors that contribute to the safety and security of these shipments. It begins with an update of DOE’s plans for shipping spent fuel to Yucca Mountain and a discussion of state transport fees, which may impact routing of these shipments. It then summarizes the results of the National Academies’ study on the safety of spent fuel transport. Finally, it discusses other domestic high-level and low-level radioactive waste shipments and the status of waste shipments from California’s reactor sites.

Waste Shipments to Yucca Mountain

DOE has not publicized a detailed plan for selecting rail and highway routes for spent fuel shipments to Yucca Mountain, nor has it determined how it will collaborate with affected states, tribes, local agencies and other parties (National Academies 2006, p.18). In other spent fuel shipment programs, DOE has selected potential highway routes in consultation with states and tribes and has made final route selections "by taking into account security, state and tribal preferences, and information from states and tribes on local transport conditions” (National Academies 2006, p.15). DOE has selected rail routes in consultation with rail carriers, states, and tribes (National Academies 2006, p.15).

California, like many states, has designated highway routes for controlled quantities of radioactive material in order to minimize impacts and risks. States have limited regulatory authority over railways, however, due to the largely private ownership of rights-of-way. Suggestions that the U.S. Department of Transportation create rail routing guidelines similar to highway regulations to reduce rail shipments of radioactive materials through highly populated areas have not been adopted, and the railroad industry is strongly opposed to new regulations. Since the highest quality tracks, interchange points, and signal systems serve the high-density traffic between major cities, it will be difficult to avoid railroad routing through major urban areas (Energy Commission 2006e, p.143). These issues are discussed further in the *2005 Status Report*.

DOE's Current Transport Plans

DOE continues to develop plans for shipping spent fuel to Yucca Mountain. In 2005 DOE selected rail as its primary means of transport ("mostly rail" option). As shown in Figure 15, the "mostly rail" option would route shipments cross-country using Memphis and Kansas City as major gateways, with shipments from the south routed through California en-route to Yucca Mountain.

DOE is currently investigating routes for a new rail spur in Nevada.[61] DOE initially identified as its preferred route the 319-mile Caliente corridor. This route begins in southeastern Nevada, travels around the Nevada Test Site, and then turns southeast to Yucca Mountain (DOE 2007g). (See Figure 16.) (With adoption of the Caliente corridor, shipments through California would travel along a rail line through California's Central Valley and enter Nevada near Las Vegas.) In October 2006 DOE announced its intent to also consider the Mina rail corridor (DOE 2006g, p.60484). This corridor, which is referred to as the Proposed Route to Yucca Mountain in Figure 16, enters Nevada from the north and then travels south along the western side of the state.

The Mina corridor had previously been considered as a possible route but was eliminated as an option in 1996, when the Walker River Paiute Tribe, across whose land the route traverses, informed DOE that it would not allow nuclear waste to be transported across its reservation. In May 2006, following discussions with DOE, the Paiute Tribe gave permission to DOE to complete an EIS studying this transportation option and announced that it would make a final decision on whether or not to allow these shipments after it had studied the EIS, which was scheduled to be released on June 30, 2008 (Bechtel 2006, pp.8-9; DOE 2007c).

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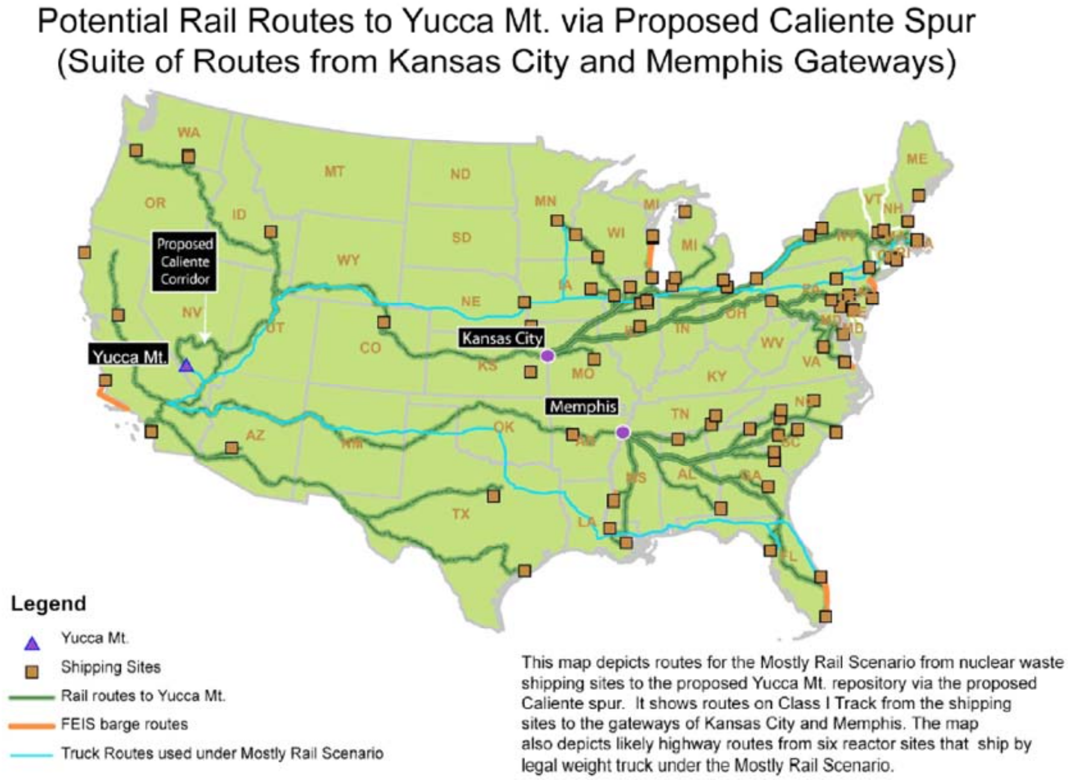
[61] DOE investigated a "mostly truck scenario," in which all shipments would be made by legal-weight truck except for naval spent fuel (which would be shipped by rail), and a "mostly rail" scenario, in which all sites would ship by rail except for the six commercial sites that do not have the capability to load rail packages. For the mostly rail scenario, DOE assumed that the sites without rail loading capability would ship by legal-weight truck until they are shut down. They would then be upgraded to load rail packages and would ship by direct rail (or heavy-haul truck or barge). Another 24 commercial sites that do not have rail access would ship by heavy-haul truck or barge to railheads (National Academies 2006, p.147). SMUD expects that Rancho Seco will be able to ship its waste by direct rail, while PG&E expects that DOE will need to heavy-haul Diablo Canyon's waste to a rail spur. SCE has not provided information on waste transport plans for SONGS (PG&E 2007b, D1; SMUD 2007, D1; SCE 2007a, D1).

Figure 15: Map of Proposed National Rail Routes to Yucca Mountain



Source: (Nevada 2007a)

The Mina corridor is 280 miles long; by incorporating existing Department of Defense rail lines it would require only 240-254 miles of new rail line (Bechtel 2006, p.5). DOE identified other advantages and disadvantages of the Mina corridor in a DOE feasibility study which found that 90 percent of the corridor lies on federal land managed by the Bureau of Land Management and that the corridor does not cross any wilderness areas or areas of critical environmental concern. In addition, few conflicts with cultural and natural resources were identified.

> Based on DOE's preliminary analysis, in comparison with other rail corridors, the Mina corridor appears to offer potential advantages to the extent it would cross fewer mountain ranges, utilize existing rail bed, and also be a shorter distance. These potential advantages would simplify design and construction of a rail line, and therefore would be less costly to construct. The Mina corridor also would appear to have fewer land use conflicts, and would involve less land disturbance, which tends to result in lower adverse environmental impacts overall (DOE 2006g, p.60484).

However, DOE identified four locations in addition to the Paiute Reservation where private property cannot be "reasonably avoided" (Bechtel 2006, pp.32-33).

Figure 16: Map of Proposed Nevada Rail Routes to Yucca Mountain

Source: (YMIO 2007)

Both California and Nevada object to the Mina route, in part because of the large number of shipments that would be routed through major population centers in these states. The State of California objected to the Mina route, because it could “impact more California communities and result in far greater numbers of shipments than routes previously identified” (Energy Commission 2006b, pp.4-5).The State of Nevada estimated that “at least 10 percent of the rail shipments from commercial reactors in Arizona, Texas, Louisiana, Oregon and Washington, as well as large quantities of high-level nuclear waste from Hanford, Washington” could be routed through California if the Mina route is selected (Energy Commission 2006b, p.2). These shipments would be routed either through Sacramento across to Reno, Nevada or down the spine of central and southern California to Yucca Mountain (Boyd 2006, p.3).

State of Nevada officials also raised concerns about the Mina route, in part out of concern that nuclear waste from California would travel through Reno and Sparks, Nevada (LVRJ 2007a). Robert Loux of the Nevada Agency for Nuclear Projects expressed concern that DOE had not given the Mina rail plan sufficient examination or analysis given its potential impact on Nevada and California. Loux noted that the Mina route affects more communities and metropolitan areas than any previously proposed route and that it will require extensive analysis and a truly comprehensive EIS. Further, Loux noted that DOE has not consulted with California and Utah, through which nearly all of the waste would be transported. Loux requested that DOE consider "the public's high perception of risk…and the impacts that derive from such perceptions, and possible stigmatizing effects resulting from the proposed action” in addition to the standard EIS impacts (Nevada 2006a, p.18).

The Western Interstate Energy Board (WIEB) expressed many of the same concerns as the State of Nevada. In particular, WIEB criticized DOE “that the quantity and quality of public meetings held in connection with [the Notice of Intent to consider the Mina corridor] were inadequate. No public meetings were held in the States of California or Utah, and the meetings that were held in Nevada did not provide sufficient opportunity for a public exchange of information” (WIEB 2006, p.3). Further, the WIEB stated that DOE must conduct "a thorough review of the risks of terrorism and sabotage against spent fuel and [high level waste] shipments" to insure that adequate safeguards are in place prior to the start of shipments (WIEB 2006, p.2).

The debate over the use of the Mina corridor may be moot. In April 2007 the Walker River Paiute Tribal Council passed a resolution removing the Tribe from the EIS stating “the Tribe will not allow nuclear waste to be transported on rail through our reservation” (LVRJ 2007a).This resolution, if it remains final, will exclude the Mina corridor from further consideration.

Projected Quantities of Shipments

DOE estimates that the mostly rail option will require 9,600 rail shipments and 1,100 highway shipments to transport the legally mandated limit of 70,000 metric tons of spent fuel and high-level waste to the Yucca Mountain repository (National Academies 2006, p.16). This represents 25 times the number of rail shipments and 22 times the volume of spent fuel that have been shipped in the U.S. since 1964 (See Table 15.) (National Academies 2006, p.118; NRC 2006l, p.12).

Table 15: Commercial Spent Fuel Shipments in the U.S.

Time Period	**Mass of Spent Fuel Shipped** (MTHM)		**Number of Shipments**		**Tonne-Miles** (Thousands)	
	Truck	Rail	Truck	Rail	Truck	Rail
1964-1978	473	348	1,565	126	N/A	N/A
1979-1988	356	433	1,085	76	139	219
1989-1997	1	663	96	77	1	121
1998-2005	17	857	90	100	23	184
1964-2005 Total	846	2,301	2,836	379	N/A	N/A
Yucca Mountain (est.)	**70,000**		**1,100**	**9,600**	**N/A**	**N/A**

Source: (National Academies 2006, p.118; NRC 2006l, p.12)

Waste Packaging Requirements

In November 2006 DOE released the preliminary performance specifications for its proposed transportation, aging and disposal (TAD) canister system for spent fuel being delivered to Yucca Mountain (OCRWM 2006). The concept behind the TAD canister system is that a single canister outfitted with different overpacks can be used for spent fuel storage, transport, handling, and disposal. A TAD canister would be loaded with spent fuel and sealed at the reactor. It would then be placed inside a storage overpack for temporary storage at the reactor site or inside a transportation overpack for shipment to Yucca Mountain. At Yucca Mountain, it would either be placed inside a shielded transfer cask for transport among surface facilities or retained in an aging overpack for temporary storage on the aging pad. Finally, it would be sealed inside a waste package overpack for emplacement in the repository (OCRWM 2006, pp.1-3).

DOE explained to NRC that the TAD canister system is a means “to reduce the individual handling of bare fuel assemblies at the repository” and that the result of using this system “is a significant simplification of repository surface facility operations” (NRC 2007x, pp.7-8).However, not all facilities would be able to use TAD canisters: DOE is presuming at this time that 10 percent of the waste stream would not be transported in TAD canisters.[62] This waste would be transferred into TAD canisters at a wet handling facility at the Yucca Mountain site. Spent fuel from Rancho Seco, which no longer has a spent fuel pool, would likely be among the waste that is not transported in TAD canisters.

[62] The 10 percent figure can be readily adjusted at a later point, if required, since the waste handling facilities are modular (NRC 2007x, pp.7-8). See discussion by Paul Harrington.

The State of California has requested information from DOE on “the implications of the TAD system for the surface facilities at Yucca Mountain and repository performance, which could have potential groundwater impacts in California, as well as the implications of the TAD system for reactor waste storage, management and transportation practices” (Energy Commission 2006b, p.2).In addition the State asked DOE to describe “how and where fuel currently stored in dry casks will be repackaged for shipment to the repository and/or blended with fuel remaining in reactor spent fuel pools to meet DOE's repository waste emplacement requirements” (Energy Commission 2006b, p.2).This information has not yet been provided.

The State’s concerns over the TAD canisters are not unique. Alan Hanson of AREVA questioned whether DOE’s TAD canister initiative is even realistic. Hanson noted that this initiative imposes disposal criteria on storage and transportation and that the TAD canisters have lower capacity, lower heat loads, and require longer cooling times than other candidate canisters (AREVA 2006).

Transport Fees

One factor that may impact the routing of spent fuel is the relative level of fees charged by each state to cover the costs to the state of radioactive shipments, including inspections, escorts, emergency preparedness, and response. As shown in Table 16, these fees vary widely from state to state. California, which charges an initial $100 annual fee per carrier along with a $75 annual renewal fee, has a relatively modest fee. Some states impose no fee at all, while others impose fees in excess of $2,000 per truck or rail cask. At the higher end, a single state’s fee can make up more than 10 percent of the total cost of a truck shipment and about 1 percent of the cost of a rail shipment.[63] There is an obvious financial incentive for carriers to avoid shipments through states with higher transportation fees.

The 2005 IEPR noted that a comparison of fees assessed by various states on transporters of nuclear material suggests that California’s fees may be insufficient to cover state activities associated with spent fuel shipments, including shipment inspections, tracking and escorts. The IEPR recommended that the state should reexamine the adequacy of California’s nuclear transport permit fees and explore federal funding programs to cover state activities associated with spent fuel shipments (Energy Commission 2005b, p.85).

[63] According to DOE figures, the cost to transport spent fuel to Yucca Mountain via truck will be about $55,000 per MTHM. According to data provided in Table 15, each truck shipment consists of about .31 MTHM. The average truck shipment can thus be estimated at $17,000. The cost of a rail shipment has been estimated at $200,000-$500,000 per cask (Harvard 2001, p.22; ORNL 2004).

Table 16: State Fees for Nuclear Waste Transport

State	Transportation Fee
California	$100 annual initial fee per carrier $75 annual license renewal fee (all hazardous material shipments)
Colorado	$500 annual permit fee plus $200 per shipment (all highway route-controlled quantity (HRCQ) radioactive material shipments)
Connecticut	$25 per trip permit fee
Florida	$100 permit fee (low-level waste shipments)
Georgia	$100 or $25 per trip
Idaho	$5-$250 annually per truck (all hazardous material shipments)
Illinois	$2,500 per truck cask plus $25 per mile for each mile over 250 miles in Illinois $4,500 for the first rail cask plus $3,000 for each additional rail cask (spent fuel, high-level waste, transuranic waste and HRCQ shipments)
Indiana	$1,000 per cask (spent fuel and high-level waste) $100 per low-level waste shipment (by road: $100 for all trucks from the same site passing through the state in one day)
Iowa	$1,800 per truck cask plus $20 per mile for each mile over 250 miles in Iowa $1,300 for the first rail cask plus $125 for each additional rail cask (spent fuel, high-level waste, and transuranic waste shipments) $125 per cask low-level waste
Kentucky	$25 permit fee
Minnesota	$1,000 per vehicle and $50 registration fee (high-level waste shipments)
Mississippi	$2,500 permit fee
Missouri[64]	$1,800 per truck cask plus $25 per mile for each mile over 200 miles $1,300 for first rail cask plus $125 for each additional cask (spent fuel, transuranic waste, high-level waste and HRCQ) $125 for each truck or train for low-level waste
Nebraska	$2,000 per rail or truck cask (spent fuel, high-level waste, and transuranic waste shipments)
Nevada	$500 permit fee every three years $150 additional per truck plus actual cost of investigation
New Hampshire	$5 per vehicle

[64] Note Legislation has been introduced but has not passed. See (MO H.252 2007)

State	Transportation Fee
New Mexico	$250 annual fee or $75 per shipment fee
New York	$25 for first vehicle, $5 for each additional, $300 max (low-level waste shipments)
Ohio	$50 registration fee $600 permit fee every 3 years (all hazardous material shipments)
Oregon	$500 annual permit fee or $70 per shipment, whichever is less (Class 7 (radioactive) shipments)
Pennsylvania	$1,000 per shipment $10 per truck turnpike permit fee
South Carolina	$75 or $750 based on volume and level of radioactivity
Tennessee	$1,000 per cask for truck shipments $2,000 per cask for rail shipments $400 per low-level waste shipment
Utah	No transportation fee, however waste disposal charges include annual site access permits and volume-based fees
Vermont	$1000 per shipment
Washington	No transportation fee, but allows counties to assess impact fees
West Virginia	$50 registration fee (all hazardous materials shipments)
Wyoming	$200 permit fee per package (HRCQ and Waste Isolation Pilot Plant)

Source: (CSG 2005; NCSL 2006; UER 2003; WIEB 2005a)

Transport Safety and Security

The large-volume shipping program that will need to occur as part of the relocation of spent fuel from reactor sites to Yucca Mountain raises safety and security concerns. In 2006 The National Academies' Committee on Transportation of Radioactive Waste (TRW Committee) published a study on the transportation of spent fuel, entitled *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*. The principal finding of this study is as follows (National Academies 2006, pp.7-8):

> The committee could identify no fundamental technical barriers to the safe transport of spent nuclear fuel and high-level radioactive waste in the United States. Transport by highway (for small-quantity shipments) and by rail (for large-quantity shipments) is, from a technical viewpoint, a low-radiological-risk activity with manageable safety, health, and environmental consequences when conducted with strict adherence to existing regulations. However, there are a number of social and institutional challenges to the successful initial implementation of large-quantity shipping programs that will require expeditious resolution…The challenges of sustained implementation should not be underestimated.

Overall, the TRW Committee found that the public risk from shipments to Yucca Mountain would be very small, even if some of the shipments were involved in accidents (National Academies 2006, p.147). However, they also made it clear that the large-scale transport of spent fuel would not be risk free:

- Workers and members of the public who would be exposed to radiation from the transportation packages could have an elevated risk of developing fatal cancer (National Academies 2006, p.147).
- All tasks would need to be "carried out with a high degree of care" and all regulations would need to be strictly followed for spent fuel transport to remain a low-risk activity (National Academies 2006, p.8).
- Intentional attacks on spent fuel shipments could present a risk to the public. However, the TRW Committee was unable to assess the impact of these attacks "because of information constraints" (National Academies 2006, p.8). They recommended that a committee with access to restricted information conduct a separate study on the security of high-level waste shipments.

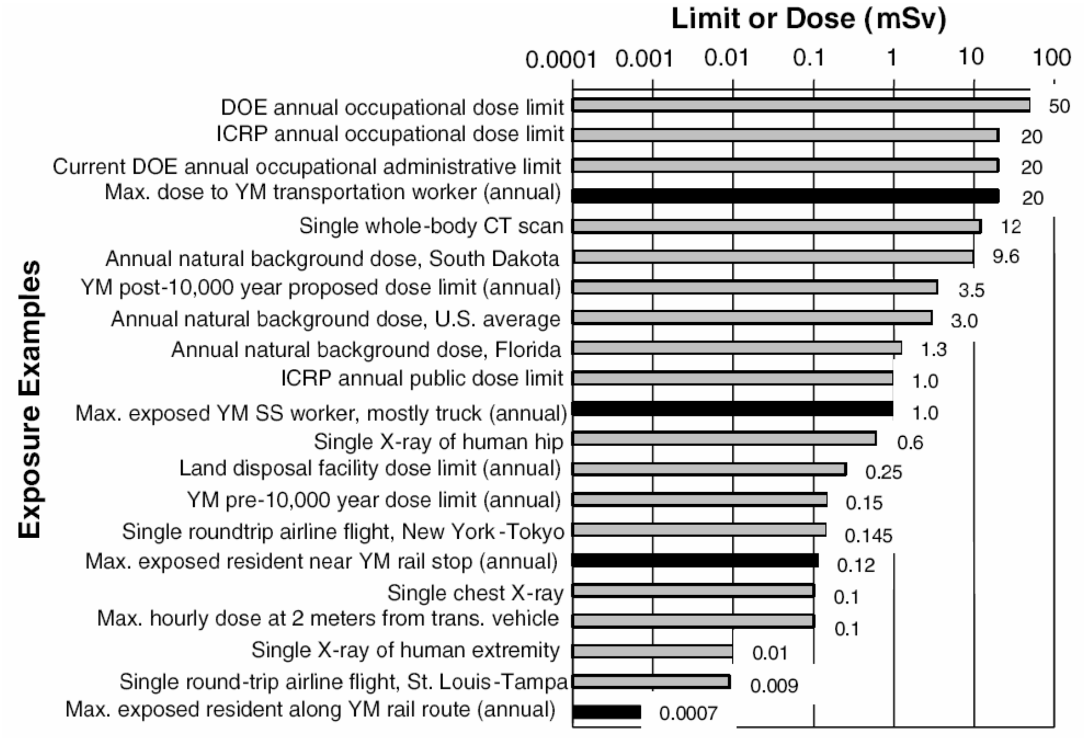
The TRW Committee evaluated the radiological risk from spent fuel transport and discussed how this risk might be mitigated by using operational controls, relying on rail shipment where possible, and shipping the oldest fuel first. They also discussed the importance of acknowledging and mitigating the social risks from spent fuel transport. These discussions are summarized below.

Radiation Risk from Spent Fuel Shipments

Federal waste regulations provide "that a spent fuel package (cask) shall prevent the loss or dispersion of the radioactive contents, provide adequate shielding and heat dissipation, and prevent nuclear criticality under both normal and accident conditions of transportation" (NRC 2006l, p.1). According to the TRW Committee, these regulations "include built-in safety margins for package design and rigorous standards for design, construction, testing, and quality assurance of spent fuel packages" (National Academies 2006, p.179). Consequently, radiation risk from routine shipment is low, even in accident situations. To the knowledge of the TRW Committee, "there has never been a large-scale release of radioactive materials reported from the failure of a spent fuel package during an accident" (National Academies 2006, p.179).

The radiation risk from routine spent fuel transport, based on figures provided by DOE, is shown in Figure 17 in comparison with other routine radiation exposures. The maximum exposure to a member of the public (not a Yucca Mountain employee) is expected to be less than 10 percent of the annual natural background radiation in Florida, which is the state with the lowest estimated natural background radiation (National Academies 2006, p.167, 172).

Figure 17: Comparison of Radiation Doses[65]



Source: (National Academies 2006, Figure 3.3 p.172)

According to the TRW Committee, exposure risks during accidents involving spent fuel shipments are "well understood and generally low," with the possible exception of risks from extreme accidents involving long duration, fully engulfing fires (discussed below) (National Academies 2006, p.178). As shown in Table 17, of the nine accidents involving spent fuel transport between 1971 and 2005, none resulted in the release of radioactivity. However, all but the first of these accidents were too minor to test the integrity of the transport package containment. Consequently, the TRW Committee cautioned that "claims about this safety record in the United States have to be interpreted carefully given that spent fuel transport quantities are quite limited, especially for rail transport" (National Academies 2006, p.122).

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[65] The dose data are plotted on a logarithmic scale to better illustrate the spread of values (i.e., equal distances represent equal percent changes, rather than equal absolute differences). Doses shown in the figure are annual limits or exposures except for medical procedures and round-trip airline flights, which are one-time exposures. Black bars depict doses to workers or residents for the Yucca Mountain (YM) transportation program (SS = service station). The maximally-exposed Yucca Mountain transportation employee was assumed to receive the maximum allowable DOE occupational administrative dose. Doses are measured in millisieverts (mSV), which is a measure of the biological impact of radiation (National Academies 2006, pp.170, 172).

Table 17: Transportation Accidents Involving Commercial Spent Fuel, 1971-2005

Mode	Date	Location	Description
Truck	December 8, 1971	Tennessee	Package thrown free of trailer and landed in ditch following head-on collision with car. No package damage or release. Driver killed.
Truck	February 2, 1978	Illinois	Trailer collapse while crossing railroad tracks. No package damage or release.
Truck	August 13, 1978	New Jersey	Trailer collapse while empty package was being loaded. Package not damaged.
Truck	December 9, 1983	Indiana-Illinois border	Trailer's fifth wheel failed. No package damage or release.
Train	March 29, 1974	North Carolina	Empty package struck by a derailed tank car on adjacent track. Superficial package damage. (No release.)
Train	March 24, 1987	Missouri	Train-auto collision at grade crossing. No package damage or release.
Train	January 9, 1988	Illinois	Train carrying empty packages derailed. No damage to packages.
Train	December 14, 1995	North Carolina	Railcar carrying empty packages derailed. No damage to packages.
Train	September 22, 2005	New York	Railcar carrying an empty spent fuel package derailed in a rail yard. Railcar tipped over. No release.

Source: (National Academies 2006, Table 3.4 p.123)

In particular, transport packages have not been tested under the conditions of an extreme accident involving a long-duration fire. For the mostly rail scenario, DOE estimated that the likelihood of such an accident is 2.8 over 10 million years and that this possibility contributes an annual collective dose risk of just .028 millisievert (mSV).[66] However, DOE also estimated that in the event of an extreme accident of this kind, the maximally exposed person could receive 290 mSV of radiation, and 5 cancer fatalities could ensue (National Academies 2006, pp.143-144).

The TRW Committee noted that these dose estimates are based on the conservative assumption that the accidental release occurs at the center of a large urban area. In addition, the collective doses include very small doses affecting a large number of people (National Academies 2006, p.148). Moreover, they concurred with DOE that the likelihood of these extreme accidents is low. However, they also found that the occurrence of such an accident cannot be ruled out. They recommended that route-specific analyses be conducted and simple operational controls be implemented to identify and mitigate hazards (National Academies 2006, pp.10, 14). For example, a route analysis could identify facilities close to the route that use or store large quantities of flammable materials and route conditions that could make it difficult to deploy an effective firefighting capability. Likewise, operational controls could include restrictions to prevent co-location of trains carrying

[66] As shown in Figure 17, DOE's annual occupational administrative limit is 20 mSV.

spent fuel with trains carrying flammable materials in tunnels, in rail yards, and on sidings (National Academies 2006, pp.107, 180). Where routes could not be altered to avoid hazards, shipments could be scheduled to minimize encounters with other hazardous materials trains or emergency response preparedness could be improved along specific route segments of concern (National Academies 2006, p.180).

The TRW Committee also noted that the "potential for radioactive material releases from packages involved in such fires and the consequences of such releases are incompletely understood at present" (National Academies 2006, p.102).They recommended that additional analyses of the response of packages to fire exposure be conducted, and they "strongly [endorsed] the use of full-scale testing to determine how packages will perform under both regulatory and credible extraregulatory conditions" (National Academies 2006, p.14).However, they concluded that "deliberate full-scale testing of packages to destruction through the application of forces that substantially exceed credible accident conditions would be marginally informative and is not justified given the considerable costs for package acquisitions that such testing would require" (National Academies 2006, p.14).

At a 2006 conference, the State of Nevada responded to these conclusions of the TRW Committee with the following specific recommendations regarding full-scale testing (Nevada 2006c, p.7):

- Stakeholders should have a meaningful role in the development of testing protocols and selection of test facilities and personnel.
- Full-scale regulatory tests (drop, puncture, fire, and immersion, in sequence) should be performed on each cask design to be used for repository shipments, either prior to NRC certification or prior to DOE procurement.
- A truck cask, and possibly a rail cask, should be subjected to an engulfing fire for 3 hours at 1,475°F-1,800°F, which matches the conditions of a Baltimore tunnel fire.
- Shipping cask and spent fuel failure thresholds should be determined by computer simulations, scale model testing and component testing (not by full-scale cask testing).
- There is no need at this time to evaluate costs and benefits of destructive testing of a randomly-selected, production model cask.

Safety Implications of Transport Mode

The TRW Committee supported DOE's decision to use a mostly-rail shipping option and recommended that DOE examine the feasibility of an expanded use of intermodal transportation to allow the shipment of rail packages from plants that do not have direct rail access (National Academies 2006, p.17). They identified the following safety, operational, and policy advantages that rail service has over highway transport for large-quantity shipments of highly radioactive waste (National Academies 2006, p.217):

- Rail service reduces the total number of shipments to the federal repository by roughly a factor of five, which reduces the potential for routine radiological exposures, conventional traffic accidents, and severe accidents.
- Rail shipments have a greater physical separation from other vehicular traffic and reduced interactions with people along transportation routes, which also contributes to safety.
- Operational logistics are simpler and more efficient.
- There is a clear public preference for this option.

The TRW Committee also supported DOE's decision to use for the rail transports dedicated trains that will carry only spent fuel and high-level waste (DOE 2005b). While they did not find "a clear radiological risk-based advantage for either [dedicated or general train service]," they did find "clear operational, safety, security, communications, planning, programmatic, and public preference advantages that favor dedicated trains" (National Academies 2006, p.18).The State of Nevada concurred with the TRW Committee, asserting, "the assumption that DOE will use dedicated trains is a prerequisite for meaningful rail route analysis" and it will "provide significant benefits to DOE and address the concerns of stakeholders" (Nevada 2006b, p.9).

Safety Implications of Waste Acceptance Order

The waste acceptance order mandated by the NWPA is based on the order that spent fuel is discharged from owners' reactors: whenever spent fuel is discharged from a reactor, the owner receives an allocation for an equivalent amount of spent fuel in DOE's waste acceptance queue. However, the owner is not required to provide fuel to DOE in the order that it was discharged and may, in fact, provide fuel from any of its sites or even, with DOE approval, exchange positions in the queue with another spent fuel owner (National Academies 2006, p.19).

The TRW Committee concluded that this acceptance order is suboptimal from the perspective of a transportation plan. Following this acceptance order could require DOE to initiate its transportation program with long cross-country movements of recently released (and highly radioactive) spent fuel from multiple commercial sites. According to the TRW Committee, there are "clear transportation operations and safety advantages to be gained from shipping older (i.e., radiologically and thermally cooler) spent fuel first and for initiating the transportation program with relatively short, logistically simple movements to gain experience and build operator and public confidence" (National Academies 2006, p.19).

The TRW Committee recommended that DOE negotiate with commercial spent fuel owners to ship older fuel first or that Congress consider amending the NWPA to require that older fuel be shipped first[67] (National Academies 2006, p.20).

California's spent fuel owners have not determined which spent fuel will be shipped first because DOE does not have plans to ship fuel to Yucca Mountain in the near future:

- PG&E indicated to the Energy Commission that it "has not determined which of its spent fuel it will seek to move first once DOE begins to accept spent fuel" (PG&E 2007b, D4).
- SCE reported that "for reasons that include the fact that DOE suspended the [Delivery Commitment Schedule] process and has not yet finalized the design of the canister system DOE intends to use to transport and/or store spent fuel, SCE cannot at this time predict which fuel will be first delivered to DOE" (SCE 2007a, D4).
- SMUD noted that all of its fuel will have cooled for at least 18 years prior to shipment (SMUD 2007, D4).

Social Risks of Spent Fuel Shipments

The TRW Committee found that the social risks of highly radioactive waste shipments, including increased stress, loss of sense of security and safety, and a loss of trust and confidence in government and government agencies,

> …pose important challenges to the successful implementation of programs for transporting spent fuel and high-level waste in the United States. Such risks, which can result in lower property values along transportation routes, reductions in tourism, and increased anxiety, have received substantially less attention than health and safety risks, and some are difficult to characterize (National Academies 2006, pp.11, 151).

The TRW Committee noted that the perception of risk is often attributed to ignorance and "coupled with calls for better public education about risk, with the unspoken implication that such education would encourage the public to behave more rationally (i.e., more like technical experts)." They warned,

> …such 'information deficit' approaches to behavior change have largely been discredited. In fact, people may be acting rationally if they oppose spent fuel and high-level waste transportation on health and safety grounds even if they agree with the experts that the estimated health and

[67] Researchers at UC Berkeley and Lawrence Livermore National Lab developed a tradable repository space permit system that, according to researchers, would eliminate almost completely the incentive to ship any materials to Yucca Mountain for at least several decades, except for defense wastes and limited quantities of spent fuel from decommissioned reactor sites. DOE has not adopted a repository space permit system (Energy Commission 2005f, p.232).

> safety risks are low. Most people recognize that transportation programs are run by fallible institutions and that institutional and human errors play a large role in determining transportation risks. There are many examples of technological systems where the experts were wrong or overly optimistic. They also recognize that the risk of an accidental release from a spent fuel shipment, while low, is not zero and, moreover, that such a release can have a range of consequences: health, safety, and social. Rational people care about all consequences that can impact their lives and communities, not just health and safety consequences that are the main concern of technical experts (National Academies 2006, p.154).

The TRW Committee concluded that DOE would benefit by taking steps to inform the public of transport needs, options, risks, and benefits, and by taking steps to better understand the public's responses (National Academies 2006, p.160):

> Current research and practice suggest that transportation planners and managers can take early proactive steps to characterize, communicate, and manage the social risks that arise from their operations. Such steps may have additional benefits: they may increase the openness and transparency of transportation planning and programs; build community capacity to mitigate these risks; and possibly increase trust and confidence in transportation programs (National Academies 2006, p.11).

WIEB and the States of California and Nevada have all protested to DOE that DOE's communication with impacted states regarding transportation routes and impacts has been insufficient. In addition, the State of California has been requesting since 1989—to no avail—that DOE identify and analyze potential route-specific and mode-specific impacts to populations and the environment along shipment corridors (Energy Commission 2006b, pp.4-5). Examples of route-specific conditions of concern in California are certain high-risk sections of track with prior major derailments and hazardous materials spills; steep terrain and heavily weather-impacted rail and truck routes over the Donner Summit; and the heavily populated and congested Sacramento, Central Valley, and Los Angeles regions.

Moreover, the State of Nevada has repeatedly expressed the lack of trust in DOE's transportation program that the TRW Committee warned could result from insufficient open communication between transportation planners and the public. For example, the State (unsuccessfully) argued before the U.S. Court of Appeals in 2006 that DOE exceeded its "authority in selecting the Caliente Corridor and that its conditional decision to ship waste by truck, should the repository at Yucca be operational before completion of a branch rail line, was arbitrary and capricious."[68]

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[68] The U.S. Court of Appeals ruled that it was premature to review the State of Nevada's claims: the first claim could become subject to review should DOE determine to operate the branch line as a common carrier, and the second claim could become subject to review should DOE formulate a plan to ship waste by truck. The Court also rejected five claims regarding the Yucca Mountain EIS. The State does not plan to appeal the ruling (Nevada v. DOE 2006, p.7; LVRJ 2006a).

Transuranic Waste Shipments to the Waste Isolation Pilot Plant

Since 1999 DOE has shipped transuranic radioactive waste from seven of its sites around the country to the Waste Isolation Pilot Plant (WIPP) in southern New Mexico.[69] In 2005 the Western Governors' Association (WGA) issued a Policy Resolution recommending that the WIPP transportation program be used as a model when developing the transportation program for Yucca Mountain.[70] In particular, WGA highlighted the WIPP Transportation Safety Program, the use of regional cooperative groups to propose shipping routes, and the use of flexible funding sources (WGA 2005).

WGA also formulated, along with other state regional groups, a list of expectations for the Yucca Mountain transportation program, in part based on lessons learned from the WIPP transportation program (WIEB 2005b). The expectations focus on the need for DOE to cooperate with and support impacted states:

- DOE must assist states in developing the capability to help prevent accidents and respond in a timely, appropriate fashion to accidents involving spent fuel and high-level radioactive waste shipments.
- Funding to states must be predictable and must be provided at least three years prior to the start of shipments. Financial and technical assistance for training and operations activities must continue as long as shipments continue along a shipping corridor.
- States must have a minimum of three years after routes are identified to prepare routes before shipments begin, and scheduling of shipments must take into account impacts on state and local responders.
- States must have maximum flexibility to implement accident prevention and emergency response programs that best meet their needs.
- DOE must continue to support the state regional groups (such as WGA) to ensure consistency and compatibility of shipment planning activities.

Waste Shipments under the Global Nuclear Energy Partnership

The amount of radioactive waste that needs to be transported would increase with the adoption of the reprocessing fuel cycle envisioned under GNEP. (See Chapter 4.) The current fuel cycle requires just one transport, the transport of spent fuel to a

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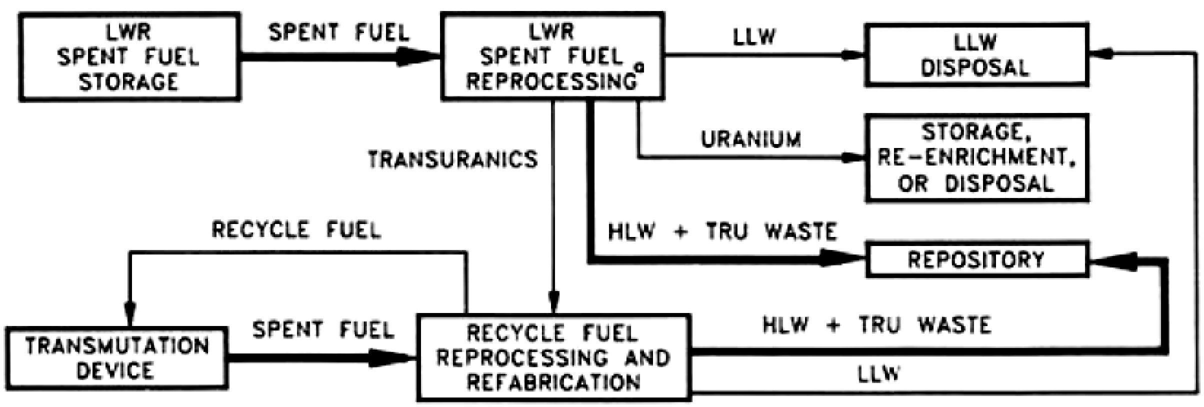
[69] Transuranic elements have atomic numbers higher than uranium. Plutonium is a transuranic element.

[70] WGA's recommendation refers to lessons learned from the WIPP transportation program, not specific transportation routes. The State of California, in particular, would be opposed to WIPP transportation routes being used as a precedent for other shipments, as the State has objected to the routing of waste from the Nevada Test Site to WIPP through California (Energy Commission 2007d).

repository. As depicted in Figure 18, a reprocessing fuel cycle would require the transport of spent fuel to a reprocessing facility, the transport of reprocessing wastes to disposal facilities and a repository, the transport of transuranic elements to a fuel fabrication facility, the transport of the recycled fuel to a fast reactor, the transport of recycled fuel fabrication wastes to disposal facilities, and the transport of fast reactor spent fuel back to the fuel reprocessing and fabrication facility. Many of these transports could be consolidated by building a reprocessing park that included reprocessing facilities, fuel fabrication facilities, and fast reactors, and some of the transports would be low-risk transports of low-level wastes. (Bold lines in Figure 18 indicate high-risk transports.) However, even with consolidated parks, reprocessing would significantly increase the amount of radioactive material that would need to be transported due to the need to ship secondary wastes, spent fuel, recycled fuel, and high-level reprocessing wastes (National Academies 1996, p.102). If reprocessing facilities were located outside of California, these additional shipments might not impact the state.

Figure 18: Transportation of Spent Fuel under GNEP Fuel Cycle



Source: (National Academies 1996, p.103)

In addition to the domestic radioactive waste shipments generated by a reprocessing fuel cycle, GNEP's fuel leasing program could result in the long term in shipments of foreign spent fuel through California. Shipments of foreign spent fuel are likely many decades away, since they will not begin until the advanced reprocessing technologies have been developed and commercialized. The volume of this fuel is difficult to predict at this point, as it depends on how many countries engage in the fuel-leasing program, how many choose to lease fuel from the U.S., and how many of the U.S. shipments come in through the West Coast.

If foreign waste is accepted for reprocessing in the U.S., some of this waste may be routed through a port in California as was done previously to return to the U.S. spent fuel from foreign research reactors (DOE 1998). (At the time, the Energy Commission objected to the choice of routes, since there were shorter, more direct routes that impacted fewer heavily populated areas (Energy Commission 1997).) Spent fuel could also be imported via the Port of Portland or other West Coast ports and then transported through California en route to a reprocessing facility.

Shipments of foreign waste through California present additional risk that is not present in domestic shipments. The packaging and transport of waste abroad will likely not be as closely monitored as it is in the U.S. This has been a problem with reprocessing shipments in Britain, France, Germany and Japan, where "abnormally high" levels of radiation have leaked from transport casks, sometimes as high as 3,000 times normal levels, and the nuclear industry and regulators have been implicated in withholding and possibly even falsifying safety information (Environment 1999, pp.12-15, 34-39). Moreover, the transport will pass through many hands: from its original location, it will be transported by a combination of highway and rail, possibly across several borders, to a port, where it will be transferred to a ship. When it reaches the U.S., it will again be transported through a combination of road and rail to the reprocessing facility. Each of these transfers presents an opportunity for intentional or unintentional mishandling of the waste. In particular, the transport of spent fuel across national borders presents opportunity for terrorist intrusion.

Low-Level Waste Shipments

The proposed Yucca Mountain repository will accept only spent fuel and high-level waste. Low-level waste disposal became a state responsibility with the passage of the Low-level Radioactive Waste Policy Act of 1980. Current law is based on the Low-Level Radioactive Waste Policy Amendments Act of 1985 (NRC 2007l).

There are currently few options available for disposing of low-level waste, and for most states these options are dwindling. Beginning in mid-2008 there will be no facility available to California for disposal of any but the coolest of radioactive materials.

The NRC describes low-level waste as follows:

> Low-level waste includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. This waste typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipments and tools, luminous dials, medical tubes, swabs, injection needles, syringes, and laboratory animal carcasses and tissues. The radioactivity can range from just above background levels found in nature to very highly radioactive in certain cases such as parts from inside the reactor vessel in a nuclear power plant (NRC 2007l).

Low-level waste is classified as Class A, B, or C depending on its concentration of radionuclides. For example, a material containing ^{90}Sr is considered Class A if its concentration of ^{90}Sr does not exceed .04 curies per cubic meter, Class B if its concentration of ^{90}Sr is between .04 and 150 curies per cubic meter, and Class C if its concentration of ^{90}Sr is between 150 and 7,000 curies per cubic meter. (10 CFR 61.55) The Class C waste has a concentration of ^{90}Sr that is 175,000 times higher than Class A waste and 47 times higher than Class B waste. The allowable concentration varies for each radionuclide, but it can be generalized that Class C wastes are much hotter than Class B wastes, which are much hotter than Class A wastes.

Low-Level Waste Facilities

The Low-Level Radioactive Waste Policy Amendments Act of 1985 encouraged states to enter into regional compacts that would allow member states to dispose of low-level waste at a common disposal facility. It specified that, after the conclusion of a seven-year transition period in 1992, states would be allowed to exclude from their facilities waste that had been generated outside of their compact (CRS 1986). While ten compacts have been formed encompassing 43 states, only one new disposal facility has been built since the Act was passed and this facility accepts only Class A waste (NRC 2007l). Moreover, a facility located in Beatty, Nevada that had been open at the time of the Act has since closed (NSC 2002). Today, there are only three operating low-level waste disposal facilities in the U.S. (NRC 2007l):

- EnergySolutions Barnwell Operations, Barnwell, South Carolina—Accepts low-level waste in Classes A-C from all U.S. generators except those in the Rocky Mountain and Northwest Compacts. Beginning July 1, 2008, will accept waste only from Atlantic compact states (Connecticut, New Jersey, and South Carolina)
- EnergySolutions Clive Operations, Clive, Utah—Accepts Class A waste from all U.S. generators
- US Ecology, Richland, Washington—Accepts low-level waste in Classes A-C only from the Northwest and Rocky Mountain compacts

As shown in Table 18, four million cubic feet of commercial low-level radioactive waste, encompassing 530,000 curies of radioactivity, was disposed of at these facilities in 2005. While 98 percent of this waste by volume was disposed of at the Utah (Class A) facility, 98 percent of this waste by radioactivity was disposed of at the Barnwell (Class A-C) facility. The Barnwell facility will not be available to most states beginning in mid-2008.

Table 18: Low-Level Waste Disposal in 2005

Facility	**Volume** (Cubic Feet)	**Radioactivity** (Curies)
Clive, Utah	3,940,775	3,262
Barnwell, S. Carolina	430,114	517,693
Richland, Washington	30,026	6,247
Total	*4,013,815*	*527,202*

Source: (NRC 2007l)

There have been several unsuccessful attempts over the past 25 years to develop new low-level waste facilities or to expand access to existing facilities. According to a 2003 National Academies study on low-level radioactive waste management, after the passage of the Low-Level Radioactive Waste Policy Amendments Act of 1985, “states and compacts spent about $600 million in mostly failed siting efforts” (National Academies 2003, p.37). A current effort to develop a hazardous waste facility in Andrews County, Texas appears the most promising. The Andrews County facility developer anticipates that it will receive a license to accept Class A-C low-level waste as early as August 2007 and that the facility will begin to accept radioactive waste beginning in the fourth quarter of 2009 (WCS 2007b). However, the facility will accept waste only from its compact states (Texas and Vermont) and government facilities (WCS 2007a, p.5.2-1-5).

Other attempts, including several that would have received waste from California, failed due to political or public opposition. A failed California siting effort and failed efforts to keep the Barnwell facility open to non-compact waste and to license the Utah facility to accept Class B and C waste are described below.

Ward Valley Siting Failure

California belongs to the Southwest compact, along with Arizona, North Dakota, and South Dakota, and it has been designated a host state for a low-level waste facility. California spent over a decade trying to develop this facility, beginning in 1982. The California Department of Health Services selected US Ecology as the commercial site developer and in 1991 selected the federally-owned Ward Valley site in the Mojave Desert for the facility. The California Department of Health Services granted US Ecology a license to proceed with site development. In 1993 the outgoing U.S. Interior Secretary agreed to sell the land to California. However, the land transfer was challenged in court, and Bruce Babbitt, the Clinton administration’s incoming Interior Secretary, rescinded the transfer in order to study the site further (AGI 1998; Radwaste Solutions 2001, pp.16-18).

At the direction of Secretary Babbitt, the National Academies investigated seven concerns raised by three USGS geologists concerning the suitability of the site, including the potential for groundwater contamination and the destruction of very high quality tortoise habitat. The National Academies did not find any significant concerns but recommended specific areas that would benefit from further study, monitoring, or engineered solutions (National Academies 1995, pp.1-14).

After the National Academies’ report was released in 1995, Secretary Babbitt offered to transfer the land to California if the state would accept the authority of the U.S. Department of the Interior (DOI) to enforce the state’s compliance with the National Academies’ recommendations. The state of California committed to carrying out the recommendations but rejected DOI’s offer, since the recommendations relate to radiological safety, which is a state responsibility. The State then sued DOI in attempt to compel the land transfer (AGI 1998, pp.16-18; DHS 1997).

In 1996, Deputy Interior Secretary John Garamendi ordered additional studies at the site after tritium and carbon-14 were found around the Nevada low-level waste facility, which was seen as similar to the Ward Valley site. However, testing was held up by further disagreements between the state and federal governments. The project stalled, and US Ecology sued the California Department of Health Services for failing to pursue acquisition of the site. No alternative sites have since been considered within California or elsewhere in the Southwest compact (AGI 1998).

Closure of the Barnwell Facility to Non-Compact States

The Barnwell, South Carolina facility is currently the only low-level waste facility that accepts Class B and C waste from California. As discussed above, according to the Low-Level Radioactive Waste Policy Amendments Act of 1985, it has not been obligated to accept waste from states outside of its compact since 1992. In 2000 South Carolina entered into an agreement with the Barnwell facility operators to keep Barnwell open to non-compact waste only through June 30, 2008 (AP 2007).

Local officials in the vicinity of the Barnwell facility objected to this agreement and fought to keep the site open to non-compact states in order to protect the high-paying jobs and taxes that the facility provides. The Barnwell facility reportedly "provides roughly 10 percent of the county's overall budget and pumps $1 million a year into local schools. A portion of its disposal fees also has contributed more than $430 million for school building projects statewide" (AP 2007).

Legislation which would have kept Barnwell open to non-compact waste through 2023 was introduced in the South Carolina House of Representatives in February 2007 (SC 2007). The House Agricultural Committee "voted overwhelmingly against" this legislation, and the governor of South Carolina spoke in favor of Barnwell's closure to non-compact waste (AP 2007). It is expected that non-compact waste will be excluded from the site, as legislated, beginning July 1, 2008.

Abandoned Utah License Amendment

The Utah Envirocare facility (now EnergySolutions) was initially licensed to accept only Class A waste. In 1999 Envirocare applied for and received a license amendment to accept Class B and C waste. However, political sensitivity of the waste-disposal issue was heightened by the proposed PFS spent fuel storage facility that was to be located near the Envirocare facility. As a result, Envirocare deferred seeking the approvals from the state legislature and the governor that were required before the amendment would become effective (National Academies 2003, p.37). In 2005 Envirocare was bought by EnergySolutions. The new owners promised not to seek the right to dispose of higher-level wastes and asked the state to rescind the conditional license to accept Class B and Class C wastes (PDH 2005).

Waste Shipments from California's Reactor Sites

The NRC reports that between 1979 and 2005, 7.6 MTHM of spent fuel was shipped out of California, including 6.8 MTHM of spent fuel from SONGS to a General Electric facility in Morris, Illinois and 0.7 MTHM from the General Electric Vallecitos reactor to Argonne National Lab, Hanford Washington, and other destinations (NRC

2006l, p.7). In addition, the utilities have been shipping low-level radioactive waste out of state, mainly to the low-level waste disposal facilities in South Carolina and Utah.

PG&E reports that is has disposed of all the Class A, B and C waste generated prior to 2007 at Diablo Canyon, except for activated metal in the spent fuel pools, which is being accumulated until a sufficient quantity is available for packaging. This waste and waste from Humboldt Bay have been shipped to facilities in Richland, Washington (prior to 1993), Beatty, Nevada (1991 and 1992 only), Barnwell, South Carolina and Clive, Utah. Should the Barnwell facility close to California generators in July 2008, as expected, remaining Class B and C waste will be stored onsite (PG&E 2007b, B9e). More information on PG&E's low-level waste storage and disposal activities since 2002 is shown in Table 19and Table 20.[71]

Table 19: Diablo Canyon Power Plant Waste Disposal

Year	**Waste Class**	**Disposal Volume** (ft^3)	**Disposal Activity** (Ci)	**Burial Site**
2002	Class C	162.82	147	Barnwell, SC
	Class B	195	176.54	Barnwell, SC
	Class A	267	1.4	Clive, UT
2003	Class C	87.0	63.72	Barnwell, SC
	Class B	87.9	112.94	Barnwell, SC
	Class A	919	4.4	Clive, UT
2004	Class C	186	140.86	Barnwell, SC
	Class B	98	61.82	Barnwell, SC
	Class A	1,388	1.2	Clive, UT
2005	Class C	23.44	23.38	Barnwell, SC
	Class B	98	203.09	Barnwell, SC
	Class A	3,760	17.1	Clive, UT
2006	Class C	88	48.96	Barnwell, SC
	Class B	227.2	229.79	Barnwell, SC
	Class A	843.55	4.3	Clive, UT

Source: (PG&E 2007b, Table B.9.a-2)

[71] SCE declined to provide to the Energy Commission information on its waste storage and disposal activities, stating that it would be "unduly burdensome" (SCE 2007a, B9e).

Table 20: Humboldt Bay Power Plant Waste Storage and Disposal

Year	**Waste Class**	**Disposal Volume** (ft^3)	**Disposal Activity** (Ci)	**Burial Site**
2002	Class A	1824	0.0184	Clive, UT
2003	Class A	2281	0.0205	Clive, UT
2004	Class A	3602	0.11	Clive, UT
2005	Class A	2000 (estimated)	0.1 (estimated)	Storage on-site
2006	Class A	2000 (estimated)	0.1 (estimated)	Storage on-site
2007	Class C	14.72 (as of 03/01/07)	579.8	Barnwell, SC

Source: (PG&E 2007b, Table B.9.a-1)

SMUD reports that since 1992 it has shipped only Class A waste from Rancho Seco and that it has been storing Class B and C wastes on-site for future disposal at a suitable disposal facility. These wastes were generated both during plant operations and during decommissioning, and in some cases the wastes from the two periods have been co-mingled. More information on Rancho Seco's waste storage and disposal activities is shown in Table 21 (SMUD 2007, B9).

Table 21: Rancho Seco Waste Storage and Disposal

Waste Category	**Volume** (m^3)
Total waste generated during plant operations	4,291
Total waste generated during decommissioning through 2006 (Class A)	5, 844
Class B waste in storage	31.6
Greater than Class C waste in storage in the ISFSI	10.7
Class C waste in storage	61.0
Estimated total future decommissioning waste generation (all Class A)	11,400

Source: (SMUD 2007, Table B9)

Most of the waste shipments from the California utilities have been uneventful. However, SCE has had great difficulty in transporting the SONGS 1 reactor vessel offsite and has abandoned plans to ship it until at least 2026 (Energy Commission 2006e, p.88; SCE 2007a, H6).[72] In addition, the closure of the Barnwell facility will soon preclude the utilities from shipping Class B and C low-level waste offsite.

In anticipation of the closure of the Barnwell facility to California waste, PG&E is expediting its low-level waste shipments from Humboldt Bay. According to PG&E, all available space at the facility beginning in July 2007 has already been reserved, so there is just a short window of opportunity to take advantage of the facility (PG&E 2006a, pp.2, 5).

[72] PG&E also plans to keep Diablo Canyon's eight steam generators and two reactor vessel heads on-site (PG&E 2007b, B9e).

Conclusion

According to the National Academies, spent fuel transport need not be a risky operation if it is managed well. However, social impacts could ensue along transportation routes if the public lacks confidence in DOE's ability to develop a transportation plan and safely manage the program. These impacts could include lower property values, a reduction in tourism, and increased public anxiety.

California could be strongly affected, since many spent fuel shipments could be routed through the state en-route to Yucca Mountain. The 2005 IEPR recommended that California evaluate DOE's proposed use of California routes to transport nuclear waste to and from Nevada, and reexamine the adequacy of the state's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments (Energy Commission 2005b, p.86). California has repeatedly expressed concerns to DOE over route selection and has requested that additional public meetings be held in the state; however, DOE has not been responsive to these concerns. The state has not yet adjusted its nuclear waste transport fees as recommended in the 2005 IEPR.

Lessons learned from previous national radioactive transportation programs, including the WIPP Transportation Safety Program, are useful for developing the national repository transportation program. DOE's effort to self-regulate repository shipments and make them exempt from federal, state, tribal, and local requirements runs counter to the National Academies' finding that these shipments can be expected to be safe only if made in strict compliance with existing regulations.

Low-level waste shipments, on the other hand, are expected to become less of a concern to California, as the Barnwell, South Carolina facility closes to waste from California and other states. Beginning July 2008, California utilities will have access to off-site storage facilities only for the least radioactive grade of low-level waste from the power plant sites; other grades of radioactive waste will remain on-site.

CHAPTER 6: COSTS OF CALIFORNIA'S NUCLEAR POWER PLANTS

The CPUC has used a combination of traditional ratemaking and incentive-based ratemaking to determine cost recovery for nuclear power plants. In general, incentive-based ratemaking methods are intended to shield ratepayers from cost overruns and poor operating performance. Incentive mechanisms have had a secondary impact of making it more difficult to determine in retrospect the true costs of these plants.

This chapter discusses historic ("sunk") costs and the plants' major going-forward costs. Major going-forward costs include large capital investments to replace faulty or degraded reactor components and operating costs for nuclear fuel procurement and disposal, security, and decommissioning. These costs were reviewed in substantial detail in the *2005 Status Report*.

Diablo Canyon Sunk Costs

PG&E ratepayers paid $34.3 billion (2006 dollars) for power from Diablo Canyon from 1985 through 2006, averaging $99.76 per MWh.[73] (PG&E 2007b, M1) This figure, however, may not be an accurate representation of the cost of Diablo Canyon power because for much of this period PG&E's rate recovery structure for the plant was based on negotiated, fixed per-kWh payments rather than PG&E's costs. The amount that ratepayers have paid for generation from the plant has ranged from a low of $33 per MWh in 2002 to a high of $157 per MWh in 1994. The difference in these rates reflects the different cost recovery mechanisms that were in place at the time, as shown in Table 22.

Table 22: Cost Recovery Mechanisms for Diablo Canyon

Period	**Method of Cost Recovery**	**Average Ratepayer Cost** (per MWh)
1985 – Mid-1988	Partial cost recovery	$84
Mid-1988 – 1996	Fixed price per kWh (independent of cost of service)	$139
1997 – 2001	Fixed costs plus incentive	$108
2002 – 2006	Cost-based recovery	$38

Source: (PG&E 2007b, M1)

Due to the different cost recovery structures, it is difficult to isolate cost components and track them throughout the plant's life. Some costs during some periods were tracked independently. Fuel costs were recovered separately from other costs from 2003 to 2006. During this period, fuel costs averaged $5.06 per MWh, accounting for

[73] All figures in this section are in 2006 dollars unless otherwise noted. Nominal dollars converted to 2006 dollars using the Gross Domestic Product implicit price deflator (BEA 2007).

13 percent of overall plant costs. In addition, between 1987 and 2002 decommissioning costs were calculated separately from other charges. During this period, decommissioning charges averaged $3.53 per MWh, which was equal to 3 percent of the rates paid for Diablo Canyon power during these years (PG&E 2007b, M1).

SONGS Sunk Costs

Cost recovery for SONGS 2 and 3 has mostly been based on traditional ratemaking methods, with the exception of the period between 1997 and the end of 2003 when the plants' revenue requirements were recovered through an incentive-based mechanism. [74] SCE has declined to identify the nuclear-related portions of these revenue requirements or to provide other estimates of its historic nuclear-related costs (SCE 2007a, M1).

Going Forward Capital Costs

Diablo Canyon, SONGS, and Palo Verde are all facing significant capital improvement programs to replace faulty reactor components. The largest of these projects are the replacement of the steam generators at each reactor. Much less expensive but still significant are the projects to replace the reactor vessel heads at each reactor. The status of these projects is discussed below.

In addition, other capital projects that are anticipated to cost in excess of $20 million each are being planned at SONGS and Palo Verde. At SONGS, the reactors' high-pressure turbine rotors will be replaced and some office trailers will be replaced with permanent structures (SCE 2007a, G5, G7). At Palo Verde, the reactors' turbine rotors are being replaced along with the reactors' steam generators, some of which have been replaced or are being replaced, and several projects are planned related to the plant's evaporation pond and security (SCE 2007a, G5, G7). (Diablo Canyon's turbine rotors were recently replaced, and no additional large capital projects are currently planned for the facility) (SCE 2007a, G5, G7). Schedules and cost estimates for these projects are not available.

Steam Generator Replacement Projects

The future cost to operate and maintain California's nuclear power plants will depend in large part on the costs of the steam generator replacement projects. The steam generators use heat from water circulated through the reactor to evaporate another stream of water into steam that runs the turbines (CPUC 2005a, p.4). They were initially intended to last the lifetime of the plants, but they have degraded and need to be replaced.

Similar degradation of steam generators has been observed at all other U.S. pressurized water reactors including Palo Verde (PG&E 2004b, p.1-1). Palo Verde

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[74] This mechanism, the Incremental Cost Incentive Procedure, is discussed in *Nuclear Power in California: Status Report*.

Unit 2's steam generators were replaced in 2003 at a total cost of about $237 million, and Unit 1's steam generators were replaced in 2005 (SCE 2005a). Unit 3's steam generators will be replaced in the fall of 2007 (SCE 2007a, G1). SCE's share of the costs for replacing all three units' steam generators is estimated to be about $115 million (SCE 2007b, p.14).

PG&E and SCE are both preparing to replace the steam generators at their own reactors. PG&E plans to replace the steam generator for Diablo Canyon Unit 2 during an outage planned for February through April 2008, and it plans to replace the steam generator for Unit 1 during an outage planned for January through April 2009. The replacement steam generators are scheduled to be delivered to Diablo Canyon in early November 2007 (PG&E 2007b, G1, G2). SCE plans to replace the steam generators for SONGS Unit 2 in 2009 and for Unit 3 in 2010 (PG&E 2007b, G1). The replacement projects need to be completed if the plants are to continue operating through the remainder of their operating licenses.

In 2005 the CPUC approved both PG&E's application to replace Diablo Canyon's steam generators and SCE's application to replace SONGS' steam generators.[75] The CPUC made the following findings in approving the utilities' applications (CPUC 2005a, pp.2-3; CPUC 2005b, pp.2-3):

- The utilities' estimates of $706 million (PG&E) and $680 million (SCE) in SGRP-related expenditures are reasonable.
- If expenditures exceed these amounts or are suspected to be unreasonable, the CPUC may subject the entire project's cost to a reasonableness review.
- Recoverable expenditures are to be capped at $815 million (PG&E) and $782 million (SCE).
- Expenditures are to be added to rates in the year following the re-start of commercial operation of each unit.

Reactor Vessel Head

Reactor vessel head degradation is a widespread problem among nuclear power plants. The NRC has ordered upgraded inspections of reactor vessel heads to identify any stress corrosion cracking. Plans are in place to replace the reactor vessel heads at Diablo Canyon (fall 2009 and fall 2010), SONGS (April 2011 and April 2012), and Palo Verde (between spring 2009 and spring 2010) (PG&E 2007b, G6; SCE 2007a, G6). PG&E estimates that the cost to replace the reactor vessel heads at Diablo Canyon will be $67 million (2004 dollars) (PG&E 2004a, 5A-23; PG&E 2007b, G6).

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[75] On June 15, 2006 the CPUC made corrections to its SONGS steam generator replacement decision and granted a limited rehearing to take into account corrected results of the net present value calculation and to determine the amount of the greenhouse gas adder. On November 30, 2006 the CPUC affirmed the cost-effectiveness of the SONGS steam generator replacement based on the corrected model and the greenhouse gas adder value and closed the proceeding (CPUC 2006d, p.1).

Going Forward Operating Costs

Unlike the capital projects discussed above, which are one-time projects to replace faulty equipment, operating costs are routine costs incurred through regular operations.

Some operating costs associated with nuclear power plants are shared by fossil-fueled plants, such as fuel costs. Operating costs that are unique or much higher at nuclear power plants include costs for security, waste transport and disposal, and reactor and site decommissioning. These costs are significantly more expensive for nuclear power plants due to the radioactive waste and contamination generated by these plants and the much greater security concerns related to radioactive contamination.

Nuclear Fuel Costs and Supply

The value of nuclear fuel purchases made by PG&E and SCE over the last three years is shown in Table 23 below.

Table 23: Nuclear Fuel Purchases

$Millions (2006 dollars)

	PG&E	SCE
2004	$117	$74
2005	$150	$61
2006	$100	$81

Source: (PG&E 2007a; SCE 2006b)

PG&E purchases fuel for Diablo Canyon in contracts with terms ranging from two to five years. It entered into six new contracts in 2005 for deliveries through 2009 and five new contracts in 2006 for deliveries through 2010. In 2006, PG&E also extended an existing contract by five years. PG&E has $539 million in nuclear fuel contracts; it has not specified what percentage of its fuel needs this represents (PG&E 2006c; PG&E 2007a). PG&E has also not specified how much fuel it has in inventory. It appears that in the past three years PG&E has spent almost 50 percent more for nuclear fuel than it has recovered from ratepayers.[76] This may indicate that PG&E has purchased excess fuel in order to build inventories; however, it could also indicate that the fuel purchased was more expensive than the average cost of fuel that ratepayers consumed during this period.

As of the end of 2006, contractual arrangements were in place to supply 100 percent of the projected uranium and uranium conversion requirements for SONGS through 2008 and for Palo Verde through 2007. In addition, enrichment services were

[76] This assessment is based on a comparison of the amount spent by PG&E on nuclear fuel, as shown in Table 23 and on the amount recovered by PG&E for its nuclear fuel costs, as reported in (PG&E 2007b, M1)

contracted for SONGS through 2008 and for Palo Verde through 2010, and fabrication services were contracted for SONGS through 2014 and for Palo Verde through 2015 (SCE 2006b). However, in September 2006 SCE reported that its nuclear fuel commitments had increased by an average of $7 million per year through 2009 due to higher uranium enrichment and fuel fabrication costs (SCE 2006c, p.50). This may indicate that some of SCE's supply contracts are tied to market prices. While these contracts provide resource security, they may not provide cost security.

Security Costs

Security costs at nuclear power plants are determined by the actions required for the plant to be in compliance with an NRC-issued design basis threat, which is the largest threat that a plant licensee is required to design and protect against. The NRC upgraded its design basis threat following the September 11, 2001 attacks. The revised design basis threat led to substantial security investments by the California utilities.[77]

- PG&E estimates that it spent $15.5 million in NRC-mandated security additions at Diablo Canyon in 2004 and that it would spend an additional $1 million per year from 2006-2009 to meet NRC-mandated security requirements. PG&E also identified over $11 million in other security-related capital expenditures that it will make between 2005 and 2009. PG&E did not identify security-related O&M expenditures (PG&E 2005b).
- SCE estimated that SONGS would require capital expenditures of $69.9 million in 2004 and 2005 and O&M expenditures of $4.5 million in 2004 and $9.8 million a year in 2005 and 2006 for physical changes to meet the NRC's design basis threat upgrade (SDG&E 2004, p.15). SCE explained that there "are no available sources of funding from the federal government or other outside entities for SCE to recover all or a portion of the increased security costs to comply with NRC security requirements resulting from the September 11, 2001 terrorist attack" (SCE 2005b).

The NRC is currently reviewing other security issues that could lead to updated physical protection requirements (NRC 2007r). Cost estimates for PG&E and SCE to meet these requirements are not yet available.

If an accident or security breach does occur at Diablo Canyon, SONGS, or Palo Verde, PG&E and SCE would be protected from most of the liability through primary insurance coverage, mutual insurance coverage with other U.S. reactors, and the Price-Anderson Act. However, the mutual insurance could also make PG&E and SCE each liable to contribute up to $30 million per year per incident up to a total of $201 million per incident if an accident occurs at any other U.S. reactor. In addition, if losses exceed the funds available in the insurance programs, the utilities could

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[77] This is discussed further in Chapter 10

each be assessed retroactive premiums of up to $42 million per year (SCE 2007a, K1; SCE 2007b, p.167).

Waste Transport and Disposal

Nuclear power plant operators contribute to the federal NWF, from which the construction and operation of a federal nuclear waste depository is to be funded. The NWF is also intended to pay for the transport of spent fuel to the repository. To date, PG&E customers have paid over $315 million into the NWF for spent fuel from Diablo Canyon and over $5 million for spent fuel from Humboldt Bay. Customers of SCE and its co-owners at SONGS have contributed a total of $390 million to the NWF for spent fuel from SONGS, and customers of SCE have contributed $74 million for its share of spent fuel from Palo Verde (SCE 2007a, D5).

PG&E, SCE, and APS have also made substantial investments to construct interim storage facilities to store their spent fuel until it can be shipped to a federal repository. PG&E estimates that it will require $12.3 million in 2007, $7.9 million in 2008, and $6.3 million in 2009 for capital and O&M expenditures related to construction of ISFSIs at Diablo Canyon and Humboldt Bay, plus over $8 million a year in operating costs (PG&E 2005b). SCE estimates that it will require $11.7 million in 2006, $21.4 million in 2007 and $11.4 million in 2008 for SONGS dry cask storage costs (TURN 2005, p.57). PG&E, SCE, and APS have all sued DOE to recover their dry cask storage costs.[78] (See Chapter 3.)

The utilities also are responsible for the costs to dispose of low-level waste generated as part of nuclear power production activities. Between 1993 and 2003, low-level waste disposal costs in the U.S. increased at a rate of about 20 percent per year. Due to uncertainties about shipping low-level wastes off-site in the future (see Chapter 5), PG&E's and SCE's future costs for disposing of low-level waste are uncertain at this time. However, PG&E has budgeted $1 million per year to cover the ongoing costs of low-level waste disposal at Diablo Canyon, including costs for packaging, shipping, and transportation fees (PG&E 2007b, B9). PG&E currently anticipates that it will pay a total of $104 million to dispose of low-level waste from Diablo Canyon and Humboldt Bay through the end of decommissioning, and SCE has declined to provide information on its plans and expected costs for low-level waste transport and disposal.

Decommissioning

The utilities are responsible for the costs to decommission their reactor sites. Decommissioning includes dismantling structures, disposing of waste, and decontaminating the site.

[78] PG&E was awarded $42.8 million for costs through 2004. SCE's trial has not yet commenced (PG&E v. U.S. 2006, pp.147, 150; SCE 2007a, C11).

The Humboldt Bay Unit 1 possess-but-not-operate license expires in 2015. PG&E is evaluating a plan that would complete decommissioning and site restoration in the 2009-2011 timeframe. Currently, Humboldt Bay is in the early phase of decommissioning. A below-ground dry cask storage facility is being constructed at the site to allow for the emptying of the spent fuel pool and the decommissioning of equipment in the refueling building. In addition, a radiological survey program that will be used for the decommissioning process is being developed (PG&E 2007b, H1). The cost for these decommissioning activities is estimated at $333.6 million, and the unit's decommissioning trust fund contains $213.9 million. PG&E has estimated that the difference will be made up by $41.5 million in ratepayer funding through mid-2009 and $78.2 million in earnings from investments, interest, and tax advantages over the next 10 years (NRC 2006p, A-7).

SONGS Unit 1 is 70 percent completed with the first phase of decommissioning, which involves decontaminating, dismantling, and disposing of nearly all equipment, components, and buildings (SCE 2007a, H1). The steam generator and pressurizer have been shipped off-site for disposal, but the reactor pressure vessel is now scheduled to remain onsite until around 2026 because of difficulties in arranging for its off-site shipment. SCE plans to submit a request to leave in place the off-shore portions of Unit 1's intake and outlet pipes and release them for unrestricted use. SCE is also considering leaving some of the below-grade portions of Unit 1's structures in place. Full decommissioning is not expected to take place until after the closure of Units 2 and 3 (NRC 2006p, A-15).

Rancho Seco is currently in the process of being decommissioned. Most of the plant has been dismantled, and the pressurizer and steam generators have been shipped to off-site storage (SMUD 2006, Attachment 2). SMUD submitted a License Termination Plan for the plant to the NRC in 2006; the plan is currently under review (NRC 2006r, Enclosure D). Decommissioning is expected to be completed in 2008 for a cost of $518.6 million (2002 dollars) (NRC 2006p, p.A-14).

PG&E, SCE, and SDG&E recently completed their 2006 triennial nuclear decommissioning trust fund proceedings (CPUC 2007a). According to the CPUC's ruling, PG&E will receive $2 million of the $9.5 million requested for the Diablo Canyon trust fund and $25 million of the $28 million requested for the Humboldt Bay Unit 3 trust fund;[79] SCE will receive $42 million of the $58 million requested for the SONGS 2 and 3 and Palo Verde trust funds; and SDG&E will receive $9 million of

[79] PG&E was not required to establish an Independent Board of Consultants (IBC) to oversee the decommissioning process and expenditures of Humboldt Bay Unit 3. The CPUC ruled instead that the three utilities should "perform in-depth analyses of storage costs and contingencies for the next triennial proceeding" (CPUC 2007a, p.2). PG&E had argued that an IBC was unnecessary because the decommissioning activities involve straightforward applications of federal, state and local regulations with little room for PG&E discretion. Moreover, SONGS Unit 1 is being decommissioned without an IBC. PG&E proposed to provide sufficient accounting information for the CPUC to monitor and evaluate the reasonableness of its decommissioning expenditures (PG&E 2005a, pp.7-1 – 7-7).

the $12 million requested for the SONGS 2 and 3 funds (CPUC 2006a, pp.5-6; CPUC 2006e, pp.2-5).

Conclusion

The cost of power from California's nuclear power plants over the upcoming years will be driven largely by the cost of the steam generator replacement projects and by the extent to which additional large capital projects will be required as the plants age. Unexpected long-term outages and additional NRC security requirements could also impact overall costs.

CHAPTER 7: NEW PLANTS—RANGE OF POTENTIAL COSTS

In the 1950s it was expected that nuclear power would be "too cheap to meter" (Strauss 1955). In the 1980s nuclear power proved in many cases to be a financial burden. Today, with the high cost of natural gas, impending limitations on greenhouse gas emissions, and significant subsidies in the EPAct 2005, some utilities are considering making another round of commitments to nuclear power. One of the fundamental but as yet unanswered questions is: what will be the cost of new nuclear commitments?

Historic utility development costs for nuclear power plants ranged from just a couple of hundred dollars per kilowatt (kW) for early plants that were subsidized by vendors to several thousand dollars per kW for most of the plants that began operating during or after 1984 (Constellation Energy 2006; Harding 2007a). Development costs for new power plants are highly uncertain, since there has been very little reactor development in the U.S. for the past 20 years. In addition, reactor development projects are complex projects that require large capital investments and regulatory approvals from several layers of government, and they may be subject to large sways in public opinion. These factors all contribute to the great risk involved in nuclear power plant development.

This chapter begins with a discussion of the expected construction and operating costs of new reactors given historic experience in the U.S. and more recent experience abroad. It then discusses the risks of reactor development, the credit implications of these risks, and financial, operational, regulatory, and legislative strategies that can be used to mitigate these risks.

Construction and Operating Costs

Estimates of nuclear power plant overnight construction costs, which exclude the costs of financing and operating the plant, range from a low of $1,200 per kW to a high of $4,000 per kW.[80] Levelized cost estimates, which incorporate all of the costs associated with the construction, financing and operation of the plants, range from 3.7 cents per kWh to 9.8 cents per kWh (MIT 2003, pp.42-23; Turnage 2007, pp.42-46; University of Chicago 2004, pp.5-17 – 5-23).

Overnight Construction Costs

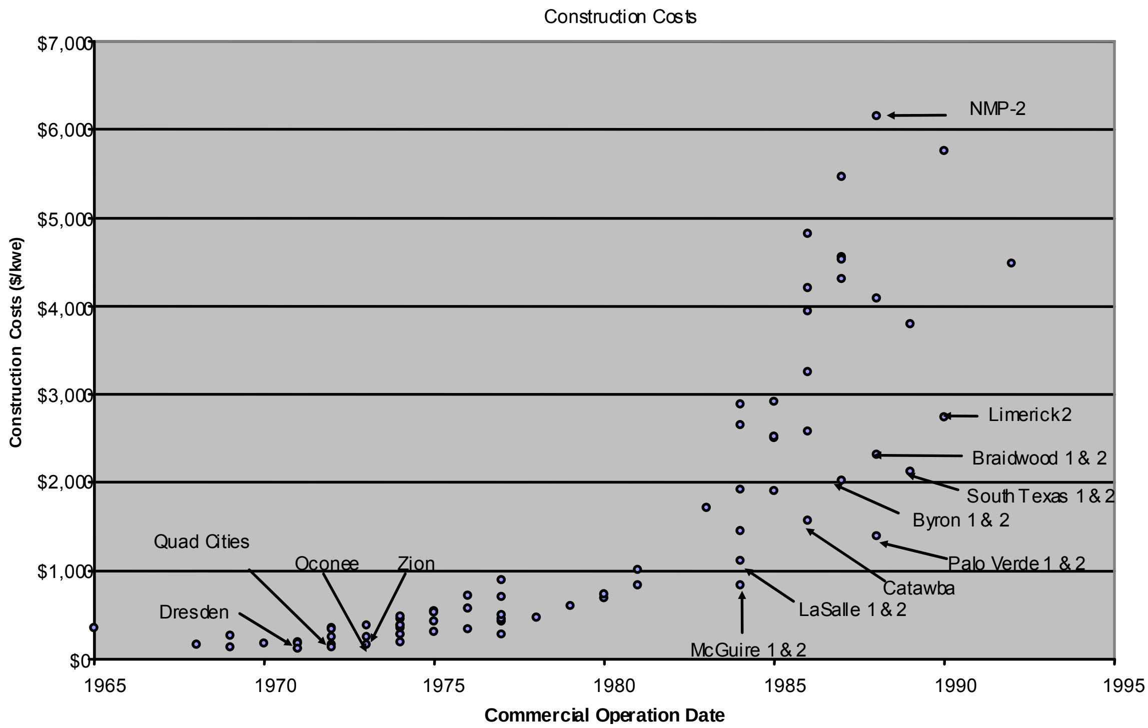
The dearth of recent cost data for nuclear power plant construction means cost estimates are somewhat speculative. Recent estimates of the overnight construction

[80] Overnight construction cost is defined as "the hypothetical cost of a generating plant if it could be built instantly ('overnight')…[and it] does not reflect inflation, the costs of construction financing, or the length of time that it takes to build the plant and associated cash flows" (CEEPR 2006, p.12).

costs of new plants range from around $1,200 per kW to $4,000 per kW. As shown in Figure 19, this range encompasses the costs of many of the plants that were completed in the U.S. in the 1980s and 1990s.

Figure 19: Construction Costs of U.S. Nuclear Power Plants

(nominal dollars)



Source: (Harding 2007a)

Estimates of overnight construction costs for some of the advanced nuclear power plant designs are shown in Table 24 and Table 25. (Advanced nuclear reactor technologies are described in Appendix F.) Estimates from utilities considering new nuclear power plant development and from government agencies tend to be higher than estimates from vendors and from the University of Chicago, which estimated nuclear power construction costs on behalf of DOE.

Table 24: General Advanced Nuclear Power Plant Cost Estimates

($ per kWe)[81]

Study	Cost Estimate
International Energy Agency	$2,100
U.S. Energy Information Administration	$2,400
UK Energy Review	$2,700-$3,400

Source: (MIT 2003, pp.137-139)

[81] All estimates escalated to $2007 using implicit price deflators based on the U.S. gross domestic product.

Table 25: Cost Estimates for Specific Nuclear Power Plants

($ per kilowatt electric (kWe)) [82]

Technology	Vendor Estimates	Other Estimates
General Electric -Advanced Boiling Water Reactor (ABWR)	$1,700-$1,900[83]	$1,300 (Univ. of Chicago)
Westinghouse AP 600[84]	$2,500 – FOAK $2,000 – NOAK	
Westinghouse AP 1000	$1,600 – FOAK $1,200 – NOAK	$1,600 (Univ. of Chicago) $1,800-$2,700 (Duke Power)
Mitsubishi-U.S. Advanced Pressurized Water Reactor (APWR)	$1,500	
Framatome -European Pressurized Water Reactor		$1,900 (Univ. of Chicago) $2,000 (Constellation Energy)

Source: (Duke Energy 2006a; Duke Energy 2006b; MIT 2003; Turnage 2007; DOE 2001; University of Chicago 2004)

Dr. Paul L. Joskow, Director of the MIT Center for Energy and Environmental Policy Research, reviewed these and other estimates and concluded that a reasonable base case estimate of the cost to construct a nuclear power plant is $2,000 per kilowatt electric (kWe) ($2002), higher than both the industry and University of Chicago estimates but lower than the construction costs for the most recently built U.S. plants (MIT 2003, p.39). In a December 2006 paper he reaffirmed this base case estimate and noted that it is equivalent to $2,300 in 2006 dollars (CEEPR 2006, p.10). MIT professors John Deutch and Ernest Moniz expressed confidence in Joskow's analysis since it "is grounded in past experience and actual performance of existing plants, not in promises from the nuclear industry" (Scientific American 2006a, p.80).

In evaluating these cost estimates, it is instructive to consider the history of cost overruns in nuclear power plant construction projects and why upcoming projects may or may not face similar overruns. In the early days of large nuclear power plant construction, the Atomic Energy Commission's estimates of the cost to build a 1,000 MW nuclear power plant increased by over 250 percent in four years, from $135 per kW in 1968 to $350 per kW in 1972. Over the next two years the Atomic Energy Commission estimate more than doubled again to $720 per kW (Perry 1977, pp.42-43). These increases were attributed to a number of factors, including increased safety and environmental requirements, increased design complexity, higher labor

[82] All estimates escalated to $2007 using implicit price deflators based on the U.S. gross domestic product.

[83] General Electric expects that its Economic Simplified Boiling Water Reactor will be less expensive than its ABWR.

[84] For the Westinghouse plants, separate estimates are provided for first-of-a-kind (FOAK) plants and nth-of-a-kind (NOAK) plants. It is expected that the first plant that uses any particular technology (i.e., FOAK plants) will be more expensive than subsequent plants that use the same technology (i.e., NOAK plants).

and materials costs, increased interest owing to longer construction and licensing time requirements, and high inflation. Removing the impact of inflation, the cost to build a nuclear power plant increased by 55-60 percent during this period (Perry 1977, pp.42-44).

Former NRC Chairman Joseph Hendrie (then of Brookhaven National Lab) vividly captured the failure of cost predictions during that period in a 1976 statement:

> Construction costs have gone up out of all sight and reason, for an assortment of causes, and hardly any of the causes or the associated cost increments were perceived correctly as to nature, timing, or magnitude by the so-called experts…the fact remains, utility executives would have done as well examining the entrails of strangled cats as studying their plant cost projections, when they had to decide what kind of plant to build (Perry 1977, p.46).

The impact of these cost increases can be seen in Figure 20, which shows the average cost overruns of the 75 U.S. nuclear power plants that were constructed before the 1979 Three Mile Island accident and which were operating in 1986. In many cases, cost overruns were even higher after the Three Mile Island accident due to increased delays and regulatory costs.

Figure 20: U.S. Nuclear Reactors Construction Costs
Prior to the Three Mile Island Accident

Construction Started	Estimated Overnight Cost	Actual Overnight Cost	% OVER
1966-67	$ 560/kWe	$1,170/kWe	209%
1968-69	$ 679	$2,000	294%
1970-71	$ 760	$2,650	348%
1972-73	$1,117	$3,555	318%
1974-75	$1,156	$4,410	381%
1976-77	$1,493	$4,008	269%

Source: (Harding 2007a, p.6)

Diablo Canyon and SONGS were among the plants that were under construction both before and after the Three Mile Island accident, and they both experienced massive cost overruns. Construction costs at Diablo Canyon exceeded the initial $320 million estimate (1968 dollars) by more than $5 billion, and construction costs for SONGS Units 2 and 3 exceeded the initial $436 million estimate by over $4 billion.[85] (CPUC 1988, p.2)

[85] For more information on Diablo Canyon and SONGS construction costs and cost recovery, see (Energy Commission 2006e, pp.65-67)

In a January 2007 report, Standard & Poor's (S&P) identified two factors that it expects will reduce the likelihood of new plants encountering such large construction cost overruns. First, the process for obtaining a combined NRC construction and operating license (which was not available during the last round of nuclear construction) moves "all design, technical, regulatory, and licensing issues to the front of the licensing process, before any significant capital spending occurs. As a result, safety, environmental, and licensing issues are to be addressed well before construction begins, avoiding lengthy delays, disputes, and spiraling costs during the actual construction period" (S&P 2007, p.2). Second, the trend toward standardized reactor designs should lead to lower manufacturing and construction costs (S&P 2007, p.5).

However, construction costs for non-nuclear power plants have been increasing, with the capital cost of new coal plants in 2006 almost double what they had been in 2002 and 40 percent higher than they had been one year prior[86] (Innovest 2007). The S&P report cautioned that "in light of recent increasing construction costs for coal- and gas-fired generation, for which the technology is known and construction experience is plentiful, the proposed construction cost estimates [by the vendors] could be viewed as aggressive or optimistic" (S&P 2007, p.6). The report did not propose a better estimate, but it used $2,000 per kW in its own cost calculations.

Levelized Costs

Levelized costs, unlike overnight construction costs, incorporate the full lifecycle cost of nuclear power plant construction and operation. However, they are subject to greater uncertainty since, in addition to the assumptions embedded in the calculation of overnight construction costs, they also incorporate assumptions about construction time, plant life time, capacity factor, fuel costs and O&M costs.

Estimates of the levelized costs of power from new reactors are shown in Table 26. These results, which range from 3.7 cents per kWh to 9.8 cents per kWh, are largely driven by capital cost and financing assumptions. According to Joskow, the 6.7 cents per kWh MIT study estimate that is shown in Table 26 falls to 5.2 cents per kWh if the plant is built and financed by a regulated utility with ratepayers bearing the investment risk (CEEPR 2006, pp.15, 28). Similarly, federal loan guarantees can reduce the financing costs of a plant. According to an April 2007 Cambridge Energy Research Associates report, government funding or loan guarantees can reduce the levelized cost of nuclear generation by 10-15 percent (CERA 2007).

In a February 2007 presentation to the Northwest Power Council, energy economist Jim Harding identified a number of what he considers to be overly optimistic assumptions embedded in many of the levelized cost estimates discussed in the industry. According to Harding, these estimates assume a construction time of four

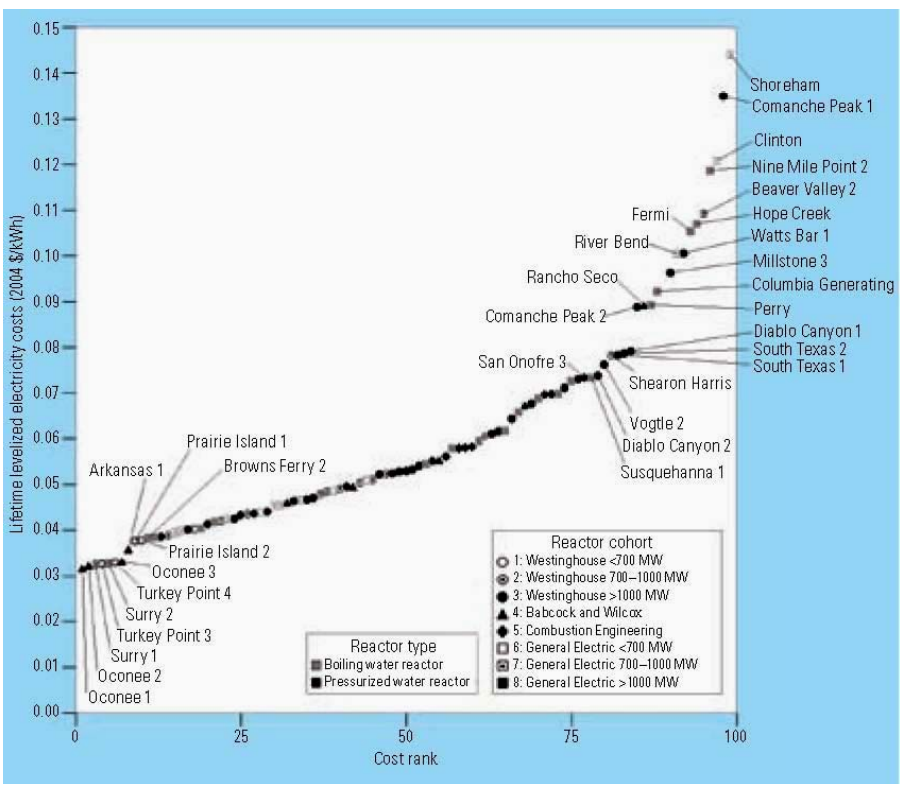
[86] On February 28, 2007, the North Carolina Utilities Commission approved just one of Duke Energy's proposed two coal plants after Duke announced in late 2006 that its estimated cost for the plants had increased by 50 percent to $3 billion (News & Observer 2007).

to five years and inexpensive financing. In addition, they omit owner costs and contingency costs, remove “first of a kind” engineering costs and, most importantly, assume declining real escalation during construction. They also assume that recent improvements in Asian construction techniques, such as batch concrete plants, open containment during construction, and large cranes, will be readily transferable to the U.S. (Harding 2007a).

In evaluating these figures, it is again instructive to consider the experience of the current fleet of reactors. In an April 2007 study of the levelized costs of 99 U.S. reactors, Nathan Hultman of Georgetown University and University of Oxford, Jonathan Koomey of Stanford University and Lawrence Berkeley National Lab, and Daniel Kammen of the University of California, Berkeley found that the range of levelized costs of these reactors was very different from would normally be expected. In fact, the distribution of costs was skewed “beyond what might be expected in the rational world” (ES&T 2007, p.2091). This distribution, which is shown in

Figure 21, ranged from about 3 cents per kWh to 14 cents per kWh, with a median cost of about 5 cents per kWh ($2004) (ES&T 2007, p.2091). While the levelized costs of most of the reactors fell within the range of estimates shown in Table 26, 16 percent had levelized costs above 8 cents per kWh and 5 percent had levelized costs above 12 cents per kWh (ES&T 2007, p.2090).

Figure 21: Levelized Cost of Power—Current Fleet of U.S. Reactors



Source: (ES&T 2007, p.2090)

Table 26: Levelized Cost of Nuclear Power

	Constellation ($2006)	**U Chicago** ($2003)	**MIT** ($2002)	**Harding** ($2007)
Levelized Cost	3.7¢ per kWh - 8.0¢ per kWh	4.7¢ per kWh - 7.1¢ per kWh	6.7¢ per kWh -7.5¢ per kWh	7.8¢ per kWh - 9.8¢ per kWh
Assumptions:				
Overnight Construction Costs	$1,935 per kWe	$1,200-$1,800 per kWe	$2,000 per kWe	$3,200 per kWe- $4,000 per kWe
Plant Life, years	Unspecified	40	40	Unspecified
Capacity Factor	95.3 percent	85 percent	75 - 85 percent	75 - 90 percent
Construction Time	5-6 years	5-7 years	5 years	5-6 years
O&M Costs	0.5¢ per kWh (inc. fuel)	~1.0¢ per kWh	1.5¢ per kWh (inc. fuel)	Unspecified
Fuel Costs	Included in O&M costs	0.44 ¢ per kWh	Included in O&M costs	Unspecified (low case); 2-4x early 2007 prices (high case)
Debt/Equity	80/20 with fed. loan guarantees (low case) 50/50 without loan guarantees (high case)	50/50	50/50	50/50
Cost of Debt/Equity	5.5 percent/ 18 percent (low) 12 percent/ 18 percent (high)	10 percent/ 15 percent	8 percent/ 15 percent	Unspecified
Escalation During Construction	4 percent real	Unspecified	Unspecified	0 - 4 percent real
Production Tax Credits	1.1¢ per kWh (low); None (high)	None	None	None

Source: (MIT 2003, pp.42-23; Turnage 2007, pp.42-46; University of Chicago 2004, pp.5-17 – 5-23)

International Experience

The construction costs of nuclear power plants recently built in Asia range from $1,790 to $2,800 per kWe, as shown in Table 27. However, caution should be employed when making use of these cost estimates, due to "[d]ifferences in the relative costs of local resources and construction technologies, government regulations, labor productivity, and the fact that a large fraction of nuclear power plant costs depend on local labor and construction resources and are not tradable across countries" (MIT 2003, p.141).

The 1,600 MW Olkiluoto-3 plant that is currently under construction in Finland may provide a better cost model for U.S. plants than the Asian plants because European regulations and cost structures more closely resemble those in the U.S. Siemens and AREVA initially agreed to build the plant for $4 billion, or $2,500 per kWe, but estimates of cost overruns are approaching $1 billion and construction is now expected to continue for 18 months past its original mid-2009 deadline (Wall Street Journal 2007c). Moreover, these numbers do not include the 1.5-2 billion euros ($1.92-$2.56 billion) that reactor builder AREVA has separately agreed to devote to the project, and, according to the UK Sustainable Development Commission (SDC), they are also "clouded by hidden subsidies" (Wall Street Journal 2007a; NRDC 2007, p.3; UK SDC 2006c, p.10).

Table 27: Asian Power Plant Overnight Construction Costs

	Location	**Commercial Operation Date**	**Overnight** (in $2002)
Genkai 3 (pressurized water reactor (PWR))	Japan	1994	$2,818 per kWe
Genkai 4 (PWR)	Japan	1997	$2,288 per kWe
Onagawa 3 (boiling water reactor (BWR))	Japan	2002	$2,409 per kWe
Kashiwazaki-Kariwa 6 (ABWR)	Japan	1996	$2,020 per kWe
Kashiwazaki-Kariwa 7 (ABWR)	Japan	1997	$1,790 per kWe
Yonggwang 5 and 6	South Korea	2002	$1,800 per kWe

Source: (MIT 2003, pp.141-142)

The UK SDC evaluated the available information on the cost to build new nuclear power plants and concluded that "attempts to estimate the cost of a new nuclear programme are unlikely to be accurate…because there is not enough reliable, independent and up-to-date information available on the nuclear power plant designs" and because waste and decommissioning costs are not yet fully known (UK SDC 2006c, p.9). They also noted that costs to the public are typically excluded from construction cost estimates. These include (UK SDC 2006c, p.10):

- The risk that companies “may be willing to take on higher levels of risk than otherwise under the expectation that the Government would be unwilling or unable to let the project or enterprise fail.” If this should occur, the risk of high construction costs and long-term delays are shifted from ratepayers/investors to taxpayers. (This is known as moral hazard.)
- The risk that taxpayers will be required to step in if a company has set aside insufficient funds for waste disposal and decommissioning
- Externalities, such as safety and security arrangements, limited liability guarantees, health issues, complex licensing and planning arrangements, and the cost of possible foreign policy interventions in securing access to uranium

The UK SDC concluded that, in light of a history of cost overruns, the “burden of proof would now seem to be on the nuclear industry to show that updated designs, combined with private sector financing and project management, could lead to a different outcome. However, this must take place on a truly equal and transparent basis, so that costs are internalized and the taxpayer is protected from long-term liabilities. An assessment of the cost—and public acceptance—of nuclear waste policy is essential for this to take place” (UK SDC 2006c, p.13).

Credit Implications of Nuclear Power Development

Nuclear power plants are inherently risky investments because they are capital intensive. According to the credit agency Standard & Poors (S&P), the $1.5 to $2 billion capital cost of a single plant can be equal to as much as 5 percent to 10 percent of a large utility’s total capital (S&P 2007, p.6). Nuclear power plants also bear unique risks that other power plants do not, including the potential for incurring large and unexpected costs associated with accumulating spent fuel, severe accidents, and decommissioning. Accordingly, “nuclear plant ownership tends to be less supportive of credit quality because it introduces added levels of operating, regulatory, and environmental risk to a business profile” (S&P 2006b, p.1). Utilities and companies planning to invest in nuclear power must be aware of how such investments could affect their credit ratings.

The list of possible risks associated with nuclear power is lengthy. An executive with Constellation Energy, a company that has expressed an interest in building new nuclear power plants, identified 23 risks of nuclear power (Turnage 2007, p.18). He classified 13 of these risks as current risks that are effectively managed or mitigated. These include security, public support, nuclear fuel supply, and NRC engagement. He classified six of these risks as having emergent issues requiring elevated attention. These risks relate to spent fuel storage, obtaining long-lead materials, financing, transmission constraints, qualified labor pool, and securing equity partners. He classified the final four risks as those that require the highest level of vigilance. These relate to market risks, regulatory/ratemaking, construction management, and capital costs. Since many reactor components are being purchased from overseas, U.S. nuclear power plant developers also face exchange rate risks, as a weakening of the dollar would increase the cost of these purchases.

S&P considers nuclear power plant construction to pose greater risks than nuclear power plant operations. According to S&P, "[once] a plant is in service, the ability to operate the plant in a reliable manner, with high capacity utilization and availability, will allay, but not eliminate, the inherently higher operating risk" (S&P 2007, p.8). Yet, operating a nuclear power plant entails more risk than operating a coal-fired plant. "This is because operational problems at nuclear plants can cause damage that can be far more catastrophic than comparable damage at a coal-fired facility" (S&P 2007, p.9). During a 2005 workshop on issues concerning nuclear power, Peter Bradford illustrated this point, recalling that "private investors saw [the Three Mile Island nuclear power plant] transform from a $2 billion asset to a $1 billion clean up job in about 90 minutes" (Bradford 2005, p.273).

The risks and therefore the credit implications of investing in nuclear power are different for regulated utilities and for unregulated merchant generators. Support from regulators for a utility's investment can give confidence to creditors and credit rating agencies. "Ongoing regulatory support combined with a disciplined and tightly monitored construction schedule will provide the necessary assistance and confidence to allow a utility's credit profile to withstand moderate weakness in credit metrics without leading to lower rating" (S&P 2007, p.9). In evaluating the extent of regulatory support, S&P considers whether the utility is allowed to recover construction costs prior to the start of the plant's operation: "[until] the plant goes into service, the recovery of all or a majority of financing costs in rates, such as construction work in progress (CWIP) would not only demonstrate regulatory support and a willingness to provide ongoing support in the future, but also ensure that a utility's cash generation does not suffer" (S&P 2007, p.6).

Merchant generators are at greater risk during construction, since they typically are unable to recover costs until the plant is generating power, and they often need to capitalize their financing costs. In addition, investors pay all development costs associated with licensing, site studies, and engineering studies and bear all "construction cost, operating performance, fuel price, and wholesale power market risks, as well as residual regulatory risks associated with a restructuring and deregulation process that is still a work in progress" (CEEPR 2006, p.9). In light of this risk, S&P emphasized the importance of a strong balance sheet for merchant generators to maintain credit ratings during construction of a nuclear reactor and encouraged these generators to enter into well-structured purchased-power agreements with creditworthy counterparties to "eliminate most of the volatility during construction" (S&P 2007, p.9).

Risk Mitigation

Effective risk mitigation depends on a fundamental principle: risks should be allocated to those most able to manage them. George Schaefer of General Electric Credit Corporation provided an overview of how this principle can be implemented (Weedall, et. al. 1986, p.217):

> The basic tenet of any risk containment strategy is to identify, quantify, and allocate risks to the participant that can best assess and control them. For example, the engineering firm should guarantee the design of the project, the general contractor should absorb the construction risks, the equipment vendors should bear the risks for the equipment performance, the project operator should bear the O&M risks and the financier should absorb the risks of changes in the financial market. The host facility should be responsible for the consequences of changes in the operation of the specific facility.

Risk management strategies may be particularly important for utilities or merchant generators that are developing nuclear power plants, since the development risks are many and large. They can roughly be divided into two categories: regulatory and legislative strategies and financial and operational strategies.

Legislative and Regulatory Strategies

Legislative acts and regulations can reduce a developer's risk by shifting the risk to other parties. For example, the federal government included incentives for nuclear power plant development in EPAct 2005 that shift risk to taxpayers. Several states have passed or are considering legislation or regulations that would provide greater assurance of cost-recovery to nuclear developers by shifting risk to ratepayers. However, some of these incentives apply only to a limited number of reactors, and most of the regulations stop short of providing complete cost-recovery assurance.

EPAct 2005 Incentives

EPAct 2005 includes three new programs to help utilities and developers finance new nuclear reactors. These programs are intended to reduce the uncertainties and risks associated with developing and investing in advanced nuclear power plants in the U.S. The three programs offer loan guarantees for reactor construction, risk insurance to cover regulatory or construction delays, and a production tax credit for generation from new reactors.

Loan Guarantee Program

Title XVII of the EPAct authorizes DOE to administer a loan guarantee program for commercial projects that "avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases and employ new or significantly improved technologies as compared to technologies in service in the United States at the time the guarantee is issued" (EPAct 2005). Eligible technologies include renewable energy systems, advanced fossil energy technology, hydrogen fuel cell technology, advanced nuclear energy facilities, carbon capture and sequestration practices and technologies, efficient electrical generation, transmission, and distribution technologies, efficient end-use energy technologies, production facilities for fuel efficient vehicles, pollution control equipment, and refineries.

The loan guarantee program could substantially affect the economics of new nuclear projects. Loan guarantees may enable lenders to offer loans at lower interest rates since the loan guarantee ensures the lender will be reimbursed in case of default. Also, loan guarantees shift some of the project risk to the guarantor, which may allow some projects to use a larger share of debt financing, rather than equity. (The average cost of capital for a project can be reduced by substituting debt for equity up to a certain point.) EIA examined the potential impacts of DOE's loan guarantee program on the economics of nuclear power projects. EIA found that DOE's loan guarantee program could reduce the levelized cost of generation for a nuclear power project by 25 percent (EIA 2007, p.50). Similarly, Constellation Energy estimated that the *combined* incentives provided through EPAct to new nuclear power plants could reduce the required market clearing price from as much as $80 per MWh to a low of $37 per MWh (Turnage 2007, p.48). According to Constellation Energy, if a new nuclear power plant must earn $80 per MWh in order to be built, no new plants will be built.

In May 2007 DOE issued proposed policies and procedures for the EPAct loan guarantee program (DOE 2007l, p.27471). Under the proposed policies, eligible loan guarantees will be limited to 90 percent of the total face value of any single debt instrument and 80 percent of the total project cost. [87] In addition, applicants must have a significant financial commitment to the project and are dissuaded from seeking multiple forms of federal financial assistance. "Nonetheless, the receipt of other forms of assistance will not disqualify a project from being eligible for a DOE loan guarantee, and DOE furthermore recognizes that in some situations--such as, for example, with respect to the first new nuclear generating facilities…multiple forms of federal assistance to the same project could advance important national energy policy priorities" (DOE 2007l, p.27476).

The proposed policies also set forth the fees that will be required of applicants. The fees address two types of costs: subsidy costs, which represent the federal government's expected liability from issuing loan guarantees (due to expected loan defaults), and administrative costs, which include costs to review applications and administer the loans (DOE 2007l, p.27475). The U.S. Government Accountability Office (GAO) warned that estimating the subsidy cost "could be difficult because the program targets innovative energy technologies, and loan performance could depend heavily on future economic conditions, including energy prices, which are hard to predict accurately" (GAO 2007, p.3). DOE did not specify in its proposed policies how it plans to calculate the subsidy cost.

In August 2006 Energy Secretary Bodman announced the opening of the first solicitation for these loan guarantees. In March 2007 DOE announced that 143 projects had submitted pre-applications for more than $27 billion in loan guarantees.

[87] This is a change from DOE's August 2006 proposal to limit a loan guarantee to 80 percent of the total face value of any single debt instrument. The August proposal was criticized as "significantly [eroding] the value of the loan guarantees" (NEI 2006b).

This is substantially more than the $4 billion in loan guarantees that DOE has authority to grant under current Congressional appropriations.[88]

Advanced nuclear projects, while eligible for the loan guarantee program, were not permitted to submit an application for this first cycle (DOE 2006n, pp.2, 4). According to DOE, the debt guarantee for a single nuclear project would likely be substantial and could prevent the program from making multiple guarantees in the initial round of funding. DOE's FY 2008 budget proposal includes $4 billion in loan guarantees for central power generation facilities, including nuclear power plants (DOE 2007l, p.27472).

Regulatory Risk Insurance

Title VI, Section 638 of EPAct creates a standby support program for the first six advanced nuclear power facilities to be constructed in the U.S. The program is a form of insurance against risks project developers may face as early adopters. It provides protection against NRC-related delays in reviewing and approving applications and litigation-related delays. It does not provide protection against normal business risk, such as employment strikes and weather delays, or delays that could have been prevented by the project sponsor, such as PG&E's errors during the construction of Diablo Canyon. Final program rules were adopted in August 2006 (DOE 2004a).

EPAct 2005 allocates up to $2 billion to cover the full cost of eligible delays for the first two nuclear reactors permitted and under construction (up to $500 million each) and 50 percent of the cost of delays for the next four reactors (up to $250 million each). These six reactors may not utilize more than three reactor designs. Losses eligible for compensation include principal and interest on loans and purchases of replacement power to satisfy contractual obligations.

Production Tax Credit

Title XIII, Section 1306 of EPAct provides a federal tax credit of 1.8 cents per kWh for energy produced at advanced nuclear generation facilities over an 8-year period beginning when the facility is placed into service. This credit is authorized only for the first 6 gigawatts (GW) of new nuclear capacity, which is equivalent to approximately five new reactors. It is to be shared by all plants that have filed an application with the NRC by the end of 2008 and are under construction by January 1, 2014. To be eligible for the credit, the facility must use a reactor design that has been approved by the NRC after 1993, and the facility must be in service prior to 2021. If new capacity exceeds 6 GW, credits will be prorated among all eligible plants.

The production tax credit will be limited to no more than $125 million per GW of allocated capacity per taxable year (IRS 2006). A reactor would receive this

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[88] Congress restricted DOE's ability to use this $4 billion until the agency has issued a final rulemaking establishing the implementation guidelines for the loan guarantee program.

maximum allowance if it obtains a capacity factor of 79 percent. Incentives will also be limited to a total of $750 million per year.

The Internal Revenue Service published interim guidance for claiming this tax credit in May 2006. The Internal Revenue Service and the Treasury Department expect that final regulations will incorporate the rules set forth in the Internal Revenue Service notice (IRS 2006).

State-Level Cost Recovery Assurance

Several states have recently enacted or are considering legislation to support nuclear power development by establishing mechanisms to provide greater assurance of cost recovery. Most of the state-level efforts to reduce the risk of nuclear power development aim to provide a measure of cost recovery assurance to the developer while protecting ratepayers from large cost overruns and imprudent investments. This follows S&P's prescription for supporting credit during nuclear power plant developments. S&P has said that it "does not expect, nor does it espouse, full and unfettered recovery of all requested costs," in evaluating the credit implications of nuclear reactor development activities, but it does look "for a regulatory framework that provides for a fair opportunity to recover prudently incurred costs, even through changing regulatory commissions" (S&P 2007, p.8). The proposals vary in the balance of risk placed on ratepayers and taxpayers. For instance, in addition to the question of CWIP recovery, they differ in whether they will guarantee cost recovery if a plant is ultimately not built. A partial comparison of these proposals is provided in Table 28.

Table 28: Comparison of Nuclear Legislation and Regulations[89]

Issue	Florida	Georgia	North Carolina	South Carolina	Louisiana
Allows recovery of pre-construction investments prior to commercial operation	Yes	No	To be determined	No	Yes
Allows recovery of cancelled plants	Yes	Yes	Not applicable	Yes	Not applicable
Cash earnings on CWIP	Yes	No	To be determined	No	Yes
Cost subject to prudence review	Yes	Yes	Yes	Yes	Yes

A critical decision regulators must make with regard to cost recovery is whether to permit the recovery of CWIP. The importance of CWIP recovery to utilities was underscored by S&P when it stated that nuclear developers could reduce their risk by building plants in states where mechanisms exist for utilities to recover CWIP (Barber 2006). California does not allow CWIP recovery; however, several other states do.

[89] Louisiana Public Service Commission, Staff Report, Docket No. R-29712, March 14, 2007, p.15

California

California has a long-standing policy prohibiting recovery of CWIP and does not authorize rate recovery for a power plant's construction costs until the plant has begun to operate. As the CPUC explained in August 1980, "the investor is compensated when the demonstration phase is concluded and the plant is included in rate base at which time it can earn a rate of return. The cost of any deferred money used during the demonstration period but collected afterwards is accounted for through the addition of [allowance for funds used during construction] to the investment. In this way, the financial burden is shifted from present ratepayers to future ratepayers to account for the entry of the plant facilities into regular utility service at a future date" (CPUC 1980a).[90] Moreover, in the event that the plant is not built, the utility is not guaranteed recovery of construction costs or allowance for funds used during construction.

SDG&E ran up against these policies in the late 1970s with regard to its proposed Sundesert nuclear project. In seeking to establish financing for the project, SDG&E requested CWIP recovery from the CPUC but was denied (Wellock 1998, p.192). Later, after SDG&E had abandoned the project, it requested recovery of its allowance for funds used during construction costs. The CPUC again denied SDG&E's request. The CPUC explained, (CPUC 1979)

> After due consideration we will adhere to our long-standing policy on allowance for funds used during construction by disallowing allowance for funds used during construction accumulated in connection with the Sundesert project as a recoverable expense for SDG&E. It would be inappropriate and unreasonable for the investors to realize a capitalized return on funds invested to date on this uncertificated and now indefinitely deferred proposed project. Allowance for funds during construction covers the investors' risk when a project is undertaken and carried through to completion. When a proposed project is terminated, and siting and site-related costs are included in plant held for future use and/or amortized, it is proper to exclude the allowance for funds used during construction allowance for investor risk because the project did not come to fruition.
>
> Considerations of equity also strongly support the disallowance of accumulated Sundesert allowance for funds used during construction. While recognizing that SDG&E's promotion and development of the Sundesert project was not imprudent, the commission finds itself neither disposed nor entitled to shield the utility's investors from all risk associated with its new plant investments. Ratepayers ought not to bear the entire burden of a failed project, and certainly not to the extent of providing a return on funds invested therein.

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[90] See also (CPUC 1976a; CPUC 1976b; CPUC 1977) as cited in (CPUC 1980b)

PG&E ran up against these policies a few years later when it requested CWIP recovery to ease the financial burden of the carrying costs of Diablo Canyon and other large construction projects. The CPUC acknowledged PG&E's constrained financial position and increased its rate of return on equity but rejected "PG&E's proposals for various ratemaking changes such as allowance of CWIP in rate base and changed depreciation policies that many other state regulatory commissions permit…which reduce risk to the utility by shifting it to the ratepayers." The CPUC explained, "[we] <u>do not and have never permitted</u> such [CWIP] to go into rate base, and we reject that concept again today" (emphasis added) (CPUC 1981, p.4).

Florida

In February 2007 the Florida Public Service Commission (PSC) adopted a rule that allows Florida utilities to recover prudently incurred site-selection costs and pre-construction costs and to receive cash earnings on CWIP throughout construction if the Florida PSC determines a need for a new nuclear power plant. In addition, once costs have been deemed reasonable they will not be subject to disallowance or further prudence review even if the plant is not ultimately constructed (FL Administrative Code 25-6.0423; FL PSC 2007).

Georgia

In March 2006 the Georgia legislature passed a resolution resolving that "the Public Service Commission is urged to take appropriate measures to encourage Georgia utilities to consider building nuclear power plants and to encourage utilities to take reasonable steps to maintain the nuclear generation option in Georgia" (GA 2006).

The Georgia PSC responded in June 2006, when it approved Georgia Power Company's request to record for future rate recovery up to $51 million in costs (plus carrying costs) that are incurred while obtaining an early site permit and/or combined construction and operating license for a new nuclear power plant (GA PSC 2006). However, the PSC did not guarantee that these funds would be recovered (GA PSC 2006). Rather, according to the PSC ruling, if the NRC licenses a plant, prudently incurred costs will be transferred to the account that tracks construction work in progress; otherwise, potential cost recovery will be reviewed following the cessation of work on the project.

North Carolina

In September 2006 Duke requested from the North Carolina Utilities Commission that it be allowed to recover the North Carolina portion of costs incurred through the end of 2007 for the development of new nuclear generation "whether or not a new nuclear facility is constructed" (NCUC 2007, p.2). The North Carolina Utilities Commission provided Duke general assurance that its activities in assessing the development of new nuclear generation are appropriate. However, it deferred decisions on rate recovery to future proceedings (NCUC 2007, pp.22-23).

South Carolina

The Governor of South Carolina signed legislation in May 2006 that permits the South Carolina Public Service Authority to jointly own with a private entity any new nuclear generating units to be built at or near the site of the existing V.C. Summer nuclear power plant in South Carolina (SC 2006). In February 2007 a bill was introduced in the House that would allow the recovery of costs incurred to develop and construct new base load plants, including nuclear power plants.

Louisiana

In May 2007, the Louisiana PSC passed a rule allowing the costs from new nuclear power plant construction to be recovered before the plants begin operation if the plant owner proves that cost recovery is in the public interest (Times-Picayune 2007). The rule makes construction costs the easiest to recover but also allows for the possibility of reimbursement for site selection, licensing, design and development costs (Forbes 2007).

Texas

In January 2007 the Public Utility Commission of Texas found that it would be difficult for an unregulated power generation company to satisfy the NRC's decommissioning funding requirements without the ability to impose a non-bypassable charge on ratepayers (TX PUC 2007, p.100-102). In response, the Texas House of Representatives passed a bill in April 2007 that would require nuclear power plant owners to pay into a nuclear decommissioning trust fund. Retail customers would be responsible for paying into this fund only if there are insufficient funds to cover costs at the time of decommissioning or if the power plant owner does not remit the required funding. In the latter case, the Public Utility Commission of Texas would be allowed to terminate the power generation company's registration (TX 2007).

Financial and Operational Strategies

In addition to risk-sharing with taxpayers and ratepayers, nuclear power plant developers have many options to mitigate their risks through financial and operational strategies. Examples of financial and operational risk mitigation options include the following:

- Engineering, procurement, and construction (EPC) contracts with vendors and construction companies
- Forward contracts for power sales
- Turnkey projects with vendors
- Utilization of standard reactor designs
- Joint development and financing of projects

Turnkey projects were common in the early days of nuclear power commercialization, when General Electric and Westinghouse offered turnkey projects to “overcome the reluctance of utilities to accept the financial risks associated with the new technologies” (Perry 1977, p.30). However, vendors lost an estimated $875 million to $1 billion (nominal dollars) on 13 turnkey plants, and by 1968 they had stopped offering turnkey contracts.[91] From that point on, utilities purchasing reactors were forced “to absorb whatever unanticipated cost increases the construction process brought on” (Perry 1977, p.37). Looking ahead, it remains to be seen how much risk the nuclear power plant vendors will be willing to absorb in new reactor builds.

Utilities and merchant generators can also mitigate their risks by relying on standardized reactor designs and economies of scales and by joining with other partners. These are some of the strategies that Constellation Energy is employing in planning its new nuclear power plants (Turnage 2007, p.19). For example, Constellation elected to build a reactor of the same type that is under construction in Finland. Moreover, while Constellation is primarily interested in just one new reactor, it is planning on building a four-plant fleet of identical reactors and selling the other reactors or the power from the other reactors (Turnage 2007, pp.24, 38).

Constellation is also securing long-lead materials, investigating financing options, and characterizing reactor sites, so that the “level of uncertainty will be reduced to an acceptable level of risk prior to making a Go/No Go decision on committing to construction” (Turnage 2007, p.40). In addition, Constellation has established pre-defined exit ramps and will make a final decision on whether to pursue the plants only after obtaining conditional financing, regulatory certainty, and certainty over the level of EPAct incentives (Turnage 2007, p.27).

NRG Energy is emphasizing similar risk management strategies in planning for its nuclear reactor. NRG is also looking for joint development and financing opportunities and has selected a reactor design that is NRC-certified and which has already been built in Japan (NRG 2006, pp.12, 15). In addition, NRG is focusing its early expenditures on salable assets so that it can reduce its involvement or sell its investment, should the company decide not to build the plant. For example, NRG expects that it would be able to sell all, or shares of, its NRC license development activities or its NRC license prior to the plant’s construction (NRG 2006, p.14). It also expects that it would be able to sell long-lead materials that it has purchased on a secondary market (NRG 2006, p.28).

However, even with these risk management strategies, significant risk remains. For instance, the ability to sell a reactor license or reactor construction materials depends on whether other companies are interested in building new reactors. Should federal subsidies for new nuclear power plants be scaled back, the cost of alternative generation options fall, or public opposition prevents the siting of new

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[91] SONGS Unit 1 was the only one of the turnkey projects that came in approximately on budget. This is because its initial cost estimate was about twice as large per kW as the cost estimates for the other plants that were developed at that time (Perry 1977, p.35).

reactors, the market for new reactors in the U.S. could quickly dry up and the secondary market for reactor parts could become saturated. In addition, some of these strategies may be difficult to carry out. For example, Joskow warns that “it is unlikely that the long-term contractual arrangements that the owner of the new nuclear power plant in Finland has with large buyers of the power supporting the project could be replicated widely in those areas of the U.S. that rely on competitive wholesale and retail electricity markets (CEEPR 2006, p.9).

Moreover, risk-sharing agreements with contractors and vendors are limited by the strengths of the contracts and by the ability of these entities to pay. For example, many contractors are not able to pay more than the liquidated damages designated by their contracts, and even these amounts need to be supported by a letter of credit or a bond and can at times be difficult to collect. These limitations have been exposed in a number of recent power plant construction projects that have suffered from equipment malfunctions. For example:

- The Milford combined-cycle power plant was scheduled to start operating in 2001 (Megawatt Daily 2003). However, faulty turbines and other difficulties delayed the construction for several years. In 2002 and 2003, El Paso Corporation lost $110 million from its investment in the plant, and in December 2003 El Paso transferred its 95 percent ownership share to its lender in order to terminate all of its obligations associated with the plant (El Paso 2004, p.160). The construction contractor paid only $18 million in liquidated damages and supplied a $10 million credit to be applied to future services (El Paso 2003, p.46).
- Around 2002 the construction contractor for the Berkshire power plant in Massachusetts “failed to deliver a plant capable of operating on both gas and fuel oil, or capable of operating at its designed capacity.” The contractor paid no cash in damages but provided a $6 million credit to be applied to future services and agreed to perform plant upgrades at no charge (El Paso 2003, p.46).
- Turbine vibration and damage at Japan’s Chubu Electric Power’s ABWR nuclear reactor caused the plant to shut down for nine months (Chubu Electric Power 2006; Chubu Electric Power 2007).The company has considered suing the turbine manufacturer for its replacement power costs, which exceeded $870 million during the first six weeks of the outage. Hideki Aoki of the Japan Federation of Bar Association noted that the insurance held by the manufacturer, Hitachi, might not cover these losses: “If Hitachi turbines were not designed to withstand earthquake shocks, and that caused the cracks and vibrations, then insurers could argue this constitutes gross negligence and refuse to pay" (Reuters 2006).It is unclear whether the turbines should have been designed to withstand the vibrations (which were caused by a mechanical failure, not an earthquake) and whether Hitachi would be able to pay for damages should they not be covered by Hitachi’s insurance.

For utilities seeking power purchase agreements with power plant developers, another financial mitigation strategy is available: collateral requirements. However, as will be discussed, these requirements come with their own costs and risks.

The risk to a utility in signing a power purchase agreement with the developer of any large power plant is significant: 20 percent to 30 percent of all large power procurement efforts experience contract failure nationwide. Moreover, 50 percent or more of large power procurement efforts face failure where there are siting, permitting, and resource supply barriers to development, as might be expected for new nuclear power plant siting cases in California (Energy Commission 2007a, p.4).In addition, power purchase agreements can be more expensive for utilities than equivalent utility-owned projects, since these agreements can be considered equivalent to debt from a credit standpoint. For capital-intensive nuclear power projects with a power purchase agreement, the utility typically would take on large fixed payment obligations over the term of the agreement that are similar to the utility's long-term debt obligations. To the extent that some or all of the fixed payment obligations in a power purchase agreement are viewed as debt-equivalent, a significant amount of “compensating equity” (together with a reduction in actual debt) could be required for the power purchaser to maintain its capital structure, increasing its overall cost of capital and creating costs for the utility that are in addition to the cost of the power purchase agreement itself.

In order to mitigate these risks, many utilities require merchant generators to put down collateral against the possibility that the project is not completed on time. For example, the collateral required by California utilities from respondents to their 2006 renewable power requests for offer (RFO) is shown in Table 29. At these rates, for a 1,000 MW reactor, PG&E and SCE would require a $3 million bid deposit at the time the project was short-listed, $20 million in development security when the project had obtained CPUC approval, and operating collateral of 12 months revenue at the start of commercial operations.

Table 29: California Utilities’ Collateral Requirements

	PG&E, SCE *2006 Renewable Request for Offers*	**SDG&E** *2006 Renewable Request for Offers*
Bid Deposit	$3 per kW at short-list	None
Development Security	$20 per kW	$10 per MWh
Operating Collateral	12 Months Revenue	$30 per MWh

Source: (Energy Commission 2006c)

These credit requirements are costly. Black & Veatch estimated that the requirements of the California utilities, which are among the highest in the nation, amount to roughly 2 percent of the project cost (Energy Commission 2007a, p.13, 16).This cost adds risk to the project. As Steve Zaminski of Starwood Energy Group explained, “excessive credit requirements have the unintended side effect of making projects more susceptible to failure by increasing the financial risks for developers (Energy Commission 2007a, p.13).In other words, by providing the utilities with greater financial assurance, the collateral requirements increase the overall project cost and the risk of project failure.

Conclusion

Estimates for the costs of new nuclear power plants are wide-ranging. On the one hand, there is concern that new reactor developers could face extreme cost overruns comparable to those experienced in the 1980s and 1990s, especially since no reactors have been built in the U.S. since that time. On the other hand, there is optimism that new technologies, federal subsidies, standardized reactor designs, and revised NRC licensing procedures will keep developers' costs down, especially given that the financial climate today is much better for large investments than the period of 14 percent inflation and 21 percent interest rates ("the maximum we have ever experienced in modern U.S. history") during which most of the current fleet of reactors was constructed (Energy Commission 2005e, p.143). The cost of the reactor being built in Finland, which can be expected to have similar costs to a new U.S. reactor, is difficult to assess, given the many hidden subsidies involved.

Given these uncertainties, Dr. Paul L. Joskow, Director of the MIT Center for Energy and Environmental Policy Research, has expressed guarded optimism about the future of nuclear power.[92] He concluded a December 2006 paper by noting that the "future for investment in new nuclear plants in the U.S. is brighter than it has been for many years;" however, "investment in new nuclear plants is likely to proceed more slowly than may be implied by the recent euphoria in the industry" (CEEPR 2006, p.19).

Companies considering nuclear power development are likewise remaining cautious, and they are focusing on risk mitigation strategies to contain their costs. Strategies include forming partnerships, entering into risk-sharing contracts with vendors and contractors, and obtaining cost-recovery assurance from regulators. Most regulators that have faced requests in recent years for nuclear power development cost-recovery assurance have provided only limited assurance.

The success of risk mitigation strategies in containing a utility or merchant generator's nuclear reactor construction costs will likely be key in determining whether or not a significant number of new reactors are built. While federal EPAct incentives have fueled strong interest for NRC licenses, it remains to be seen whether this interest will be translated into new reactor development. Indeed, some developers are pursuing these licenses as salable assets that provide the options to build, rather than as commitments to build.

[92] Dr. Joskow is also Elizabeth and James Killian Professor of Economics and Management at MIT.

CHAPTER 8: COST IMPLICATIONS OF A “NUCLEAR RENAISSANCE”

Revival of interest in nuclear generation is sometimes referred to as a “nuclear renaissance.” Such a “renaissance” may pose cost implications for utilities that own nuclear power plants even if they do not build new reactors.

Prices for nuclear fuel have already risen sharply in anticipation of a large worldwide increase in demand. There are concerns over temporary fuel shortages should demand increase rapidly, as uranium supplies and enrichment capability have not been developed to meet the demands of a rapidly growing nuclear industry. In addition, the location of both uranium ore and existing enrichment capacity raises questions of availability to U.S. nuclear operators.

There are also concerns over shortages in reactor materials and skilled nuclear operators and engineers. These shortages could impact utilities seeking to replace reactor components or a retiring workforce. They could also slow down new nuclear development.

This chapter discusses these three potential impacts of new nuclear power development.[93] The chapter begins with an evaluation of the nuclear fuel supply and demand balance and the impact of potential shortages or price increases on U.S. nuclear power plant operators. It then discusses the potential for shortages of reactor materials and the potential for shortages of trained workers to operate the nuclear power plants.

Fuel Supply and Cost Issues

Over the past five and a half years, uranium spot prices have increased more than ten-fold, from less than $10 per lb of uranium oxide in December 2001 to $135 per lb of uranium oxide in June 2007 (Ux Consulting 2006, p.4; Ux Consulting 2007b).Much of this increase has occurred over the past two and a half years (Ux Consulting 2007a).Enrichment prices have also increased during this period, from $99 per separative work unit (SWU) for enrichment services in December 2001 to $139 per SWU in June 2007 (Ux Consulting 2007a).

These prices are still well below their (inflation-adjusted) historic highs of $120 per pound of uranium and over $200 per SWU for enrichment services, which occurred in the 1970s.[94] (NER 2006, p.44) Moreover, because most uranium is procured via

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[93] An increase in the number of operating nuclear reactors could also increase the likelihood of a major accident or incident at a U.S. nuclear power plant. Due to the mutual insurance obligations of the owners of nuclear power plants, an accident at any one plant could create significant costs for all plants. The impacts of an accident at a U.S. nuclear power plant are discussed further in the *2005 Status Report*.

[94]Adjusted to 2006 dollars.

medium and long-term contracts, the volume of uranium sales represented by these spot prices comprises less than 20 percent of the uranium market (NY Times 2007a).Still, the sudden price increases have raised concerns about the availability of uranium to fuel an expansion of nuclear power.

Historical Uranium Prices

The history of uranium mining is a rollercoaster of dramatic swings in price and production. A1977 RAND study noted that in “the 1960s uranium was so abundant that the federal government had to subsidize its price to maintain production; in the 1970s the supply was so uncertain that the prospect of future shortages was the chief justification for a breeder reactor development program that promised to cost some $200 billion” (Perry 1977, p.vii).

In the 1980s and 1990s uranium prices again fell sharply. The depressed prices resulted in large part from the liquidation of excess government uranium inventories, primarily from decommissioned U.S. and Soviet weapons, and the reduced demand for new reactors following the Three Mile Island accident. In addition, low uranium prices encouraged utilities to liquidate their inventories to save on storage costs, further depressing prices (NER 2006, p.41; Greenwire 2007d).

Drivers of Supply and Demand in the Current Market

The primary source of the recent increases in the prices for uranium and enrichment services is the near-term tightening of supply due to underinvestment and contraction in mining and enrichment capacity during the 1980s and 1990s when prices were depressed. As excess supplies have decreased and talk of a nuclear renaissance has begun to spread, the industry has found itself unprepared to meet the potential surge in demand (NY Times 2007a).This demand is being fueled in part by large nuclear programs announced by China, Russia, and India and has been exacerbated by the lack of success that these countries have had in developing new uranium mines. The supply crunch has been exacerbated by a number of recent disasters at mines and conversion plants (Nuclear Energy 2006, pp.1-2).

In addition, hedge funds and other institutional investors entered the market in late 2004 and have since purchased about 20 million pounds of uranium yellowcake, representing about 20 percent of the supply being mined each year. According to Ux Consulting, the funds are withholding most of this stock from the market as they wait for prices to rise, and they have sold only about 2 million pounds of stock so far (Wall Street Journal 2007b).

Analysts agree that there are enough uranium reserves in the ground to meet market demand and that current prices will encourage investment in mining capacity, which will ultimately drive prices back down. However, in the near term, mined uranium may be in short supply. As explained by Matthew Bunn of Harvard,

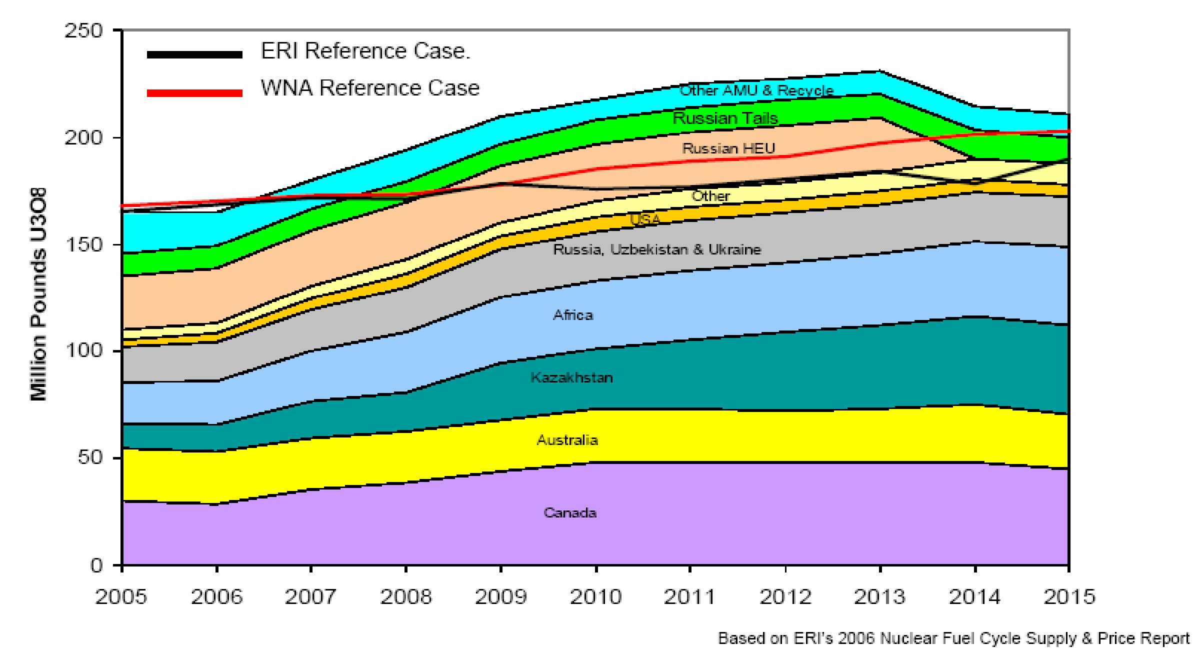
> The current run-up in uranium prices has nothing to do with a lack of resources in the ground, but only with constraints on bringing on new

production to exploit those resources to meet market demand. At a current price of over $100 per kgU, producers able to provide supply at costs of less than $40 per kgU are making immense profits; market players, seeing those profits, will attempt to bring additional supply on-line, ultimately bringing demand and supply into better balance and driving prices down. This will be difficult to do quickly, because of regulatory and political constraints in uranium-producing countries. But it would be surprising indeed if the price remained far above the cost of production for decades" (Bunn 2006).

Outlook for U.S. Nuclear Power Plant Operators

The U.S. is expected to face stiff global competition for nuclear fuel in the near term. As businessman Jack Edlow points, "[w]e import two-thirds of our oil, but 90 percent of our uranium" (NY Times 2007b). Figure 22 shows the expected global uranium supply-demand balance through 2015. Through mid-2013, one of the major sources of uranium is expected to be Russian highly enriched uranium from the U.S.-Russia highly enriched uranium Agreement of 1993. Approximately half of the fuel supply for U.S. reactors comes from Russian highly enriched uranium as a result of this agreement, and it is uncertain whether the agreement will be extended after contracted inventories are depleted in 2013 (Merrill Lynch 2005, p.8; Greenwire 2007d).As shown in Figure 22, without these inventories world uranium supply is expected to fall in 2015 to within about 5 percent to 10 percent of demand, according to demand projections by the World Nuclear Association and Energy Resources International (DOE 2006i, p.6).Some of the drop-off in Russian highly enriched uranium imports could be offset by an increase in the enrichment of Russian uranium tails. However, Russia has reportedly announced that it will cease tails re-enrichment (NER 2006, p.44). Absent Russian highly enriched uranium or Russian tails and absent the development of additional capacity, there could be a shortage of mined uranium to fuel global nuclear growth beginning in 2014 if total worldwide production of nuclear power markedly increases.

Figure 22: Uranium Supply-Demand Balance



Source: (DOE 2006i, p.6)

Moreover, according to Thomas Neff of MIT, there is less global supply of enriched uranium than is commonly projected. This is because the uranium supply-demand balance is generally calculated assuming that uranium will be enriched to a high degree and the enrichment supply-demand balance is generally calculated assuming that the uranium will be enriched to a lower degree. (A higher degree of enrichment extracts more fissile uranium from the ore, which reduces the requirements for uranium ore and increases the requirements for enrichment capacity.) Neff claims that these assumptions lead to an overly-optimistic picture of the supply-demand balance for enriched uranium. Putting the uranium and enrichment supply curves together, Neff has shown that while the potential exists for sufficient uranium and enrichment capacity to meet projected demand in 2015, existing and planned capacity will fall far short of meeting this demand (NER 2006, p.19). He has warned that while "nuclear fuel supply industries may thus be able to expand output enough to fuel existing nuclear power plants, the supply for a wave of new plant orders in a nuclear renaissance will require heroic efforts and, most likely, substantial increases in prices to stimulate the needed investment in the short time available" (NER 2006, p.44). Neff anticipates that there will be sufficient fuel for existing reactors even without an expansion in uranium or enrichment capacity: "It should be noted here that the question is not one of fueling existing reactors—there is likely to be enough supply for that. Rather, the question is whether supply can expand fast enough to fuel new nuclear power plants, and at what price" (NER 2006, p.44).

However, there is not universal agreement that there is reason for concern. The U.S. Department of Commerce and DOE have both concluded that the supply situation for uranium and enrichment services is not as tight as others are claiming.

The Department of Commerce investigated this issue as part of its review of the current restrictions on the import of uranium products and services from Russia. These restrictions were first imposed in 1992 in response to Russian uranium being dumped in the U.S. market at below-production prices. An “Ad Hoc Utility Group,” which reportedly represents 85 percent of the U.S. utilities that produce nuclear power, submitted comments to the Department of Commerce in 2006 contending that worldwide demand for enriched uranium is increasing faster than worldwide supplies, that Russian suppliers are unlikely to redirect substantial quantities of uranium products and services toward the U.S. market, and that they are certainly unlikely to do so at “dumped pricing levels” (Spetrini 2006, pp.5, 8). The U.S. Enrichment Corporation (USEC), which currently has the sole right to import and blend down highly enriched uranium from Russian weapons and which is currently planning a new enrichment plant in the U.S, countered that Russia has “increasing and underutilized production capacity and substantial inventories” and contended that the import restrictions are necessary to stabilize the market and prevent dumping (Spetrini 2006, p.4). In June 2006 the Department of Commerce ruled that the import restrictions should continue. It noted that “Russia is the largest enricher in the world” and that it plans to increase its enrichment capacity by 2010 (Spetrini 2006, p.6). Furthermore, Russia has large inventories and low domestic demand, making it likely that Russia would redirect significant enrichment capacity and uranium products to the U.S. market at low prices in the absence of import restrictions (Spetrini 2006, pp.6, 8).

DOE has similarly concluded that Russia has available uranium and enrichment capacity. According to the Wall Street Journal, Deputy Secretary Clay Sell has said that Russia’s claim that it will cut supplies to the U.S. after 2013 in order to supply its own planned growth in nuclear power is merely bargaining rhetoric. Sell agrees that there are near-term problems for uranium and enrichment services but has said that the overall situation is manageable. He reported that DOE is considering ways to increase the domestic supply of enriched uranium, including blending down highly enriched uranium from retired U.S. nuclear warheads and reprocessing uranium tails (Wall Street Journal 2006).

Yet, the U.S. is not well-positioned to compete for new uranium supplies. For instance, joint ventures between Kazakhstan, a major uranium supplier, and companies from Canada, France, Japan, China, and South Korea are expected to tie up Kazakhstan’s supply for decades to come (Nuclear Energy 2006, p.2). In addition, Russia has already sold out its enrichment capacity and reportedly has ambitions to export large numbers of reactors to China, India, Iran, and other countries, complete with fuel (NER 2006, p.42).

The impact on U.S. utilities of price increases and increased competition for supplies will depend on utilities' inventories and supply contracts. (See Figure 23.) Nationwide, U.S. utilities hold about 15 months worth of uranium requirements in inventory, up from about 10 months worth in 2003 (Nuclear Energy 2006, p.2). They tend to have long-term contracts for both uranium and enrichment; however, many of these contracts come due over the next couple of years and most come due within five years (Harding 2007b, p.13). Some utilities are reportedly seeking supply security by striking deals to purchase uranium at a future date at the prevailing market price on the delivery date (Wall Street Journal 2007b). Utilities now also have the option to purchase uranium on the New York Mercantile Exchange uranium futures market, which began trading in May 2007 (NYMEX 2007). The futures market enables the utilities to secure quantities of uranium for future delivery at a known price.

Figure 23: PG&E Nuclear Fuel Strategy

PG&E is actively working to mitigate the risk of a nuclear fuel shortage. In its long-term procurement plan testimony, PG&E outlined a two-pronged strategy to ensure supply at reasonable prices. First, it plans to work with a nuclear fuel distributor in order "to guarantee supply through a diversity of suppliers." Second, it plans to use a combination of forward- and base-escalation pricing mechanisms in its nuclear fuel supply contracts to "provide a reasonable composite total fuel cost."

PG&E and SCE fuel supply contracts and inventories were discussed further in the Section Nuclear Fuel Costs and Supply.

Source: (PG&E 2007c, pp.IV 16-17)

Expansion of the U.S. Nuclear Fuel Supply

Efforts are underway to expand the supply of nuclear fuel in the U.S. The Ad Hoc Utility Group is lobbying the U.S. government to allow Russia to sell enriched fuel directly to U.S. utilities. This effort is opposed by USEC (Wall Street Journal 2006).

In addition, DOE had the equivalent of 135 million pounds of U_3O_8 (51,980 MTU) in surplus inventory as of the end of May 2006 and has proposed to sell up to 5 million pounds per year to the U.S. industry. This upper sales limit (equivalent to 10 percent of the total annual U.S. nuclear fuel requirement) is intended to limit the impact of these sales on the market price and to prevent underinvestment in capacity (DOE 2006i, pp.9-10). Indeed, DOE has warned that it might not have sufficient uranium in the right form to meet a severe shortage and that its inventories "will not be used to solve strictly commercial shortfalls of supply when market forces can attract more supply. However, in the event that supply is unavailable at any price, we may consider stepping in to resolve a crisis" (DOE 2006b, p.1).

NEI supports DOE's proposal to sell its surplus uranium and has recommended that DOE also establish a strategic nuclear fuel reserve from which industry could borrow to supply the initial measure of uranium needed for new nuclear power plants and to prevent outages in the event of "severe and unexpected disruptions in the commercial nuclear fuel market" (Nuclear Energy Overview 2007). PG&E also supports this proposal, as it "believes that over the course of the next five to seven years, the demand for uranium will continue to outpace the ability of suppliers to produce uranium for the market. Until the supply and inventory levels available for the market are increased to a point of near-equilibrium, there will be the potential for potential uranium shortage over the market. The release of government inventories would assist production to meet demand" (PG&E 2007b, J4).

In addition, there are commercial plans in the works to increase domestic uranium and uranium enrichment capacity:

- Mining companies have begun to buy mineral rights, apply for permits, and begin mining uranium in Texas, Wyoming, Nebraska, and Colorado. Over 3,800 new uranium claims on Colorado federal lands were filed in 2006 and an additional 2,700 claims were filed during the first three months of 2007 (Rocky Mountain News 2006; NY Times 2007a). There has also been interest in mining on Navajo lands, which have been referred to by Mark Pelizza of Uranium Resources, Inc. as the "Saudi Arabia of uranium" (LA Times 2006b). However, the previous uranium mining boom on Navajo land left severe environmental and health damage that the Navajos are still contending with, and in April 2005 the tribal council passed the Diné Natural Resources Protection Act of 2005, which outlawed the mining and processing of uranium on Navajo lands (Navajo Nation Council 2005b).

- In June 2006 the NRC issued a license to Louisiana Energy Services (LES), which is wholly owned by Urenco, to construct and operate a gas centrifuge uranium enrichment facility in Lea County, New Mexico.[95] Construction has begun, and production is scheduled to begin in 2009 (Science 2007, p.1784). At full capacity this facility, called the National Enrichment Facility, is projected to produce 3 million SWU of uranium each year. This is roughly equal to 25 percent of the current U.S. market for low enriched uranium (NRC 2007j).

- USEC, which currently operates the only domestic enrichment facility, was granted a license in February 2004 for a gas centrifuge enrichment demonstration and test plant, which is currently under construction (NRC 2007j; NRC 2007af). The facility had been expected to begin operating in the fall of 2006; however, construction activities have fallen nearly a year behind schedule

[95] LES is wholly owned by Urenco, which is a consortium of British Nuclear Fuels, Ltd., the Dutch government and several German nuclear utilities. Duke Power, Exelon and Entergy had been part of the LES consortium during the license process (National Enrichment Facility 2006). Urenco is a European company that currently supplies over 20 percent of the world's enrichment services (Urenco 2007, p.2).

(Science 2007, p.1782). In April 2007, USEC was granted an additional license to construct a commercial gas centrifuge enrichment plant with a capacity of 3.8 million SWU of uranium per year (NRC 2007j). USEC expects that constructing the facility will cost $2.3 billion, and that the facility will be operating at full capacity in 2012 (NRC 2007j). In February 2007 USEC announced that it will require outside investment or government funding in order to complete the project (USEC 2007b). According to an article in *Science*, most observers do not anticipate that the government will provide funding and some doubt that USEC will be able to gather the financial resources to build the commercial plant. There is also concern over USEC's ability to develop its planned advanced centrifuge technology and over USEC's ability to compete against the LES and General Electric facilities (Science 2007, pp.1782, 1784).

- General Electric Nuclear signed an agreement in early 2006 with Australia's SILEX Systems Limited to license and develop the company's Separation of Isotopes by Laser Excitation (SILEX) enrichment process. According to General Electric, this third-generation enrichment process is more efficient and more cost-effective than either gaseous diffusion or centrifuge enrichment (GE 2006). General Electric plans to begin operating a test loop to demonstrate engineering scale enrichment in November 2007 and to submit a license application for a full-scale facility around December 2007, with approval anticipated in 2009 (NRC 2007t). General Electric has not yet announced the capacity of its planned enrichment facility.

Material Shortages

Developers of new nuclear power plants are also expected to face shortages in key reactor materials, as they compete against other developers for supplies of highly specialized products for which little production capacity remains. These shortages could impact owners of currently operating nuclear power plants, if they need to replace specialized reactor components.

The developers of the Olkiluoto reactor that is currently under construction, have already run into trouble procuring heavy forgings, which are required for making the steel pot that hosts the chain reaction, the pressurizers, the steam generators, and complex pipes. Philippe Knoche, the AREVA project manager, explained that only a handful of factories can supply these parts and that it will be difficult to expand production capacity, because the "know-how is in people's heads and there aren't that many who master the technology" (Wall Street Journal 2007c).

Dale Klein of the NRC has urged nuclear developers to "get in line and scour the globe for available components and materials," because "many of the world's nuclear manufacturers are now operating at capacity, the lead time for delivery of reactor vessels is upwards of four years, and other key components have equally long backlogs (NRC 2007b, pp.2-3).

Developers of wind power have faced a similar situation since 2004. Inconsistent production tax credit policies in the prior years discouraged investments in manufacturing and led to a shortage in wind turbines and other components when demand surged in late 2004. The shortages have reportedly forced some developers to postpone or cancel their projects and are thought to have limited the growth in capacity additions and increased development prices. They have not, however, kept the industry from record growth (EER 2006).

Labor Shortages

Another roadblock that is expected to face operators of new and operating nuclear power plants is a shortage of skilled labor as the current labor force retires. As Tom Christopher of AREVA has warned, “when you look at our age profile, and that of the utilities, and nuclear-related vendors, like architect engineers, you've got an industry that is aging rapidly, whose median age is probably over 50 years old. When you factor in retirements, it's an industry that is going to require 10-20,000 new people over the next four to five years” (EIR 2006).

Dale Klein of the NRC has also cautioned that the kind of growth that is being spoken of “won’t be possible over the long haul unless we address…the need to prepare the next generation of construction workers, engineers, technical workers, and managers.” Klein cited a 2001 nuclear industry survey, which estimated that demand for nuclear engineers and radiation protection professionals would be about 150 percent and 160 percent of supply, respectively, through 2010. Klein then pointed out that this survey “predated the recent movement toward new reactor planning, and I’m told the next industry survey, due out later this year, will show an even more acute shortage of candidates to fill the waiting jobs” (NRC 2007b, pp.2-3).

PG&E and SCE are preparing for their aging workforces by recruiting and training new employees.

- The average age of Diablo Canyon employees is 47.6 years, and in five years, 42 percent of the employees at Diablo Canyon will be eligible for retirement. PG&E requested $3 million in its 2007 rate case to hire and train an additional 37 workers for Diablo Canyon. The California Division of Ratepayer Advocates argued that PG&E should not be awarded funding for a staffing increase, since it had not performed a cost-effectiveness study. The increase ultimately was subsumed into a larger settlement that provided PG&E with $451 million of its requested $457 million for generation O&M expenses.[96]
- SCE requested $5.9 million in its 2006 rate case for additional hiring and training at SONGS to replace workers who will retire through 2008.[97] The CPUC found

[96] PG&E’s award for this expense was included as part of an overall settlement (CPUC 2007b, p.105).

[97] This includes costs that would be allocated to other SONGS co-owners.

that SCE did demonstrate that its workforce is aging but did not fully support its forecasted level of costs. The CPUC awarded SCE $5.4 million for hiring and training costs (CPUC 2006b, pp.29-32).

Conclusion

The costs of power from California's nuclear power plants cannot be fully predicted from historic power costs. In addition, costs over the next decade or two may differ from historic costs if an expected increase in demand for nuclear fuel, reactor components, and skilled workers drives up prices for these materials.

Utilities can offset price increases by running their plants efficiently and with high capacity factors. They can also moderate price increases with effective hedging and management strategies. For example, utilities can use long-term fuel contracts, material procurement and management strategies, and proactive employee training and retention programs to keep their costs down and to prevent a disruptive shortage in nuclear fuel or skilled labor.

CHAPTER 9: NUCLEAR POWER AND THE ENVIRONMENT

The past few years have seen a resurgence of interest in nuclear power as part of a response to concerns over greenhouse gas (GHG) emissions and global warming. However, designating nuclear power as “clean” because of the low emissions directly associated with electricity generation is controversial (SCC 2006). Nuclear power generation poses direct environmental risks, including aquatic impacts from once-through cooling; risk of groundwater contamination with tritium; radiation hazards associated with the disposal of radioactive waste; and risk of radioactive releases triggered by earthquakes, tsunamis, accidents, or sabotage. Additional environmental impacts are associated with the full nuclear lifecycle, which starts with uranium mining and extends through reactor construction and operation to spent fuel storage/disposal or reprocessing and finally, to decommissioning. In addition, nuclear power has other social costs. According to Harvard University Professor Dr. John Holdren, “there is no doubt that the proliferation of reactors is accelerating the spread [of nuclear weapons capability] beyond what would otherwise be possible or likely…This is an awesome social cost indeed” (ARE 1976, p.564; ARE 1980, p.245).[98]

Nevertheless, nuclear power is “cleaner” than fossil-fueled power in at least one respect: the lifecycle GHG emissions from nuclear power production are much less than the lifecycle GHG emissions from either coal- or natural gas-generated power and are about equal to the lifecycle GHG emissions from solar power generation. For this reason, nuclear power is seen by some as an important tool for reducing GHG emissions. This, too, is controversial.

The first section of this chapter discusses the direct environmental impacts of nuclear power generation with an emphasis on the impacts from once-through cooling. The second section of this chapter broadens the discussion of environmental impacts to consider the impacts from other parts of the nuclear lifecycle. The final section of this chapter evaluates the GHG emissions from the nuclear lifecycle and the role that nuclear power might have in reducing California’s GHG emissions.

Environmental Impacts of Nuclear Power Generation

Some of the direct environmental impacts of nuclear power include the entrainment and entrapment impacts from the use of once-through cooling, the accumulation of highly radioactive nuclear waste, the risk of groundwater contamination in the vicinity of the reactor, and the risk of widespread radiation contamination from potential

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[98] Dr. Holdren is Teresa and John Heinz Professor of Environmental Policy and Director of the Program on Science, Technology, and Public Policy at the Kennedy School, as well as Professor of Environmental Science and Public Policy in the Department of Earth and Planetary Sciences at Harvard University.

radioactive material releases resulting from natural disasters, severe accidents, or terrorist attacks.

Water Use and Ocean Impacts

California's operating nuclear power plants, like many coastal power plants, use once-through cooling to re-condense the steam that is used to generate power at the plants.[99] However, due to the high amounts of heat produced during the nuclear reaction, nuclear power plants use much more water per MWh of electricity than the other coastal power plants (Energy Commission 2005f, p.71). Diablo Canyon is authorized to use 2.5 billion gallons of ocean water per day, and SONGS is authorized to use 2.4 billion gallons of ocean water per day (Reinhardt 2005, p.7). By comparison, the gas-fired Moss Landing power plant, which is larger that either Diablo Canyon or SONGS, is authorized to use 668 million gallons of ocean water per day. The large amounts of water used by California's nuclear power plants pose a threat to the marine environments near the plants.[100]

Federal and State Regulatory Initiatives

Federal and state governments have raised concerns over the impacts of once-through cooling, and new regulations are emerging that may limit the use of once-through cooling at new and existing power plants. Two key concerns are impingement (the trapping of fish and other aquatic life against the cooling water intake screens) and entrainment (the drawing of aquatic organisms, eggs, and larvae into the cooling system, through the heat exchanger, and back out into the ocean).[101] (EPA 2007a)

At the federal level, regulations adopted by the EPA for existing power plants would have required power plants using ocean water for cooling to adopt the "best technology available" (BTA) to reduce the impingement and entrainment impacts on

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[99] Water is piped from the ocean into the power plants and then discharged back out to the ocean.

[100] PG&E asserts that its cooling system does not adversely impact the local marine ecosystem. PG&E cites a 2006 study that found that, while certain species of rockfish have been declining in the northeast Pacific since the late 1970s, these species (with one exception) have not been declining along the south-central coast of California. According to PG&E, this "recent independent study provides technical evidence that the power plant once-through cooling (OTC) system is not adversely impacting part of the marine ecosystem present at DCPP. If the operation of DCPP's OTC system was adversely impacting marine populations through entrainment and destruction of larval fish and eggs, the rockfish population, a species entrained by DCPP, would be expected to have degraded overtime, and it has not done so" (PG&E 2007b, A5).

[101] Thermal pollution (raising water temperatures) is another significant impact of once-through cooling. For example, Diablo Canyon's water discharge system noticeably heats the water in and around Diablo Cove. The Central Coast Regional Water Quality Control Board "had a major battle with PG&E" in 2000 over the issue (Energy Commission 2005f, pp.75-76). SONGS discharges its water far from shore through a diffuser, which at least partially alleviates the thermal impacts since the water is relatively cool by the time it is discharged (Energy Commission 2005f, p.70). New regulations focus on impingement and entrainment impacts. Older regulations already govern thermal and other discharges.

the marine environment, unless the costs of implementing this technology significantly outweigh the benefits. The U.S. Court of Appeals for the Second Circuit, however, remanded significant aspects of the EPA's regulations and ruled, among other matters, that Section 316(b) of the Clean Water Act does not allow BTA to be based on a cost-benefit analysis (Riverkeeper v. EPA 2007).The California State Lands Commission (CSLC) embraced the EPA's regulations when it proposed to deny extensions or amendments to land leases for existing power plants that do not comply fully with federal and state water regulations. The CSLC proposal also went further, allowing the CSLC to require holders of lease extensions to upgrade their discharge controls should a superior technology become available, regardless of the cost of this technology (CSLC 2006a). The State Water Resources Control Board (SWRCB) also proposed a policy based on the EPA's regulations but with more stringent requirements. The SWRCB policy would require coastal power plant operators to meet the upper end of the EPA's impingement and entrainment standards and to install the best technology available regardless of cost considerations. It would also place restrictions on the use of restoration measures in place of impact mitigation measures[102] (SWRCB 2006, pp.15-17). (See Figure 24.)

The U.S. Court of Appeals has effectively blocked the implementation of the EPA's regulations for existing sources, ruling that the regulations do not meet the requirements of the CWA. In particular, according to the Court's decision, the new regulations may not use a cost-benefit test in evaluating appropriate technologies and may not use restoration measures in place of minimizing impacts[103] (Riverkeeper v. EPA 2007, pp.21-22, 42). In light of the court decision, the EPA has suspended the regulations (EPA 2006a).

The expected new EPA regulations and state policy that may be adopted could have a significant impact on California's nuclear power plants. The Energy Commission found that, if the CSLC resolution stands, Diablo Canyon and SONGS will be required either to shut down or to replace their once-through cooling systems with systems that use reclaimed water or with dry cooling systems when their current leases expire in May 2019 and in February 2023, respectively (Energy Commission 2006a, p.8; CSLC 2006b, p.2). The Energy Commission also found that there may not be sufficient reclaimed water for use in a cooling tower at Diablo Canyon and SONGS, that a retrofit to install these cooling towers would be an expensive engineering challenge, and that dry cooling at these plants may be infeasible from an engineering perspective (Energy Commission 2006a, pp.4, 7). The Regional Water Quality Control Board similarly found that "it would be difficult, if not

[102] The SWRCB proposed policy will need to be revised to comply with the 2007 court decision remanding EPA's regulations for existing facilities. Any policy change would impact Diablo Canyon and SONGS soon after implementation, as NPDES permits are issued for terms of just five years (SWRCB 2003).

[103] If the cost of an option is so great that it cannot "be reasonably borne by the industry," then that technology is not considered to be "available" and is not required to be used (Riverkeeper v. EPA 2007, pp.21-22).

impossible, to construct an alternate cooling system" at Diablo Canyon (CSLC 2006b, p.7).

These assessments are consistent with studies done by PG&E that have found that the cost to eliminate once-through cooling at Diablo Canyon far outweighs the benefits (ASA 2003, pp. 3, 12) (Energy Commission 2005d, p.65). PG&E estimated that installing cooling towers would create "significant adverse environmental impacts including: 1) 7 million pounds of salt drift annually causing negative impacts for flora and fauna, as well as electrical arcing incidences on the 500 kV line; 2) the remaining discharge would be 69 million gallons a day of saltier, warmer water; 3) significant safety and visual issues from the vapor plume, as well as noise issues" (PG&E 2007b, A.1.e).

Concern over the impacts of the various federal and state once-through cooling initiatives on the state's electricity system has led the Energy Commission to encourage flexibility in implementing the regulations. Chairman Pfannenstiel stated that the Energy Commission supports efforts to reduce the environmental impacts of once-through cooling as long as generators and regulators are provided sufficient time to comply with any new regulations so that electricity system resource adequacy targets can be maintained during the transition. She emphasized that California "cannot afford to have additional generating units retire in response to the proposed [SWRCB] regulations without new resources being available to meet summer peak demands and provide reserve capacity for unplanned system outages" (Energy Commission 2006d, pp.1-3).

The California Council for Environmental and Economic Balance, whose members include PG&E, SCE and the owners of all of the other coastal power plants affected by the CSLC resolution, petitioned California's Office of Administrative Law seeking to find that the CSLC Resolution is "an underground regulation that should be voided." The California Council for Environmental and Economic Balance argued that the resolution was passed without following the procedures of the California Administrative Procedure Act. The Office of Administrative Law determined that the clauses of the resolution that prohibit the CSLC from approving certain leases or lease extensions or amendments do constitute an underground regulation, as charged by the California Council for Environmental and Economic Balance, since they use "unambiguous language to establish an explicit rule" (CA OAL 2006, pp.10-11). This determination does not require the CSLC to revoke its resolution, but it sets the stage for legal cases against the resolution.[104]

[104] As explained in the ruling, this determination "is not enforceable against the agency through any formal administrative means, but it is entitled to 'due deference' in any subsequent litigation of the issue" (CA OAL 2006, p.4). The CSLC has not yet issued a formal public response to this determination. Recent lease approvals have deferred to federal and state once-through cooling regulations (CSLC 2007, p.4).

Figure 24: Federal and State Once-Through Cooling Regulations

In July 2004 the EPA established final regulations for cooling water intake structures at existing power plants. The regulations were intended to be in compliance with Section 316(b) of the Clean Water Act. The regulations stated that beginning in July 2008 National Pollutant Discharge Elimination System (NPDES) permits, which are required for all facilities that discharge pollutants into U.S. waters, may not be issued unless intake structures use the best technology available to reduce marine life impingement mortality by 80 to 95% and entrainment by 60 to 90%. They also authorized an NPDES permit director to establish site-specific alternative requirements that minimize adverse environmental impacts without resulting in undue costs in the event that the cost of compliance at a plant would significantly outweigh the environmental benefits.

In January 2007, the U.S. Court of Appeals for the Second Circuit remanded significant aspects of the EPA's regulations, ruling that they do not adequately establish the protections required by the Clean Water Act. The Court ruled that the Clean Water Act does not allow for a cost-benefit analysis to guide which level of benefit will be achieved. Rather, either the best technology available or an alternative technology that achieves essentially the same results as the best technology available must be used. Accordingly, the EPA's rejection of closed-cycle cooling due to cost considerations was improper. The Court additionally found that compliance through restoration measures is impermissible, because it substitutes "after-the-fact compensation for adverse environmental impacts that have already occurred for the minimization of those impacts in the first place." The EPA suspended its regulations in response to the Court's decision.

In April 2006, the California State Lands Commission adopted a resolution that denies land leases for new power facilities that would use once-through cooling technologies and denies extensions or amendments to land leases for existing plants that use once-through cooling unless the plants are in full compliance—or working toward full compliance—with federal and state water regulations, including the EPA's regulations. The CSLC resolution also added a provision to lease extensions allowing the CSLC to re-open leases if a permitting agency finds that an alternative environmentally superior technology exists that can be feasibly installed. The resolution does not specify an exception in the event that the cost of the new technology far outweighs its benefits.

In June 2006 the staff of the State Water Resources Control Board presented a proposed statewide policy for implementing NPDES requirements. The policy would have required existing power plants to achieve the upper end of impingement and entrainment reduction ranges permitted by the Clean Water Act (i.e., 95% reduction in impingement mortality and 90% reduction in entrainment) with the possibility of using restoration measures to achieve up to one-third of the entrainment reduction when operational and structural controls are infeasible. Nuclear power plants would have been allowed to use any combination of operational or structural controls and restoration measures to achieve their impingement and entrainment standards if implementing operational and/or technological measures would conflict with NRC safety requirements. This proposed policy would not have allowed for a site-specific determination of BTA based on cost considerations; all feasible mitigation measures to attain the reduction targets would have been required. Because of the 2007 court decision on EPA's regulations for existing power plants, the SWRCB staff is now expected in 2007 to issue a revised proposal consistent with the court's decision.

Source: (CSLC 2006a; Riverkeeper v. EPA 2007, pp.21-22, 32-33, 42; SWRCB 2006, pp.15-17; EPA 2004; EPA 2006a)

The California Council for Environmental and Economic Balance also objected to the stringency of the SWRCB's proposed policy and requested that state policy follow the regulations adopted by the EPA. It noted that the differences in environmental benefits between the proposed policy and the EPA regulation have not been quantified and that the consequences of the proposed policy on grid stability and air quality have not been considered (CCEEB 2006).

Mitigation Measures at California Plants

Measures to mitigate the environmental impacts of once-through cooling are already in place at SONGS and are currently being developed for Diablo Canyon. The SONGS mitigation plan cannot simply be applied to Diablo Canyon. The natural and marine environments at the two plants differ, and the impacts of the plants on their respective environments also differ. For example, SONGS' intake and discharge pipes reach 2,000 and 8,000 feet out to sea from the shoreline, respectively, whereas Diablo Canyon's pipes feed directly into Diablo Cove immediately adjacent to the shoreline. The resulting marine impacts are substantially different. In addition, SONGS' discharge system includes a diffuser, which discharges the heated water over a length of pipe and reduces the thermal shock at any one discharge point (Energy Commission 2005f, p.70).

The mitigation measures in place at SONGS include behavioral barriers, wetland restoration, and kelp reefs (Reinhardt 2005, p.8). For wetland restoration, SCE has set aside 115 acres as mitigation for entrainment losses and has installed a fish return system at SONGS that helps reduce impingement mortality by 80 percent. A technical staff and scientific advisory panel oversee the mitigation activities (Energy Commission 2005f, pp.72-73). SCE is investigating the cost and efficacy of additional technologies to reduce impingement and entrainment, and the SONGS site is participating in a statewide study of cooling towers conducted by the Electric Power Research Institute (SCE 2007a, A5).

Mitigation measures for Diablo Canyon were investigated as part of Diablo Canyon's 2003 NPDES permit renewal process with the Central Coast Regional Water Quality Control Board (CCRWQCB) (CCRWQCB 2005). The settlement agreement between PG&E and the CCRWQCB called for the permanent protection of 5.7 miles of habitat as well as further investigations into mitigation options. In July 2005 independent scientists concluded that the two primary mitigation options are marine reserves and artificial reefs. Though the scientists showed no preference toward one option over the other, the CCRWQCB decided that marine reserves were the better option. According to Michael Thomas of the CCRWQCB, the board felt that marine reserves would provide a permanent, tangible benefit, while they questioned the impact of adding "200 acres of artificial reef to an area that already has thousands or tens of thousands of acres of reef habitat" (Energy Commission 2005f, pp.87-88).

Independent scientists also investigated and ruled out a number of other mitigation measures and cooling alternatives. For example, they found that saltwater cooling towers would lead to salt drift into the air, which would have an adverse, unacceptable effect. Freshwater cooling would require massive supplies of freshwater that are not available in the region. Dry cooling too, would be unfeasible, due to its extensive space requirements that cannot be met at Diablo Canyon (Energy Commission 2005f, p.84). Fine mesh screens have been investigated as an experimental technology to prevent the intake of even very small organisms, but the experimental nature of the technology and potential debris loading and biofouling ruled it out as a feasible addition to the cooling intake system (CCRWQCB 2005, pp.2-3).

Fish hatcheries were ruled out as an alternative mitigation measure due to their inability to focus on more than a few specific species when hundreds are affected by the cooling process. Restoration of marine habitat was ruled out since no areas of ocean habitat could be identified where physical restoration would increase larval productivity (CCRWQCB 2005, pp.5-7).

Nuclear Waste

Properly managed, nuclear waste need not present an environmental hazard. There are temporary storage facilities for spent fuel at 125 sites in 39 states across the U.S. This waste is predominantly stored at reactor sites in large pools of water or in dry storage casks. According to DOE, these “storage methods shield any harmful radiation and are presently safe. However, modern aboveground storage structures are designed for temporary storage only, and will not withstand rain, wind, and other environmental factors for the tens of thousands of years during which the waste will be hazardous” (DOE 2004b).

Accordingly, the U.S. is seeking to develop a geologic repository for the nation’s spent fuel and high-level waste. According to a National Academies study,

> [Geologic disposal] remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management… [A] well-designed repository represents, after closure, a passive system containing a succession of robust safety barriers. Our present civilization designs, builds, and lives with technological facilities of much greater complexity and higher hazard potential (National Academies 2001, p.3).

However, there are concerns that the Yucca Mountain site may not be suitable for permanently isolating the wastes from the environment. The State of Nevada has raised concerns about groundwater contamination, vulnerability of the site to earthquakes and volcanoes, and the potential for human intrusion on the site during exploration for natural resources (Nevada 1998). The State of California has likewise raised concerns that contamination from the repository could contaminate California's groundwater.[105]

The slow progress in developing the Yucca Mountain repository has led to new proposals to re-evaluate the repository concept and move toward above-ground regional storage or continued interim at-reactor storage. These proposals pose their own environmental risk management challenges:

> [Safe] and secure surface storage is technically feasible as long as those responsible for it are willing and able to devote adequate resources and political attention to maintaining and expanding the storage facilities…The major uncertainty is in the confidence that future societies will continue to monitor and maintain such facilities. It is not prudent to pursue only storage, without development of the geological disposal option, unless a society believes it can credibly commit to permanent maintenance of its storage facilities (National Academies 2001, pp.2-3).

Groundwater Impacts

Over the last 10 years, inadvertent tritium releases have been discovered at over a dozen domestic nuclear power reactors, including recent discoveries at Palo Verde and SONGS Unit 1 (NRC 2006m). The Palo Verde release was discovered on March 1, 2006. Contaminated water was found in Unit 2 and Unit 3 subsurface soils, but only Unit 3 soils contained tritium levels above the EPA drinking water standard. Plant staff concluded that the contamination had been caused by past operational practices that were discontinued in the mid-1990s and that there was no offsite release of contaminated water (NRC 2006m). The SONGS Unit 1 leak was reported in July 2006. It was discovered in non-potable water that was being removed from between the containment sphere and the concrete foundation as part of the decommissioning process (SCE 2006d, p.4). Tritium levels in this water exceeded the EPA's drinking water limit by up to 1,600 percent. However, no tritium was found in the closest source of drinking water, which is located in San Clemente about two miles from the reactor, and there is no evidence that any contaminated water leaked off the plant site. SCE piped the contaminated water 8,600 feet offshore, and it plans to send the contaminated soil to a nuclear-waste disposal facility. The source or timing of the leak is unknown (LA Times 2006a).

On March 10, 2006 the NRC established a Liquid Radioactive Release Lessons Learned Task Force, and throughout the spring of 2006, the Task Force held a series of public meetings with NEI to discuss industry and regulatory responses to these releases (NRC 2006m). In response to these events, NEI launched a voluntary "Industry Initiative on Groundwater Protection" that requires each plant to have a site-specific plan in place by the end of July 2006 to "detect, monitor, assess, and report groundwater contamination" (NRC 2006q, p.5).

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[105] Potential impacts of the Yucca Mountain repository on California are discussed further in Chapter 3.

In July and August 2006, PG&E, SCE and APS each returned a voluntary data collection questionnaire to the NRC regarding the monitoring practices at Diablo Canyon, SONGS, and Palo Verde respectively. PG&E reported that Diablo Canyon has had just one significant incident of inadvertent release of radioactive liquids and that this release occurred in 1993 and did not extend beyond the plant site. SCE reported a series of inadvertent releases and mitigation measures beginning in 1983. Both PG&E and SCE noted that they do not have any potable groundwater to monitor since their plants are coastal plants; however, they do sample off-site water sources (PG&E 2006d). APS reported that Palo Verde has had two inadvertent releases of radioactive liquids, including the March 2006 release, and that APS plans to install monitoring and remediation wells in the areas where tritium has been found (APS 2006).

Seismicity and Tsunamis

Damage to reactors and fuel storage facilities from earthquakes or tsunamis could potentially precipitate the release of large amounts of radiation. California's nuclear reactors and fuel storage facilities were constructed to withstand the most severe earthquake and tsunami that might be expected in their vicinities without releasing radiation to the public.

The NRC has exclusive jurisdiction over identifying the design basis earthquake and tsunami for each plant and ensuring that each plant is built and maintained to the adopted standards. However, several California agencies have also been concerned with seismic and tsunami hazards at the plants. When PG&E and SCE applied for local permits to build temporary fuel storage facilities, the California Coastal Commission and the County of San Luis Obispo took the opportunity to consider the safety of the proposed facilities and the surrounding areas in the event of an earthquake or a tsunami. While the Coastal Commission found current design standards to be sufficient, the county of San Luis Obispo concluded that concerns over the seismic stability of Diablo Canyon's proposed ISFSI were significant[106] (CCC 2004, p.61). In April 2004 the county required PG&E to begin updating Diablo Canyon's Long Term Seismic Plan as a condition of being granted a permit to construct its spent fuel storage facility.[107]

In a recent study of the vulnerability of Diablo Canyon to a tsunami, PG&E reported that the plant is at a sufficient elevation such that even a tsunami at high tide with high winds and rainfall should not damage the plant. The only parts of the plant

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[106] The Coastal Commission found the Diablo Canyon ISFSI design standards to be sufficient in all regards, but it was concerned that some of the cutslopes could be "susceptible to wedge, planar sliding, and/or topple failures" under worst-case seismic conditions if the rock bolts and tiebacks that will be installed to support the slopes deteriorate. The Coastal Commission required PG&E to monitor the rock bolts and tiebacks and keep them maintained (CCC 2004, p.61).

[107] More information about seismic and tsunami studies at California's nuclear plants can be found in the 2005 Status Report on Nuclear Power (Energy Commission 2006e).

within the projected sea wave zone are the auxiliary saltwater pump, which is believed to be able to withstand a tsunami wave, and buried water intake pipes outside of the pumps, which were structurally enhanced based on the recommendations of a 1996 Bechtel study (PG&E 2006b, pp.2-15).

Environmental Consequences of Accidents or Terrorism

The Monterey Institute Center for Nonproliferation Studies has found that a successful terrorist attack at a nuclear reactor would not necessarily result in a large release of radioactivity, since U.S. reactors all have containment structures. While U.S. reactors were designed only to prevent a catastrophic release of radiation in the event of "normal" failures and not intentional sabotage or attack, "it is highly improbable that the consequences of a terrorist attack on a U.S. nuclear power plant would approach that of the Chernobyl accident," due to the containment structure and other safety features built into U.S. reactors (Monterey Institute 2004 , pp. 235-236).

However, some fear that an attack on a spent fuel pool could have a devastating impact. A 2003 study by Alvarez, et al found that an attack that released just 10 percent of the 35 megacuries (MCi) of cesium-137 that is contained in the average U.S. spent fuel pool would contaminate with over 100 Curies per square kilometer (Ci per km^2) an area five to nine times larger than the area similarly contaminated by the Chernobyl accident. Living in an area with 100 Ci per km^2 of contamination for 10 years is associated with an additional 1 percent risk of cancer. Releasing all of the radiation in the spent fuel pool would contaminate an area about 10 times this size, and also contaminate thousands of square kilometers with radiation levels of over 1,000 Ci per km^2 (Alvarez et. al. 2003, pp.1-10).

The NRC objected to the assumptions used in the Alvarez paper. They asserted that a 10-100 percent radiation release "is neither a realistic estimate nor an appropriate assumption for a risk assessment of security issues where realism is needed" (NRC 2003). Moreover, the Alvarez study does not account for interventions to provide emergency cooling, even though "longer times than previously estimated are available for operators to intervene to restore water" (NRC 2003). The NRC concluded that in the U.S. "spent fuel, in both wet and dry configurations, is safe and measures are in place to adequately protect the public" (NRC 2003).

However, a 2006 National Academies study concluded in agreement with Alvarez that "under some conditions, 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 to the environment" (National Research Council 2006, p.57). It also found that successful terrorist attacks on spent fuel pools, though difficult, are possible (National Research Council 2006, p.3).

The security implications of spent fuel and reactors are discussed further in Chapters 3 and 10.

Environmental Impacts of the Nuclear Lifecycle

The environmental impacts of nuclear power are spread throughout the nuclear lifecycle and are not concentrated at the electricity generation phase. Many of the impacts are associated with the lifecycle (i.e., the development, transport, treatment, and disposal of nuclear fuel). The nuclear lifecycle generates emissions of GHG and radiation, as well as potential groundwater contamination. In addition, there are GHG emissions and other environmental impacts from reactor construction and decommissioning activities and, as discussed above, from the use of large amounts of ocean water for cooling. There can also be groundwater impacts when plant operations result in tritium contamination. (See Table 30.)

Significant uncertainty persists regarding the risks associated with hazardous waste from the nuclear lifecycle. Many assessments of the environmental impacts of nuclear power do not consider the potential impacts of hazardous waste, because the uncertainties are too great. This does not, of course, mean that there are no impacts, but rather that the assessments are still incomplete. (See Figure 25.)

Technological changes could significantly reduce the impacts of nuclear power. For example, in-situ mining obviates the need for uranium milling and removes the hazard of mill tailings, and centrifuge enrichment uses just a small fraction of the energy required by gaseous diffusion enrichment. However, these “solutions,” if not carefully applied, can also create new hazards, such as groundwater contamination from the leaching of toxic elements in in-situ mining and proliferation concerns from centrifuge enrichment.

Figure 25: Limitations of the Lifecycle Analysis

Lifecycle analysis (LCA) studies investigate the environmental and health impacts that result from each stage of a technology's "lifecycle" and attempt to quantify the impacts of each of the related activities using monetary values or other indices. LCA studies can identify the range of impacts from a particular technology, the parts of the lifecycle that pose the greatest risk, how these risks might change over time, and, in certain cases, the relative risk of different technologies with respect to specific well-defined parameters.

In a 1976 paper, Dr. Robert Budnitz and Dr. John Holdren reviewed the numerous types of impacts of energy systems and the available methods to assess their costs. They concluded that the difficulties inherent to LCA assessments are overwhelming: "the criteria and indices by which impacts are judged and compared are under dispute; the methods for quantifying impacts and costs are in many cases poorly developed or seriously flawed; and the inability to compare apples and oranges makes the final goal unattainable in many (perhaps all) important situations."

Thirty years later, the observations and conclusions of Budnitz and Holdren remain relevant. LCA studies can be useful for qualitatively identifying the range of impacts and risks associated with nuclear generation and those parts of the generation process that contribute the most risk. However, there are numerous problems with the quantitative data, which ultimately limit our ability to compare the results of these studies or even interpret any one study on a stand-alone basis. These problems, as identified by Budnitz and Holdren, fall into four broad categories:

1. Scope of Analysis: The challenges here are which stages of the lifecycle should be included, which technologies should be examined, which impacts should be assessed, and over what time-frame should these impacts be examined.
2. Data Issues: Much of the data needed to quantify impacts is unavailable or very uncertain. This is especially true for non-routine occurrences, such as large radiation releases.
3. Quantification and Interpretation: How should impacts be measured? How should impacts at a later date be valued? How should different risks be weighed against each other?
4. Methodology and Assumptions: There is no standard methodology for LCA studies. A handful of input assumptions significantly impacts the results, and the results of some studies are relevant only to a particular country, region, or plant.

Many LCA studies provide very limited information on data sources, modeling techniques, and assumptions, making it impossible to determine how comparable their results are to others in the literature. Moreover, some studies have obvious, predetermined biases or simply lack the scope necessary to be useful. Studies that aim to review results of others are also difficult to use because of the attempted comparison of what amounts to apples and oranges. These difficulties and the assumptions most important to the nuclear power LCA are discussed in Appendix B. A list of select nuclear lifecycle analyses is provided in Appendix C.

Source: (ARE 1976, p.578)

Table 30: Environmental Impacts of the Once-Through Nuclear Lifecycle[108]

Lifecycle Stage	**Impact**
Uranium Mining and Milling	The conventional mining process is disruptive to land and habitats at the mining site. An alternate mining process called in-situ leaching is a potential source of groundwater contamination. Radioactive residues of the milling process (mill tailings) can have severe health impacts on workers and people residing in the vicinity of the mills. (See Appendix D.)
Uranium Enrichment	Gaseous diffusion enrichment, which is the only enrichment technology used in the U.S., uses an enormous amount of electricity. Electricity production yields emissions of carbon dioxide (CO_2), sulfur oxides, nitrogen oxides, and particulate matter.[109]
Construction Activities	The construction and decommissioning of the reactor, spent fuel storage facilities, and auxiliary units use energy and impact local environments, similar to other construction projects.
Generation	There are minuscule amounts of radioactive emissions associated with routine nuclear power plant operation, although there are a variety of radioactive by-products from the fission process within the reactor core, and to a lesser degree from other nuclear reactions associated with the neutron flux within the reactor. There may also be significant impacts to the marine environment from the use of once-through cooling.
Interim Spent Fuel Storage	When spent fuel is discharged from a reactor, it is initially stored in a spent fuel pool. As discussed above, there is a small risk that a spent fuel pool fire could result in a large release of radiation.
Spent Fuel Transport	Many shipments will be required to transport spent fuel from reactor sites nationwide to Yucca Mountain. In some cases, new rail lines will be required and roads will need to be built or improved to handle these shipments. Concerns have been raised about the vulnerability of spent fuel casks to accidents or sabotage during transport and the potential for radiation release. (See Chapter 5.)
Spent Fuel Disposal	Many believe that the geological disposal of spent fuel will be safe and will not contaminate the environment outside of the repository. However, controversy remains concerning the potential ease of water and radioactive contaminant transport through the Yucca Mountain repository to the underlying groundwater, the adequacy of engineered barriers, and the likelihood of new volcano formation in the region.

Source: (Energy Commission 2005e, pp.186-187; Macfarlane 2006, pp.6, 8, 15; NRC 2007j)

[108] Environmental implications of reprocessing are discussed in Chapter 4.

[109] Gas centrifuge enrichment requires just 2-3 percent of the electricity required by gaseous diffusion enrichment (Energy Policy 2007, p.2553). However, gas centrifuge plants are a greater proliferation risk than gaseous diffusion plants (NPEC 2004, pp.13-14). All of the enrichment facilities in the U.S., for both reactor fuel and weapons-grade material, use gaseous diffusion technology. However, since most of the nuclear fuel used in the U.S. is enriched abroad, only about 20-35 percent of the nuclear fuel used in the U.S. is enriched via gaseous diffusion technology (USEC 2004) (EIA 2006a, p.18).

Greenhouse Gas Emissions and the Nuclear Lifecycle

In 2006 California took the bold step of passing legislation that requires the state to reduce GHG emissions to 1990 levels by 2020. State agencies including the CPUC, the Energy Commission, and the Air Resources Board are already developing the policies and regulations to implement this landmark legislation. As a significant sectoral contributor to statewide GHG emissions, the electricity sector will be a near- and medium-term target of GHG emissions reduction policies.

Indeed, the Energy Commission and the CPUC have recognized for several years now the importance of encouraging the use of energy sources with low GHG emissions. For example, the 2003 IEPR established what has come to be known as a loading order for California energy resources. The policy requires new generation to be met “first with renewable and distributed generation resources and second with clean fossil-fueled generation” (Energy Commission 2005b, p.68). The 2005 IEPR also emphasized the need to consider the environmental impacts of new generation, including GHG emissions, and highlighted the CPUC’s requirement that utilities use a CO_2 adder in evaluating resource options for their long-term procurement plans (Energy Commission 2005b, p.12).

A law adopted in 2006 takes these policy recommendations one step further. Senate Bill 1368 established an emissions performance standard that encourages long-term investments in clean energy sources and requires that utilities’ investments in baseload power, if made for five years or longer, have an emissions rate under 1,100 pounds of CO_2 per MWh. The CPUC approved regulations implementing this legislation in 2007. Significantly, the CPUC determined that it would not conduct lifecycle emissions analyses but would instead consider only the emissions from the power plants (CPUC 2007c, p.261). The Energy Commission has not yet released its rules pertaining to publicly-owned utilities. The Energy Commission rules are due by June 30, 2007 (SB 1386 2006, p.2).

Nuclear power is not directly addressed in these legislative and policy directives. However, insofar as these rulings impact the power procurement options of the utilities, they may increase the demand for generation sources that have low GHG emissions. These sources include efficient gas-fired power, renewable and cogeneration power sources, nuclear power, and energy efficiency.[110]

This section investigates the role of nuclear power within a GHG reduction strategy. It provides an assessment of the GHG emissions from the nuclear lifecycle and considers the potential roles that nuclear power could have in meeting GHG reduction targets.

[110] While new nuclear power plants cannot be built in California until the moratorium is lifted, these policies could encourage additional imports of nuclear power from out of state.

Estimates of Nuclear Lifecycle Greenhouse Gas Emissions

Lifecycle assessments of the GHG emissions from nuclear generation have produced a wide range of estimates. At the low end of the range, GHG emissions associated with the nuclear lifecycle are estimated to be just 5 grams of CO_2-equivalent per kWh (AEA 2005). A much higher estimate pegs the GHG emissions rate at 140 grams of CO_2-equivalent per kWh (Storm and Smith 2006). Much of this spread is a result of differences regarding three key assumptions: the percentage of enrichment that is done via centrifuge technology, the fuel source for the energy inputs, and the reactor lifetime. The estimates also vary as a result of differences in which stages of the lifecycle are considered in the analyses. For example, estimates that omit uranium enrichment and spent fuel handling yield relatively low rates of GHG emissions. Table 31 provides estimates of the GHG emissions from the nuclear lifecycle as reported in eight different studies. Where available, estimates from the front end of the lifecycle, which includes reactor and facilities construction and all the stages of fuel fabrication and transport, are also reported.

The Brookhaven analysis summarized in Table 31 defines a range of reasonableness (16-55 g CO_2-eq per kWh) that is consistent with most of the other studies shown. The analysis incorporates the entire lifecycle, from uranium exploration to geologic disposal of waste, including terms for reactor construction and decommissioning and the permanent disposal of both high- and low-level waste. The analysis does not, however, include impacts from the construction of auxiliary buildings at the reactor site, and its figures for the back-end of the lifecycle remain speculative and may be low, depending on how the scope of analysis is defined. (For instance, mine clean-up is not included.) The study thus provides a floor for the emissions of current U.S. reactors but not a ceiling. In addition, as noted in Brookhaven's article, these results may not hold in the future. A shift to increased reliance on centrifuge enrichment would significantly reduce the GHG emissions from nuclear power, as would the use of clean fuels to power gaseous diffusion enrichment. However, use of lower grades of uranium ore would require additional energy in the ore conversion phase of the lifecycle, generating additional greenhouse gases (Energy Policy 2007, pp.2555-2556).

All of the studies considered at least some of the elements of the front end of the lifecycle, and studies that considered similar elements of the lifecycle are largely consistent in results. The Fission Technology Institute study estimated an emissions rate of 14 g CO_2-eq per kWh from the front end of the lifecycle (including operation).The ExternE-UK study, which incorporates only plant construction, and the GREET study, which incorporates the front end of the lifecycle excluding plant construction, together provide an estimate of about 21 g CO_2-eq per kWh from the front end of the nuclear lifecycle. The Oko-Institute calculated 33 g CO_2-eq per kWh

Table 31: Estimates of GHG Emissions from the Nuclear Lifecycle

Study Sponsor/ Author	Grams CO_2-eq per kWh	Lifecycle Stages	Lifecycle Assumptions
British Energy	Total: 5	Many elements of the lifecycle; Excludes construction and decommissioning of fuel fabrication, reprocessing and storage plants.	100 percent centrifuge enrichment; 40 year reactor lifetime; Models lifecycle of Torness nuclear power station (Scotland); Includes reprocessing
ExternE-UK (EU)	Total: 5 Front End: 5	Plant construction only	Based on average emissions per £ from input sectors
Fusion Technology Institute (University of Wisconsin, Madison)	Total: 15 Front End: 14	Mainly the front end of the lifecycle; Small amounts of emissions included for the back end	100 percent centrifuge enrichment; 40 year reactor lifetime
Argonne National Lab (GREET)	Total: 16 Front End: 16	Front end, excluding plant construction; Includes fuel transport, enrichment, conversion, and fabrication	75 percent centrifuge enrichment; Mix of fuels used to power nuclear lifecycle
Brookhaven National Lab	Baseline: 25 Best Case: 16 Worst Case: 55 Likely range: Total: 25-55[111] Front End: 20-48	Full lifecycle; Does not include environmental remediation of mine and reactor sites	Independent estimate of emissions from Yucca Mountain; Compilation of inputs from a variety of studies
Oko Institut	Total: 33	Front end and electricity transmission only	70 percent centrifuge enrichment
Storm van Leeuwen	Total: 90-140 Front End: ~45	Full lifecycle; Includes environmental remediation of mine and reactor sites	70 percent centrifuge enrichment; Oil used to power all stages of nuclear lifecycle; 24 full-year equivalent reactor lifetime
Oxford Research Group (van Leeuwen)	Currently 84-122, but projected to increase as high-purity ore is depleted	Full lifecycle	35 year reactor lifetime 85 percent average load factor 0.15 percent uranium ore grade Enrichment method not specified

Source: (AEA 1998; AEA 2005; Oko-Institut 2006; Energy Policy 2007; Storm and Smith 2006; Oxford Research Group 2007, p.41; White and Kulcinski 1999; Nuclear Technology 2006)

[111] The authors note that the best (16 g CO_2-eq per kWh) and baseline cases (~25 g CO_2-eq per kWh) likely underestimate emissions while the worst case (55 g CO_2-eq per kWh) likely overestimates emissions (Energy Policy 2007, p.2555).

from a similar set of processes. These are all consistent with the 12-48 g CO_2-eq per kWh (and likely range of 20-48 g CO_2-eq per kWh) from the front end of the lifecycle found in the Brookhaven study.[112]

Emissions from the back end of the lifecycle are more difficult to estimate, in large part because there has been only limited experience with decommissioning facilities and disposing of high level waste. Estimates in the studies reviewed range from less than 0.9 g CO_2-eq per kWh to 75 g CO_2-eq per kWh.[113] Differences in assumptions and scope also are greater for this part of the lifecycle. The critical assumptions relate to the extent of the clean-up and the way in which spent fuel will be handled: Will it be reprocessed? Will it be stored in an interim storage facility prior to reprocessing or geologic disposal? What will be involved in building a geologic repository? The scope can be defined narrowly to encompass only the transport of spent fuel from a plant to a fuel handling or storage facility plus the decommissioning of the reactor. A broader scope would encompass the construction and decommissioning of interim storage and handling facilities for spent fuel and other radioactive wastes, the excavation and construction of a geologic repository, and the environmental remediation required to return all mining, reactor, and repository sites to their original conditions.

Comparisons to Other Generating Technologies

In comparing the estimates of nuclear lifecycle emissions to the lifecycle emissions of competing generation technologies, care must be taken that the emissions figures from the competing technologies have been derived using similar input assumptions and scope as the nuclear emissions figures. This requires a significant effort that is

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[112] The results of just three of the studies lie outside the range defined by the Brookhaven study. The 5 g CO_2/kWh calculated by British Energy, which includes some elements of the front end of the lifecycle and some elements of the back end of the lifecycle, underestimates emissions from U.S. power plants because it is assumes 100 percent centrifuge enrichment. The van Leeuwen study, which shows approximately 45 g CO_2/kWh from the front end of the lifecycle plus an additional 18 g CO_2/kWh from the maintenance and refurbishing of reactor facilities, likely overestimates emissions from U.S. power plants because it assumes that all lifecycle and construction functions are powered by oil. This study also uses a conservative 24-year reactor lifetime and a larger scope of analysis than the other studies. (Most U.S. reactors are licensed for 40 years with a possible license extension of an additional 20 years.) The Oxford Research Group study is an update of the van Leeuwen study and likely includes many of these same assumptions.

[113] Only the Fusion Technology Institute, Brookhaven, and van Leeuwen studies attempt to incorporate elements from the back end of the lifecycle. The Fusion Technology Institute study does not explain its assumptions nor what range of technologies is included in its estimates. It calculates just 1.4 g CO_2/kWh for waste disposal and transport and .011 g CO_2/kWh for decommissioning and land reclamation. The Brookhaven study estimates waste disposal emissions of 0.9-2.7 g CO_2-eq/kWh, based on an independent analysis of emissions from Yucca Mountain. (Decommissioning costs are not separated out from construction costs.) The van Leeuwen study uses a very broad scope of analysis and estimates that the emissions from the back end of the lifecycle are ~25-75 g CO_2-eq/kWh, depending on the extent of clean-up incorporated in the decommissioning effort.

beyond the scope of this report. A sample of results from the literature on other generation technologies is provided for illustrative purposes only:

- A 2002 study by the Center for Global and Regional Environmental Research found the lifecycle emissions from coal-fired generation to be 1,028 g CO_2-eq per kWh. This figure includes emissions from coal mining, transport, combustion, and coal waste transport (CGRER 2002, pp.16, 20).
- A 2000 study from the National Renewable Energy Laboratory analyzed emissions from a combined cycle natural gas power plant. The analysis included the power plant operation, natural gas production and distribution, power plant and pipeline construction and decommissioning, and ammonia production and distribution. It concluded that the lifecycle emissions from a combined cycle natural gas plant total 499 g CO_2-eq per kWh (NREL 2000, p. 29).
- The Brookhaven study cited above found the lifecycle GHG emissions from photovoltaic and nuclear lifecycles to be comparable, with both in the range of about 15-60 grams of CO_2-eq per kWh (Energy Policy 2007). The authors noted that a 2003 ExternE report that showed photovoltaic installations as emitting 180 grams of CO_2-eq per kWh was based on technologies from the late 1980s. This illustrates one of the difficulties in performing lifecycle assessments on new technologies that are still in stages of rapid transformation.

Potential Role of Nuclear Power in Reducing Greenhouse Gas Emissions

As shown by the comparisons of lifecycle GHG emissions, the GHG emissions from nuclear power production are much less than the GHG emissions from either coal- or natural gas-generated power and are about equal to the GHG emissions from solar powered generation. For this reason, nuclear power is seen by some as an important tool for reducing GHG emissions. Others argue that nuclear power should not have a role in GHG emissions reduction strategies; yet others take a cautious, middle-of-the-road approach and neither rule out nuclear power nor embrace it whole-heartedly.

Those who favor nuclear power as one option for fighting climate change argue that the urgent need to address climate change precludes “closing off any major option, including nuclear power. Peter Schwartz of GBN agreed that “you cannot, in good economic sense and in good ethical sense, …afford to take the risk of removing a major supply option like nuclear power from our supply portfolio” (Energy Commission 2005e, pp.166-167).

Similarly, Professors Robert Socolow and Stephen Pacala, leaders of the Carbon Mitigation Initiative at Princeton University, identified a possible role for nuclear power in stabilizing GHG emissions by 2056. They found that doubling today’s nuclear generation to displace coal-fired generation would account for a step in GHG emissions reduction, which they refer to as a stabilization wedge. (See Figure 26.) However, nuclear power may not be critical for meeting their target, as only about seven of the 15 wedges identified must be pursued to meet this target (Scientific American 2006b).

Figure 26: Reducing GHG Emissions with Stabilization Wedges

Professors Robert Socolow and Stephen Pacala of Princeton University have proposed a comprehensive GHG reduction strategy called the "stabilization triangle." The strategy is based on the concept of two emissions paths: one representing business as usual with a constant increase in annual emissions, and the other representing the adoption of policies to stabilize annual emissions at the current rate of 7 billion tons of carbon per year. The difference between these two paths when shown graphically creates a triangle known as the stabilization triangle. The stabilization triangle represents the emissions reductions required to stabilize atmospheric CO_2 at a level below the doubling of pre-industrial CO_2 concentrations, which is considered by many to be the lower bound of dangerous emission levels.

Taken as a whole, the triangle is quite large, so it has been broken up into 7 parts each representing a reduction of 25 billion tons of carbon over 50 years. These 7 parts, called stabilization wedges, are designed to be immediately attainable using deliberate policy actions. Socolow and Pacala argue that any number of a variety of policies can be used to fill these seven wedges and that choice should be tailored to available resources, economic needs, and preferences. They propose 15 possible wedges, though only seven are needed to meet the target. Wedges include a 30 mile per gallon increase in fuel economy, a 25% reduction in residential electricity use, replacing 1,400 large coal-fired plants with gas-fired plants, doubling the use of nuclear power to replace coal power, installing carbon capture and storage technology at coal-fried plants, and expanding wind or solar generation.

Source: (Scientific American 2006b)

The UK Sustainable Development Commission (SDC) evaluated the role of nuclear power in reducing the UK's GHG emissions and reached a somewhat different conclusion. The SDC determined that "there is no justification for bringing forward plans for a new nuclear power programme at this time, and that any such proposal would be incompatible with the [UK] Government's own Sustainable Development Strategy" (UK SDC 2006c, p.20). The conclusion of the SDC was based on their finding that the UK's energy needs and GHG reduction goals could instead be met by a combination of energy efficiency, renewable energy, and more efficient use of fossil fuels combined with carbon capture technologies (UK SDC 2006c, p.19). The main concerns of the SDC with regard to nuclear power were the intergenerational impacts of nuclear waste, proliferation and security impacts, and opportunity costs that would arise from investing in nuclear power instead of other technologies.[114] These opportunity costs are described in Figure 27 (UK SDC 2006c, p.20).

Figure 27: Opportunity Costs from UK Nuclear Power Investments

The SDC identified four opportunity costs that would arise if the UK made substantial investments in nuclear power:

- Public funding of energy efficiency and renewable power programs would likely suffer.
- Political attention to energy efficiency and renewables could wane. "Even the speculative prospect of an expanded nuclear power programme in the future is already being treated by some politicians as a 'get out of jail free card,' and by some energy users as reassurance that the pressure for increased energy efficiency will soon be eased."
- Investments would likely be diverted from the network reinforcements required for high-levels of decentralized generation and the transmission lines required for new renewable generation. This would reinforce the UK's reliance on a centralized grid system at the expense of a more flexible grid optimized for renewable power.
- The UK could lose an opportunity to become a leader in a global export market for energy efficiency, large-scale renewables, and micro-generation as these technologies gain greater market penetration throughout the world.

Source: (UK SDC 2006a, pp.9-10)

The Natural Resources Defense Council (NRDC) also is concerned about the opportunity costs of investments in nuclear power. The NRDC is skeptical that the roughly $10 billion in EPAct 2005 subsidies will jumpstart the nuclear industry and believes that they will instead finance only the construction of an initial set of units that can directly benefit from the subsidies. Investments in new nuclear power plants may take 10 to 15 years for planning, licensing, and construction, and they will have an investment recovery period on the order of 25 to 40 years. Comparable investments in solar technology would yield comparable capacity additions with payback periods of just 5 to 10 years, and investments in energy efficiency would displace the need for building new power plants in the near term. Subsidies for nuclear power thus "displace government funding that could otherwise be directed toward cleaner, more competitive technologies with a much wider market potential for reducing global warming pollution" (NRDC 2007, pp.1-3). Indeed, Amory Lovins, energy expert and long-time advocate of replacing capacity additions with efficiency improvements, has concluded that "nuclear power seems about the least effective climate-stabilizing option on offer," since cogeneration, energy efficiency, and wind

[114] "Opportunity cost" refers to the cost of lost opportunities. For instance, there is an opportunity cost to keeping money under a mattress, because the money could instead be kept in a savings account where it could earn interest.

power can all be deployed faster and at less cost than nuclear power (Scientific American 2005, p.80; Lovins 2005, p.23).

The middle-of-the-road approach recognizes that there are significant challenges associated with nuclear power but believes that the magnitude of our climate change problem requires an inclusive portfolio of options. For example, NCEP and the United Nations Intergovernmental Panel on Climate Change both highlighted safety, weapons proliferation, and nuclear waste as key problems that would likely limit the role of nuclear power in the global electricity supply portfolio (IPCC 2007; NCEP 2004, pp.58-59). UCS further cautioned that a single major accident or successful terrorist attack at a nuclear power plant could stop new nuclear power development and even lead to the closing of operating plants (UCS 2007b, p.2). If nuclear power is relied upon as a major component of the nation's global warming strategy, U.S. emissions reductions could be held hostage to these risks.

To different extents, these experts all support including nuclear power in the energy portfolio in order to preserve all GHG reduction options[115] (NCEP 2004, p.41). The Council on Foreign Relations similarly concluded that to "reduce the deleterious effects of climate change, the United States will need to increase use of all low- and no-carbon emission energy sources," including nuclear power (CFR 2007, p.11).

These experts also stressed that nuclear power should be just one many GHG reduction strategies, as "nuclear energy alone does not provide a solution for at least the next few decades for significantly reducing the U.S. contribution to global warming" (CFR 2007, p.11). In addition, relying predominantly on nuclear power to reduce U.S. emissions would delay emissions reductions until at least 2014, which is the earliest that a new plant could be completed, and delay significant emissions reductions for at least 20 years, which is the earliest that a major expansion of nuclear power could be effected (UCS 2007b, pp.2, 4).

Conclusion

Supporters and opponents of nuclear power both emphasize the importance of using a number of different technologies to combat global warming. Supporters argue that the urgent need to address climate change precludes ruling out any major option, including nuclear power. Opponents argue that nuclear power development could slow down GHG emissions reductions by shifting investments away from low-GHG power alternatives, such as renewable energy and energy efficiency, which could be deployed more quickly and more cheaply than new nuclear reactors.

Ultimately, this debate over whether nuclear power should be part of a GHG reduction strategy is constrained by our limited knowledge of what other resources

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[115] NCEP recommends the pursuit of nuclear power in the near term along with other climate change mitigation options, whereas UCS recommends that nuclear power be considered only as a long-term GHG reduction strategy if other clean generating sources prove inadequate (NCEP 2007, pp.21-22) (UCS 2007b, pp.3-4).

will be available. Consequently the best path right now may to pursue all options and defer decisions until more is known, as stated by Dr. Holdren:

> [Society] might decide that the combination of improved energy efficiency, advanced fossil fuel technologies and renewable energy technologies of a variety of kinds can meet this [climate change] challenge without nuclear energy. My position is agnostic on this, we don't know yet what the best mix is, we should be trying fix the problems of fission to see if we want it to be a part of this mix and at the same time we should be pursuing with tremendous vigor the possibilities available to us in improving energy efficiency in renewable energy options and in advanced fossil fuel technologies (ABC Radio 2002).

CHAPTER 10: SECURITY FOR REACTORS AND SPENT FUEL

The protection of nuclear power plants and spent fuel storage facilities from land-based assaults, attacks by commercial aircraft, and other terrorist attacks has received considerable attention in the wake of the terrorist attacks of September 11, 2001. This heightened concern over security has been reinforced by the many extensions of operating reactors' licenses, a surge of interest in building new nuclear power plants, and growing stockpiles of spent fuel.

Terrorists' interest in nuclear power plant attacks has been well-documented. In a petition to the NRC requesting that impacts of accidents or terrorism be considered prior to the approval of high-density spent fuel pool storage, the California Attorney General cited numerous statements from the federal government about plans for such an attack (CA Attorney General 2007b, pp.8-10):

- January 9, 2002: President Bush noted that U.S. intelligence agencies had uncovered documents showing U.S. nuclear power plants at Al-Qaeda bases in Afghanistan, indicating that attacks at those facilities may have been planned.
- January 31, 2002: The NRC released an alert that warned of the potential for an attack by terrorists who planned to crash a hijacked airliner into a nuclear facility.
- May 14, 2002: A spokesman for the Office of Homeland Security noted that Al-Qaeda had been gathering information and looking at nuclear facilities and other critical infrastructure as potential targets.
- March 20, 2003: Former Energy Secretary Abraham announced that terrorists might have targeted the Palo Verde plant.
- September 4, 2003: The GAO reported that commercial nuclear power plants are possible terrorist targets and criticized the NRC's regulation of plant security.

The NRC is charged with ensuring that operators of commercial nuclear power plants are capable of protecting the public from acts of radiological sabotage. In fact, the NRC has required nuclear power plant operators to make substantial investments in enhanced security measures since 2001. However, the agency struggles to balance the concerns of plant operators that additional security requirements are excessive and too costly with critics' concerns that the same requirements are inadequate. Part of the challenge faced by the NRC in responding to critics' concerns is that much of the information about nuclear power plant security measures is withheld from the public for security reasons (i.e., to prevent terrorists from obtaining information that could aid in the plan of an attack on a nuclear power plant), and also from blue ribbon panels established by the National Academies whose independent evaluations might have resulted in enhanced public confidence.

This chapter presents an overview of current security regulations imposed by the NRC on nuclear power plant operators and the agency's steps to revise the regulations in the post-9/11 period. The chapter also reviews critics' positions on nuclear power plant security. A very public aspect of recent discussions about nuclear power plant security has been the threat posed by an attack using a commercial aircraft. This chapter reviews the results of several studies that attempted to assess this threat. Finally, the chapter briefly considers the safety of spent nuclear fuel storage and recent legal initiatives to expand the regulatory review of spent nuclear fuel storage facilities to include terrorist attacks.

Security Regulations for Operating Reactors

The NRC's Office of Nuclear Security and Incident Response oversees security at operating nuclear power plants. This office interacts with the Department of Homeland Security and other intelligence and law enforcement agencies to coordinate security for nuclear facilities.

The security requirements that nuclear power plants must adhere to are contained in 10 CFR Part 73—Physical Protection of Plants and Materials.[116] The key provisions relate to the design basis threat (10 CFR Part 73.1), physical protection requirements (10 CFR Part 73.55), and access requirements (10 CFR 73.56). Each of these is discussed in more detail below.

The Design Basis Threat

The "design basis threat" (DBT) is the basis upon which the NRC establishes safeguard systems to protect against acts of radiological sabotage at nuclear power plants and certain fuel cycle facilities and to prevent the theft of nuclear materials from those fuel cycle facilities. The DBT "characterizes the elements of a possible attack, including the number of attackers, their training, and the weapons and tactics they are capable of using." Importantly, the DBT "does not represent the maximum size and capability of a terrorist attack that is possible," but rather "the threat that the nuclear power plants must be prepared to defend against 'to ensure adequate protection of public health and safety'" (GAO 2006a, p.2). Operators of nuclear power plants use the DBT to formulate defensive strategies which are implemented through security plans, safeguards contingency plans, exercises, and guard training plans.

The DBT regulations are designed to protect against specific ground-based threats, a water-based assault, and the threat posed by an insider.[117] Before the NRC grants a license to operate a nuclear power plant, the plant operator must develop a security plan describing how the plant will defend against the types of attacks

[116] The two categories of security threats that federal regulations address are radiological sabotage and theft or diversion of nuclear materials.

[117] Nuclear plant operators are required to be prepared to defend against an "adversary force" under 10 CFR 73.1, but they are not required to defend their facilities against "an enemy of the United States" under 10 CFR 50.13.

characterized in the DBT. The NRC must approve this security plan as part of the licensing process.[118]

The NRC first issued DBT regulations in the mid-1970s (42 CFR 10838). In 1993, following the first terrorist attack at the World Trade Center in New York City and a vehicle intrusion at the Three Mile Island nuclear power plant, the NRC made substantive changes to these regulations to address the possible safety threats of a truck bomb. The NRC next reviewed the security measures and amended the DBT in the wake of the September 11 terrorist attacks.

EPAct 2005 directed the NRC to initiate a rulemaking to consider additional modifications to the DBT (PL 109-58 2005). The law spelled out 12 factors primarily focusing on different types of terrorist threats that the NRC was to take into consideration (PL 109-58 2005). The NRC launched the required rulemaking to amend the DBT in November 2005 and in January 2007 approved a final rule that amended the regulations governing the DBT (U.S. Code 2007a).[119] One significant change in the rule is the inclusion of the threat of a cyber attack as an explicit element of the DBT. Previously, cyber security threats were not addressed by the DBT.

The NRC declined to modify the DBT rule to address the threat of an airliner being intentionally flown into a reactor or waste fuel storage facility. (The threat posed to nuclear power plants by an aircraft attack is discussed below in the section *Aircraft Crash Threat to Nuclear Power Plants*.) The exclusion of an attack by a commercial airliner was a rejection of the Committee to Bridge the Gap's proposal.[120] The NRC pointed to its requirement that plant operators "take steps to mitigate the effects of large fires and explosions from any type of initiating event" (NRC 2007r). The Commissioners also pointed out that a nuclear power plant's private security forces are not the appropriate means to defend against an aircraft attack. In April 2007 the NRC announced an agency proposal that would require an applicant for a new reactor design to assess how protections can be built in to the design to avoid or mitigate the effects of a large commercial aircraft impact.

In February 2007 the Project on Government Oversight and the Union of Concerned Scientists (UCS) filed a joint petition for rulemaking, arguing that the NRC should amend its regulations to require periodic demonstrations by applicable local, state and federal entities that nuclear power plants can be adequately protected against

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[118] The general requirements of the DBT are contained in NRC's regulations 10 CFR 73.1. Specific details of the DBT are withheld from the public for security reasons.

[119] The guidance documents containing the specific measures associated with the rule are not disseminated to the public for security reasons.

[120] In 2004 the Committee to Bridge the Gap asked the NRC to "upgrade the [DBT]…and associated requirements for protection of domestic reactors from nuclear terrorism." One component of the petition asked the NRC to require all nuclear power plants to build giant steel shields consisting of I-beams and cabling—the beamhenge proposal—around the reactor units as a defense against an impact by a commercial airliner (NRC 2004).

radiological sabotage greater than the DBT (NRC 2007aa). As of May 2007, one comment had been filed—that of a concerned citizen—that asserted that the Project on Government Oversight /UCS arguments were vague and that the DBT should be strict enough to begin with so as not to necessitate that entities demonstrate a capability beyond it (NRC 2007y). The comment period for the Project on Government Oversight /UCS petition closes in June 2007, after which the NRC will issue a ruling.

GAO Assessments of Design Basis Threat

Since the September 11 attacks on the World Trade Center and the Pentagon, GAO has twice reviewed the NRC's DBT rule and its efforts to revise that rule in light of the attacks (GAO 2004a; GAO 2006a). In 2004 a GAO representative testified before the House of Representatives on the DBT as part of a broader review of security measures at nuclear power plants. The GAO followed this Congressional testimony with a report in 2006 that reviewed the process the NRC used to update the DBT in 2003.

In 2004 the GAO testified that the NRC needed to make improvements in several key areas. First, GAO found that the NRC's review of new security plans that were to be implemented by October 2004 was rushed and largely paper-based, without actual site visits. Moreover, it would take up to three years for the NRC to test the implementation of the new plans through exercises at all facilities. GAO also criticized the NRC for selecting one single company to provide both the adversary force in force-on-force exercises and the full-time security guards for about half the facilities to be tested. GAO characterized this as a conflict of interest that compromised the effectiveness of the exercises (GAO 2004a, pp.3-4).

GAO again reviewed the DBT rule in 2006. GAO found that while the process that the NRC used to revise the DBT for nuclear power plants in April 2003 was generally logical and well defined, certain problems persisted. For example, GAO reported that a lapse in protection of information about planned scenarios for a mock attack may have given nuclear power plants' security officers knowledge that allowed them to perform better than they otherwise would have (GAO 2006a, p.8). In addition, GAO noted that the NRC made changes to the NRC staff's recommendations on what should be included in the mock attacks and "decided against including two weapons that the threat assessment staff had concluded could plausibly be used against a U.S. nuclear power plant" (GAO 2006a, p.7). While these decisions "can certainly be considered by the commissioners in approving changes to the DBT," the GAO was disappointed that the NRC did not identify criteria for their decisions. According to the GAO, the absence of explicit criteria reduced the transparency of the NRC's decisions and "also potentially reduced the rigor of the decision-making process" (GAO 2006a, p.7). In particular, GAO found that "the process by which NRC used the threat assessment staff to obtain stakeholder feedback created the appearance that changes were made based on what the industry considered reasonable and feasible to defend against rather than on an assessment of the terrorist threat itself" (GAO 2006a, p.6).

GAO made the following recommendations for improving the DBT process (GAO 2006a, p.8):

- The NRC should assign responsibility for obtaining feedback from the nuclear industry and other stakeholders on proposed changes to the DBT to an office within NRC other than the Threat Assessment Section, thereby insulating the staff and mitigating the appearance of industry influence on the threat assessment itself.
- The NRC should develop explicit criteria to guide the commissioners in their deliberations to approve changes to the DBT. These criteria should include setting out the specific factors and how they will be weighed in deciding what is unreasonable for a private security force to defend against.

Physical Security Requirements

Light water reactors in the U.S. include containment buildings around the reactor vessel, steam generators, and pumps. These containment buildings are constructed of concrete with a steel liner, and are designed to limit radiation emissions even under a loss-of-coolant event. The strength of the containment should provide substantial physical protection against terrorism. While some argue that containment buildings will deter terrorists, who tend to target “soft” targets, others have noted examples of terrorist interests in nuclear power plants (Energy Commission 2005e, p.171). For example, Federal Bureau of Investigation Director Robert Mueller testified before the Senate Committee on Intelligence: “Another area we consider vulnerable and target rich is the energy sector, particularly nuclear power plants. Al-Qa'ida planner Khalid Sheikh Mohammed had nuclear power plants as part of his target set and we have no reason to believe that al-Qa'ida has reconsidered” (FBI 2005).

Current NRC requirements for physical protection of nuclear power reactors against radiological sabotage include a number of measures:

- Plant operators must establish a security organization, including guards, to protect their facilities against radiological sabotage.
- A contract guard force can be used, but the plant operator must show that it is responsible for maintaining safeguards in accordance with NRC regulations.
- The security personnel are required to demonstrate their ability to perform their assigned duties.
- One full-time member of the security organization who has the authority to direct the physical protection activities of the security organization must be onsite at all times.
- Plant operators are required to locate vital equipment within a protected area such that access to vital equipment requires passage through at least two physical barriers of sufficient strength and far enough apart to meet performance requirements. The barriers must be surrounded by well-lit isolation zones large

enough to permit observation of the activities of people on either side of the barriers.

- All of the walls, doors, ceilings, floors, and any windows in the walls and in the doors of the reactor control room must be bullet-resisting.
- Vehicle control measures must be constructed that protect against the use of a land vehicle to gain unauthorized proximity to vital areas (U.S. Code 2007a).

Access Requirements

NRC's regulations for personnel access to nuclear power plants and authorization requirements require that individuals undergo background checks into employment history, criminal activity, military experience and other areas. If these background checks do not raise doubts about an individual's trustworthiness, the individual may be granted unescorted access rights to protected areas of nuclear power plants. All individuals who are authorized access to protected areas without escort must be issued a numbered badge containing a picture. An up-to-date list of authorized people is kept by the plant operator, and unmanned areas are thoroughly locked and alarmed (U.S. Code 2007a).

In addition, licensed nuclear power plants must control all points of personnel and vehicle access into protected areas. Identification and search of all individuals and their belongings must be made at these points. Firearms and explosive detection equipment are used to detect firearms, explosives, and incendiary devices. Only bona fide federal, state, and local law enforcement personnel on official duty are exempt from these equipment searches. Plant operators conduct pat-down searches when there is a cause for suspicion that an individual is attempting to introduce weapons into protected areas. The individual responsible for controlling admission to the protected area must be isolated within a bullet-resisting structure.

In February 2007 UCS filed a petition requesting that the NRC undertake a rulemaking proceeding to amend regulations related to access requirements for nuclear power plants (NRC 2007ab). According to the petition, an individual who failed to meet the NRC's regulatory standard for trustworthiness and reliability as determined by an extensive background check nevertheless can enter protected areas of nuclear power plants as long as he is accompanied by an escort. Comments on UCS' petition are due in June 2007.

Figure 28: Contingency Plans and Emergency Procedures

The NRC requires nuclear power plant operators to have safeguards contingency plans and emergency procedures. Contingency plans guide an operator's response in the event of threats, thefts, or radiological sabotage relating to nuclear facilities or material. The plans include comprehensive logistical information including specific chain of command responsibility delegation as well as a description of the events that would kick-off a security procedure. They organize the response effort at the plant operator level with predetermined, structured responses and ensure the integration of the operator response with the responses of other entities. Contingency plans must be reviewed once per year by individuals who are independent of the security team. The reports must be maintained in auditable form and available for inspection for a period of three years.

The current framework for emergency planning was established following the Three Mile Island accident in 1979 when the NRC re-examined the role of emergency planning for protection of the public in the vicinity of nuclear power plants. A regulation was issued that established two emergency planning zones around each nuclear power plant: one for a plume exposure pathway about 10 miles in radius and one for an ingestion pathway about 50 miles in radius. Regulations also established planning procedures including preparation of notification methods, exercises and drills, and medical and public health support. In April 2001 the NRC initiated guidelines that require that consideration be given to providing potassium iodide to the general public living within 10 miles of a nuclear power plant in order to help prevent thyroid cancer. California responded in 2003 with a one-time program to distribute potassium iodide to interested parties living in the 10 mile emergency planning zone.

Evacuation models implemented for severe accidents generally use the following principles: all people within a specified radius of the incident (usually 2 miles) are evacuated, and people living downwind from the projected path of plume travel and bordering sectors are also evacuated. Under some conditions, sheltering in place is used instead of evacuation. The determination to evacuate or to shelter depends on weather conditions, competing events, whether the release was fast-breaking or short-term, and traffic conditions.

Source: (OES 2003; NRC 2007d; NRC 2007g)

Post-9/11 Enhancements to Power Plant Security

Security at U.S. nuclear power plants has been tightened since September 11, 2001. The nuclear industry claims to have spent more than $1 billion upgrading nuclear power plant security. Nevertheless, many critics believe nuclear power plants remain vulnerable to sabotage or a terrorist attack. This section discusses specific security enhancements undertaken by nuclear power plant operators in conjunction with the NRC over the past few years.

Security Exercises

Force-on-force exercises assess a nuclear power plant's capability to defend against the DBT. A full force-on-force exercise, spanning several days, includes both table-top drills and simulated combat between a mock commando-type adversary force and the nuclear power plant security force. During the attack, the adversary force attempts to reach and damage key safety systems that protect the reactor's core or the spent fuel pool, potentially causing a radioactive release to the environment. The nuclear power plant's security team, in turn, seeks to stop the adversaries from reaching the plant's equipment and causing such a release. These exercises include a wide array of federal, state, and local law enforcement and emergency planning officials in addition to plant operators and NRC personnel.

The NRC has carried out force-on-force exercises regularly at commercial operating nuclear power plants since 1991. Before September 11, 2001, NRC carried out force-on-force exercises roughly every eight years at all 65 reactor sites nationwide with exercises occurring at roughly eight sites each year. According to UCS, approximately half of the tests conducted between 1991 and 1998 revealed serious security problems (UCS 2003). Following September 11, 2001, force-on-force exercises were temporarily put on hiatus due to fears that mock attacks could distract security personnel from real threats. Then after two years of testing at almost two-thirds of the nation's nuclear power plants, the NRC redesigned its force-on-force program. The details of the force-on-force exercises are protected by law from public disclosure under the Atomic Energy Act, but it is known that an expanded table-top exercise program was conducted during 2002 and an expanded force-on-force exercise program was carried out during 2003. In addition, the NRC decided to increase the frequency of security exercises to once every three years at each plant site with tactical security drills in the intervening years. The NRC conducted 23 exercises in 2005 and planned to conduct an additional 24 in 2006 (NRC 2006a).

UCS voiced its concern that because the DBT is not based on the maximum credible threat to a nuclear power plant—rather, it is based on the largest reasonable threat—nuclear power plant security will remain vulnerable to the type of attack that occurred on September 11, 2001 (UCS 2006b). In addition, UCS believes that power plant operators are notified too far in advance of an upcoming force-on-force exercise. (The NRC provides two months advance notification.) "The advance notice provides the opportunity for security guards to drill over and over from specifically designated posts" (UCS 2006b).

A credible, well-trained composite adversary force is fundamentally important to the force-on-force program's success. Previously, the composite adversary force was made up of individuals from a number of backgrounds. Security officers from the licensed power plant site being tested, for example, were put on teams with officers from other sites, and state police officers. These diverse sources led to inconsistencies in team performance, so the NRC worked with the nuclear industry to develop a composite adversary force that is trained to NRC standards. The force is managed by a company (Wackenhut) that provides much of the security for U.S. nuclear power plants and is well-versed in the security operations of power plants.

As discussed above in the section *GAO Assessments of Design Basis Threat*, in September 2004 the GAO expressed reservations about having the same company manage both the adversary force and the security force (GAO 2004a, p.4). The NRC acknowledged "that there may be a perception of a conflict of interest" where the management company may not adequately attempt to break through its own security mechanisms; however, the agency believes the problem is remedied by making the plant security force and composite adversary force clearly separate, with no member of the force participating in an exercise at his or her home site (NRC 2007h).

Security Personnel

In the wake of the September 11 attacks, the NRC required nuclear power plant operators to both increase the number of security personnel and to improve the training that security personnel receive. Plant security officers are now trained under more realistic conditions, for example, by training to defend against moving targets. Officers are held to tougher fitness standards and restricted work hours.[121] Officers are fingerprinted and go through extensive background checks in accordance with EPAct 2005 (NRC 2007h).

Cyber Security

Cyber security is a relatively new area of concern for nuclear power plants in the post-September 11 world. In 2002 the NRC directed plant operators to address cyber safety and security vulnerabilities. The NRC also provided plant operators with methodologies to perform cyber security self-assessments. The NRC is considering new requirements to protect nuclear power plants' information technology. One proposed rule would require nuclear power plants to implement strategies to protect computer systems, detect cyber attacks, and isolate and neutralize cyber intruders (NRC 2007h). The NRC also added a cyber threat component to the DBT rule adopted in January 2007.[122]

Vulnerability Assessment

Following the September 11 attacks, the NRC initiated a security and engineering review to discover what might happen if terrorists used an aircraft to attack a nuclear power plant. Other types of potential attacks were reviewed as well. The studies' results are classified, but the NRC concluded that "the plants are robust, and the

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[121] In April 2007 the NRC proposed to revise the work schedule requirements for security guards at nuclear power plants. If adopted, the new schedule would restrict working hours and require that more time off be given between shifts (NRC 2007e).

[122] The NRC defined a cyber attack as "the capability to exploit site computer and communications system vulnerabilities to modify or destroy data and programming code, deny access to systems, and prevent the operation of the computer system and the equipment it controls" (U.S. Code 2007b).

likelihood of a radioactive release affecting public health and safety is low" (NRC 2007h).

The NRC also analyzed the ability of nuclear power plants to withstand damage to, or loss of, large areas of the plant caused by a range of postulated attacks that could result in large fires and explosions. After examining a number of emergency scenarios involving operating reactors, spent fuel pools, and dry-cask storage installations, the NRC concluded that the public near those facilities can be adequately protected should an attack occur (NRC 2007h).

As discussed in the following section, other assessments of the ability of nuclear power plants to withstand severe attacks have found the plants to be more vulnerable than suggested by the NRC's public statements.

Aircraft Crash Threat to Nuclear Power Plants

The attacks on the World Trade Center and the Pentagon combined with a statement that Al Qaeda initially planned to include a nuclear plant in its 2001 attacks intensified concerns about an attack by a large commercial airliner on a nuclear power plant. Whether an air attack by a large jet is a credible threat that nuclear power plant operators should defend against has been a widely debated subject in the years since 2001.

One of the challenges in reaching a conclusive assessment of the threat posed by an aircraft crash is that the consequences of such a crash on a nuclear facility depend on a range of factors such that the consequences become scenario-specific or site-specific (NAS 2005). For example, the type of aircraft, the speed of the aircraft at impact, the fuel loading at impact, the angle of attack, and the point of impact all would affect the outcome of an aircraft's impact on a nuclear facility. Similarly, the construction of the nuclear facility, the facility's location vis-à-vis ground level, and whether other structures surround the facility all could affect the resulting consequences from an aircraft attack on a nuclear facility.

In 1982 Argonne National Lab analyzed the potential threat to nuclear power plants posed by an aircraft crash. The report, *Evaluation of Aircraft Crash Hazards Analyses for Nuclear Power Plants,* was prepared at the request of the NRC, which wanted to determine whether future site selection for nuclear power plants should be judged on the basis of proximity to concentrations of commercial and military aircraft activities (ANL 1982).[123] The report described the two major threats associated with an aircraft crash as 1) the damage to power plant structures from a collision of the

[123] The report was available for download on the NRC Web site for years until, following the September 11, 2001, attacks, the NRC decided to remove evidence of its existence from its Web site. In 2006, journalists discovered that the study was still available in paper format at libraries around the nation with little to nothing stopping members of the public from reading its contents. This caused some to question whether NRC was adequately safeguarding the details of the study. Indeed, at least one copy can still be read at a public library in California.

aircraft and 2) the fire hazard resulting from fuel spillage in a crash. The 1982 study did not anticipate the use of airplanes by terrorists for an intentional crash, but rather looked into the consequences of an accidental aircraft crash into a nuclear power plant.[124]

The study made a number of findings:

- The major threats associated with an aircraft crash are the impact loads resulting from the collision of the aircraft with power plant structures and components and the thermal and/or overpressure effects which can arise due to the ignition of the fuel carried by the aircraft (ANL 1982, p.5).
- Any kind of crash into or near a nuclear power plant would have unpredictable results.
- Depending on the trajectory of the aircraft and the amount of jet fuel on the plane at the moment of impact, it is possible that the damage caused by the plane crash impact could be matched by the damage of the fuel explosion (ANL 1982, p.75).
- In certain scenarios it is possible for core meltdown to occur and radioactive materials to be released into the environment (ANL 1982, p.52).
- While it is possible to envision a chain of events "which could lead to severe consequences…to obtain a substantial radioactive release…it is necessary to have multiple initiating events…The crash of a large aircraft with the resulting projectile impacts, fuel spillage, and fire/explosion scenarios suggests that multiple initiating events may also be possible" (ANL 1982, pp.79-80).

A more recent study on the subject of nuclear power plant susceptibility to aircraft crash hazards was completed by GRS, a German scientific-technical research organization (Greenpeace 2002).[125] The major results of the study, which focused on

[124] The study's approach was to consider the probability that an airplane might crash near an airport or major air route (the probability drops off with distance from airports and routes) and then looked at how close nuclear power plants were to airports and major air routes. From those statistics, the authors estimated the likelihood that a plane would happen to crash directly into or in the vicinity of a plant (ANL 1982, pp.45-47).

[125] GRS stands for Gesellschaft für Anlagen - und Reaktorsicherheit mbH. GRS provides interdisciplinary knowledge and advanced methods for assessing and improving the safety of technical (especially reactor) facilities. The GRS study evaluated the dangers to Germany's nuclear power plants from aircraft crashes posed by three aircraft weight types traveling at two possible velocities crashing into five different reactor types. Mechanical, thermal, and vibration impacts were taken into account with various degrees of severity. A professional flight simulator was used to assess various flight impact trajectories and speeds. The report's findings were considered so sensitive that it was never released publicly and remains classified by the German government. A confidential summary made by the Ministry of Environment apparently was leaked to the German and Austrian press. In 2004, Greenpeace Germany translated the leaked document into English. This section is based on that translation.

Germany's reactors, are as follows:

- Plants that were designed to withstand an accidental airplane crash generally would fare better in an intentional attack, even though large passenger aircraft are considerably larger than the jets used as references in the plant designs.[126]
- Predictions for the fallout of a crash are subject to a great deal of uncertainty.
- In almost all circumstances, release of radioactive material only occurs when there is extensive destruction of the reactor building, penetration of the reactor building, and/or destruction of the control room by debris or fire.
- The location of the spent fuel pool can impact the vulnerability of the site -- one reactor with a spent fuel pool located high up in the reactor building was shown to be particularly vulnerable.
- Physical protection of the control room from fire and impact damage is nearly as important as protection of the reactor itself.

The study recommended that, as a preventative measure, objects be erected outside of a reactor to reduce the accessibility of the target and the forces acting on it (Greenpeace 2002, p.5). It also stressed that plant-specific analysis is needed because local variations and specific plant designs have major impacts on the vulnerability of a plant.

Security of Commercial Spent Fuel Storage

Spent fuel stored either in a pool or in dry casks is not protected by the same containment structure that protects a nuclear reactor. Thus, some critics argue that spent fuel storage areas are more vulnerable to attack than reactors. If an attack on a spent fuel pool breached the pool's concrete walls, leading to drainage of the water, the spent fuel's zirconium cladding could overheat and catch fire or melt, potentially releasing harmful levels of radioactive material to the surrounding area.

Robert Alvarez along with other scientists published a study in 2003 that included a number of proposals and design recommendations to limit the chance of a fire in a spent fuel pool (Alvarez et. al. 2003). The study recommended that Congress decide the probability of a terrorist-caused spent fuel pool fire, and that the NRC require nuclear power plant operators to have the capability to repair spent fuel pools under accident conditions or after an attack. The study noted that all of its proposals required further detailed analysis and some would involve risk tradeoffs that also would have to be further analyzed.

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[126] According to the translated summary, GRS identified five reference plants including three PWRs and two BWRs. Of these five reference plants, two (one PWR and one BWR) had been designed to withstand a crash by a Phantom jet, one (a PWR) for a Starfighter jet, and two had not been explicitly designed against an airplane crash.

In a 2005 study the National Academies' Committee on the Safety and Security of Commercial Spent Nuclear Fuel (Spent Fuel Safety Committee) investigated the vulnerability of commercial nuclear power plant spent fuel storage facilities to terrorist attack (NAS 2005). The Spent Fuel Safety Committee concluded that spent fuel storage facilities cannot be ruled out as potential targets, that attacks by knowledgeable terrorists with access to appropriate technical means are possible, that dry cask storage has inherent security advantages over spent fuel pool storage. and that "under some conditions, 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" (NAS 2005, pp.35, 37). To reduce the likelihood of a zirconium cladding fire in the event that a spent fuel pool was partially or completely drained, the Spent Fuel Safety Committee presented two recommendations (NAS 2005, p.59):

- Spent fuel stored in pools should be configured such that recently discharged fuel assemblies are stored near older and colder ones, rather than near other recently discharged fuel assemblies.
- Sprinkler systems should be installed that could operate even if the spent fuel pool or overlying building was badly damaged.

The Spent Fuel Safety Committee noted that siting spent fuel pools below grade and surrounding them by other structures make them less attractive as potential terrorist targets (NAS 2005, pp.43, 59). The Spent Fuel Safety Committee also noted that the NRC's determination that the committee "did not have a need to know" certain information prevented the evaluation of "several important issues," and recommended that "an independent review of post-9/11 spent fuel storage security be undertaken" (Energy Commission 2005e, p.195).

Legal Requirements

In 2003 the San Luis Obispo Mothers for Peace (MFP) challenged the NRC's approval of the Diablo Canyon ISFSI, claiming, among other things, that the NRC should have considered the potential environmental impacts of a terrorist attack on the facility as part of the NEPA EIS process.[127] This legal challenge, which intended to expand the regulatory review of spent fuel storage facilities to include terrorist attacks, has been repeated by California and Massachusetts.

The U.S. Ninth Circuit Court of Appeals agreed with MFP that the NRC must weigh the environmental effects of a terrorist attack in its analysis of industry construction projects. The court ruled that the NRC had improperly determined that a terrorist attack is too far removed from the natural or expected consequences of agency action and sent the matter back to the NRC for reconsideration (MFP v. NRC 2006, p.6096).

[127] The California Attorney General filed a brief with the Ninth Circuit Court in support of MFP (CA Attorney General 2004).

PG&E filed a petition for a Writ of Certiorari with the Supreme Court asking the court to review the appellate court decision. The U.S. Chamber of Commerce and NEI filed amicus curiae briefs in support of PG&E's petition (PG&E v. MFP 2006). The U.S. Chamber of Commerce argued that Congress never intended NEPA to address national security or threat assessments and that the ruling would lead to endless litigation and red tape that would greatly burden the industry in the future. PG&E, in its petition for Writ of Certiorari, listed the following adverse consequences that it believed would result if the appellate court ruling were left to stand (U.S. Supreme Court 2006):

- The decision would unduly burden PG&E and other participants in the NRC regulatory process without advancing NEPA's goals.
- Adoption of the court's logic would necessitate that any agency conducting a NEPA review for a proposed chemical plant, oil pipeline, liquefied natural gas pipeline, skyscraper, dam, bridge, or tunnel somehow establish that terrorist attacks on such a facility are highly speculative or else postulate a successful attack and evaluate its environmental consequences.
- The decision creates uncertainty and potential delay for PG&E at the Diablo Canyon Nuclear Power Plant.
- The decision raises serious national security concerns as it may necessitate the disclosure to the public of security details otherwise left secret.

The Supreme Court rejected the petitions in January 2007, sending the matter back to the NRC (PG&E v. MFP 2006). In response, the NRC conducted a supplemental environmental analysis to consider the impact of a terrorist attack on the Diablo Canyon ISFSI. The NRC concluded that the probability of a successful terrorist attack on an ISFSI is very low and that, in the event of a successful attack, the radiation dose to members of the public near the facility would be below the dose limit for workers in the nuclear industry (NRC 2007u).

The decisions of the Ninth Circuit Court and the Supreme Court have been cited by a number of petitioners in recent NRC license renewal proceedings to bolster arguments that the risks of terrorism should be considered as part of the EIS process in these contexts. (License renewal proceedings are discussed further in Chapter 12.) The NRC has thus far resisted these efforts. The NRC explained its position in a Memorandum and Order in the Oyster Creek license renewal proceeding, providing six reasons that the impact of terrorism should not be considered in the EIS review (NRC 2007n, pp.5-18):

1. The NRC has already examined the environmental impacts of terrorism and found them to be similar to the impacts of severe reactor accidents, which were considered as part of the license renewal generic EIS process in 1996.
2. While the NRC will comply with the Ninth Circuit decision in the Diablo Canyon proceeding, it disagrees with this decision and will not apply it to all of its proceedings. As explained in the Memorandum: "[The] NRC is not obliged to adhere, in all of its proceedings, to the first court of appeals decision to

address a controversial question. Such an obligation would defeat any possibility of a conflict between the Circuits on important issues" (NRC 2007n, p.5).

3. Terrorism contentions are security matters and not aging-related matters. Consequently, they are "beyond the scope of, not 'material' to, and inadmissible in" license renewal proceedings (NRC 2007n, p.5).
4. The environmental impacts of terrorism are too far removed from the "natural or expected consequences of agency action" to be relevant to an EIS process. "[T]he claimed impact is too attenuated to find the proposed federal action to be the 'proximate cause' of that impact" (NRC 2007n, p.6).
5. An additional review of the risks of terrorism would be superfluous, since the NRC "has undertaken extensive efforts to enhance security at nuclear facilities, including (most recently) proposing a new and more stringent 'design basis threat rule.'…[This] rulemaking is the appropriate vehicle for addressing the current terrorism risk—a risk faced by nuclear facilities in general (and for that matter by other industrial facilities), rather than a risk peculiarly related to operating a nuclear facility beyond its initial license…[p]articularly in the case of a license renewal application, where reactor operation will continue for many years regardless of the Commission's ultimate decision, it is sensible not to devote resources to the likely impact of terrorism during the license renewal period, but instead to concentrate on how to prevent a terrorist attack in the near term at the already licensed facilities" (NRC 2007n, pp.7, 12).
6. Security difficulties could be created by the review of impacts of terrorism within a *public* EIS process (NRC 2007n, p.8).

In the license renewal proceeding for Entergy's Pilgrim Nuclear Power Station, the Massachusetts Attorney General requested a hearing to consider the adequacy of the EIS, which did not consider environmental impacts of terrorism, in light of the Ninth Circuit's ruling in NRC vs. Mothers For Peace. NRC staff denied the hearing request, following the reasoning outlined above, and advised that in order to litigate this issue, the Attorney General must first petition for a change in the rule (NRC 2006s, pp.1-12).

In August 2006 the Massachusetts Attorney General filed a petition for rulemaking with the NRC requesting that all NRC regulations that imply or assume that the environmental impacts of storing spent fuel in high-density pools are insignificant be revised or revoked; that the NRC issue a determination that these impacts, including the impacts of intentional sabotage of a spent fuel pool, are significant; and that the NRC require that these environmental impacts be considered in all NRC licensing decisions (including license renewals) that approve high-density pool storage. The petition also requests that the Pilgrim and Vermont Yankee license renewal decisions be withheld pending the results of this rulemaking (MA Attorney General 2006, pp.2-3, 5).

The comment period for this petition ended on March 19, 2007, and 68 public comments were received (NRC 2007m). The NRC has not yet announced whether it will open the requested rulemaking.

On March 16, 2007, the California Attorney General filed a similar petition for rulemaking that more directly requests that the impact of terrorism on spent fuel pools be considered (CA Attorney General 2007a, pp.1-2):

> [No] NRC licensing decision that approves high-density pool storage of spent nuclear fuel at a nuclear power plant or other storage facility may issue without the prior adoption and certification of an environmental impact statement that complies with NEPA in all respects, including full identification, analysis, and disclosure of the potential environmental effects of such storage, including the potential for accidental or deliberately caused release of radioactive products to the environment, whether by accident or through acts of terrorism, as well as full and adequate discussion of potential mitigation for such effects, and full discussion of an adequate array of alternatives to the proposed storage project.

The petition notes that federal agencies routinely predict the degree and scope of the terrorism threat, and so, to a certain extent, the risk of an attack directed at a particular nuclear facility is quantifiable. It notes further that it is reasonably foreseeable that there will be an attempted terrorist attack on at least one American nuclear facility. Since spent fuel pools are less protected than reactors, an attack on a spent fool pool "could have devastating effects on the environment" (CA Attorney General 2007a, p.11). The NRC has not yet announced a schedule for considering this petition.

Conclusion

In 2004 the National Commission on Energy Policy made the following observation about nuclear safety and security:

> Nuclear power reactors of contemporary design have compiled an excellent safety record. If the number of nuclear reactors in the United States is to double or triple over the next 30 to 50 years, however, and the number worldwide is to grow ten-fold…one would want the probability of a major release of radioactivity, measured per reactor per year, to fall a further ten-fold or more. This means improved defenses against terrorist attack as well as against malfunction and human error…License extensions for existing plants and the issuance of licenses for new plants should be contingent on the [NRC's] affirmative judgment that that the plants…[are] adequately resistant to terrorist attack (NCEP 2004, pp.58, 60).

Over the past five years, the NRC has instituted a number of measures to improve the security of U.S. reactors. However, the NRC's process for determining which concerns need to be addressed and how they should be addressed has not always been transparent, even to governmental or quasi-governmental organizations such as GAO and the National Academies.

This secrecy, particularly with regard to the GAO and the National Academies, has made it difficult for the NRC to develop public confidence in its actions. Indeed, critics and members of the public continue to question the adequacy of the NRC's security regulations.

CHAPTER 11: RELIABILITY AND SAFETY OF U.S. NUCLEAR REACTORS

The aging of the U.S. fleet of nuclear power reactors presents challenges in terms of the reliability and performance of nuclear power plants and also the safety of these plants. California has a clear interest in ensuring the reliability of each of the three nuclear power plants providing electricity to the state for a number of reasons:

- The plants provide about 15 percent of the state's electricity supply.
- The reliability of nuclear power plants is closely linked to their safety, as many of the events that lead to unexpected or extended plant shutdowns also compromise plant safety.
- Nuclear power plants are very capital intensive but have relatively low operating costs. Capital costs can be recovered through the sale of power only while the power plants remain online and generate power.
- Nuclear power plants have relatively low operating costs relative to gas-fired generation. The more nuclear power that is available, the lower the overall cost of electricity to ratepayers.
- California's nuclear power plants are among the largest power plants in the state, and SONGS, in particular, provides substantial reliability benefits to the state's transmission system (Energy Commission 2006e, pp.51-56).

In recent years, U.S. nuclear power plants have proven to be reliable generation sources, with an average availability rate of 90 percent in 2006. However, some plants have experienced significant difficulties and poor availability. In all, of the 130 power reactors ever licensed in the U.S., 41 have had at least one outage lasting a year or more.

In addition, industry critics argue that the current reactor oversight process is ineffective at spotting and preventing problems before they require expensive repairs and extended shutdowns. If their concerns are correct, reliability levels at a plant could plummet with little warning at any time, as they did at Davis Bessie in 2002 and at Palo Verde beginning in 2003.

The first section of this chapter describes the regulatory framework that oversees the safety and reliability of these plants and critics' concerns about the effectiveness of this framework. The second section presents an overview of the reliability status of U.S. nuclear power plants. The final section discusses the reliability of the California nuclear power plants, the impact on California when its nuclear units are shut down, and the causes of and responses to the recent difficulties at Palo Verde.

Regulatory Framework

The safety and reliability of U.S. nuclear power plants is overseen both by the NRC and by a private, industry-funded group called the Institute for Nuclear Power

Operations (INPO). NRC regulations carry legal authority, while INPO provides an additional layer of oversight that is backed by peer pressure rather than the force of law. Some critics maintain that oversight of reactor reliability and safety is insufficient even with this dual government/industry approach.

NRC Oversight

The NRC is responsible for ensuring the safe operation of the 103 commercial nuclear power plants operating in the U.S. Following the Three Mile Island accident in 1979, the NRC implemented the Systematic Assessment of Licensee Performance. Yet, serious problems have persisted at some plants. Considerable reactor vessel head degradation was discovered at Ohio's Davis-Besse nuclear power plant in 1985 and the Dresden nuclear power plant near Chicago was on the NRC's Watch List for eight years during the 1990s.

In 2000 the NRC launched the Reactor Oversight Process (ROP), which is the current regulatory framework for ensuring reactor performance and safety. The ROP is a risk-informed approach to reactor safety. In other words, issues or activities that most affect safety become the focus of inspections and the level of regulatory oversight increases as a plant's performance declines.

There are essentially two components that feed into the ROP: plant inspections conducted by the NRC and nuclear power plant operators' reporting to the NRC of various plant performance indicators. Plant inspections are characterized as baseline, supplemental, or special. All plants are subject to baseline inspections. Supplemental inspections and special inspections are conducted when performance problems arise or when a specific incident warrants further investigation. Nuclear power plant operators are required to self-report their performance across a set of established indicators.

The ROP framework monitors nuclear reactors' performance in three broad areas: reactor safety, radiation safety, and safeguards. Within these areas, performance is further measured across seven "cornerstones," which are areas fundamental to plant performance and operation.[128] A four-color system—green, white, yellow, and red—is used to characterize the NRC's findings within each of these cornerstones. A finding of green indicates that the NRC expects no safety impacts while white, yellow, or red findings represent increasing degrees of safety concerns. Depending on the number of white, yellow, and red findings, the NRC categorizes each plant into one of five columns in its Action Matrix, which is shown in Table 32 along with the NRC action for each classification.[129]

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[128] The seven cornerstones are initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection.

[129] The assessment for each plant and other ROP results are available to the public on the NRC's Web site.

Table 32: NRC Action Matrix Assessments

Assessment	NRC Response
Licensee Response	• Routine inspector and staff interaction • Baseline inspection program • Annual assessment public meeting
Regulatory Response	• NRC staff to hold public meeting with utility management • Utility corrective action with NRC inspection follow-up on white inputs and corrective action
Degraded Cornerstone	• Senior NRC regional management to hold public meeting with utility management • Utility to conduct self-assessment with NRC oversight • Additional inspections focused on cause of degraded performance
Multiple/ Repetitive Degraded Cornerstone	• NRC Executive Director for Operations to hold public meeting with senior utility management • Utility develops performance improvement plan with NRC oversight, and NRC team holds an inspection focused on cause of degraded performance • NRC issues a Demand for Information, Confirmatory Action Letter, or Order
Unacceptable Performance	• Plant not permitted to operate • NRC Commission meeting with senior utility management • NRC issues an order to modify, suspend, or revoke license

Source: (NRC 2007ag)

Since 2001, the ROP has resulted in more than 4,000 inspection findings of plant non-compliance with safety requirements, and the NRC has subjected more than 75 percent of U.S. plants to increased oversight for varying periods. Most of these inspections findings were for actions that the NRC considered of low safety significance but necessary to correct (GAO 2006b).

As of May 2007, two reactors, including Palo Verde Unit 3, were listed in the Multiple/Repetitive Degraded Cornerstone column. Eight reactors, including Palo Verde Units 1 and 2, were listed under the Degraded Cornerstone column, and 24 reactors were listed under the Regulatory Response column. Diablo Canyon Units 1 and 2 and SONGS Units 2 and 3 plus all the remaining reactors were listed under the Licensee Response column.[130] No reactors were listed under the Unacceptable Performance column.

[130] All inspection findings and all licensee-reported performance indicators were categorized as green for both Diablo Canyon and SONGS in 2006 (NRC 2007ag).

INPO Oversight

In addition to NRC oversight, INPO provides voluntary, quasi-regulatory oversight of U.S. nuclear power plants. INPO is a private organization established and funded by the nuclear utility industry following the accident at the Three Mile Island nuclear power plant. As described by Paul MacAvoy and Jean Rosenthal,

> INPO can be seen as an industry-wide effort to enhance performance beyond that which is strictly consistent with regulatory compliance…Unlike most trade groups, which act to protect their constituents from regulations, INPO has taken on the role of super-regulator, attempting to define safe operations more rigorously than the NRC and to require management's voluntary compliance with these higher standards across the country (MacAvoy and Rosenthal 2005, pp.37-38).

INPO conducts periodic plant inspections as part of its mission to promote operational excellence at nuclear power plants in the U.S. For a typical inspection, 15 to 20 evaluators remain at the reactor site for two weeks. Their inspection report identifies strengths and areas for improvements and provides an overall rating for the plant (ACC 2006b, p.15). INPO "uses pressure, described as 'peer humiliation,' to impress upon management the importance of higher-level safety in operations found in other plants, to break down the insularity of companies and encourage the sharing of expertise" (MacAvoy and Rosenthal 2005, p.38).

INPO publicly releases only high-level summary data on nuclear power plants' operating performance and requires power plant operators to hold INPO performance evaluation information in strict confidence. The high confidentiality standards are meant to "to minimize nuclear power plant operator concerns about divulging information to INPO for fear that the information will later be used against a nuclear power plant operator" (SCE 2007c, pp.7-8).

The (limited) data released by INPO for 2005 portrays an overall positive picture of the safety and reliability of U.S. nuclear power plants while highlighting areas for improvement (INPO 2005):

1. The nuclear industry met or came within 1 percent of meeting its targets for unit capability, unplanned automatic emergency shutdowns (scrams), unplanned capability loss, and industrial safety.
2. The nuclear industry did not meet its targets for radiation exposure. The collective radiation exposure of BWRs was 28 percent higher than the 120 person-rem per unit target; the collective radiation exposure of PWRs was 5 percent higher than the 65 person-rem per unit target.

3. Over 90 percent of plants achieved their goals for the availability of standby safety systems and for chemistry performance.[131] Only 76 percent of units achieved the goal for fuel performance of having zero defects in the barrier that surrounds the fuel.
4. The unplanned scram rate in 2005 was zero compared with a benchmark target of 1.0 scrams per 7,000 hours critical. According to INPO, a low scram rate for a plant indicates "effective operations, engineering, maintenance and training programs" (INPO 2005, p.22).

Critics' Concerns with the Regulatory Framework

Critics of the ROP argue that the "sea of green" findings provide a false sense of strong plant performance and safety. ("Sea of green" refers to the very high number of reactors that achieve a green finding across the seven cornerstones in the ROP framework.) To underscore their point, UCS and other critics point to the Davis-Besse reactor vessel head incident.

In 2002 it was discovered that the Davis-Besse plant had extensive corrosion, including a pineapple-sized cavity in the reactor vessel head. This corrosion, which was unexpectedly discovered during an outage to repair the control rod drive mechanism nozzles, presented a potentially dangerous situation. The process to repair the plant and assure the NRC that the plant had an acceptable safety culture resulted in an outage lasting over two years. However, just before the discovery of the corrosion, the NRC had completed an inspection and awarded the plant a perfect score with 18 green ratings (Energy Commission 2005f). The NRC had also considered Davis-Besse to be one of the best performing plants in the region (UCS 2006a). This discovery led the NRC to reexamine its safety oversight to determine how such corrosion could have been missed and to make several changes to the ROP accordingly (GAO 2006b, p.2).

Incidents like the one at Davis-Besse have led to concern over the ability of the ROP program to ensure the safe operation of the country's plants. Peter Bradford has alleged that the Davis-Besse incident in 2002 was a case where "the NRC allowed the economic interests of the plant owner to override a staff recommendation that the plant be shut down for inspection" (Energy Commission 2005f). NRC described the incident as a "significant learning experience for both the NRC and the industry" and issued a series of recommendations designed to prevent similar problems in the future (Energy Commission 2005f). According to GAO, NRC oversight has improved in recent years; however, concerns remain over the NRC's ability to identify and address problems before they result in significant performance or safety issues. (See Figure 29.)

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[131] The standby safety systems are two main cooling systems and their backup power supplies. Chemistry performance is a measure of the chemistry control based on the concentration of impurities and corrosion products.

Additional concerns about the nuclear reactor oversight process emerge from considering the history of extended outages at U.S. nuclear power plants and the events leading to the shutdown of the Millstone plant. These are discussed below.

Figure 29: GAO Assessment of the NRC's Plant Safety Oversight

In 2006 GAO conducted an assessment of the NRC's plant safety oversight program. GAO found that the NRC has begun to focus its inspections on areas most important to safety, has reduced the time needed to determine the risk significance of inspection findings, and has improved the way that some performance indicators are measured. However, GAO also found that work still needs to be done to improve the NRC's ability to identify and address early indications of declining plant safety performance, particularly as it relates to improving plants' safety cultures.

GAO found that deficiencies in safety culture can have a significant impact on plant performance. In fact, according to GAO, plant performance decline is often the result of ineffective problem identification and resolution programs, problems related to human performance, or complacent management. GAO recommended that the NRC "aggressively monitor; evaluate; and, if needed, implement additional measures to increase the effectiveness of its safety culture changes and make publicly available more information on nuclear power plants' safety culture."

Source: (GAO 2006b)

UCS Review of Year-Plus Reactor Outages

UCS analyzed decades of data on outages at U.S. nuclear reactors and found that over the past 40 years reactor shutdowns lasting a year or longer have occurred 51 times at 41 different plants. Year-plus outages should not occur regularly and are seen as evidence of underlying safety and management problems. In many circumstances extremely dangerous accidents have been only narrowly avoided. The UCS study found that "the vast majority of these extended outages were caused not by broken parts but a general degrading of components to the point that safe operation of the plant required a shutdown for broad, system-wide maintenance" (UCS 2006a, p.1). According to the study, these outages have resulted in 135 reactor years of downtime or the equivalent of 3.4 reactor lifetimes.

The UCS study attributed the majority of year-long outages to a number of oversight problems at management and regulatory levels. For example, the study identified issues of regulatory leeway given to plant operators, exclusion of public participation, inability to address concerns in a timely manner, and poor communication within the NRC. The study also drew attention to the performance of facility Corrective Action Programs in the identification of safety issues. Each facility is required to have an effective Corrective Action Program or internal Quality Assurance program to identify and address safety concerns. The purpose of the Quality Assurance program is to prevent safety problems; thus failure of the Quality Assurance program is implied in each incidence of NRC findings of safety issues. "Yet findings by NRC inspectors are treated no differently than findings by individual workers, their supervisors, and internal auditors. The NRC inspector's finding is entered into the very Quality Assurance program that has just proven faulty, raising concerns that the finding will not be used effectively to improve the situation" (UCS 2006a, p.29).

Among the three "worst" year-plus outages discussed in the study was the outage that occurred at SONGS Unit 1 between February 1982 and November 1984. Concerns had been raised about the ability of SONGS 1 to withstand seismic activity as required by regulations, but petitions to shut down the reactor were denied. In 1982 when the reactor was brought down for scheduled refueling, it was discovered that vital reactor equipment could not withstand an earthquake of the size mandated by regulations. SCE voluntarily began upgrading the reactor, and in August 1982 the NRC subsequently issued an order requiring the upgrades. In 1984 the CPUC ruled that if it was not in service by the end of the year SONGS 1 would be removed from the rate base. In response to this ruling and SCE lobbying NRC allowed SONGS 1 to be restarted despite the fact that it was not in compliance with the August 1982 order (UCS 2006a, p.31). According to UCS, incidents such as this illustrate concerns about the ability of the NRC to effectively ensure the safety of operating nuclear power plants.

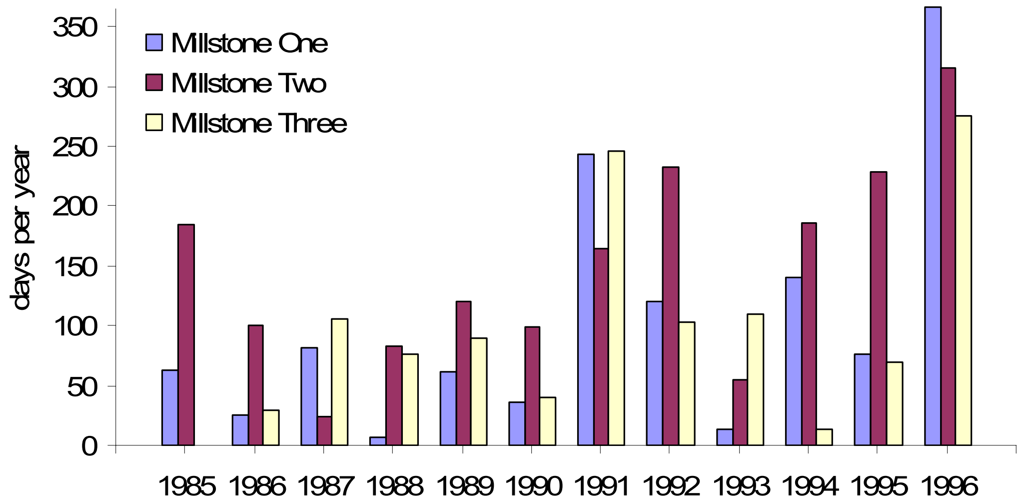
Millstone

In 1996 the NRC shut down the three Millstone units in order to force the plants' owner, Northeast Utilities, to address longstanding and significant safety concerns that had resulted from over a decade of cost-cutting and risk-taking at the plants. Cost cutting, which included reducing the number of nuclear engineers and eliminating all capital projects that were not strictly necessary to sustain operations, reduced revenue requirements for Millstone by over 15 percent between 1987 and 1989 (MacAvoy and Rosenthal 2005, pp.43-45). However, it also impacted the plant's safety and performance. A 1990 internal memo described the situation as follows:

> We have clearly become more efficient…At the same time we have increased demands on some of our employees beyond reasonable levels and have moved away from an overall proactive environment…[The chemistry department] has been unable to respond to plant needs due to lack of certified instructors. There are insufficient resources to support the expansion of inspections. Updates of the [safety reports are] not being done adequately or in a timely manner…Technicians have been working 10 percent overtime for two years and are continuing to lose ground (MacAvoy and Rosenthal 2005, p.45).

Northeast Utilities' cost-containment policies quickly began to affect the performance of the plant. One or more of the units had an extended outage each year of operation during the 1990s due to "unexpected technical and operating difficulties" and “weaknesses in work control processes” that led to equipment failures (MacAvoy and Rosenthal 2005, p.78). (See Figure 30.)

Figure 30: Millstone Outages, days per year[132]



Source: (MacAvoy and Rosenthal 2005, p.51)

The NRC took note of these repeated failures and conducted special investigations at the Millstone facilities. NRC reports described the problem-solving process and safety evaluations at Millstone as having too narrow of a focus. They also described a lack of a questioning attitude in problem-solving and a lack of an effective corrective actions process. In addition, they noted instances in which “degraded and nonconforming conditions were not properly corrected, line management did not respond to findings from their own quality assurance organization, and the root causes and programmatic implications of identified issues were not addressed in a timely fashion” (MacAvoy and Rosenthal 2005, pp.93-94).

INPO also took note of these failures and presented a highly critical report of Northeast’s nuclear performance to the Northeast Utilities Board of Trustees in 1995. There is no documented response to this meeting—INPO’s strategy of ‘peer humiliation’ appears to have been ineffective in this case (MacAvoy and Rosenthal 2005, p.79).

Ultimately the NRC shut down all three units. Northeast Utilities spent more than $1 billion to reconstruct and relicense two of the units, which were subsequently auctioned off to another generating company. Its third unit was closed permanently. Northeast Utilities also faced and admitted to criminal charges related to certain high-risk operating practices (MacAvoy and Rosenthal 2005, pp.xi, 88).

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[132] Outage data is not available for Millstone One in 1985.

In *Corporate Profit and Nuclear Safety*, Paul MacAvoy and Jean Rosenthal analyzed the strategic decisions by Northeast that led to these events and offered two views of Northeast's strategy. In one view, management knowingly took on what were initially relatively small risks in order to cut costs and did not know that they were placing the plants at greater risk until it was too late to turn them around. In the other view, management gamed the NRC regulatory process:

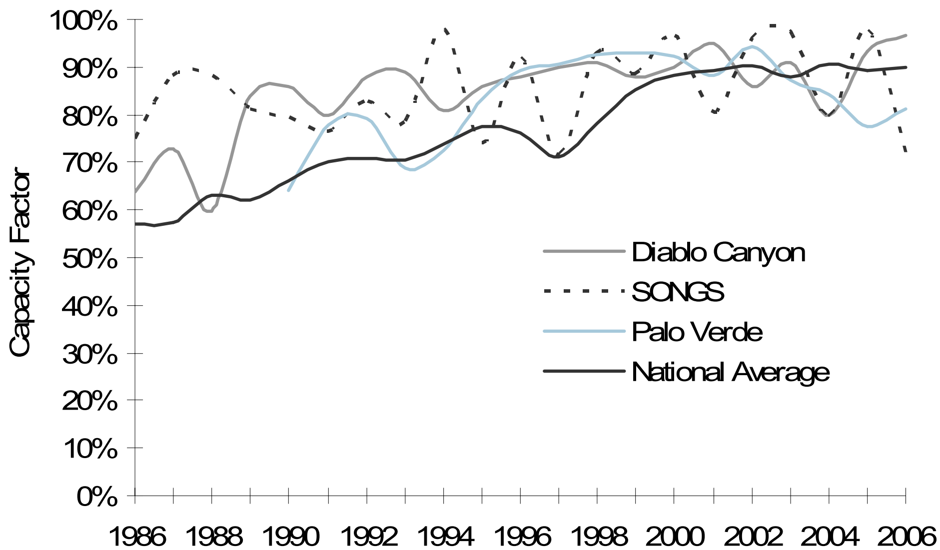
> [Northeast] management treated cost containment and NRC rules in nuclear plant operations as if they were conceptual trade-offs, and deliberately chose a low-cost/lax-rule option. In this view, management was far from incompetent, or distracted, in choosing an option that contained increasing risk of NRC shutdown. With top-down budgeting, it implemented a strategy with significant increases in earnings and with significant and sustained risk of nuclear operational problems. That risk was high compared to regulatory risk in other strategies; there was never a certainty of shutdown, but it was embedded in the strategy of choice. This implies that cost containment was not merely a source of conflict in solving operational problems, but instead was an established plan for not solving operational problems because it could not permit making the expenditures required to provide those solutions (MacAvoy and Rosenthal 2005, pp.108-110).

Upon reviewing events that led to the Millstone shutdown, the NRC Inspector General found that "Millstone changes in program initiatives and management reorganization lulled the NRC staff into allowing an excessive amount of time for proposed corrective action to take effect. The sporadic improvements neutralized the NRC staff willingness to take prompt action" (MacAvoy and Rosenthal 2005, pp.108-110).

Reliability of U.S. Nuclear Power Plants

The overall reliability of U.S. nuclear power plants has markedly improved since the 1980s and even the 1990s. (See Figure 31.) According to the Analysis Group, an economic, financial, and strategy consulting practice, improvement in nuclear power plant performance in recent years can be attributed in part to consolidation of ownership and operations of nuclear power plants, which has occurred mainly in competitive wholesale markets. Consolidation "has had a significant impact on the amount of nuclear energy available to the market and consequently on production costs…As a general rule, owners with more nuclear capacity have tended to be more efficient than owners of just a single unit" (Analysis Group 2007b, p.28). In fact, the Analysis Group found that ownership changes at New York nuclear power plants increased the output of these plants by 10 percent (Analysis Group 2007a).

Figure 31: Capacity Factors of U.S. and California Nuclear Power Plants[133]



Source: (NEI 2005; NEI 2007d; PG&E 1985-2004, p.402; SCE 1985-2004, p.402)

Reliability of California's Nuclear Power Plants

California nuclear power plants, which are owned by utilities that operate just a few nuclear units, lagged behind the national industry average during the five-year period from 2002 through 2006. The capacity factors of the California units were 89 percent (Diablo Canyon and SONGS) and 85 percent (Palo Verde), as compared to the national average capacity factor of 90 percent. In 2006, the capacity factors of SONGS (72 percent) and Palo Verde (81 percent) were both well below the 90 percent national average capacity factor for the year, while the capacity factor of Diablo Canyon (97 percent) was above the national average (NEI 2007d). The low capacity factor at SONGS can be attributed to extended refueling outages at both units.[134] The reasons for the low capacity factor at Palo Verde are discussed below.

As indicated by these figures and shown directly in Table 33, the amount of time that a plant is offline due to planned and unplanned outages varies from reactor to reactor. Among the three nuclear power plants serving California, Diablo Canyon's reactors spent the least amount of time offline between 2001 and 2006, with each unit shut down for an average of 34 days per year (PG&E 2007b, I1). PG&E estimates that it spent $731.4 million ($2006), or $122 million per year, on

[133] The capacity factor measures the availability of the power plant throughout the year.

[134] The refueling outage for Unit 2 lasted for 109 days, and the refueling outage for Unit 3 lasted for 57 days (SCE 1995-2004, p.24).

replacement power costs during this period.[135] These costs were especially high during 2001 and 2002 when market prices were very high. Replacement power costs from 2003 to 2006 averaged $103 million ($2006) per year (PG&E 2007b, I2).

Palo Verde Unit 1 spent the most time offline during this period, averaging 64 days per year throughout and 99 days per year from 2004 through 2006. As discussed below, most of these outages were due to unexpected difficulties at the plant; only about 40 days can be attributed to the reactor's extended refueling outage in the fall of 2005 for the steam generator replacement (SCE 2007a, I1). SCE did not provide an estimate of its replacement power costs during SONGS and Palo Verde outages. However, it has been reported that SCE spent $4.5 million per month to purchase replacement power or fuel when Palo Verde was taken out of service during the first half of 2006 (Greenwire 2006).

Table 33: Outages at Nuclear Power Plants Serving California

2001-2006	**Total Outage Time** (Days)		**Duration of Refueling Outages** (Days)		
	Refueling	*Other*	*Average*	*Shortest*	*Longest*
Diablo Canyon 1	149	62	50	30	78
Diablo Canyon 2	171	22	43	30	52
SONGS 2	210	51	70	43	109
SONGS 3	222	184	56	32	92
Palo Verde 1	191	192	48	33	77
Palo Verde 2	206	87	51	32	79
Palo Verde 3	178	111	44	33	66

Source: (PG&E 2007b, I1; SCE 2007a, I1)

Table 33 also shows that refueling outages, which are required roughly every 18-20 months, often extend longer than their target of about 30 days, sometimes extending two or three times as long (or more) (PG&E 2007b, I1; SCE 2007a, I1). In the event of an extended outage, PG&E and SCE would use alternate sources of power to meet customers' demand. For example, they could dispatch other utility-owned resources, purchase spot market power, rely on the forward markets, and/or seek replacement power through a request for offers or a new utility-owned generation project, depending on the relative costs of these options and the expected length of the outage (PG&E 2007b, I4, I5; SCE 2007a, I4, I5). However, PG&E has warned that obtaining replacement power would likely be "at significant additional financial cost to PG&E customers and, depending on the duration of the outage, with up to 8-10 million tons of GHG emissions annually, assuming 2,300 MW of fossil-fueled replacement power" (PG&E 2007b, I4, I5).

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[135] Replacement power cost estimates for 2001 and 2002 are based on DWR's remittance rate during this period. Replacement power cost estimates for 2003 through 2006 are based on day-ahead prices on the Inter-Continental Exchange (PG&E 2007b, I2).

Replacement power costs would be at least partially defrayed by the insurance that PG&E and SCE carry. After a 12-week waiting period, the insurance would pay a maximum of $4.5 million per week for the first 52 weeks ($3.5 million for SONGS) and $3.6 million per week for subsequent weeks ($2.8 million for SONGS), up to a total of $490 million for a single-unit outage or $784 million for a dual-unit outage (PG&E 2007b, K4; SCE 2007a, K4).

Palo Verde's Performance

Performance of the Palo Verde power plant has degraded significantly since 2002, and by a number of different measures, the "performance of Palo Verde between 2003 and 2005 was at the bottom of the U.S. nuclear industry" (ACC 2006b, p.9). As shown in Table 34, the plant's capacity factor dropped from 94 percent in 2002 to 77 percent in 2005. For the period 2003-2005, Palo Verde ranked 35th in capacity factor out of the 36 domestic multi-reactor sites, and Palo Verde Unit 1 ranked 99 in terms of capacity factor out of the 103 domestic operating nuclear power plants (ACC 2006b, p.9).

Table 34: Palo Verde Capacity Factor

	Palo Verde
2002	94 percent
2003	87 percent
2004	84 percent
2005	77 percent
2006	81 percent
5-year average	*85 percent*

Source: (NEI 2007d; PG&E 1989-2004; SCE 1995-2004)

Since 2004, Palo Verde has had multiple reactor trips and unplanned outages. In 2005 alone Palo Verde plants had eight unplanned outages, one planned outage, and two refueling outages (ACC 2006b, p.2). Palo Verde's difficulties continued during much of 2006. The plant had an estimated 67 percent capacity factor through August, in large part due to the 29 percent capacity factor of Unit 1, which operated at about 25 percent power level from December 25, 2005 through March 18, 2006 and was then taken offline through July 7, 2006 (NEI 2006e; PWCC 2006, p.44). Unit 1 was shut down again from September 19 through October 16, 2006, due to recurring problems with five of its pressurizer heaters (Arizona Republic 2006).

Performance at Unit 1 improved by the end of 2006, increasing Palo Verde's 2006 overall capacity factor to 81 percent; however, problems at Palo Verde continued (NEI 2007d). In late 2006 the NRC found that an emergency generator at Unit 3 had been inoperable for much of September and downgraded the rating for that plant into the Multiple/Repetitive Degraded Cornerstone column of the NRC's Action Matrix (NRC 2007v). While the NRC concluded that overall, in 2006 Palo Verde "operated in a manner that preserved public health and safety," the NRC also stated in no uncertain terms that “improvements in performance are needed” (NRC 2007c; NRC 2007v).

The NRC’s Response

Palo Verde has faced increased NRC oversight since the fourth quarter of 2004 when NRC inspectors found that APS may have compromised the operation of the plants’ emergency core cooling systems by incorrectly leaving in air pockets. The NRC found that underlying this issue were performance problems including “a lack of questioning attitude, lack of technical rigor and poor operability determinations by workers.” The NRC also identified two substantive cross-cutting issues in the areas of human performance and problem identification and resolution (NRC 2007v). Due to these deficits, the NRC issued a Yellow finding and rated the plant within the Degraded Cornerstone Column of the NRC’s Action Matrix, which indicates that objectives are being met with minimal reduction in safety margin (NRC 2007ag).

Units 1 and 2 remain in the Degraded Cornerstone Column because the NRC is not satisfied that the root causes of these problems have been corrected. Unit 3 has been demoted to the Multiple/Repetitive Degraded Cornerstone Column, as mentioned above (NRC 2007ag). Any further demotion would place Palo Verde Unit 3 into the Unacceptable Performance Column. If that were to happen, the plant would not be permitted to operate and the NRC would issue an order that the plant license be modified, suspended, or revoked (NRC 2007ag).

In demoting Palo Verde Unit 3 to the Multiple/Repetitive Degraded Cornerstone, the NRC clarified that while it had characterized the failure of the emergency generator as White (i.e., low to moderate increased importance to safety), the “actual safety significance of these findings could have been much greater” had APS not increased its frequency of testing as a corrective action in response to prior NRC findings of violation (NRC 2007i, p.4). The NRC also emphasized that the demotion was the result of longstanding problems at the plant, particularly associated with the 2004 Yellow finding that remains open due to APS’s inadequate response (NRC 2007c).

Between 2005 and 2007, the NRC repeatedly expressed concerns related to APS’s problem-solving identification and resolution. For instance, the NRC found in 2005 that some of APS’s corrective actions were narrowly focused, that monitoring criteria and reviews were not fully established, and that implementation of some of the corrective actions had not been demonstrated to be fully effective. In August 2006 the NRC reported that APS had addressed specific issues associated with the cooling system piping but that “corrective actions taken in response to the root causes and related programmatic concerns involving questioning attitude, technical rigor, and operability determinations have not been fully effective…[and] performance monitoring measures (e.g., metrics) necessary to fully assess the effectiveness of the corrective actions within these areas do not take into account all the relevant data” (NRC 2006k, pp.1-2). Then in October the NRC reported that APS continued “to conduct inadequate technical reviews of emerging issues; did not routinely question the validity of engineering assumptions used to support operability decisions; did not consistently implement a qualify, validate, and verify process; and did not consistently notify operations personnel of immediate operability concerns" (NRC 2006k, p.2). In March 2007 the NRC noted that throughout 2006 "the results of our inspections consistently determined that APS took some corrective actions to address these issues; however, the actions were not completely effective, were still being developed, or were only partially implemented. This is the same performance status noted in our March 2 and August 31, 2006, assessment letters" (NRC 2007c).

The NRC also identified 26 problems at the plant in the area of human performance. Many of these problems can be characterized by the themes of ineffective communication of decisions to personnel, inadequate procedures and instructions, ineffective human error prevention techniques, and procedures not being followed (NRC 2007c).

In response to these findings and to Unit 3's position in the Repetitive Degraded Cornerstone, the NRC plans to meet with APS to develop a corrective action plan for the plant. The NRC will issue a Confirmatory Action Letter to document APS's commitments and will conduct supplemental inspections to assess APS's corrective actions. The NRC will also meet with APS periodically to discuss performance (NRC 2007z, pp.14-15). In addition, the NRC intends to meet with APS staff to discuss the scope of a safety culture assessment that is planned at APS for May 2007 (NRC 2007c).[136]

Arizona Public Service Corporation's Response

In October 2005 APS issued a Performance Improvement Plan to set out "clear direction for how performance improvement will be achieved" at Palo Verde (APS 2005a). APS attributed the decline in Palo Verde performance to "the realignment of key site leadership that in turn caused the team to be more focused on day-to-day tactical matters, and less focused on strategic planning, standards and accountability" (APS 2005a, p.1). It also acknowledged that APS management had been slow to recognize the declining performance and attributed this in part to the plant's record of good performance. In order to correct these deficits, the Performance Improvement Plan established a Performance Improvement Team responsible for overseeing improvement initiatives in five focus areas: accountability, human performance, standards, corrective actions, and leadership (APS 2005a, pp.5, 7-8). These focus areas are described in Figure 32.

[136] The NRC will meet with APS officials on June 6, 2007 to discuss Palo Verde's performance improvement plan and plans for a comprehensive inspection at the plant (NRC 2007w).

Figure 32: Palo Verde Performance Improvement Plan

The Palo Verde Performance Improvement Plan focuses on correcting the following performance deficits:

- Accountability: Palo Verde leaders have not consistently held themselves and the workforce accountable for the implementation of and compliance with program and process requirements.
- Human Performance: Palo Verde has not yet corrected the underlying trend associated with the increase in human performance errors between 2001 and 2004.
- Standards: The leadership team does not consistently hold the organization to high standards but is instead inclined to make exceptions to more easily accommodate a current situation.
- Corrective Action Program/Problem Identification & Resolution: Palo Verde has not, in all cases, adequately evaluated problems, developed corrective actions and assessed effectiveness such that issues are permanently resolved.
- Leadership: Palo Verde leaders have not consistently demonstrated fundamental leadership skills. These skills include clearly communicating standards of performance, leading by example with regard to those standards, maintaining focus on the Palo Verde mission, goals and objectives, engaging the workforce, and holding themselves and the workforce accountable for meeting expectations.

Source: (APS 2005a, pp.7-8)

Arizona Corporation Commission's Response

On November 9, 2005, the Arizona Corporation Commission (ACC) opened an investigation into the frequency of unplanned outages during 2005 at Palo Verde. The investigation examined the causes of the outages, the procurement of replacement power and the impact of the outages on APS's customers (ACC 2006a). As part of this investigation, ACC staff commissioned GDS Associates to investigate the causes of Palo Verde's unplanned outages in 2005. GDS Associates concluded (ACC 2006b, p.1):

> While the operating and regulatory performance of Palo Verde during 2005 was poor, GDS has not found any evidence or indication that operation of the plant has compromised safety. None of the outages investigated resulted in or from unsafe operations and, in fact, demonstrated that APS was willing to shutdown the plant when any safety concerns were identified. Palo Verde was safely operated throughout 2005.

However, GDS Associates also found that at least four of the outages were "avoidable and the result of imprudent actions by APS," while the others were the result of faulty equipment supplied by vendors or other indeterminate causes (ACC 2006b, p.2). The outages were largely a result of faulty oil seals on reactor core pumps, the Unit 1 steam generator replacement, and the excessive vibration that developed in the Unit 1 cooling line following the steam generator replacement (ACC 2006b, p.8).

GDS Associates recommended that the ACC take four steps:

1. Disallow $17.4 million in costs that GDS Associates had identified as avoidable and imprudent
2. Establish a Nuclear Performance Standard that penalizes APS when Palo Verde's performance falls below the minimum levels
3. Require APS to submit semi-annual reports to the ACC describing plant performance and explaining any negative reports by the NRC or INPO
4. Require APS to evaluate its programs for managing aging equipment at Palo Verde and report to the ACC regarding actions taken to improve these programs (ACC 2006b, pp.3-4).

ACC staff concurred with GDS Associates that a Nuclear Performance Standard should be instituted at Palo Verde. According to the staff's plan, Palo Verde's three-year capacity factor would be compared against a target value determined by the three-year capacity factor of comparable U.S. pressurized water reactors. If Palo Verde's capacity factor fell below this target, the ACC would have the discretion to disallow the fuel and replacement power costs that were incurred by not achieving the target. Total disallowances would be capped "at a level which prevents severe financial penalty" (ACC 2007, pp.114-115).

APS objected to this plan on a number of counts. The utility claimed that the existence of the plan would not change how APS operates Palo Verde and noted that the "NRC has expressed concern about the effect that penalty-only, capacity factor-only NPSs have on safety" (ACC 2007, pp.115-116). APS also objected to some of the specific elements of the proposal and to the vagueness of some other elements. Finally, APS argued that a performance standard should include "equal opportunities for rewards and penalties" and that it should apply to the entire system (ACC 2007, pp.115-116).

In an April 2007 recommendation to the ACC, an ACC Administrative Law Judge concluded that "clearly, the evidence shows that the Commission should be concerned about Palo Verde's recent performance and should be monitoring APS's operation of the Palo Verde plants." The Administrative Law Judge recommended that the Commission disallow $13.9 million in Palo Verde outage-related costs and direct ACC staff and APS to work out a detailed Nuclear Performance Standard to be considered in a separate proceeding" (ACC 2007, 117, 133). The Administrative Law Judge also supported the adoption of the recommendations of GDS Associates regarding plant performance and aging equipment management reporting requirements (ACC 2007, pp.134-135). As of May 2007 the ACC had not ruled on whether or not to adopt the Administrative Law Judge's recommendations.

Conclusion

In recent years, most U.S. nuclear power plants have been extremely reliable. However, the significant operational difficulties at Palo Verde and the shortcomings identified in the GAO's regulatory assessment raise concerns about the ability of the current regulatory oversight system to prevent problems before they lead to extended outages, expensive repairs, and potential safety hazards.

Moreover, the NRC found that problem-solving processes at both Millstone and Palo Verde had too narrow of a focus and were marked by the lack of a questioning attitude, resulting in band-aids being applied in place of real solutions. While Palo Verde is not facing the safety concerns that were prevalent at Millstone and while the attitude of APS does not resemble the attitude of Northeast Utilities, these findings are troubling. It remains to be seen whether regulators will have better success with turning around Palo Verde's performance than they did with Millstone. It also remains to be seen whether Diablo Canyon and SONGS will experience difficulties similar to those at Palo Verde, particularly as the plants undergo complex steam generator replacements.

CHAPTER 12: THE FUTURE OF NUCLEAR POWER IN THE U.S.

Commercial nuclear power is riding a wave of renewed interest and support in the U.S. A number of Bush administration policy initiatives and some of the financial incentives contained in EPAct 2005 have led several U.S. utilities to consider building new nuclear power plants. In addition, many operators of nuclear power plants are pursuing license renewals, which will allow their plants to continue operating for an additional 20 years.[137]

Forty-eight out of the 103 operating commercial nuclear reactors have received approval to receive license renewals, eight applications are pending and at least 25 additional applications are anticipated in the coming years (NRC 2007af). The NRC license renewal process focuses on ensuring that the aging of plant components will not degrade reactor safety and that significant environmental impacts will not ensue from the license renewal. Cooling water impacts are among the environmental impacts considered by the NRC. However, some other issues of concern to the State of California, such as seismic safety and terrorist risks, are not considered, and the State has only a limited role within the proceeding. The State can have a role in determining whether or not a utility applies for or uses an extended operating license. For example, the CPUC recently ruled that PG&E, which has begun a license renewal feasibility study, must obtain CPUC approval prior to applying for a license renewal (CPUC 2007b, p.98).

Alongside these activities, the first new U.S. reactors in 30 years are being planned, and research is underway to improve the economics, performance, and safety of the next generation of nuclear reactors. Much of this development activity is being spurred by subsidies under EPAct 2005 for the first new reactors that will be built, by concerns about natural gas price volatility and by potential greenhouse gas policy that could favor nuclear power over fossil fuel-based power (CEEPR 2006, p.5). If no new reactors are built, the last units in the U.S. nuclear fleet will cease operating by 2056, even if all currently operating reactors receive 20-year license renewals.

This chapter investigates the future of nuclear power in the U.S. over the coming decades. The first section describes the NRC license renewal process and the potential roles for the state within this process. The next section discusses new reactor technologies, the process and incentives for building new reactors in the U.S., and the potential for developing new reactors in the U.S. including in California.

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[137] The existing fleet of U.S. nuclear reactors is also being extended by other means. For example, since 2000 the NRC has approved 67 applications to increase the generating capacity of reactors (known as "power uprates"), and it expects to receive applications for 25 additional power uprates representing 1,383 MW through 2011 (NRC 2007ad). In California, PG&E has gained additional time for the Diablo Canyon operating license through "recapture," which refers to the extension of the operating license by the amount of time that had been spent on low-power testing prior to the plant's initial startup (NRC 2006b). Also, the Browns Ferry Unit 1 nuclear plant, which sat idle for more than 20 years, is beginning restart operations (NRC 2007ag).

Operating Nuclear Power Plant License Renewal

The NRC grants licenses for commercial nuclear power plants for a 40-year period, with the option of a 20-year extension. Over 40 percent of the 103 currently operating U.S. reactors will complete their initial 40-year periods by 2015, and 48 reactors have already received 20-year license extensions (NRC 2007af).[138] To date the NRC has granted extensions to all applicants (NRC 2007af).

The complete license renewal process takes about 22 months (or, if a hearing is required, about 30 months) at a cost to the plant owner of approximately $10-$20 million per reactor (EIA 2001). An application for license renewal may be submitted as early as 20 years prior to the license expiration date. Facilities that submit applications at least 30 days before the license expiration date are allowed to continue operating through the end of the NRC review process, even if the process extends past the license expiration date (NRC 2007k). Currently pending license renewal applications are listed in Table 35.[139]

Table 35: License Renewal Applications Under Review

Facility Operator (State) **Facility Name**	**Application for License Renewal**	**License Expiration**
AmerGen Energy Co. (NJ) Oyster Creek Nuclear Generating Station	July 2005	April 2009
Entergy Nuclear Operations (MA) Pilgrim Nuclear Power Station	January 2006	June 2012
Entergy Nuclear Operations (VT) Vermont Yankee Nuclear Power Station	January 2006	March 2012
Entergy Nuclear Operations (NY) James A. FitzPatrick Nuclear Power Plant	August 2006	October 2014
PPL Susquehanna (PA) Susquehanna Steam Electric Station	September 2006	Unit 1: July 2022 Unit 2: March 2024
Wolf Creek Nuclear Operating Corp. (KS) Wolf Creek Generating Station	October 2006	March 2025
Carolina Power & Light Co. (NC) Shearon Harris Nuclear Power Plant	November 2006	October 2026
Entergy Nuclear Operations (NY) Indian Point, Units 2 & 3	April 2007	September 2013

Source: (NRC 2007af)

California's two operating nuclear power plants are among the newer facilities in the U.S. fleet. However, while their licenses do not expire until at least 2022, they are

[138] The possibility for a second 20-year license has been discussed by NRC Chairman Dale Klein; however, current law allows just a single license renewal (CFR 2007, p.9).

[139] A list of all approved, pending, and planned license renewal cases can be found in Appendix E.

already eligible to seek license renewals, and other plants of the same vintage have already done so. As discussed below, PG&E has initiated a license renewal feasibility study for Diablo Canyon. SCE has not announced plans for a similar study or a decision on whether or not it will pursue a license extension. At this time, there have been no public discussions of renewing Palo Verde's operating license.

Table 36: License Periods for California's Operating Nuclear Reactors

Unit	Capacity	Online Date	License Expiration Date
Diablo Canyon #1	1,087 MW	November 2, 1984	November 2, 2024
Diablo Canyon #2	1,087 MW	August 26, 1985	August 26, 2025
SONGS #2	1,070 MW	September 7, 1982	February 16, 2022
SONGS #3	1,080 MW	September 16, 1983	November 15, 2022

Source: (EIA 2004a; EIA 2004b)

An overview of the NRC license renewal process is presented in the next section. Treatment within this process of potential impacts from once-through cooling, seismicity, and terrorism, and the potential roles for the State of California in the Diablo Canyon and SONGS license renewal processes are also discussed.

NRC License Renewal Process

The NRC license renewal process focuses on ensuring that the aging of plant components will not degrade reactor safety over the license extension period.[140] The NRC also evaluates the environmental impacts of refurbishment activities required for continued operations and the impacts of 20 years of continued reactor operations (NRC 1999, p.4).[141]

The license renewal process does not include a reevaluation of the design bases of reactors, as the NRC is confident that the "regulatory process is adequate to ensure that the licensing bases of all currently operating plants provide and maintain an acceptable level of safety during the period of extended operation" (NRC 2006n,

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[140] The 40-year license period was established in the Atomic Energy Act of 1954 for economic and antitrust reasons and does not appear to have been based on any anticipated limitations of nuclear technology. However, the NRC is concerned that some individual plant and equipment designs may have been engineered for an expected 40-year service life (42 USC 2011-2259, p.14; NRC 2007af).

[141] This focus is much narrower than sought by the Energy Commission. The Energy Commission recommended that the NRC consider as part of the license renewal process, along with aging power plant issues, terrorism issues, alternative electricity sources, accumulation of spent fuel at reactor sites, seismic risks, thermal damage to marine environments, the potential impact on transmission system reliability from the closure of the plants, transportation impacts from spent fuel shipments, quality assurance for spent fuel casks, plant safety culture, any plant history of long-term safety violations, and the impact of deregulation on plant safety (Energy Commission 2003b).

pp.1-3). The NRC’s analyses are compiled in a Safety Evaluation Report (SER) and an Environmental Impact Statement (EIS).

The SER analyzes the reliability of aging power plant components that are relied upon for safety-related functions. It focuses on “passive and long-lived” structures such as the reactor vessel, coolant system piping, and steam generators. Active components, such as motors, diesel generators, switches, and fans, do not require additional review during the license renewal application process, because it is expected that degradation of these components will be detected through regular inspections and maintenance (NRC 2007af).

The EIS consists of two parts. The first part is an industry-wide generic EIS, which was issued in 1996. The generic EIS evaluated impacts related to 92 issues and found that 69 of these are common to all plants and do not warrant plant-specific mitigation measures. These issues include radiological impacts of normal operation and environmental impacts of design basis accidents and waste storage (NRC 1996). The remaining issues and any additional plant-specific issues are addressed in a supplemental EIS. For example, the impacts of a once-through cooling system and socioeconomic impacts are addressed in the supplemental EIS. The need for power and the economic costs and benefits of license renewal are not considered as part of the supplemental EIS (NRC 1999, p.6).

In assessing environmental risks associated with nuclear power generation, the NRC uses a three-level ranking system in the EIS (NRC 1996):

> Small: Environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. Small impacts require no mitigation.
>
> Moderate: Environmental effects are sufficient to alter noticeably but not to destabilize important attributes of the resource.
>
> Large: Environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

The NRC reviews and, where warranted, assigns mitigation for all impacts that it considers to be moderate and large (NRC 2005). During the 30 supplemental EIS reviews completed through April 2007, the NRC classified nearly all impacts as small. In three cases (Millstone, Oyster Creek, and Pilgrim), once-through cooling impacts were identified as moderate or potentially moderate for certain species, and in one case (Quad Cities) electric shocks from induced current through transmission line corridors were identified as a moderate impact (NRC 2006f, Supplements 16, 22, 28, 29). In addition, the chronic effects of electromagnetic fields were identified as having uncertain impact in several cases (NRC 2006f, Supplements 22, 23, 25, 26). In each of these cases, NRC staff recommended that “the Commission determine that the adverse environmental impacts of license renewal for [the plant] are not so great that preserving the option of license renewal for energy-planning decisionmakers [sic] would be unreasonable" (NRC 2006f, Supplement 29).

Opportunity for public participation through meetings and comment periods occurs throughout the safety and environmental review processes. Two initial public meetings near the reactor site are held to explain the renewal process and to solicit input on the scope of the environmental review approximately three months after the NRC receives a license renewal application, and two additional public meetings near the reactor site are held following publication of the draft supplemental EIS, about nine months later (NRC 2007af). Some of the NRC's meetings with the applicant are also open to the public; however, many of these meetings are held at NRC offices on the outskirts of Washington, DC.

Members of the public who would be impacted by a license renewal decision may file a request for a hearing to litigate specific issues of concern. The NRC is required to accept a hearing request only if the petitioner's contentions have been demonstrated to be within the scope of the proceeding, material to the decision, and supported by facts or expert opinions. In addition, the petitioner must demonstrate that a "genuine dispute exists with the applicant/licensee on a material issue or law or fact" (NRC 2007a, (f)). The NRC also has discretion to accept requests that do not meet these criteria if a hearing is already to take place (NRC 2007a, (e)). Determinations on whether to accept a petition for hearing can be made by the NRC or by an NRC-designated Atomic Safety and Licensing Board (ASLB) (NRC 2007a, (a)). In practice, the ASLB provides an initial determination and, upon appeal, the NRC reviews the ASLB's determination.

Under new rules that took effect on February 13, 2004, the hearings conducted in licensing proceedings are informal. They do not include traditional discovery (though parties are required to make certain mandatory disclosures), witness questioning is conducted by a hearing officer rather than by the litigants, and an opportunity for cross-examination is not guaranteed. These rules were upheld when they were challenged in court; however, the judge in the case noted that the rules "may approach the outer bounds of what is permissible" (CAN v. NRC 2004).

In practice, requests for hearings are rarely granted. In the few cases where contentions have been admitted (discussed below), they have pertained to specific inadequacies of either the SER or the EIS and have been supported by expert opinion or documentation. Contentions not specifically related to the impacts of aging on the safety of the reactor during the license renewal period or the environmental impacts of the reactor over the license renewal period have been ruled as immaterial to the proceeding. This includes contentions related to security, terrorism, and spent fuel storage (NRC 2006j, pp.9-17).

The first hearing approved by the ASLB was in Duke Power's joint license renewal proceeding for the McGuire and Catawba plants. On January 24, 2002, the ASLB admitted contentions of the Nuclear Information and Resource Service (NIRS) and the Blue Ridge Environmental Defense League related to the planned use of MOX fuel at the plants, the failure of the safety analysis to consider a Sandia Study on direct containment heating for plants with ice condenser containments, and the failure of the study to consider a dedicated electrical line to mitigate against blackout-induced accidents. However, the NRC later reversed the ASLB's decision, and denied the request for hearings. The NRC denied the MOX contention as beyond the scope of the proceeding, denied the Sandia study contention because NIRS/Blue Ridge Environmental Defense League had not demonstrated that consideration of the study would have led to a different conclusion, and rejected the dedicated line because NIRS/Blue Ridge Environmental Defense League had not provided sufficient support to show this to be a viable option (NRC 2002, pp.2, 6-15).

In 2006, limited hearings were granted in three proceedings, Oyster Creek, Pilgrim, and Vermont Yankee, to address specific contentions raised about the inadequacies of the supplemental EIS or the SER. These cases are highly unusual in that state agencies and state representatives are among the petitioners. However, most of the state contentions relate to terrorism and spent fuel, which the NRC has ruled as beyond the scope of license renewal proceedings. As shown in Table 37, only one state contention has been admitted for hearings. Obviously, being allowed to litigate a specific issue is no guarantee of the ASLB or NRC accepting a party's contentions.

Table 37: NRC Rulings on Requests for Hearings

Case	Party	Contention	Ruling
Oyster Creek	NIRS et al.	Containment vessel corrosion testing plan is inadequate	Admitted
	NJ Department of Environmental Protection	EIS did not address vulnerability of the plant to aircraft attacks or spent fuel pool vulnerability	Denied (beyond scope of proceeding)
Pilgrim	Pilgrim Watch	Aging management program is inadequate with regard to inspections for corrosion of buried pipes and tanks and detection of leakage of radioactive water	Admitted
	Pilgrim Watch, Mass. Attorney General	EIS did not address vulnerability of the spent fuel pool to accidents	Denied (beyond scope)
Vermont Yankee	Mass. Attorney General	EIS did not address vulnerability of the spent fuel pool to accidents	Denied (beyond scope)
	VT Dept. of Public Service	Age-related impacts of non-safety-related systems that could impact safety-related systems should have been evaluated	Denied (beyond scope)
	VT Dept. of Public Service	Age management of primary containment concrete is inadequate	Admitted
	VT Dept. of Public Service	EIS did not address impacts on long-term at-reactor spent fuel storage	Denied (Impacts need not be evaluated)
	New England Coalition	Plan to monitor and manage effects of aging on key reactor components, steam dryer, and plant piping is inadequate	Admitted
	New England Coalition	EIS includes insufficient analysis of thermal impacts from once-through cooling.	Admitted
	New England Coalition	Plans to monitor and manage aging effects of the condenser and primary containment boundary are inadequate	Denied (beyond scope and/or lacks sufficient basis)
	Town of Marlboro	Marlboro was erroneously excluded from emergency planning zone	Denied (beyond scope)

Source: (NRC 2006g, p.37; NRC 2006h, pp.10-13; NRC 2006i, pp.2, 21; NRC 2006j, pp.17-82)

Select Issues of Potential Interest to California

The environmental impacts of once-through cooling and the environmental impacts of a terrorist attack have been raised during license renewal proceedings in other states and are expected to be among the issues raised during license renewal proceedings for California's nuclear power plants. In most cases, the NRC has addressed the impacts of once-through cooling by deferring to state environmental agencies to impose mitigations where warranted. The NRC has refrained from addressing the impacts of terrorist attacks, referring to the ongoing rulemaking for revising the design basis threat for nuclear power plants as the appropriate forum in which to address these concerns.

Seismic Safety Issues

Seismicity concerns have not been addressed in other license renewal proceedings; however, these concerns may be important in California. Indeed, in the 2005 Energy Commission workshops on nuclear power, Assemblyman Blakeslee asked Bill Jones of the NRC whether there would be an opportunity within a license renewal proceeding "to start from scratch and look at seismic vulnerability issues" (Energy Commission 2005f, p.41). Jones responded that "the NRC is always considering new [seismic-related] information" and that "if we were to get any new information at any time, then we would go and look at that" (Energy Commission 2005f, pp.41-43). Since seismic issues are not specifically related to aging, they are not part of the standard license renewal safety reviews.

Once-Through Cooling Issues

Impacts of once-through cooling are primarily addressed by state and regional agencies as part of NPDES permitting and renewal processes. However, the NRC also investigates these issues as part of the license renewal environmental review and could deny a license renewal application due to significant impingement and entrainment impacts. The NRC has identified moderate (or possibly moderate) risks from impingement or entrainment for three plants, but it has not up to now rejected a license renewal application on this (or any) ground, ruling that these impacts are insufficient to not allow the plant's license to be extended and deferring to state agencies to assign appropriate mitigation measures.

The three cases where moderate (or possibly moderate) impingement or entrainment impacts have been identified are AmerGen Energy Company's Oyster Creek Nuclear Generating System in New Jersey, Dominion's Millstone Nuclear Power Station in Connecticut, and Entergy's Pilgrim Nuclear Power Station in Massachusetts.

1. Oyster Creek: The NRC was unable to determine whether impingement impacts from Oyster Creek are small or moderate, because the most recent completed study had been published in 1989 and was considered to be out of date. The NRC did not impose specific mitigation measures for this possibly moderate impact, because mitigation measures are currently being evaluated

as part of Oyster Creek's NPDES permit renewal process. The NRC determined that there is a reasonable possibility that under the new NPDES permit Oyster Creek will be required "to either install a closed-cycle cooling system or employ a combination of design and construction technologies, operational measures, and restoration that would result in compliance with the intake performance standards" (NRC 2006f, Supplement 28). The NRC evaluated the impacts of these mitigation alternatives and found them to be mostly smaller than the impacts of once-through cooling (NRC 2006f, Supplement 28).

2. Millstone: The NRC identified a potentially significant environmental impact, in that the Niantic River winter flounder is near collapse. However, the NRC was unable to determine the extent to which entrainment from the Millstone once-through cooling system has contributed to this near-collapse (NRC 2006f, Supplement 22, pp.4-22). Consequently, the NRC labeled the impact as moderate and deferred assignment of mitigation measures to the Connecticut Department of Environmental Protection (NRC 2006f, Supplement 22, pp.4-22). These measures were assigned in August 2006, nine months after the NRC had granted the Millstone license renewal (CT DEP 2006; NRC 2007p).
3. Pilgrim: The NRC found that continued operation of the Pilgrim plant would have moderate entrainment impacts on the local winter flounder and moderate impingement impacts on rainbow smelt and that additional mitigation measures may reduce these impacts. The NRC did not assign specific mitigation measures, as Entergy is currently conducting a once-through cooling impact study for the EPA, and the NRC expects that mitigation measures assigned by the EPA will address the NRC's concerns (NRC 2006f, Supplement 29).

The NRC also studies the thermal impacts of once-through cooling systems, and in all cases the NRC has determined that these impacts are small. However, in the Vermont Yankee case the New England Coalition challenged the adequacy of the EIS assessment related to thermal impacts, protesting that Entergy did not conduct an independent assessment of the thermal impacts of its once-through cooling system but instead assumed that since it has received NPDES permits these impacts must be small. New England Coalition argued that this reasoning is insufficient because the Vermont Yankee plant's NPDES permit is under appeal and, even if granted, will last only five years and not throughout the duration of the license renewal period. New England Coalition was granted a hearing to pursue this contention (NRC 2006j, pp.47-48). This appears to be the first once-through cooling issue that has been admitted into a license renewal hearing.

Terrorism

A number of recent license renewal cases have elicited public and legislative concerns over the potential impacts on nearby communities and the environment should a plant be the target of a terrorist attack. Participants in license renewal proceedings have argued that these impacts should be considered as part of the EIS process. These demands have been bolstered by the Supreme Court's refusal in January 2007 to review the Ninth Circuit's ruling in NRC vs. Mothers For Peace, which requires the NRC to consider the environmental impacts of terrorism in the Diablo Canyon ISFSI EIS (PG&E v. MFP 2006). However, the NRC has thus far resisted efforts to include impacts of terrorism as part of the EIS process (see Chapter 10).

Potential Role for the State

The State of California does not have an explicit statutory role in NRC license renewal decisions. However, as discussed in the section on cooling water impacts, as part of the environmental review the NRC confers with appropriate state agencies and defers to state agencies with appropriate regulatory authority. State agencies, legislators, and attorneys general may also submit particular contentions and participate in a license renewal proceeding as interested parties. Such interventions, for example, took place in the original Diablo Canyon NRC operating license proceeding. Alternately, a state may participate as an "interested state." In this case, the state is given "a reasonable opportunity to participate in [an existing] hearing" by introducing evidence, interrogating witnesses where cross-examination by the parties is permitted, advising the NRC, filing proposed findings in proceedings where findings are permitted, and petitioning the NRC for review of admitted contentions (NRC 2006j, p.87). The state is not guaranteed the right to a hearing on issues of concern, and, as noted above in the discussion around Table 37, few petitions for hearings have been granted to states or other parties.[142]

However, as explained by the NRC, the state can have a role in determining whether or not a utility uses its extended operating license (NRC 2006f, Supplement 28):

> Although a licensee must have a renewed license to operate a reactor beyond the term of the existing [operating license], the possession of that license is just one of a number of conditions that must be met for the licensee to continue plant operation during the term of the renewed license. Once an [operating license] is renewed, State regulatory agencies and the owners of the plant will ultimately decide whether the plant will continue to operate based on factors such as the need for power or other matters within the State's jurisdiction or the purview of the owners.

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[142] The State of New York is pursuing an alternate avenue for participation in the Indian Point license renewal proceeding. Follow an announcement in April 2007 that the NRC is levying a fine on Entergy, the owner of Indian Point, for failing to meet the deadline set for installing a new emergency siren plan, Governor Spitzer wrote a letter to Dale Klein, Chairman of the NRC, calling for an Independent Safety Assessment of the nuclear power plant (Spitzer 2007a); (Spitzer 2007b). Spitzer's action complements bills introduced in February by Congressman John Hall and Senator Hillary Clinton requiring that the NRC conduct an Independent Safety Assessment prior to making a license renewal determination for this plant (Congress 2007a).

As described below, the State of Vermont is asserting its authority with a law that requires Vermont utilities to receive authorization from the state prior to operating nuclear power plants past the plants' current operating licenses (VT Bill 2006b). That law could be tested in 2008 when the Vermont Yankee license renewal decision is due.

In the 2005 Energy Commission workshops on nuclear power, in response to concerns over the limited state role in license renewal proceedings, Robert Kinosian of the CPUC recommended that California utilities be required to obtain CPUC approval prior to submitting a license renewal application with the NRC in order to be eligible for recovery of license renewal costs (Energy Commission 2005f, p.53). Gary Schoonyan of SCE agreed with Kinosian that addressing license renewal at the state level prior to seeking NRC approval "seems to make sense" (Energy Commission 2005f, p.149). This issue first arose in practice in 2006 when PG&E requested ratepayer funding for a license renewal feasibility study. The CPUC followed the path recommended by Kinosian and required that PG&E receive its approval before seeking a Diablo Canyon license renewal. The CPUC expects to make a decision on the Diablo Canyon license renewal in 2013 (CPUC 2007b, p.103).

Vermont Law

In May 2006 the Governor of Vermont signed into law S.0124, "A certificate of Public Good for Extending the Operating Life of a Nuclear Power Plant" (VT Bill 2006b). According to this law:

> No nuclear energy generating plant within this state may be operated beyond the date permitted in any certificate of public good granted pursuant to this title, including any certificate in force as of January 1, 2006, unless the general assembly approves and determines that the operation will promote the general welfare, and until the public service board issues a certificate of public good under this section.

The law requires that a petition for approval to renew the license of a nuclear power plant be submitted to the public service board no later than four years prior to the end of the operating license. The public service board will then arrange for studies to be conducted to evaluate the long-term economic and environmental benefits, risks, and costs related to the operation of the plant, to assess the potential need for operation of the facility, and to assess all practical alternatives to license renewal that may be more cost-effective or that may better promote the general welfare. The public service board will hold at least three public meetings, the general assembly will conduct proceedings it deems appropriate, and then the public service board will make its determination. This law is in keeping with the state's policy that "a nuclear energy generating plant may be operated in Vermont only with the explicit approval of the General Assembly expressed in law after full, open, and informed public deliberation and discussion with respect to pertinent factors, including the state's need for power, the economics and environmental impacts of long-term storage of nuclear waste, and choice of power sources among various alternatives" (VT Bill 2006a).

NRC spokesman Neil Sheehan has reportedly said that Vermont could risk litigation if it tried to block the Vermont Yankee license extension, because federal law places jurisdiction over safety issues solely with the NRC (Boston.com 2007). However, in the past the court has ruled that states do have the right to restrict the use of nuclear power for economic and land use reasons (PG&E v. Energy Commission 1983). An NRC decision on the license extension is due by July 28, 2008 (or November 27, 2007, if no hearing is required) (NRC 2007ah). The Vermont law encourages a decision from the Vermont public service board by July 1, 2008 (VT Bill 2006a).

CPUC Ruling

In its most recent rate case before the CPUC, PG&E requested regulatory approval to spend $16.8 million for a license renewal feasibility study, to be completed in 2009 (CPUC 2007b). PG&E described the purpose of this study as to "analyze the equipment and operations of Diablo Canyon in order to determine whether or not to apply to the U.S. Nuclear Regulatory Commission (NRC) for a 20-year extension of Diablo Canyon's operating licenses" (PG&E 2006e, p.88).

The Alliance for Nuclear Responsibility, Sierra Club, and The Utilities Reform Network opposed this study. One of their concerns was that PG&E could "use the license renewal study to unilaterally seek license renewal without prior [CPUC] review of the study or [CPUC] authority for PG&E to submit a re-licensing application" (CPUC 2007b, p.98).

The CPUC authorized PG&E to move ahead with the study but required PG&E to include the study in an application to the CPUC on whether to pursue license renewal. The application, which is to be filed by June 30, 2011, must address (CPUC 2007b, p.103):

1. Whether renewal of the licenses is cost effective and in the best interests of PG&E's ratepayers
2. A study being conducted by the Energy Commission assessing the vulnerability of the state's large power plants to aging and seismic events[143]
3. Any legislative framework that may be established for reviewing the costs and benefits of license renewal.

[143] Under a proposed legislative bill, AB 1046, a utility that applies for a license renewal prior to the completion of the Energy Commission's assessment would be precluded from recovering costs associated with the license renewal application, costs of improvements necessary to meet NRC renewal requirements, and costs of operating beyond the term of the existing license (AB 1046 2007). The assessment is to be completed by November 1, 2008 and included in the 2008 IEPR.

The CPUC will review the application and determine by 2013 whether or not license renewal should be pursued (CPUC 2007b, p.103). This timeframe is intended to provide sufficient time for the CPUC to plan for alternative energy sources should it determine that Diablo Canyon's license should not be renewed. The CPUC has not announced whether or not it will require SCE to conduct a license extension study for SONGS over the next few years to provide time to plan for alternate resources, if required. SCE has not announced plans for such a study.

In addition to CPUC approval, in order to continue operating the plants beyond their current licenses, PG&E and SCE would also be required to receive approvals from additional state regulatory and licensing bodies. For example, they would be required to renew their leases from the State Lands Commission, which currently expire on May 31, 2019, and on February 28, 2023, respectively (CSLC 2006b, p.2). They would also be required to obtain continued renewals of their NPDES waste discharge permits, which expire every five years (SWRCB 2003). They may also require a permit from the California Coastal Commission or another agency.

Building New Nuclear Power Plants in the U.S.

Multiple factors are creating significant interest in the U.S. and globally in an expansion of nuclear power. Concerns over energy prices and energy security, natural gas supply availability both domestically and worldwide, steady energy demand growth, and serious concerns regarding global climate change are all driving the resurgent interest in nuclear power (Turnage 2007).

The U.S. EIA projects that U.S. electricity demand will grow by approximately 40 percent between 2005 and 2030 (EIA 2007, p.82). Existing nuclear power plants generate about 20 percent of the electricity consumed in the U.S. (EIA 2007). To maintain this 20 percent share as electricity demand grows, the U.S. would need to build about 45-50 one-thousand megawatt nuclear reactors (NEI 2006b).

The NRC, state and federal governments, and the nuclear industry are taking steps to lay the groundwork for licensing and building new nuclear power plants in the U.S. A revamped licensing process is in place at the NRC that divides the lengthy development and licensing process into stages thereby permitting "go/no-go" decisions by project developers at various points in the process. As discussed in Chapter 8, the federal government is establishing guidelines and rules for a package of financial incentives included in EPAct 2005 and continues to work with industry on cost-sharing projects designed to test the NRC's licensing process. In addition, some state governments have approved laws or regulations intended to address the economic challenges of the lengthy development and construction phases for nuclear power projects.

The nuclear industry is preparing to take advantage of the more favorable climate for building new nuclear power plants. According to NEI, the industry has already invested more than $1.5 billion in "design and engineering work, licensing and procurement of long-lead equipment like reactor pressure vessels and steam generators” (NEI 2006b). Companies have publicly announced plans for as many as 30 new nuclear reactors (NEI 2006b).

Significant challenges to building new nuclear reactors exist, however. In fact, many of the companies announcing intentions to submit licensing applications to the NRC caveat those statements by also stating that the license application is not a commitment to actually building a new reactor.

Next Generation Technologies: Generation III/III+

New nuclear power plants, if built, will be more advanced than currently operating reactors. In the U.S., the current fleet of U.S. reactors consists of Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR) from the 1960s and 1970s, which are classified as Generation II reactors. Evolutionary improvements to these technologies were incorporated into Generation III reactors, which were developed during the 1990s and some of which are operating or are under construction overseas. Further evolutionary improvements are being incorporated into Generation III+ reactors, which are currently being developed for deployment by 2010 (UK SDC 2006b, p.15). Generation IV reactors are more experimental designs that are still on the drawing boards; they are projected to come on line in the post-2020 timeframe (DOE 2006c). The reactor designs under consideration for construction in the near future in the U.S. are of both Generation III and Generation III+ vintages.

Newer Generation III+ technologies will generally employ “passive” rather than “active” safety systems. Passive safety systems rely on heat exchangers designed to use natural convection cycles to circulate water to remove heat from the core, while active safety systems rely on pumps, emergency diesel generators, and similar equipment to circulate water for cooling. While the mechanical components of active systems require frequent inspection and maintenance, passive systems in principle would reduce the need for aggressive surveillance or maintenance procedures (Energy Notes 2005, pp.1, 4-5).

In developing Generation III and Generation III+ technologies, the nuclear industry is focusing on two reactor types, large baseload reactors and small custom reactors. Both take advantage of large-scale prefabrication and employ advanced safety features. A summary of these technologies and their NRC certification status is provided in Table 38, and more detail on the large baseload technologies is provided in Appendix F.

In the longer-term, Generation IV designs are expected to employ modern, liquid metal cooling methods to allow for reactor temperatures that are much higher than light water cooling can safely allow. Generation IV technologies are being researched and developed through worldwide research collaboration but are unlikely to be operational for decades or longer. Further discussion of these technologies can be found in the MIT study, *The Future of Nuclear Power*, and in the UK SDC study, *The Role of Nuclear Power in a Low Carbon Economy* (MIT 2003, p.49; UK SDC 2006c, pp.19-20).

Table 38: Generation III and III+ Reactor Designs

Reactor Design	Vendor	Gen.	Approximate Capacity (MWe)	Reactor Type	Certification Status	Target NRC Certification/ Certification Date
Baseload Reactors						
ABWR	General Electric et al	III	1371	BWR	Certified	1997
AP600[144]	Westinghouse	III	650	PWR	Certified	1999
AP1000	Westinghouse	III+	1117	PWR	Certified	2006
System 80+[145]	Westinghouse	III	1300	PWR	Certified	1997
US-EPR	AREVA NP	III+	1600	PWR	Undergoing certification	2009
ESBWR	General Electric	III+	1550	BWR	Undergoing certification	2010
US-APWR	Mitsubishi	III	1600	PWR	Undergoing certification	2011
Small Reactors						
PBMR	Westinghouse, Eskom	III	180	HTGR	Undergoing certification	Not Available
ACR Series	AECL	III+	700-1200	Modified PHWR	Review inactive	
IRIS	Westinghouse et al	III++	360	PWR	Review inactive	
4S	Toshiba	n/a	10-50	Sodium-cooled	Review inactive	

Source: (EIA 2006b; NRC 2006c)

NRC's Regulatory Framework for New Nuclear Power Plants

In 1989 the NRC established a new licensing process, detailed in 10 CFR Part 52, intended to address flaws in the licensing process used in the 1960s and 1970s. Beginning in late 2000 and early 2001, the NRC initiated a review of the new reactor licensing process in anticipation of a surge in submittals of license applications for new reactors. The NRC has broken the new reactor licensing process into three steps: approval of standard reactor designs, or design certification; early approval of nuclear power plant sites; and combined construction and operating license approval.

[144] The AP600 is not considered to be cost-effective in the U.S. and is not being considered for near-term builds (UK SDC 2006b, p.16).

[145] The System 80+ is no longer being marketed in the U.S. (UC Berkeley 2007).

In the design certification step, the NRC approves a standard plant design submitted by the manufacturer. The objective is to permit stakeholders and the public to comment on design issues, particularly the safety of the plant design, before any construction takes place. In addition, the NRC expects that by certifying a standard design upfront, more companies will opt to build new reactors using the common design and leading to greater standardization across the next generation of nuclear power plants. A design certification approval is good for 15 years. To date, the NRC has granted certification for four plant designs: General Electric's ABWR (Advanced Boiling Water Reactor), Westinghouse's AP1000 and AP600, and Westinghouse's 80+. General Electric's ESBWR (Economic Simplified Boiling Water Reactor) design is under review and designs for the US-APWR (Advanced Pressurized Water Reactor), the U.S. EPR (Evolutionary Power Reactor), and the PBMR (Pebble Bed Modular Reactor) are under pre-application review.

An early site permit (ESP) essentially confirms that a proposed site is suitable for the future development of a nuclear power plant based on a review of general physical, environmental, and emergency planning criteria. The proposed site can be either a greenfield site or at an existing nuclear power plant site. An ESP, which is valid for 10 to 20 years, does not authorize the construction of a new plant.[146] A key objective of the ESP process is to permit a company to seek planning approval of a site without committing substantial investment capital in the development and construction of a plant.

Four companies have applied to the NRC for an ESP (see Table 39). Three of the four companies partnered with DOE through the Nuclear Power 2010 program in a cost-sharing arrangement to support the multi-year ESP review process. The NRC expects a fifth application for an ESP to be submitted sometime in 2007.

The third step in the licensing process is to seek a combined Construction and Operating License from the NRC. Such a license would be effective for 40 years. If an applicant references an already-approved ESP and a certified plant design, issues related to these two facets of a new reactor are treated as settled and not subject to further review. A company that receives NRC approval for a combined Construction and Operating License can move forward with building the plant, sell the license to another company, or "bank" the license for later use (Turnage 2007).

[146] An ESP can be renewed for an additional 10 to 20 years if a timely application for renewal is filed with the NRC (10 CFR 52.27).

Table 39: Early Site Permit Applications at the NRC

Site	Company	ESP Application Submittal Date	Status
Clinton (Clinton, Ill.)	Exelon Generation Company	September 25, 2003	ESP issued by NRC on March 15, 2007
Grand Gulf (Port Gibson, Miss.)	System Energy Resources, Inc.	October 21, 2003	ESP issued by NRC on March 27, 2007
North Anna (Virginia)	Dominion Nuclear North Anna	September 25, 2003	ASLB hearings underway; final NRC decision expected in late 2007
Vogtle (Georgia)	Southern Nuclear Operating Company	August 15, 2006	Final EIS expected in May 2008 with final NRC decision on ESP to follow

To date no company has filed a combined Construction and Operating License application. The first combined Construction and Operating License application could be submitted to the NRC sometime in 2008, and the NRC reported to Congress in March 2007 that it had received letters of intent from potential applicants for a total of 20 COLs for up to 29 nuclear units (NRC 2007ae). Table 40 identifies companies that are expected to submit combined Construction and Operating License applications, the likely locations and types of the new plants, and a likely timeline for when combined Construction and Operating License applications could be filed.

Reviewing each NRC license application is expected to take as much as four years, and the time required to develop, permit, and construct any new nuclear power plant will be quite lengthy. A new plant is unlikely to enter into service before 2015-2016 (S&P 2006a, p.2). These long lead times combined with the EPAct 2005 incentives for first-movers are driving the current flurry of licensing activities.[147]

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[147] In particular, the production tax credit is only available to plants that apply for a combined Construction and Operating License with the NRC prior to December 31, 2008.

Table 40: Announced Nuclear Power Plant License Applications

Probable Applicant / Company	Site(s)	Reactor Type and Number of Units	Planned Time Frame for NRC License Application
Alternate Energy Holdings	Bruneau, ID	Not yet determined	Not yet determined
Amarillo Power	Vicinity of Amarillo, TX	EPR (2)	FY 2008
AmerenUE	Callaway, MO	EPR (1)	Calendar Year 2008
Constellation Energy (UniStar)	Calvert Cliffs, MD Nine Mile Point, NY plus two other sites	EPR (4)	First submittal - FY 2008
Detroit Edison	Fermi, MI	Not yet determined	FY 2009
Dominion	North Anna, VA	ESBWR (1)	FY 2008
Duke	William States Lee, Cherokee County, SC	AP1000 (2)	FY 2008
Duke	Davie County, NC	Not yet determined	Not yet determined
Duke	Oconee County, SC	Not yet determined	Not yet determined
Entergy	River Bend, LA	ESBWR (1)	FY 2008
Entergy (NuStart)	Grand Gulf, MS	ESBWR (1)	FY 2008
Exelon	Clinton, IL	Not yet determined	Not yet determined
Exelon	Texas to be determined, TX	Not yet determined	FY 2009
Florida Power & Light	Not yet determined	Not yet determined	FY 2009
NRG Energy / STPNOC	Bay City, TX	ABWR (2)	FY 2008
Progress Energy	Harris, NC; Levy County, FL	AP1000 (2), Not yet determined (2)	Harris – FY 2008; Levy County – FY 2008
South Carolina Electric & Gas	Summer, SC	AP1000 (2)	FY 2008
Southern Company	Vogtle, GA	AP1000 (2)	FY 2008
Texas Utilities	Comanche Peak, TX; Other sites yet to be determined	APWR (2), not yet determined	FY 2008
TVA (NuStart)	Bellefonte, AL	AP1000 (2)	FY 2008

Source: (NEI 2007b)

New Nuclear Power Plants in California?

None of the anticipated ESP or combined Construction and Operating licenses are for plants that are to be located in California. This is at least in part because, as noted in Chapter 1, current California law prohibits the permitting of land use for a new commercial nuclear power plant until a federally approved means for the permanent disposal of spent fuel is available. Some other states similarly have laws restricting new nuclear power development until findings are made regarding spent fuel disposal or other issues. (See Table 41.)

Table 41: State Laws Restricting New Nuclear Power Development[148]

Finding Required before New Nuclear Plants May be Built	States
Federal government has approved a demonstrated technology for nuclear waste disposal	California, Connecticut, Illinois, Kentucky
Disposal facility exists and is accepting waste	Massachusetts, Maine, Oregon, West Virginia, Wisconsin
Spent fuel can be safely contained	Montana, New Jersey
Nuclear plant construction is economically feasible/advantageous	West Virginia, Wisconsin
The proposed capacity is needed	Massachusetts, Kansas
New nuclear plants are prohibited regardless of findings	Minnesota

Source: (WLC 2006, pp.2-3)

Neither SCE nor PG&E have expressed publicly an intention to pursue development and construction of a new nuclear power plant in California. Indeed, a PG&E official stated that “investing in new out-of-state nuclear power plants is a decade away” (CA Energy Circuit 2007, p.2). While the state’s major investor-owned utilities may not seek to develop a new nuclear power plant, a group of local businessmen in Fresno, California have announced the formation of the Fresno Nuclear Energy Group, LLC. The group intends to explore the possibility of building a nuclear power plant in Fresno. Fresno Nuclear Energy Group signed a letter of intent with UniStar Nuclear to support their efforts. Commissioner Peevey of the CPUC called the project a “nonstarter,” even though he added, “that's not to say there's not a role for nuclear power given where we are in terms of climate change” (CA Energy Circuit 2007).

Another organization, Californians for Sustainable Nuclear Energy, is advocating for the development of new nuclear power plants in the state. Californians for Sustainable Nuclear Energy points to both environmental benefits and economic benefits of nuclear power as providing the rationale for pursuing new nuclear power plants in California.

[148] Some states require additional findings, as well. For example, Massachusetts requires findings that the proposed plant is the optimal energy source, that adequate emergency planning and emissions standards are in place, and that an approved decommissioning technology exists (WLC 2006, p.3).

Assemblyman DeVore introduced a bill, Assembly Bill 719, in the California Legislature in February 2007 that would repeal the state's moratorium on building new nuclear power plants. According to the proposed legislation, "an approved means of high-level nuclear waste disposal" would likely be available "by the time a [nuclear] powerplant would be ready for operation" (AB 719 2007, p.3). Assemblyman DeVore's proposed legislation failed to be passed out of the Assembly's Natural Resource Committee.

Conclusion

The future of nuclear power in the U.S. over the coming decades will be determined in large part by the number of reactors that receive and use license renewals and the number of new reactors that are built.

Most license renewal proceedings thus far have not been seriously challenged, and no reactor has yet been denied a license extension from the NRC. However, in recent years some license renewal proceedings have generated significant opposition, including from state governmental agencies. States and interested parties have had only limited success in persuading the NRC to incorporate elements of their concerns in license renewal reviews, and some states have also or instead been exploring regulatory or legislative options to participate in the license renewal decision. The NRC has indicated that it would challenge a state attempt to block a license renewal; however, the NRC has also acknowledged that a state does have a role in determining whether or not a utility uses its extended license.

Licensing for new reactors is underway, but whether new reactors will be built remains uncertain. Even if new plants are built, there may yet be a net decrease in nuclear generation if new plant additions do not exceed the losses to the nation's nuclear fleet as existing reactors shut down at the end of their useful operating lives. According to Charles Ferguson of the Council on Foreign Relations, simply replacing the current fleet would require building approximately one new reactor every four to five months over the next 40 years (CFR 2007, p.8). There is disagreement among analysts as to whether nuclear power will make up a decreasing or increasing share of the resource mix in the coming years (Schneider et. al. 2006).

CHAPTER 13: NUCLEAR POWER 2007: IMPLICATIONS FOR CALIFORNIA

Nuclear power as an electric resource option has gained visibility in the two years since the release of the 2005 IEPR. The body of this report provides a factual background for assessing the nuclear power option for California, given the state's current resource situation and the nuclear policy embodied in the 1976 nuclear statutes. This chapter provides preliminary assessments for consideration by the IEPR Committee of how the state may be impacted by the events described in this report and how the state and the Energy Commission might respond. These preliminary assessments are intended to provide starting points for consideration by the public and Commissioners. All parties are encouraged to submit comments on this draft report and their own proposed assessments to the IEPR Committee.

New and Existing Nuclear Power Plants in California

Over the next two years the primary focus for the owners of California's operating nuclear power plants should be the safety and reliability of these plants, the successful replacement of the steam generators and other major components, and the completion of new interim spent fuel storage facilities. Transferring spent fuel from spent fuel pools to interim storage facilities is likely to enhance the safety of these power plants. Replacing the steam generators is necessary for long term operation of the plants.

In addition, California's utilities should continue to monitor the efforts of the NRC, the Arizona Corporation Commission, and the Arizona Public Service Corporation to make Palo Verde once again a reliable and low cost facility while maintaining high standards of safety. At the same time, SCE, the Southern California Public Power Authority, and the Los Angeles Department of Water and Power should develop contingency procurement plans to address the potential loss of all or part of Palo Verde generation.

California's utilities are also involved in decommissioning reactors at Rancho Seco, SONGS Unit 1 and Humboldt Bay. Decommissioning activities are relatively complete at Rancho Seco and SONGS Unit 1, and they are just beginning at Humboldt Bay. California utilities need to successfully complete these decommissioning projects.

PG&E will begin its engineering assessment of the costs and benefits of renewing its license for the Diablo Canyon facility over the next two years. The CPUC has directed PG&E to consider the results of the Energy Commission's assessment of the vulnerability of the plants to aging and seismic events ("AB 1632 assessment"), while allowing sufficient time for the CPUC to review the implications for PG&E's power procurement plans of either shutting down Diablo Canyon or extending its license. It is likely that SCE will monitor PG&E's efforts for any lessons learned, as SCE considers whether to pursue renewal of the SONGS license and whether to participate in the license renewal of Palo Verde (assuming Palo Verde can be returned to acceptable performance levels).

The Legislature should develop a suitable framework for reviewing the costs and benefits of nuclear power plant license extensions and clearly delineate agency responsibilities, scope of evaluation, and the criteria for assessment.

At this time there are no pending applications to construct new nuclear power plants in California. PG&E and SCE have stated that they are not interested in developing new nuclear power plants in California or in participating in new nuclear power plants outside of California for at least the next ten years.

The Fresno Nuclear Energy Group, LLC is exploring the option of building a nuclear power plant in Fresno, California. The group has announced that it is considering putting a nuclear initiative on the state ballot for November 2008. The proposal is at an early stage and the group has yet to commit substantial funds - securing a Construction and Operating License from the NRC will likely require $30 to $100 million, and a statewide initiative campaign is another multi-million dollar effort. CPUC President Peevey has concluded that their proposal is a “nonstarter.”

Therefore, the Energy Commission is not likely to receive a license application from PG&E or SCE or from a third party group for the construction of a new nuclear power plant in California in the next two years.

The resource plans of California utilities do not include proposals for new nuclear power plants. Challenges for future development of nuclear power in California by its utilities include overcoming highly uncertain construction costs; availability of financing in a regulatory system that has never provided CWIP recovery; seismic, security and safety concerns; scarcity of water for plant cooling; and unresolved spent fuel disposal problems.

California law prohibits the permitting and certification of a nuclear power plant in California until the Energy Commission finds that there has been developed, that the U.S. through its authorized agency has approved, and that there exists a demonstrated technology or means for the disposal of high-level nuclear waste (PRC 25524). In addition, for plants requiring the reprocessing of spent fuel, the permitting and certification of new nuclear power plants in California is prohibited until the Energy Commission finds that the U.S. through its authorized agency has identified and approved, and that there exists, a technology for the reprocessing of spent nuclear fuel rods (PRC 25524).

Since such findings have not been made to date, we conclude that the Energy Commission could not provide land use permits or certification for a nuclear power plant in California at this time. It is unlikely that the Energy Commission would be able to make such a finding in the near future.

Spent Fuel Reprocessing and Implications for California

Since the release of the 2005 IEPR, DOE has announced a research and development plan for domestic commercial reprocessing, known as GNEP. The GNEP program seeks to develop and commercialize a new generation of reprocessing technologies together with new nuclear reactor designs based on advanced technologies. The program is still being defined, but would require a major restructuring of the nuclear industry; this would be quite challenging and would likely require tens of billions of dollars and many decades.

The GNEP proposal is controversial. In the past ten years reprocessing has been evaluated by NCEP, the Harvard University Project on Managing the Atom, and an MIT interdisciplinary team focused on the future of nuclear power. All of these groups have concluded that reprocessing would increase the costs of spent fuel disposal relative to storage and disposal in a geological repository. They have also concluded that reprocessing would have substantial adverse implications for U.S. efforts to halt the proliferation of nuclear weapons material. Numerous public interest groups, such as NRDC and UCS, have reached similar conclusions. DOE's proposed "proliferation-resistant" technologies have been met by skepticism.

It is difficult to imagine DOE successfully managing the timely opening of the national repository at Yucca Mountain, the subsidy programs authorized in EPAct 2005 for new nuclear power plants, and the technology development efforts proposed under GNEP. It is unlikely that the federal government can fund all these major nuclear initiatives, while at the same time funding the energy efficiency, renewable energy, clean fuels, and clean coal sequestration programs endorsed by the National Commission on Energy Policy. The state, and specifically the Energy Commission, should convey to the federal government its preferred order of priorities for federal research development and demonstration programs, consistent with the goals set forth in the Energy Action Plan.

At this time the Energy Commission can conclude that reprocessing is still substantially more expensive than waste storage and disposal.

At this time the Energy Commission can conclude that reprocessing still has substantial implications for U.S. efforts to halt the proliferation of nuclear weapons material.

The Energy Commission should continue to monitor the GNEP program.

Waste Storage and Disposal and Implications for California

In the past two years, the announced schedule for the opening of Yucca Mountain has slid at least five years, and current expectations are that the repository will open sometime after 2020. Given the lack of progress toward opening a permanent repository, increased attention is being paid to interim storage options, including at Yucca Mountain. Some long-standing proponents of Yucca Mountain from the federal government and from industry have suggested that it is time to re-examine the alternatives to Yucca Mountain. New interim spent fuel storage installations have been or are being constructed at all the reactor sites serving California. Regional storage proposals are under consideration, though these are generally opposed by state governments.

At this time the Energy Commission has no basis to conclude that DOE will succeed in opening the permanent repository at Yucca Mountain in the near future. Until a permanent repository at Yucca Mountain or at an alternative location either begins operation or can be credibly expected to begin operation using a demonstrated disposal technology, the Commission cannot find that the federal government has approved and that there exists a demonstrated technology for the permanent disposal of spent fuel from these facilities. DOE's failure to license and operate a permanent repository has imposed substantial costs on California's consumers who have paid over a billion dollars to the federal government for this service and have had to incur the costs of building and operating interim fuel storage facilities.

The Energy Commission should continue to monitor the federal high-level waste disposal and spent fuel storage and management programs with regard to their implications for California and the moratorium on new nuclear power plant permitting and certification in the state.

There is only one low-level waste facility currently open to California utilities that will accept more than the least radioactive grade of nuclear waste. This facility will be closing to most states, including California, in 2008. California utilities will then be forced to store much of their low-level waste at the reactor sites unless a new low-level waste facility is opened. According to California's compact with other western states, California is to be the host site of any low-level waste facility to be opened in the compact states.

California has limited options for the storage and disposal of low-level nuclear wastes. California utilities may need to permanently store low-level nuclear wastes at the coastal sites of their nuclear power plants.

Consequences of Failure to Develop Yucca Mountain

The spent fuel pools at SONGS and Diablo Canyon are approaching engineering and safety limits to the amount of fuel that can be stored. Both SCE and PG&E have proposed to build or have already built on-site interim fuel storage facilities where spent fuel will be temporarily stored in dry casks rather than in spent fuel pools. The design of these interim facilities is intended to permit the safe storage of spent fuel for decades after the expiration of the existing operating licenses. In effect, the facilities buy time to design, license and construct a permanent repository correctly.

In 2005 the Energy Commission concluded that California needs a comprehensive assessment of the implications of indefinitely relying on at-reactor interim fuel storage facilities. Since that time AB 1632, requiring such a study, has been enacted. The Energy Commission will complete this study by November 2008.

PG&E, SCE, SMUD, and APS have sued DOE to recover the costs of building interim storage facilities that would not have been necessary had a federal repository opened on schedule. PG&E and SMUD have received preliminary judgments and awards (though appeals continue). These awards recover only costs already incurred. The utilities will have to return to the courts at a later date to recover additional costs.

The State should encourage the utilities to continue to seek damages from DOE to recover all costs related to interim waste storage.

In the heightened security environment since September 11, 2001, increased attention has been paid to the vulnerability of nuclear facilities to potential acts of terrorism. The licensing of the Diablo Canyon interim storage facility was successfully challenged due to concerns about impacts of a potential terrorist attack at the facility. The NRC's preliminary assessment is that these impacts are insignificant. It is likely that the storage facility will open before the Diablo Canyon spent fuel pool reaches its limits, and that no interruption to the operation of Diablo Canyon will be necessary.

The State should monitor the developments at the Diablo Canyon interim spent fuel storage facility and the likelihood that facility operation will be delayed for an extended period.

Nuclear power plants are difficult terrorist targets due to their substantial containment vessels, but spent fuel pools and interim fuel storage facilities may be more vulnerable. There has been a vigorous debate between the NRC, the National Academies, and the Government Accountability Office on this topic. Some of this debate has concerned the implications of terrorists using commercial aircraft as weapons of mass destruction.

The State should consider the implications of these disputes and encourage the NRC to work with the National Academies' panel of experts to resolve these concerns.

The California Attorney General filed a petition with the NRC in March 2007 requesting that the impacts of terrorism on spent fuel pools be considered in all decisions approving high-density spent fuel pool storage. This petition has not yet been considered, and the NRC has resisted other efforts to require it to consider the impacts of terrorism in its licensing decisions.

The State should consider other means to ensure that a study of the implications of terrorism is performed, such as a request to the Department of Homeland Security or the Government Accountability Office.

Spent Fuel Transportation

Spent fuel will need to be transported from reactor sites throughout the country to Yucca Mountain or other waste storage, treatment, or disposal facilities. In the event that interim storage or reprocessing is adopted, spent fuel may need to be transported multiple times to different facilities.

Numerous federal and state agencies are involved in regulating the transport of nuclear material and ensuring that safety standards are met. However, final coordination of spent fuel transportation will be managed by DOE, and states may not be able to direct how regulations are defined and complied with. Furthermore, DOE has ultimate control over the selection of shipment routes, and currently-proposed routes could disproportionately impact California.

The State should evaluate DOE's increasing use of California routes to transport nuclear waste to and from Nevada.

The Energy Commission should continue its participation in collaborative processes at the national and regional level to ensure that the State's interests are represented.

The Energy Commission should continue to coordinate the California Interagency Transport Working Group to plan, prepare, and initiate state needs assessments for spent fuel and other large radioactive shipments in California.

The Energy Commission should continue to participate in DOE's route selection and transportation planning proceedings.

California will incur significant costs in facilitating the safe transport of nuclear waste shipments and in providing emergency response services. California's fees for these services are lower than in some other states and may be inadequate to cover state costs incurred for shipment activities, such as shipment inspections and escorts.

As recommended in 2005, the State should reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments.

The federal government is required to provide both technical and financial supports to states that are involved with nuclear waste transport to Yucca Mountain. The apportionment of this support among states and the rules for how the support may be used are under development.

The State should continue to work with other states to ensure that DOE provides states with the support that they need to prepare for shipments and establishes flexible procedures.

Environmental Impacts of Nuclear Power Plants

Power production at nuclear power plants does not require combustion of fossil fuels. Accordingly, there are reduced emissions of air pollutants and greenhouse gases when nuclear power is used in place of gas-fired or coal-fired power.

However, there are also significant environmental impacts from activities that support nuclear power—the nuclear lifecycle. These impacts include radiological hazards from uranium mining and milling; greenhouse gas emissions from uranium enrichment, transportation, and fuel fabrication and from plant construction; aquatic impacts from once-through cooling; risk of groundwater contamination with tritium; radiation hazards associated with the disposal of spent fuel or reprocessing waste; and risks of radioactive releases triggered by earthquakes, tsunamis, accidents, or sabotage.

In light of these impacts and due to the great expense and uncertainty associated with new nuclear power development, many experts oppose relying predominantly on nuclear power to reduce U.S. GHG emissions. Experts disagree as to whether nuclear power should be included at all in a low-GHG emissions portfolio.

As part of the state policy reducing GHG emissions, the Energy Commission should examine the policy implications of lifecycle GHG assessments for energy technologies, including nuclear power. The State, in conjunction with other western states, should also decide what role imported or in-state nuclear power can play in a low-GHG emissions portfolio.

One of the significant impacts of nuclear power production results from the use of ocean water for once-through cooling. State and federal agencies have been reviewing regulations to reduce the marine impacts of once-through cooling. Some of the proposed regulations would limit compliance options and could force California's coastal power plants to switch to an alternate cooling method. For the nuclear power plants, this would be a very expensive operation and could lead to lower plant efficiency or other environmental impacts.

The Energy Commission should continue to assess the reliability implications of federal and state once-through cooling regulations.

Reliability of California's Nuclear Power Plants

California's in-state nuclear power plants have been reliable in recent years; however, the Palo Verde reactors have had significant and repeated operational difficulties that have led to extended shutdowns. The inability of the NRC and INPO to prevent these difficulties and to quickly turn around the plant's performance when troubles began raises concerns over the effectiveness of these oversight processes. In particular, the oversight processes may be ineffective at correcting weak elements of the safety culture, such as the overly-narrow problem-solving processes that have been identified at Palo Verde.

California utilities should be directed to develop power supply contingency plans in the event that performance degradation at the state's nuclear power plants leads to prolonged plant outages.

Potential Expansion of Nuclear Power

The federal government has offered significant incentives to the developers of the first new nuclear power plants in the U.S. in the coming years. These incentives, along with the need for power sources with low GHG emissions, have spurred interest in new nuclear power development. However, it remains to be seen whether this interest will result in a nuclear renaissance or just a handful of highly subsidized new reactors. The companies that have expressed the intent to apply for NRC licenses have not fully committed to building new plants. State legislators and regulators have for the most part not provided these companies with the level of cost recovery assurance that the nuclear industry has sought. Moreover, the cost of these plants remains highly uncertain, and current experience with new reactor construction in Finland raises the specter of significant cost-overruns, such as was experienced by the nuclear power industry in the 1970s and 1980s.

The State should continue to monitor the status of DOE's programs and the cost and progress of new reactor development in the U.S. When more information is available, the State should seek to determine the fuel cycle costs and performance of advanced reactors.

ACRONYMS AND ABBREVIATIONS

2005 Status Report	*Nuclear Power in California: Status Report*
ABWR	advanced boiling water reactor
ACC	Arizona Corporation Commission
APS	Arizona Public Service Corporation
APWR	advanced pressurized water reactor
ASLB	Atomic Safety and Licensing Board
BWR	boiling water reactor
CA ISO	California Independent System Operator
CCRWQCB	Central Coast Regional Water Quality Control Board
Ci	curie
CO2	carbon dioxide
CPUC	California Public Utilities Commission
CSLC	California State Lands Commission
CWIP	construction work in progress
DBT	design basis threat
DHS	California Department of Health Services
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
Energy Commission	California Energy Commission
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
EPR	evolutionary power reactor
ESBWR	economic simplified boiling water reactor
ESP	early site permit
FY	fiscal year
GAO	U.S. Government Accountability Office
GHG	greenhouse gas
GNEP	Global Nuclear Energy Partnership
GW	gigawatt
GWh	gigawatt-hour
IAEA	International Atomic Energy Agency
IEPR	Integrated Energy Policy Report
INPO	Institute for Nuclear Power Operations
ISFSI	independent spent fuel storage installation
kW	kilowatt
kWe	kilowatt electric
kWh	kilowatt-hour
LCA	lifecycle analysis
LWR	light water reactor
MCi	megacurie
MFP	Mothers for Peace
MIT	Massachusetts Institute of Technology

MOX	mixed oxide
MT	metric tons
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
MW	megawatt
MWe	megawatt electric
MWh	megawatt-hour
NCEP	National Commission on Energy Policy
NEI	Nuclear Energy Institute
NEPA	National Environmental Policy Act
NFMDA	Nuclear Fuel Management and Disposal Act
NIRS	Nuclear Information and Resource Service
NPDES	National Pollution Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
PBMR	pebble bed modular reactor
PFS	Private Fuel Storage L.L.C
PG&E	Pacific Gas and Electric
PSC	Public Service Commission
PWR	pressurized water reactor
ROP	Reactor Oversight Process
SCE	Southern California Edison
SDC	UK Sustainable Development Commission
SDG&E	San Diego Gas & Electric
SER	Safety Evaluation Report
SMUD	Sacramento Municipal Utility District
SONGS	San Onofre Nuclear Generating Station
SWRCB	State Water Resources Control Board
SWU	separative work unit
TAD	transportation, aging and disposal
TRW Committee	National Academies' Committee on Transportation of Radioactive Waste
UCS	Union of Concerned Scientists
USEC	U.S. Enrichment Corporation
USGS	U.S. Geological Survey
WGA	Western Governors' Association
WIEB	Western Interstate Energy Board
WIPP	Waste Isolation Pilot Plant

GLOSSARY OF TECHNICAL TERMS

Breeder reactor	Nuclear reactor that produces more nuclear fuel than it consumes
Closed fuel cycle	Nuclear fuel cycle that recovers fissile material from spent fuel for reuse in a reactor
COEX	Process that co-extracts equal amounts of uranium and plutonium from spent fuel
Curie	Unit for measuring radioactivity; defined as 3.7×10^{10} radioactive decays per second
Fast Reactor	Advanced reactor designed for operation by fast neutrons
Fissile	Capable of producing a nuclear fission reaction
Fission products	Waste products that result from a nuclear fission reaction
High-Level Waste	Highly radioactive waste from reprocessing; spent fuel, which is also highly radioactive, is sometimes called high-level waste
Light water reactor	Thermal reactor that uses ordinary water to slow down neutrons; includes the pressurized water reactor and the boiling water reactor
Low-level waste	Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material
Minor actinides	Transuranic elements other than plutonium
Mixed oxide fuel (MOX)	Nuclear fuel made up of uranium and plutonium
Once-through cooling	Reactor cooling in which large amounts of water are pumped through a reactor and then discharged
Once-through fuel cycle	Nuclear fuel cycle in which fuel is used only once
PUREX	Process that separates spent fuel into uranium, plutonium, and a nitric acid waste solution
Pyro-processing	High temperature process for the separation of spent fuel
Radiotoxicity	Measure of the radioactive health hazard of a material
Reprocessing	Processing of spent fuel to recover and purify the residual fissionable materials
Spent fuel	Fuel removed from nuclear reactors
Transmutation	Conversion through nuclear reactions of one chemical element or isotope into another
Transuranic elements	Elements in the periodic table with atomic numbers greater than uranium
Thermal Reactor	Reactor designed for operation by slowed neutrons
Uranium Enrichment	Process that increases the concentration of U-235 in natural uranium for use in nuclear fuel
Uranium oxide	An oxide of the element uranium; used in nuclear fuel
UREX+	Process that extracts uranium from spent fuel

APPENDIX A: COMPARISON OF REPROCESSING TECHNOLOGIES

	PUREX	COEX	UREX+	Pyroprocessing
Product streams	Uranium; Plutonium; Waste stream of minor transuranic elements and fission products	Uranium and Plutonium; Waste stream of minor transuranic elements and fission products	Uranium; Technetium; Strontium and Cesium; Plutonium and neptunium; Americium and curium (together) Waste stream of remaining fission products	Uranium, Plutonium, and other transuranic elements; Waste stream of strontium, cesium, and remaining fission products
High-level waste, kg, per kg spent fuel input	0.25 kg per kg glass logs; 0.95 kg per kg U	N/A	0.12 kg per kg glass logs	0.25 kg per kg ceramic form waste
Weapons-grade plutonium created?	Yes	Uranium-plutonium mix could be used directly in a nuclear weapon	No[149]	No
Short-lived fission products separated from long-lived transuranic elements?	No	No	Yes	No
Useful in LWR	Yes, to create MOX fuel	Yes, to create MOX fuel	Yes, to create MOX	No
Technology maturity	Commercially available	Under development; could be commercially available in the near term	Demonstrated on a Laboratory scale; Potentially commercially available in the 2020-2030 timeframe	Demonstrated on a engineering scale; Potentially commercially available between 2025 and 2055
Can be used for repeated reprocessing?	No	No	Yes	Yes
Estimated construction cost[150]	$8 billion	N/A	$6 billion	$7 billion (highly uncertain)
Estimated operating cost	$400 per kg material	N/A	$280 per kg material	$280 per kg material (highly uncertain)

Source: (Bunn 2006; DOE 2006d, p.8; DOE 2003a; DOE 2005a)

[149] Some experts argue that it is technically feasible to create bomb material from the plutonium-neptunium mixture coming from a UREX+ reprocessor.

[150] Plant capable of processing 2,000 metric tons per year.

APPENDIX B: LIMITATIONS OF THE LIFECYCLE ANALYSIS

As discussed in the main body of this chapter, the considerable limitations of lifecycle analyses make it non-trivial to interpret lifecycle analysis (LCA) results and, especially, to compare results across studies. The discussion below of the most significant of these limitations is taken from 1976 and 1980 papers by Holdren and Budnitz (ARE 1976, p.578; ARE 1980, p.245).

Scope of Analysis

There is no standard scope of analysis for an LCA study. Researchers have broad latitude in determining which stages of the lifecycle to study, which technologies to examine, which impacts to assess, and which time-frame to examine. Most analyses of nuclear power focus on a narrow range of the nuclear lifecycle, and few studies (if any) include the same subset of activities.

Even within the analysis of any particular activity, studies differ in which impacts are considered and how these impacts are measured. Impacts considered by studies include occupational hazards, routine and catastrophic radiation releases, land and water impacts, global warming impacts, and health and environmental impacts of energy inputs. Few lifecycle analyses examine the sociopolitical impacts of the energy technology, even though the "political implications of energy availability have been far-reaching" (ARE 1976, p.564; ARE 1980, p.245). While nuclear power may avoid the Middle Eastern petroleum conflicts, according to Holdren, "there is no doubt that the proliferation of reactors is accelerating the spread [of nuclear weapons capability] beyond what would otherwise be possible or likely…This is an awesome social cost indeed (ARE 1976, p.564; ARE 1980, p.245).

Furthermore, in assessing any particular impact the question of scope arises—where should the boundary be drawn around a web of interrelated activities? For instance, in assessing occupational hazards, should only the direct hazards from constructing the reactor and support structures be included, or should the hazards from mining the ore and fabricating the steel that is used in these structures also be included? Some researchers have attempted to address these issues by drawing what must inevitably be an arbitrary circle to define the scope of their analyses and then applying the same scope to multiple generation technologies. These researchers attempt to provide a fair comparison between technologies, even if they do not provide a complete assessment of the impacts of any one. However, due to the inherent differences in the technologies, one circle does not incorporate the same percent of risk from each technology. While a circle drawn around plant operation would incorporate most of the hazards of natural-gas fired generation, the circle would need to include uranium mining, milling and enrichment, spent fuel management and disposal, and risks to future generations from highly radioactive waste and catastrophic radiation releases to incorporate most of the hazards from nuclear generation.

Data Issues

Perhaps the most important limitation of LCA studies is that much of the data to quantify the impacts is unavailable or very uncertain. The links between an impact on the environment, a stress on the environment, and damage to the environment "pose some of the most intractable problems in environmental science" (ARE 1980, p.244). Consequently, environmental *impacts* are often measured instead of environmental *damage*. For instance, a study might calculate the amount of land and water used in the generation lifecycle rather than the damage to health and ecosystems due to this land and water use.

Moreover, according to Holdren, for nuclear and other non-renewable generation "there is much reason to believe that the gravest and least tractable threats to human well-being may reside in classes of damages that are highly resistant to quantification: climatic change caused by carbon dioxide from fossil-fuel combustion; nuclear explosions perpetrated by nations or by terrorists with material derived from commercial nuclear power; large-scale disruption of ecosystems by acid precipitation from fuel burning; and so on" (ARE 1980, p.245).

Accordingly, there is considerable uncertainty in the data estimates used in these lifecycle assessments. In some cases this uncertainty is great enough to undermine the estimate. For example, the best estimates of light-water reactor accident risk range from .01 to 1,000 deaths per 10^{18} joules of electricity produced. "Clearly, in a case of this kind, the uncertainty itself is as informative a measure of the burden the public is asked to bear in exchange for the technology's benefits as is the "best estimate" of expected harm" (ARE 1980, p.271).

Quantification and Interpretation

Quantification and interpretation of impacts both present significant challenges. For example, "[h]ow does one weigh a small chance of a big disaster against a persistent routine impact that is significant but not overwhelming?" (ARE 1976, p.576).

Attempts to assign a dollar value to each impact are generally unsatisfactory. For instance, the insurance value of a lost day of labor due to personal injury includes direct costs, occasional litigation, awards for liability, other fees, and occasional tort awards for suffering. It is "only a rudimentary way of accounting for items such as human suffering, dislocation, or the disruption of labor" (ARE 1976, p.576). Also, based on tort awards, the dollar value of life has increased markedly in recent years, clearly reflecting a change in social value rather than actual impact (ARE 1976, p.577).

There are also important nuances that must be taken into account when selecting metrics: lost days of life may be a better metric than number of deaths, since it accounts for deaths to different age groups; number of accidents is not instructive without additional measures of severity, such as lost work days; and loss of land use should be distinguished by the number of years that the land will be committed (e.g., land housing a windmill for 40 years vs. permanent nuclear waste repository) (ARE 1976, pp.572-573). Furthermore, the impacts of land use depend on whether the land can be used for other purposes while supporting the power facility (e.g., solar and wind farms and transmission grids can support wildlife, agriculture, and recreation; hydroelectric dams often support irrigation, flood control and recreation), and whether impacts are dispersed or concentrated (using extra space on a farm for a single windmill may be less disruptive than clearing space for a large wind farm). Many of the lifecycle analyses use metrics that do not account for the severity and permanence of the impact or our degree of control or adaptability for any given impact (ARER 2004, pp.332-333).

Another challenging area is the valuation of impacts that will occur at a future date. In general, economists discount harm that occurs at a future date relative to harm that occurs right now. However, Dr. Kammen argues that when there is only "a weak connection between the generation who benefits from the energy produced and the generation suffering the harm…the estimation of the present value of such impacts using market discount rates is inadequate" (ARER 2004, p.332). Kammen suggests that an appropriate discount rate should reflect the rate of diminishment of the physical impact that is the source of the cost, such as the fraction of CO_2 remaining in the atmosphere after its release or the persistence of isotopes in the environment. He has shown that these physical impacts remain important long after traditional market discount rates would value them as negligible (ARER 2004, p.332).

Holdren also identified the distribution of costs and benefits as a key ethical issue:

> The question of the distribution of environmental costs among different groups of people—some of whom benefit directly from the activities producing the costs and others of whom are far removed from those benefits—has received too little attention in comparative assessments so far. In the long run, it may prove decisive. If environmental costs are large, difficult to quantify, and imposed on groups far removed in space and time from those choosing the technologies and receiving the benefits (as is the characteristic of some of the costs of coal, oil, and nuclear power), then the choices of what kind and how much energy to use can be neither just nor efficient. The greatest asset of decentralized renewables may be their tendency to impose their main environmental burdens on the users of the energy or on those the users must compensate. In contrast to the case when some of the biggest costs are "exported," this permits energy users to decide rationally which sources to use and how much is enough" (ARE 1980, p.283).

Methodology and Assumptions

The methodologies and assumptions used in LCA studies vary considerably. Some studies analyze the impacts of a particular plant, whereas others use theoretical plants or averages of nationwide plants. Studies of a particular plant or studies from one country can be difficult to generalize to other plants or other countries. For example, some countries reprocess their spent fuel, while others use geologic disposal. The transport distances from the mine to the various fuel processing plants to the reactor differ from plant to plant and from country to country. The fuel used to power uranium enrichment facilities and, consequently, the impacts of this energy use differs across states and countries. The uranium enrichment technology that is used also differs across countries.

The assumptions that most impact the results will differ depending on the technology being studied. Key assumptions in the nuclear LCA are described below:

1. Accident risk: Some studies consider only normal operations and do not consider the risk of accidents. Others include a probabilistic risk assessment of one or several types of accidents. Categories of accidents that might be considered include transportation accidents, worker injury during construction and maintenance, reactor meltdowns, and radiation release from intentional sabotage of a reactor or spent fuel storage facility. Typically, studies conclude either that the risks of meltdown or other large scale catastrophe is too low to be considered or that the cost of such occurrences is too difficult to estimate.

2. Enrichment Technology: Gas centrifuge technology uses just 2-3 percent of the energy required by gaseous diffusion technology (Energy Policy 2007, p.2553). Large cascading gas centrifuges operate around the world, but the U.S. is only now beginning to develop the technology, and it plans to have its first full-size plant begin operation in 2010 at the earliest.[151] According to an Argonne National Lab model, increasing the percent of fuel enriched via centrifuge technology from 75 percent to 100 percent would reduce greenhouse gas emissions from the front end of the nuclear fuel cycle by almost 70 percent (ANL 2007a).

   Nuclear LCA studies generally assume that between 70 percent and 100 percent of uranium fuel is enriched via centrifuge technology. Actual centrifuge use for the uranium ordered for U.S. power reactors varies from year to year between about 65 percent and 80 percent, with a 2003-2005 average of about 69 percent (EIA 2006a). This figure could increase to 100 percent if the U.S. replaces its gaseous diffusion plants with gas centrifuge plants and refrains from purchasing enrichment services from France and from China's remaining gaseous diffusion plants.

3. Fuel Cycle Processes: Some studies assess every step of the fuel cycle from uranium mining to power generation to waste disposal to remediation of mining and disposal sites. Most studies, however, analyze just a subset of these steps, and it is unlikely that any two studies analyze the same subset. Some of the steps that are excluded from many of the studies include facility construction, waste disposal, and site remediation.

[151] United States Enrichment Corporation (USEC) received an NRC license on April 13, 2007 to build a commercial gas centrifuge plant in Piketon, Ohio. USEC expects that its demonstration plant will come online in 2007 and that the commercial plant will provide 3.8 million SWU when it is fully deployed in 2012 (USEC 2007a; NRC 2007j).

4. Plant Lifetime: Some of the health and environmental impacts of nuclear power generation are fixed costs that result from the plant's construction and decommissioning. These costs are incurred whether a plant is operated for one day or for 60 years. However, if a plant is operated for a long time, these costs are spread out over many gigawatt hours of generation and have a smaller per-kilowatt-hour impact. The selection of plant lifetime is thus important in assessing the unit impact of nuclear power generation. Since most modern nuclear power plants are still in operation, there is no clear average lifetime to use. Some studies use 24 years, which is the average lifetime to date. Others use the 40-year licensing lifetime. Many U.S. reactors have applied for license extensions that would extend their regulatory life to 60 years.

5. Nuclear Fuel cycle: Plants in the U.S. currently use a once-through fuel cycle, in which spent fuel is disposed of and fresh uranium is used to fabricate new reactor fuel. However, some countries use a partially closed fuel cycle, in which spent fuel is reprocessed and recycled into reactor fuel. Analyses conducted in Europe tend to include such a reprocessing stage and must be adjusted before being applied to U.S. reactors.

6. External Energy Source: Producing the cement and steel for a nuclear power plant requires large amounts of electricity. Enrichment of uranium is also power-intensive, especially in the U.S. where centrifuge technology is not yet available. Emissions from generating this power are part of the nuclear lifecycle, and the source of this power can have a large impact on the assessment of nuclear power's contribution to CO_2 and toxic air emissions. Some studies presume that a single fuel source is used for all processes, while others identify the typical fuel that is used for each of the processes. Transporting uranium, nuclear fuel, and nuclear wastes (including low-level waste and spent fuel) requires further power. Impacts of the petroleum products used to fuel transport are often not included in lifecycle analyses.

7. Transport Distances: One source of emissions in the nuclear fuel cycle is the transport of uranium between the mine, the processing plants, the reactor, and the waste disposal facilities. The distances between these locations, some of which can be overseas, as well as the transport method, will determine the total emissions from transport.

8. Technology Selection: Most analyses consider current technologies and avoid speculation over the availability of particular resources and technologies at a future date. Some do assume that certain changes will take place. For instance, some studies assume that centrifuge enrichment technology will be used exclusively or that high grade uranium ore will be depleted.

9. Risk Mitigation: Safety measures of varying costs can be employed to mitigate the risks of nuclear power. Different analyses implicitly assume different levels of risk mitigation in estimating accident risk, radiation from abandoned mill tailings, and other mitigation costs.

10. Discount rate: There is no consensus over what, if any, discount rate should be used in quantifying the health and environmental impacts that will occur at a future date.

APPENDIX C: TABLES OF SELECT LIFECYCLE ANALYSIS STUDIES

Table 42: Lifecycle Analysis Methodology and Interpretation

Author	Title	Reference Information
AEA Technology Environment	Carbon Footprint of the Nuclear Fuel Cycle: Briefing note	Technical Report prepared for British Energy; London, UK, March 2006
Bergerson, Joule and Lave, Lester	A Life Cycle Analysis of Electricity Generation Technologies: Health and Environmental Implications of Alternative Fuels and Technologies	Carnegie Mellon Electricity Industry Center; November 2002
Budnitz, Robert and Holdren, John	Social and Environmental Costs of Energy Systems	Annual Review of Energy, 1 (1976) 553-580
Fthenakis, V.M. and Kim. H.C.	A Review of Risks in the Solar Electric Life-Cycle	Brookhaven National Laboratory, Conference Paper; October 2005
Holdren, John, et. al.	Risk of Renewable Energy Sources: A Critique of the Inhaber Report	Energy and Resources Group, University of California, Berkeley; Report No. ERG 79-3, June 1979
Holdren, John, Morris, Gregory and Mintzer, Irving	Environmental Aspects of Renewable Energy Resources	Annual Review of Energy, 5 (1980) 241-291
Kammen, Daniel and Pacca, Sergio	Assessing the Costs of Electricity	Annual Review of Environment and Resources, 29 (2004) 301-344
Sundqvist, Thomas and Söderholm, Patrik	Valuing the Environmental Impacts of Electricity Generation: A Critical Survey	Journal of Energy Literature, 8:2 (2002) 3-41
U.S. Congress, Office of Technology Assessment	Studies of the Environmental Costs of Electricity	OTA–ETI–134, Washington, DC: U.S. Government Printing Office, September 1994.

Table 43: Health and Environmental Impacts of Generation Technologies

Author	Title	Reference Information
AEA Technology Environment	Generation and the Environment – a UK Perspective	Report prepared as part of the ExternE Project for the European Commission DGXII, June 1998
Bodansky, David	Electricity Generation Choices for the Near Term	Science, 207 (1980) 721-728
Gagnon, Luc; Belanger, Camille and Uchiyama, Yohji	Life-cycle assessment of electricity generation options: The status of research in year 2001	Energy Policy, 30 (2002) 1267-1278
Hohenemser,C; Kates, V.M. and Slovic, P.	The Nature of Technological Hazard	Science, 220:4595 (1983) 378-384
Holdren, J.P; Morris, G. and Mintzer, I.	Environmental Aspects of Renewable Energy Sources	Annual Review of Energy, 5 (1980) 241-291
Inhaber, Herbert[152]	Risk with Energy from Conventional and Nonconventional Sources	Science, 203 (1979) 718-723
Krewitt, Wolfram, et. al.	Health Risks of Energy Systems	Risk Analysis, 18:4 (1998) 377-383
Nuclear Energy Agency/ OECD	Externalities and Energy Policy: The Life Cycle Analysis Approach	Workshop Proceedings; Paris, France, 15-16 November 2001
Oak Ridge National Laboratory and Resources For The Future	Estimating Externalities of Nuclear Fuel Cycles, Report No. 8 on the External Costs and Benefits of Fuel Cycles	Study By the U.S. Department of Energy and the Commission of European Communities; April 1995
Spadaro, J.V. and Rabl, A. Centre d'Energetique	External Costs of Energy: Application of the ExternE Methodology in France	Final Report; Paris, France, January 1998

[152] This study has been discredited. See (Science 1979a; ERG 1979; Science 1979b; Science 1979c) In addition, Atomic Energy Control Board of Canada (now the Canadian Nuclear Safety Commission), under whose auspices Inhaber conducted his research, ultimately withdrew support for his report, and they no longer list this report among their publications. See (CNSC 2005)

Table 44: Greenhouse Gas Emissions from Nuclear Power Generation

Author	Title	Reference Information
AEA Technology Environment	Environmental Product Declaration of Electricity from Torness Nuclear Power Station	Technical Report prepared for British Energy; London, UK, May 2005
Barnaby, Frank and Kemp, James, editors	Secure Energy? Civil Nuclear Power Security and Global Warming	Briefing Paper; Oxford Research Group, March 2007
Fritsche, Uwe Coordinator Energy & Climate Division Oko-Institut Institue for Applied Energy	Comparing Greenhouse-Gas Emissions and Abatement Costs of Nuclear and Alternative Energy Options from a Life-Cycle Perspective	Paper presented at the CNIC Conference on Nuclear Energy and Greenhouse-Gas Emissions; Tokyo, November 1997
Fritsche, Uwe Coordinator Energy & Climate Division Oko-Institut Institue for Applied Energy	Comparing Greenhouse-Gas Emissions and Abatement Costs of Nuclear and Alternative Energy Options from a Life-Cycle Perspective – Updated Perspective	Oko Institut, Darmstadt, Germany, January 2006
Fthenakis, V.M. and Kim. H.C.	Greenhouse-gas emissions from solar electric- and nuclear power: A life-cycle study	Energy Policy 35 (2007) 2549–2557
Fthenakis, V.M. and Kim. H.C.	Life Cycle Analysis of Photovoltaic Systems	Brookhaven National Laboratory ,EH&S Research Center, Conference Paper; 2005
Meier, Paul J.	Life Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis	Dissertation, Doctor of Philosophy; University of Wisconsin, Madison; August 2002
Socolow, Robert and Pacala, Stephen	A Plan to Keep Carbon in Check	Scientific American, January 2006, 50-57
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White, S. and Kulcinski, G.	“Birth to Death” Analysis of the Energy Payback Ratio and CO2 Gas Emission Rates from Coal, Fission, Wind, and DT-Fusion Electrical Power Plants	Fusion Engineering and Design, 48:3-4 (2000) 473-481
Wu, Ye, et. al. Argonne National Laboratory	Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Hydrogen Produced with Nuclear Energy	Nuclear Technology, 155 (2006) 192-207

APPENDIX D: ENVIRONMENTAL IMPACTS OF URANIUM MINING

Additional environmental impacts from the nuclear power lifecycle arise from the mining and milling of uranium. For the most part, these impacts are not felt by the consumers of nuclear power; instead they are borne by mine employees and the typically-poor communities in the vicinity of the mine.

Mining impacts

In the 1980s, some U.S. uranium mining companies began to use in-situ leaching, also called solution mining (EPA 2006d). This process leaches uranium directly from rock formations and obviates the need for a separate milling process.[153] Since 2003, the number of conventional mines and the number of in-situ leaching mines have both increased in the U.S., and in 2005 there were four mines of each type. However, the four mines that used in-situ leaching accounted for 88 percent of the uranium that was extracted (EIA 2006c).

A 2002 National Academies study found that in-situ leaching is environmentally preferable to conventional mining:

> In-situ leaching has many environmental advantages over conventional mining because it generates less waste material and causes less surface disturbance (no mill tailings, overburden removal, or waste-rock piles). The major environmental concern is post-mining water quality. For example, in the case of uranium, concentrations of uranium and its associated radioactive daughter products and, in some cases, potentially toxic elements, such as arsenic and selenium, could be elevated. Site reclamation has been successful at several south Texas sites where in-situ leaching of uranium was first undertaken in the 1970s. In-situ uranium leaching also has advantages in terms of health and safety because the leaching process selectively removes uranium and leaves most of the dangerous radioactive daughter products in the ground. In addition, little heavy machinery is required to remove the large volumes of rock that would have been processed in a conventional mining operation (National Academies 2002, pp.34-35).

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[153] The in-situ leaching process is as follows: First, injection wells are dug and then used to inject a leaching solution into the formation. The solution leaches uranium and other minerals from the formation. The uranium-laden solution is pumped to the surface, where the uranium salts are filtered out and dried. Additional leaching solution is injected into the formation until insufficient recoverable uranium remains. Overall, more fluid is extracted than injected in order to create a low-pressure area. This causes groundwater to flow into the injection site rather than away from it, preventing contamination from escaping the area (EPA 2006b).

However, concerns have been raised that groundwater contamination could be significant and might not be fully remediated. For example, according to the NRDC, the “result of uranium solution mining is a profoundly contaminated aquifer, and the uranium mining industry has not restored a single Western aquifer to its original water quality solution after mining was used” (NRDC 2005, p.14). This statement reflects ongoing controversy in some clean-up cases as to whether a site has been completely remediated (San Antonio Express 2006). In addition, there are concerns that bonds posted by mining companies might not cover all the costs of remediation and that companies could simply declare bankruptcy and walk away from contaminated sites (LA Times 2006b).

Mill Tailings

Mill tailings are the waste materials from the uranium milling process. According to the EPA, 226,000,000 metric tons of uranium mill tailings are stored in mounds (tailings piles) at 26 NRC-licensed sites and 24 abandoned sites. Most of these sites are near uranium mills in the West, primarily in Colorado, New Mexico, Utah, and Wyoming (EPA 2006c).

The main radioactive component of uranium mill tailings is radium, which decays to produce radon—a radioactive gas. According to EPA estimates, radon is the leading cause of lung cancer among non-smokers (EPA 2007b). In addition, uranium has been demonstrated in mice to mimic estrogen and disrupt endocrine production. This link suggests that uranium exposure in drinking water might contribute to increased risk of reproductive cancers (NAU 2006).

The EPA lists four principal ways the public can be exposed to the hazards from mill tailings (EPA 2006c):

1. Radon gas can diffuse directly into indoor air if tailings are misused as a construction material or the backfill around buildings.
2. Radon gas can diffuse from piles into the atmosphere where it can be inhaled, and small particles can be blown from the piles into the atmosphere where they can be inhaled or ingested.
3. The radioactive decay products in tailings produce gamma radiation, which poses a health hazard to people in the immediate vicinity.
4. The dispersal of tailings by wind or water, or by leaching, can carry radioactive and other toxic materials to surface or ground water that may be used for drinking water.

In 1978 Congress found “that uranium mill tailings located at active and inactive mill operations may pose a potential and significant radiation health hazard to the public, and…every reasonable effort [must] be made to provide for the stabilization, disposal, and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from such tailings” (42 USC 7901). With the

Uranium Mill Tailings Radiation Control Act, DOE assumed responsibility for stabilizing, disposing of, and controlling mill tailings and other radioactive materials at the abandoned mill sites and for bringing the surface and groundwater contaminant levels at these sites into compliance with EPA standards (42 USC 7901). These standards require that tailing piles be made off limits to the public and covered by thick earthen material that limits emissions of radon gas into the air and prevents seepage of the tailings into groundwater. In addition, non-operating sites must be remediated as soon as possible, and new piles must be constructed to meet requirements limiting radon emissions and groundwater contamination (EPA 2006c). DOE continues to inspect and monitor abandoned uranium mill tailings disposal sites (DOE 2006e, p.vii).

Yet, significant contamination has been found in Navajo lands from abandoned mining and milling sites. For example, as reported in a recent LA Times series, in one Arizona village uranium levels in the water were seven times the EPA limit and uranium levels in abandoned pits were up to 200 times the EPA limit. The water in many of the pits also had high concentrations of radium-226, a radioactive byproduct of uranium. These high contamination levels may be associated with severe health problems that have been found in families that drank from these water sources (LA Times 2006c).

On April 29, 2005 Navajo Nation President Joe Shirley, Jr. signed the Diné Natural Resources Protection Act of 2005. The Act cites the findings of the Navajo Nation Council that past uranium mining and milling have harmed the Navajo land and people and bans these activities on tribal lands:

> The Navajo Nation Council finds that the mining and processing of uranium ore on the Navajo Nation and in Navajo Indian Country since the mid-1940s has created substantial and irreparable economic detriments to the Nation and its people in the form of lands lost to permanent disposal of mining and processing wastes, lands left unproductive and unusable because they are the sites of hundreds of abandoned uranium mines that have not been successfully reclaimed, surface waters and ground water left unpotable by mining and processing operations, livestock that could not be marketed because they were believe to have been contaminated by uranium, Navajo workers who lost thousands of person-years [of] gainful economic activity as a result of their mining-induced illnesses and deaths, and the families of Navajo uranium workers whose livelihoods, agricultural lands and homesites were diminished in value because of the illnesses and premature deaths of the workers.
>
> …No person shall engage in uranium mining and uranium processing on any sites within Navajo Indian Country (Navajo Nation Council 2005a).

APPENDIX E: SUMMARY OF LICENSE RENEWAL APPLICATIONS

Applicant (State)	**Application / License Renewal**
Approved License Renewal Applications	
Baltimore Gas & Electric Co. Calvert Cliffs Units 1 & 2 (MD)	April 1998 / March 2000
Duke Energy Oconee Nuclear Station Units 1, 2, & 3 (SC)	July 1998 / May 2000
Entergy Nuclear Operations Arkansas Nuclear One, Unit 1 (AR)	February 2000 / June 2001
Southern Nuclear Operating Co. Edwin I. Hatch Nuclear Plant, Units 1 & 2 (GA)	March 2000 / January 2002
Florida Power & Light Co. Turkey Point Nuclear Plant, Units 3 & 4 (FL)	September 2000 / June 2002
Virginia Electric & Power Co. Surry, Units 1 & 2 and North Anna, Units 1 & 2 (VA)	May 2001 / March 2003
Duke Energy McGuire, Units 1 & 2 and Catawba, Units 1 & 2 (SC)	June 2001 / December 2003
Exelon Generating Co. Peach Bottom, Units 2 & 3 (PA)	July 2001 / May 2003
Florida Power & Light Co. St. Lucie, Units 1 & 2 (FL)	November 2001 / October 2003
Omaha Public Power District Fort Calhoun Station, Unit 1 (NB)	January 2002 / November 2003
Carolina Power & Light Co. H. B. Robinson, Unit 2 (SC)	June 2002 / April 2004
Rochester Gas & Electric Corp. R. E. Ginna Nuclear Power Plant, Unit 1 (NY)	August 2002 / May 2004
South Carolina Electric & Gas Co. V. C. Summer Nuclear Station, Unit 1 (SC)	August 2002 / April 2004
Exelon Generating Co. Dresden, Units 2 & 3 (IL) and Quad Cities, Units 1 & 2 (IL)	January 2003 / October 2004
Southern Nuclear Operating Co. Farley, Units 1 & 2 (AL)	September 2003 / May 2005

Applicant (State)	**Application / License Renewal**
Entergy Nuclear Operations Arkansas Nuclear One, Unit 2 (AK)	October 2003 / June 2005
Indiana & Michigan Power Co. D.C. Cook, Units 1 & 2 (MI)	November 2003 / August 2005
Tennessee Valley Authority Browns Ferry, Units 1, 2 & 3 (AL)	January 2004 / May 2006
Dominion Nuclear Connecticut Millstone, Units 2 & 3 (CT)	January 2004 / November 2005
Nuclear Management Co. Point Beach, Units 1 & 2 (WI)	February 2004 / December 2005
Constellation Energy Nine Mile Point, Units 1 & 2 (NY)	May 2004 / October 2006
Carolina Power & Light Brunswick, Units 1 & 2 (NC)	October 2004 / June 2006
Nuclear Management Co. Monticello (MN)	March 2005 / November 2006
Nuclear Management Co. Palisades (MI)	March 2005 / January 2007
Pending License Renewal Applications	
AmerGen Energy Co. Oyster Creek Nuclear Generating Station (NJ)	July 2005
Entergy Nuclear Operations Pilgrim Nuclear Power Station (MA)	January 2006
Entergy Nuclear Operations Vermont Yankee Nuclear Power Station (VT)	January 2006
Entergy Nuclear Operations James A. FitzPatrick Nuclear Power Plant (NY)	August 2006
PPL Susquehanna Susquehanna Steam Electric Station (PA)	September 2006
Wolf Creek Nuclear Operating Corp. Wolf Creek Generating Station (KS)	October 2006
Carolina Power & Light Co. Shearon Harris Nuclear Power Plant (NC)	November 2006
Entergy Nuclear Operations Indian Point, Units 2 & 3 (NY)	April 2007

Applicant (State)	**Application / License Renewal**
Planned License Renewal Applications[154]	
Southern Nuclear Operating Co. Vogtle Electric Generating Plant, Units 1 & 2 (GA)	June 2007
FirstEnergy Nuclear Operating Co. Beaver Valley Power Station, Units 1 & 2 (PA)	August 2007
Exelon Generating Co. Three Mile Island, Unit 1 (PA)	January-March 2008
Nuclear Management Company Prairie Island Nuclear Generating Plant, Units 1 & 2 (MN)	April-June 2008
Nebraska Public Power District Cooper Nuclear Station (NE)	September 2008
STARS Strategic Teaming and Resource Sharing Plant	October-December 2008
Nuclear Management Company Duane Arnold Energy Center (IA)	October-December 2008
Entergy Nuclear Operations Entergy Plant	January 2009
Progress Energy Florida Crystal River Nuclear Generating Plant, Unit 3 (FL)	January-March 2009
PSEG Nuclear Salem Generating Stations Unit 1 & 2	September 2009
PSEG Nuclear Hope Creek Generating Station (NJ)	September 2009
STARS Strategic Teaming and Resource Sharing Plant	October-December 2009
Energy Northwest Columbia Nuclear Generating Station (WA)	January 2010
Entergy Nuclear Operations Entergy Plant	January 2010
FirstEnergy Nuclear Operating Company Davis-Besse Nuclear Power Station, Unit 1 (OH)	August 2010

[154] As indicated by submission of Letter of Intent to Apply for License Renewal

Applicant (State)	**Application / License Renewal**
STARS Strategic Teaming and Resource Sharing (STARS) Plant	October-December 2010
Exelon Generating Co. Exelon Plant	September 2011
STARS Strategic Teaming and Resource Sharing (STARS) Plant	October-December 2011
Exelon Generating Co. Exelon Plant	September 2012
Exelon Generating Co. Exelon Plant	July 2013
Exelon Generating Co. Exelon Plant	July 2013
STARS Strategic Teaming and Resource Sharing (STARS) Plant	July-September 2013
FirstEnergy Nuclear Operating Company Perry Nuclear Power Plant (OH)	August 2013

Source: (NRC 2007af)

APPENDIX F: GENERATION III/III+ TECHNOLOGIES

There are six reactors currently under consideration for new near-term reactor builds in the U.S. (NRC 2007q). Two of these, the ABWR and the AP1000, are NRC certified, and the remaining three, the ESBWR, the US-APWR, and the US-EPR, are currently undergoing NRC certification review (NRC 2006c). Brief descriptions of these reactors follow.

Advanced Boiling Water Reactor

The General Electric Advanced Boiling Water Reactor (ABWR) (NRC-certified in 1997) is the only Generation III design that has been commercially built and operated. ABWRs have a simplified and more compact design than modern boiling water reactors (BWRs), taking up roughly 70 percent of the volume of BWRs (NEI 2007a). They are also more efficient, since they use steam directly from the coolant to drive the turbines and do not require liquid to steam conversion. However, the ABWR has the disadvantages that radioactive water is not confined to the reactor and refueling is more complex than in other designs (UK SDC 2006b, pp.17-18).

Japan operates four ABWRs, and three additional units are under construction in Japan and Taiwan (GE 2007). The first ABWR began generating electricity in 1996, having been constructed in just 51 months—10 weeks ahead of schedule.

A number of design improvements that will reduce construction and O&M costs are being included in current ABWR designs. These were identified during a study (conducted by General Electric and others) of potential costs and schedules for constructing twin AWBR units at the Bellefonte plant site in Hollywood, Alabama (TVA 2005). The study recommended that modularization and offsite construction be used to the maximum extent possible. The study claimed that, with the adoption of its recommendations, an ABWR could be constructed at the Bellefonte site in 40 months.

Only one proposal for a U.S. ABWR has been announced. The proposal is for NRG Energy's South Texas Project. NRG Energy is expected to submit an NRC license application for this project in 2008, and a decision on this project is anticipated in 2011 (NRC 2007q).

AP1000

The Westinghouse AP1000 Generation III+ advanced passive reactor design was certified by the NRC certified in 2006 (NRC 2007f). Its main feature is its passive design, "using the natural laws of gravity, convection and compression" (UK SDC 2006b, p.17). This design requires fewer moving parts than an active design, which should reduce the cost of construction and the risk of failure. Construction periods are also expected to be reduced due to the plant's modular design (UK SDC 2006b, p.17). While no reactor of this type has yet been built, Westinghouse has set a construction time goal of three or four years (NEI 2007c).

There have been several proposals to build AP1000 reactors in the U.S. Southern Nuclear's Vogtle project, for which an ESP application was submitted in 2006, would use an AP1000. A decision on this application is expected in 2009. In addition, six NRC license applications to build AP1000 reactors in the southeast are anticipated in 2008. Decisions on these applications are expected in 2011 and 2012 (NRC 2007q).

Evolutionary Power Reactor

The 1,600 MW Generation III+ Evolutionary Power Reactor (EPR) is expected to receive NRC certification in 2011 (NRC 2007q). Unlike other advanced technologies, the EPR will use active systems with safety enhancements instead of passive systems. It is designed to operate with three times the burn-up efficiency as other modern reactors, so as to minimize radioactive wastes (UK SDC 2006b, pp.17-18). As discussed in Chapter 4, the development of reactors with high burn-up efficiency is one of the targets of DOE's GNEP.

Four NRC license applications for U.S. EPR reactors are expected to be submitted in 2008 or early 2009. In addition, an EPR is currently being built in Finland at Olkiluoto with a target commercialization date of 2011. This is expected to be the first operating Generation III+ reactor.[155]

Economic Simplified Boiling Water Reactor

General Electric's 1,550 MW ESBWR (sometimes called the European Simplified Boiling Water Reactor) is a Generation III+ design expected to become NRC-certified in 2010 (NRC 2007q). According to General Electric, ESBWR reactors will use natural circulation and passive safety features that will eliminate the need for safety-grade pumps and AC power. General Electric expects that these design simplifications will reduce the required building volume compared with the ABWR design, even though the ESBWR will generate nearly 15 percent more power. ESBWR technology was selected to be part of DOE's Nuclear Power 2010 program (Nuclear News 2006).

Dominion's North Anna project and NuStart Energy's Grand Gulf project, both of which submitted ESP applications in 2005, would use ESBWR reactors. NRC license applications for three projects in Virginia, Mississippi, and Louisiana that would use ESBWR reactors are anticipated in 2008 (NRC 2007q).

[155] The plant was originally targeted to be operational in 2009, but the project is running behind schedule. It is now expected to be fully operational in 2011 (Olkiluoto.Info 2006).

US-Advanced Pressurized Water Reactor

The US-Advanced Pressurized Water Reactor (US-APWR) is a 1,700 MW Generation III design that was only recently announced in June 2006. The design includes the world's highest level of thermal efficiency (39 percent), and a 20 percent reduction in plant building volume (Mitsubishi 2006). It is expected to become NRC-certified in 2011 (NRC 2007q).

The only plan for a US-APWR that has been announced is TXU Power's Comanche Peak project. TXU is expected to submit an NRC license application for this project in 2008 (NRC 2007q).

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