From: "Richard Webster" <rwebster@kinoy.rutgers.edu>
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Subject: Resending EIS comments

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As requested here are the I comments I submitted on Friday September 8, 2006 on behalf of behalf of Nuclear Information and Resource Service, Jersey Shore Nuclear Watch, Inc., Grandmothers, Mothers and More for Energy Safety, New Jersey Public Interest Research Group, New Jersey Sierra Club, and New Jersey Environmental Federation (collectively "Citizens") on the safety and security aspects of the DSEIS.

To avoid problems with e-mail size limits, I only attach to this e-mail three of the 5 exhibits. I will forward the other two exhibits in a separate e-mail. I have also sent a hard copy of these comments to the agency.

Respectully submitted

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September 8, 2006

VIA EMAIL AND U.S. MAIL

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Re: NUREG-1437: Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Supplement 28, Regarding Oyster Creek Nuclear Generating Station Draft Report for Comment: Comments on Safety and Security Aspects

Please accept these written comments submitted on behalf of Nuclear Information and Resource Service, Jersey Shore Nuclear Watch, Inc., Grandmothers, Mothers and More for Energy Safety, New Jersey Public Interest Research Group, New Jersey Sierra Club, and New Jersey Environmental Federation (collectively "Citizens") on the safety and security aspects of the above-referenced Draft Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, Supplement 28, regarding Oyster Creek Nuclear Power Plant ("DSEIS"). Comments on other aspects of the DSEIS are being submitted under separate cover by Julia Huff of this office for Citizens and additional organizations. NRC should consider and respond to both sets of comments, as they are complementary and not duplicative.

I. Summary

The DSEIS is inadequate because it fails to consider the environmental effects of a spent fuel pool fire that could be caused by accident or by an act of terrorism. This failure, among others, means

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that the analysis of Severe Accident Mitigation Alternatives ("SAMA") is woefully inadequate. Calculations by experts show that a spent fuel pool fire could result from the packing of the spent fuel into the pool at high density, which was not originally intended. Such a fire could directly cause $180 billion and $1.8 trillion worth of damage, including over 24,000 lung cancers. This is around ten times the amount of damage caused by hurricane Katrina. At an estimated probability of around 1 in 10,000 per year, this imposes a risk to society that is valued at between $200 million and $3.6 billion. AmerGen stands to make around $2.6 billion during the proposed 20 year extended operating period, provided nothing serious goes wrong with the plant during that time. Thus, the costs to society of the risk imposed by Oyster Creek are probably more than AmerGen would make from the electricity generated at the plant, even it operated at full capacity throughout the proposed 20 year extended license period.

This means that even closure of the plant would be a cost effective SAMA. Further, according to experts, transferring the spent fuel that is over five years old to dry cask storage would significantly lower the chance of a spent fuel pool fire at a cost of less than $100 million. Indeed, AmerGen has quoted the cost as around $30 million, and, incredibly, has described this as an "unnecessary expense." The failure of the DSEIS to consider the possibility of a spent fuel pool fire means that it currently violates the requirements of both the National Environmental Policy Act ("NEPA"), and the NRC regulations that implement NEPA. Thus, the SAMA analysis must be completely revised and presented as a new draft for additional public comment.

In addition, allowing Oyster Creek to continue to operate its spent fuel pool in such a reckless manner during any additional period of licensed operation would violate the Atomic Energy Act ("AEA"). Moreover, there are currently no acceptable means of containing the wastes that would be generated by further operation of the reactor. Therefore, the NRC should refuse to relicense the reactor, because to do so would be "inimical to the common defense and security or to the health and safety of the public." 42 U.S.C. § 2133(d). Furthermore, because allowing AmerGen to continue to operate a high density fuel pool does not offer "adequate protection" to public health and safety, as required by the AEA, NRC should also take urgent action to mitigate the current risk caused by the spent fuel pool at Oyster Creek. Although Citizens do not think that the Oyster Creek site is an appropriate place for the long term disposal of high level nuclear waste, the extreme imminent risk posed by the existing spent fuel pool means that Citizens are forced to accept an expedient, imperfect, and temporary solution to lower the risk. Thus, NRC should order AmerGen to transfer all spent fuel that is over five years old to the dry cask storage facility and to maintain sufficient spacing in the pool to minimize the risk of a spent fuel pool fire. The DSEIS must assess the consequences this action. In particular, the DSEIS must assess the vulnerability of the dry cask storage systems to terrorist attack and the potential for environmental release of radioactive waste, and provide methods to mitigate these risks. Furthermore, if NRC wishes to proceed with relicensing, it must also complete the evaluation of the site specific consequences of adding yet more fuel to the dry cask store over the next twenty years.

II. Requirements of NEPA

The National Environmental Policy Act ("NEPA") establishes a "national policy [to] encourage productive and enjoyable harmony between man and his environment," and was intended to reduce or eliminate environmental damage and to promote "the understanding of the ecological systems and natural resources important to" the United States. *Dept. of Transp. v. Pub Citizen*, 541 U.S. 752, 756 (2004) (*quoting* 42 U.S.C. § 4321). The application of NEPA's requirements, under the rule of reason relied on by the NRC, is to be considered in light of the two purposes of the statute: first, ensuring that the agency will have and will consider detailed information concerning significant environmental impacts; and second, ensuring that the public can both contribute to the body of information and can access the information that is made public. *San Luis Obispo Mothers For Peace v. NRC*, 449 F.3d 1016 (June 2, 2006).[1] The Supreme Court has identified NEPA's "twin aims" as "plac[ing] upon an agency the obligation to consider every significant action[, and] ensur[ing] that the agency will inform the public that it has indeed considered environmental concerns in its decisionmaking process." *Baltimore Gas & Elec. Co. v. Natural Res. Def. Counsel, Inc.*, 462 U.S. 87, 97 (1983)

NEPA is the "basic charter for protection of the environment." 40 C.F.R § 1500.1. Its fundamental purpose is to "help public officials make decisions that are based on understanding of environmental consequences, and take decisions that protect, restore and enhance the environment." *Id.* NEPA requires federal agencies to examine the environmental consequences of their actions before taking those actions, in order to ensure "that important effects will not be overlooked or underestimated only to be discovered after resources have been committed or the die otherwise cast." *Robertson v. Methow Valley Citizens Council (Robertson)*, 490 U.S. 332, 349 (1989).

NEPA goes beyond the Atomic Energy Act ("AEA") in mandating that the NRC consider alternatives to its licensing actions that may have detrimental effects on the environment. 10 C.F.R. § 51.71(d). The primary method by which NEPA ensures that its mandate is met is the "action-forcing" requirement for preparation of an EIS, which assesses the environmental impacts of the proposed action and weighs the costs and benefits of alternative actions. *Robertson*, 490 U.S. at 350-51. An EIS must be searching and rigorous, providing a "hard look" at the environmental consequences of the agency's proposed action. *Id.* at 349; *Marsh v. Oregon Natural Resources Council*, 490 U.S. 260, 374 (1989).

The environmental impacts that must be considered in an EIS include "reasonably foreseeable" impacts which have "catastrophic consequences, even if their probability of occurrence is low." 40 C.F.R. § 1502.22(b)(1). The Commission has held that probability is the "key" to determine whether an accident is "reasonably foreseeable" or whether it is "remote and speculative" and therefore need not be

[1] A petition for certiorari is expected to be filed shortly

considered in an EIS. *Vermont Yankee Nuclear Power Corp. (Vermont Yankee Nuclear Power Station)*, CLI-90-7, 32 NRC 129, 131 (1990). *See also Limerick Ecology Action v. NRC,* 869 F.2d 719, 745 (3rd Cir. 1989), *citing Vermont Yankee Nuclear Power Corp. v. Natural Resources Defense Council, Inc.*, 435 U.S. 519, 551 (1978). NRC has included consideration of the environmental impacts of design-basis accidents in its EISs since the beginning of NEPA implementation. *Limerick Ecology Action*, 869 F.2d 719 at 726, *citing* 36 Fed. Reg. 22,851 (1971).

In 1980, following the Three Mile Island accident, the Commission also began to consider the environmental impacts of severe or "beyond design-basis" accidents in its EISs. *Id., citing* NRC, *Statement of Interim Policy, Nuclear Power Plant Accident Considerations Under the National Environmental Policy Act of 1969*, 45 Fed. Reg. 40,101 (1980). In addition, recently, the Ninth Circuit, concluded that it was unreasonable for the NRC to categorically dismiss the possibility of terrorist attack on a proposed spent fuel storage installation and on the entire reactor facility as too "remote and highly speculative" to warrant consideration under NEPA. *San Luis Obispo Mothers For Peace*, 449 F.3d at 1030. The court also found, as a matter of law, that NRC's position was inconsistent with the government's efforts and expenditures to combat this type of terrorist attack against nuclear facilities including establishment of the NRC's own Office of Nuclear Security and Incident Response responsible for coordination with the Office of Homeland Security. *Id.* at 1030-31.

Furthermore, the court found that to eliminate a possible environmental consequence from analysis by labeling a risk as "unquantifiable" is not supported by any provision of NEPA or any other authority cited by the Commission. *See also Limerick Ecology Action*, 869 F.2d at 754 (J. Scirica, dissenting) (finding no "statutory provision, no NRC regulation or policy statement, and no case law that permits the NRC to ignore any risk found to be unquantifiable")

Although an NRC-sponsored study conducted as early as 1979 raised the potential for a severe accident in a high-density fuel storage pool if water is partially lost from the pool (NUREG/CR-0649, *Spent Fuel Heatup Following Loss of Water During Storage* (March 1979), the NRC has failed to take that risk into account in every EIS it has prepared including the 1979 GEIS on the environmental impacts of fuel storage and the 1996 License Renewal GEIS on which the Oyster Creek license renewal application relies. *See* NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* at 5-1 (1996).

The terrorist acts of September 11, 2001, the NRC's response to those attacks, and the finding of the Ninth Circuit in *San Luis Obispo,* show that the environmental impacts of intentional destructive acts against the Oyster Creek fuel pool are reasonably foreseeable. Taken together, the potential for severe pool accidents caused by intentional malicious acts and by equipment failures and natural disasters is not only reasonably foreseeable, but is likely enough to qualify as a "design-basis accident," i.e., an accident that must be designed against under NRC safety regulations. At minimum, such an event is a "severe accident." NRC's failure to take account of this new information when preparing the DSEIS is inconsistent with NEPA's major requirement that environmental decisions must take new information into account if the information shows that a proposed action will affect the quality of the human environment "in a significant manner or to a significant extent not already considered." *Marsh*, 490 U.S. at 374.

III. Requirements of the NRC Regulations

A. NRC Implementation of the AEA

NRC regulations implement the AEA by setting detailed minimum standards for safe and secure operation of nuclear facilities. The AEA prohibits the NRC from issuing a license to operate a nuclear power plant if it would be "inimical to the common defense and security or to the health and safety of the public." 42 U.S.C. § 2133(d). Public safety is the first, last, and a permanent consideration in any decision on the issuance of a construction permit or a license to operate a nuclear facility. *Power Reactor Development Corp v. International Union of Electrical Radio and Machine Workers*, 367 U.S. 396, 402 (1961).

Before a nuclear power plant is constructed, the NRC requires the operator to include a preliminary safety analysis report in the construction permit application. A nuclear power plant must be designed against accidents that are "anticipated during the life of the facility." *See* 10 C.F.R. § 50.34(a)(4), which provides that a construction permit application for a nuclear power plant must include:

> [A] preliminary analysis and evaluation of the design and performance of structures, systems, and components of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents.

These "anticipated" accidents, against which nuclear power plants must be designed, are called "design-basis accidents" and include some low frequency but credible events. License Renewal GEIS at 5-2.

The NRC designates accidents that are more complex and less likely than design-basis accidents as "severe accidents." License Renewal GEIS at 5-1 (severe accidents are "those involving multiple failures of equipment or function and, therefore, whose likelihood is generally lower than design-basis accidents but whose consequences may be higher"). Although severe accidents are "beyond the substantial coverage of design-basis events," they constitute "the major risk to the public associated with radioactive releases from nuclear power plant accidents." NRC, *Policy Statement on Severe Accidents Regarding Future Designs and Existing Plants*, 50 Fed. Reg. 32, 138, 32, 139 (August 8, 1985) ("Severe Accident Policy Statement").

The Commission has made the generic determination that nuclear plants can be operated safely, despite the potential for severe accidents. Nevertheless, the Commission has an ongoing program to address severe accidents in the context of its regulatory program for protection of public health and safety under the AEA, and pledges to act upon any new information that calls the safety finding into question. Severe Accident Policy Statement at 139-40.

In the particular matter of stored spent nuclear fuel and high-level radioactive waste, NRC has promulgated requirements for its protection:

> Each licensee subject to this section shall establish and maintain a physical protection system with the objective of providing high assurance that activities involving spent nuclear fuel and high-level radioactive waste do not constitute an unreasonable risk to public health and safety.

10 C.F.R 73.51(b)(1). To meet this objective, the physical protection system must be "designed to protect against loss of control of the facility that could be sufficient to cause a radiation exposure exceeding the total effective dose equivalent of 5 rem." 10 C.F.R 73.51(b)(3). Furthermore, the system must be reviewed every 24 months. 10 C.F.R 73.51(d)(12).

B. NRC Treatment of Terrorist Attack

NRC had a longstanding policy that NEPA does not require consideration of the environmental impact of a terrorist attack. This was based on four 2002 decisions (Private Fuel Storage, Duke Cogema Stone & Webster, Dominion Nuclear Connecticut and Duke Energy) and the reasoning was as follows:

1. The possibility of terrorist attack is too far removed from the natural or expected consequences of agency action to require study under NEPA
2. Because the risk of terrorist attack cannot be determined, the analysis is likely to be meaningless.
3. NEPA does not require a "worst-case" analysis
4. NEPA's public process is not an appropriate forum for sensitive security issues.

This was set out in a memorandum and order, CLI-03-1, 57 NRC 1, where the NRC accepted the Atomic Safety and Licensing Board's referral of its decision to reject the environmental contentions related to terrorism. *San Luis Obispo Mothers For Peace,* 449 F.3d 1016. As discussed above, the

Ninth Circuit has now ruled that the four reasons given by the NRC as grounds for this did not support the NRC's categorical refusal to consider the effects of a terrorist attack. Id. at 6084. Furthermore, the Ninth Circuit reiterated NEPA's direction on uncertain consequences 40 C.F.R. §§ 1502.22(b)(3), (4), which requires an agency to deal with uncertainties by including in the EIS "a summary of existing credible scientific evidence which is relevant to evaluating the reasonable foreseeable significant adverse impacts on the human environment, and... the agency's evaluation of such impacts based upon theoretical approaches or research methods generally accepted in the scientific community." The court construed the regulation to apply to those events with potentially catastrophic consequences "even if their probability of occurrence is low, provided that the analysis of impacts is supported by credible scientific evidence, is not based on pure conjecture, and is within the rule of reason." 40 C.F.R. § 1502.22 (b)(4).

In addition, the NRC has now recognized that, if it is not overturned by the U.S. Supreme Court, the *San Luis Obispo* decision will require an analysis of spent fuel pool sabotage scenarios for Oyster Creek. Earlier this week, the NRC decided to postpone its review of the dismissal of a contention by the State of New Jersey that this analysis was essential, but missing. *In the Matter of AmerGen Energy Co. (License Renewal for Oyster Creek Nuclear Generating Station), LLC*, CLI-06-24 (September 6, 2006).

The License Renewal GEIS purports to address both design-basis accidents and severe accidents. With respect to design-basis accidents, the GEIS provides a brief statement that the impacts of design-basis accidents were considered in the original EIS for each nuclear power plant, and that the design was found adequate to "accommodate" those accidents. License Renewal GEIS at 5-11. Moreover, the GEIS asserts that the consequences of design-basis accidents are not expected to change significantly as a result of aging of the plant. *Id.* Therefore, the GEIS does not provide a further discussion of design-basis accidents. *Id.* These impacts are also classified as "Category 1 in Table B-1 of Appendix B to

Subpart A of 10 C.F.R. Part 51. However, this approach fails to recognize that the build up of spent fuel at reactors is effectively an effect of aging, and that a new design-basis accident could arise from the storage of the spent fuel.

With respect to severe or beyond design-basis accidents, the License Renewal GEIS discusses the potential consequences of an array of severe accidents identified in various studies, primarily the NRC's most recent and comprehensive probabilistic analysis of nuclear power plant accidents, NUREG-1150, *Severe Accident Risks for Five U.S. Nuclear Power Plants* (1990). While recognizing the possibility that the likelihood of some severe accidents may be so low as to be "remote and speculative" and therefore not necessary to discuss in an EIS, the License Renewal GEIS does not exclude any severe accidents on the ground of their estimated probability. Severe accidents are classified as "Category 2" impacts in Table B-1 of Appendix B to Subpart A of 10 C.F.R. Part 51.

However, the License Renewal GEIS does not include any discussion of how deliberate and malicious attacks on nuclear power plants may increase the likelihood or consequences of severe accidents. In addition, the DSEIS it failed to make any assessment of the risks of sabotage. This is consistent with the NRC's long-established, but now obsolete, policy of refusing to examine such issues under NEPA. The rest of these comments show that the DSEIS is grossly deficient in this regard and is also deficient on many points of detail. The rest of the comments also provide a brief, very preliminary, assessment of the issues involved, based directly on work submitted by others to the NRC in pending license renewal proceedings.

IV. Analysis of Risk At Similar Plants From Spent Fuel Pool Fires

A recent filing by the Massachusetts Attorney General in license renewal proceedings for Pilgrim and Vermont Yankee Nuclear Power Plants, which are both G.E. Boiling Water Mark 1 plants, similar to Oyster Creek, provided a quantitative analysis of the risk of spent fuel pool fires. The filing contains two expert reports, one on the probability of a spent fuel pool fire and the options to reduce that probability, and another on the consequences of a spent fuel pool fire. The report on probability finds that where high density racks of fuel assemblies are held in spent fuel pools, a loss of cooling or rupture of the pool would probably cause a spent fuel pool fire. Gordon R. Thompson, *Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants*, 9-12 (May 25, 2006) ("Risk Report"), Ex. SC 1.

The Risk Report concluded that the probability of a spent fuel pool fire is dominated by the possibility of a malicious attack. Id. at 57. Thompson estimated the total probability of a spent fuel pool fire at 1.2×10^{-4} per year for both plants, comprised of a 1×10^{-4} per year chance of a successful terrorist attack and 2.1×10^{-5} per year chance of an accidental fuel pool fire. The accidental risk is around double the core damage frequency ("CDF") assumed by AmerGen. DSEIS at G-2.

The other report submitted by the Massachusetts Attorney General in the same proceeding provides an analysis of the consequences of spent fuel pool fire at the Pilgrim and Vermont Yankee plants. It shows that the consequences of a spent fuel pool fire are comparable or worse than core damage accidents. Jan Beyea, *Report To The Massachusetts Attorney General On The Potential Consequences Of A Spent-Fuel-Pool Fire At The Pilgrim and Vermont Yankee Nuclear Plants* (May 25, 2006) ("Consequence Report"), Ex. SC 2. The results are truly sobering. Bayea shows that, even excluding the cost of cleanup from a spent fuel pool fire, the consequences of such a fire at these plants would range from $87 billion to $878 billion and the number of induced lung cancers would range from more than 2,700 to more than 24, 000. Id. at 9, 11, 18-19.

Combining the estimates of event probability with the predicted consequences, the Risk Report shows that a consequence of $100 billion at a probability of 1×10^{-4} per year over twenty years would have a present value of $110 million to $200 million, depending on the discount rate. Risk Report at 58.

Thus, the consequence estimates of $87 billion to $878 billion combined with the probability estimate of 1×10^{-4} per year yield a range of around $100 million to $1.8 billion for the present value of the consequences. Therefore an investment in this range would be justified to avoid the consequences of a spent fuel pool fire. This is orders of magnitude greater than the screening value of $4.46 million used by the NRC in the SAMA analysis. DSEIS at G-12.

V. Risk Of A Spent Fuel Pool Fire At Oyster Creek

The magnitude of the risk that would be imposed upon Citizens by extending the license for an additional 20 years has been grossly underestimated in the DSEIS because the analysis fails to take account of the potential for a fire in the spent fuel pool at Oyster Creek due to accident or deliberate attack. At a qualitative level the state of New Jersey has stated that the consequences of a spent fuel pool fire could be worse than the consequences of the accident at Chernobyl and that Oyster Creek is particularly vulnerable to an attack because the spent fuel pool at the plant is elevated and densely packed. Letter from Lipoti to Miller, dated July 30, 2004, Ex. SC 3.

More specifically, New Jersey noted that it had reviewed a scientific paper which generically estimated the consequences of a terrorist attack on the spent fuel pool:

> The Alvarez Paper was available to New Jersey as was the NRC staff's review and comments. This paper focused on the potential generic vulnerabilities of spent fuel pools to terrorist attack. The paper also details the possible public safety and environmental consequences should such attacks successfully occur. Included in this paper were conservative estimates of the radiological release should a spent fuel zircaloy cladding fire occur due to a significant breach of a spent fuel pool. The paper states, "The long-term land-contamination consequences of such an event could be significantly worse than those from Chernobyl". The paper further states (in reference to Chernobyl), "The total area of this radiation-control zone is huge: 10,000 km2, equal to half the area of the State of New Jersey. During the following decade, the population of this area declined by almost half because of migration to areas of lower contamination".

Id. The letter then went on to highlight the plant specific vulnerability of Oyster Creek because its spent fuel pool is elevated, it has a relatively weak superstructure over the spent fuel pool, which could collapse, and it is on the coast providing an unimpeded flight path for an attacking aircraft. Id. The letter concluded by requesting NRC to provide New Jersey with site specific estimates of the consequences of an attack on the spent fuel pool. Id. As far as Citizens are aware, no such estimate has been provided. More recently New Jersey attempted to intervene in the license renewal proceeding to contend, among other things, that AmerGen's SAMA analysis was inadequate because it failed to consider the vulnerability of the spent fuel pool or mitigation measures to address this vulnerability.

Turning to a more quantitative approach, the situation at Oyster Creek is very similar to that at Pilgrim and Vermont Yankee. All three plants are G.E. Boiling Water Reactors with a Mark 1 containment system. In addition, all three plants store their spent fuel assemblies in high density racks that enclose the fuel with a neutron absorbing material to allow fuel assemblies to be placed close to each other and fit more fuel into the spent fuel pool than originally intended. NRC, Information Notice No. 87-43 (September 8, 1987); Risk Report at 9-14. In 2002, Pilgrim and Vermont Yankee stored 2,274 and 2,671 fuel assemblies, respectively. Risk Report at 41. In 1995, Oyster Creek's operator obtained permission to store 2,645 fuel assemblies in its spent fuel pool. 60 Fed. Reg. 19,309 (April 17, 1995). In 2000, AmerGen obtained permission to increase the number of fuel assemblies in the spent fuel pool by 390 to 3,035 fuel assemblies. 65 Fed. Reg. 55,061-55,064 (September 12, 2000). This action was needed to allow for continued operation of the plant. *Id.*

Citizens are aware that Oyster Creek now has a dry cask storage facility that can store spent fuel that is over five years old. However, press reports indicate that AmerGen only transfers spent fuel to dry cask storage when it runs out of room in the spent fuel pool. Robert Manor, *US: New life for old nuclear plants*, Chicago Tribune, September 18, 2004, Ex. SC 4. Thus, it appears that the amount of spent fuel currently in the elevated pool at Oyster Creek could be larger than at Pilgrim or Vermont Yankee. For simplicity, this analysis assumes that the spent fuel pool has an inventory similar to Pilgrim and Vermont Yankee.

At root, risk is comprised of two basic elements, the probability of the event and the consequences. Regarding event probability, the State of New Jersey has suggested that Oyster Creek might be a more attractive target than other similarly designed nuclear power stations because it is closer to major population centers and, because it is on the coast, there is an unimpeded flight path. Thompson's estimate for the probability of a terrorist attack assumed that all plants are equally attractive targets. Thus, the likelihood of a spent fuel pool fire at Oyster Creek may be greater than at Pilgrim or Vermont Yankee. Although, Thompson's assumption is conservative for Oyster Creek, it is not unreasonable at the current level of uncertainty. Therefore, for simplicity, this analysis uses Thompson's estimate of 1.2×10^{-4} per year as the available best estimate of the chance of a spent fuel fire. The Commission has established a threshold of 1×10^{-7} per year as the threshold probability for design basis events at nuclear power plants. *In The Matter Of Private Fuel Storage, L.L.C. (Independent Spent Fuel Storage Installation)*, CLI-01-22, 54 NRC 255 (November 14, 2001). Thus, Thompson's probability estimate is three orders of magnitude greater than the threshold probability for consideration in this nuclear power plant relicensing.

Turning to the consequences, Beyea's estimates of $87 billion to $878 billion in consequences for Pilgrim and Vermont Yankee are probably low because the population around Oyster Creek is larger, property values in the areas are higher than in Vermont or Massachusetts, contamination from a fire at Oyster Creek could contaminate major cities on the eastern seaboard, including New York City, Philadelphia, and Trenton, and the estimate excluded consideration of clean up or reconstruction of downtown areas. Thus, it is not unreasonable to estimate that the economic consequences could be at least double those estimated for Pilgrim and Vermont Yankee, ranging from around $180 billion to $1.8 trillion. At a frequency of 1.2×10^{-4} per year this is equivalent to a present value of between $200 million to $3.6 billion.

Even more importantly, the number of induced lung cancers would probably be even greater than the 2,700 to 24,000 estimated for Pilgrim and Vermont Yankee because the population density in the potentially affected area is considerably higher on average.

VI. Significance Of The Risk Estimates For Oyster Creek

The potential consequences of a spent fuel pool fire are startlingly large. As Beyea points out the US government borrows around $350 billion per year. Because the government would be forced to foot nearly all of the bill for recovery after such a huge disaster[2] it would have a massive financial impact on the nation. Furthermore, and perhaps even more importantly, such a disaster could lead to major loss of life, loss of confidence, and long-term contamination of large areas. Taken together, these effects could have a devastating long term impact on major cities, such as New York City, Philadelphia, and Trenton. To put the consequence estimates into context they are around ten times the damage estimates for hurricane Katrina.

To look at it from a different perspective, AmerGen currently claims to be making around $25 per Mwhr produced. Exelon Press Release, dated July 31, 2006 at 6, Ex. SC 5. Thus, assuming plant capacity of 619 Mw and a capacity factor of 95%, the total value of the electricity that could be produced by AmerGen at Oyster Creek during the proposed 20-year license extension is at most $2.6 billion or $129 million per year, even if nothing serious went wrong with the plant for 20 years. Thus, the externalized risk to society from the operation of the plant could actually be greater than the value to its owner of its output. In such circumstances, if no other mitigation options are available, plant closure and decommissioning would be a feasible SAMA alternative.

Plant closure and decommissioning must therefore be evaluated as a SAMA alternative in the DSEIS and Citizens believe that this is the only approach that would provide acceptable levels of risk

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2 Note that the Price-Anderson Act could limit AmerGen's liability for this huge loss to $400 million and force the federal government to meet all costs over $10 billion.

over the long term. However, because the risk is large and imminent there is a need to mitigate this risk in the short term, rather than waiting for decommissioning. Therefore, as an initial temporary option, the dry cask storage facility offers an imperfect, but nonetheless useful option to mitigate the present risk. According to Thompson, the spent fuel at Pilgrim and Vermont Yankee that is more than 5 years old could be stored in dry casks at the site at a cost of $43 million to $87 million. Risk Report at 56. AmerGen has placed the cost of dry cask storage at Oyster Creek even lower at $30 million. Robert Manor, *US: New life for old nuclear plants*, Chicago Tribune, September 18, 2004, Ex. SC 4. This cost would be incurred anyway at decommissioning, so that the net effect is to change the time at which the expenditure occurs. Risk Report at 32. Thus, the cost to AmerGen of this measure could be offset by reductions in decommissioning cost. Depending on discount rate and the life of the plant, the net cost could be between $15 million and $40 million.

In this way, the spent fuel pool could be converted back to its original function to turn a massive and unacceptable risk into a lower, but still unacceptable long-term risk, at relatively low cost. Id. at 32. Indeed, although the situation is highly uncertain, the lowest estimate of the present value of risk exceeds the highest estimate of the cost to mitigate that risk. It is therefore unclear why the NRC has not already required the risk of spent fuel pool fires to be mitigated at Oyster Creek and other reactors with elevated fuel pools. At minimum, the next draft of the DSEIS must contain a full site-specific analysis of the likelihood and consequences of a spent fuel pool fire and assess how to carry out effective mitigation.

However, merely carrying out an assessment is not enough. Even this brief assessment has shown that the densely packed elevated fuel pool at Oyster Creek currently presents terrorists with a chance of killing 20,000 to 50,000 people and causing economic disruption on a scale that dwarfs even major natural disasters like hurricane Katrina. The risk posed by the plant to totally unacceptable and has a present value of over $200 million and $3.6 billion. The net cost of transferring the fuel to a less dangerous means of storage is between $15 million and $40 million. Therefore, there is no question that this action meets SAMA requirements. To provide "adequate protection" for the public, NRC should take urgent action to lower the risk by ordering that the spent fuel that is beyond 5 years old to be moved to dry cask storage for temporary storage.

Unfortunately, dry cask storage not a risk free activity. Highly active nuclear waste was never intended to be stored at wet coastal sites in densely populated areas. The difficulty that the Department of Energy has had in showing whether the Yucca Mountain long -term disposal facility for this material could be acceptable, shows that storage of this material at the Oyster Creek site in the long term could not present an environmentally sound approach. In addition, concerns have been raised about the vulnerability of dry cask stores to terrorism. At minimum, the next draft of the DSEIS must consider the security and environmental risks of dry cask storage at this site for the current fuel inventory.

This assessment shows that at present the failure to find a responsible approach to managing nuclear waste is causing a huge risk to the people of New Jersey and other states. This risk can be reduced, but cannot be totally eliminated, by moving the spent fuel to dry cask storage as quickly as possible. Because there is currently no acceptable method of disposing of spent fuel, it is simply irresponsible to allow AmerGen to continue to generate waste. Thus, Citizens firmly believe that the NRC should not allow AmerGen to operate Oyster Creek beyond its currently licensed operating period. At minimum, the DSEIS must assess how increasing the amount of spent fuel stored at Oyster Creek by 50% would change the current risks presented by the spent fuel on the site to the public and the environment.

Although the NRC has been on notice of the potential for spent fuel pool fires since at least 1994, the risk of such a fire being caused by terrorist attack has not been assessed generically. Thus, the reliance in the DSEIS on a generic determination of environmental significance of spent fuel pool storage during decommissioning is misplaced. DSEIS at xvi-xvii. By failing to analyze the risk of spent fuel pool fire from a terrorist attack or an accident during operation, the DSEIS is grossly deficient and would violate NEPA requirements unless this deficiency is remedied.

VII. Other Inadequacies of the DSEIS

Thompson estimated the probability of an accidental fuel pool fire as 2.1×10^{-5} per year. This is around double the core damage frequency ("CDF") of 1.1×10^{-5} per year assumed by AmerGen. DSEIS at G-2. Although NRC may have looked at the chance of a spent fuel pool fire during decommissioning, many of the initiating events contributing to accidental spent fuel pool fires are not present during decommissioning. Thus, the risk of an accidental spent fuel pool fire during operation is significant and has not been assessed generically. Therefore this risk must be considered in the revised SAMA analysis, in addition to the risk of terrorist attack. At present, it is completely omitted.

The DSEIS states that the value of eliminating all internal and external severe event risk is $4.46 million, DSEIS at G-12, but fails to provide any elaboration about how this estimate was derived. Working backwards, a consequence of $100 billion at a probability of 1×10^{-5} per year has a present value of around $15 million. Risk Report at 9-2. Because the CDF in the analysis is close to this level of probability and the screening value is around a third of the present value estimated, the consequences assumed in the analysis to derive the screening value must be of the order of $33 billion.[3] This amoun is confirmed by the assumption in the appendix that the total cost of cleanup and decontamination after a severe accident would be $110 billion. DSEIS at G-28. This is surprising because the NRC has previously found that destruction of a private spent fuel storage facility would have lower consequences than a severe nuclear accident. NRC, CLI-01-22 Memorandum and Order, 54 NRC 255 (November 14, 2001). Beyea also points to another reason why the consequence estimate is far too low in the DSEIS.

[3] This is a simplistic calculation made for illustrative purposes only.

The standard value of $2,000 per person-rem used in the report, DSEIS at G-28, leads to a valuation of an avoided cancer death of $200,000, which is far too low. Consequence Report at 14. This means the SAMA analysis at Oyster Creek must be recalculated placing a much higher value on the lives of the public who live close to the plant.

In addition, an assumption of $33 billion in consequences would contrast starkly with the estimate of consequences from a spent fuel pool fire of $180 billion to $3.6 trillion and is at variance with the NRC's previous position that a spent fuel facility accident would be of less consequence than an accident involving core damage. The Risk and Consequence Reports taken together suggest that the DSEIS has failed to assess the dominant source of risk at the Oyster Creek site. It is important to remember that when the plant was initially licensed the risk from the spent fuel pool was zero, because the pool was empty. In addition, the NRC did not intend to allow spent fuel to be packed in pools in the way it is now. Although NRC may have looked at the chance of a spent fuel pool fire during decommissioning, no generic assessment of the risk from spent fuel fires during operation has been carried out. Because the risk of a spent fuel pool fire now appears to dominate the risk presented by the plant, it quite extraordinary that the DSEIS fails to address the issue in detail. Producing an evaluation that grossly underestimates the risk of an action is actually worse than producing no assessment, because it may well lead to a decision based on a completely false assurance about risk levels. This is exactly what Congress intended to prevent when it enacted NEPA.

The DSEIS suggests that there is no new significant information that leads to questions about the validity of the GEIS. DSEIS at 5-3. This is totally incorrect. The information presented by Thompson and Bayea is itself significant new information about the risks posed by the operation of BWR Mark 1 reactors. In addition to the analysis of spent fuel pool fire risks, Beyea also shows that new studies indicate that low-level radiation does could cause more cancers than thought when the GEIS was written in 1996. Consequence Report at 12-15. Both the Risk Report and the Consequence Report were submitted to the NRC on May 25, 2006, before the DSEIS was finalized in June 2006. In addition, as the Court of Appeals for the Ninth Circuit has found, the events of September 11, 2001 mean that the NRC must now take account of terrorist risks in SEIS Reports about licensing decisions. *San Luis Obispo Mothers for Peace v. Nuclear Regulatory Commission*, No. 03-74628, 2006 WL 1511889 (9th Cir. June 2, 2006). Furthermore, that assessment must be complete before the NRC can take any action to extend the license. Thus, the DSEIS must be revised to take account of much significant new information.

NRC provides a completely inadequate justification for the use of a factor of 2 times the benefit of SAMAs designed to mitigation internal events to take account for external events, including sabotage. DSEIS at 8-9. This seems totally arbitrary because it is not necessarily true that mitigation measures to prevent sabotage and earthquakes would also mitigate risks from internal events.

As discussed above, the screening level of $4.46 million, DSEIS at G-12, is unjustifiably low and must be revised substantially to take account of new cancer risk studies, higher values of life, and the substantial risks presented by the accidental triggering of a spent fuel pool fire during operation, as well as the risk of terrorism.

It is notable that Amergen's process failed to focus on the risk of terrorism or of a spent fuel pool fire. DSEIS at G-13. Thus, NRC's conclusion that the process was systematic and comprehensive is totally wrong. DSEIS at 14. In addition, the Risk and Consequence reports show that NRC's conclusion that there are no impacts related to design basis accidents beyond those discussed in the generic EIS is false. DESIS at 5-3.

VIII. Conclusion

For the reasons articulated in this comment letter, NRC should not and cannot make any conclusions about either the risks of accident or terrorism associated with the proposed relicensing of the

Facility or the license renewal application. Therefore, NRC cannot finalize the EIS and must prepare a new draft that addresses the inadequacies raised in this letter and submit it for public comment. Until a proper EIS is prepared and reviewed, NRC should not make any decisions with respect to the relicensing of Oyster Creek. To do otherwise would constitute an impermissible, irrevocable commitment of resources in violation of NEPA

We thank you for the opportunity to submit these written comments.

Sincerely,

By: ______________________
Richard Webster, Esq.
Rutgers Environmental Law Clinic, Citizens' Counsel

Energy Bulletin

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US: New life for old nuclear plants

By Robert Manor

Despite concerns over safety, including uncertainty over how long the reactors will be able to keep running, some licenses have been renewed through 2040

FORKED RIVER, N.J. -- Obscured by scrub trees and unkempt shrubs not far from the Atlantic Ocean, the Oyster Creek nuclear plant, which has generated electricity since Richard Nixon became president in 1969, is looking at a prolonged life, as regulators allow utilities to run reactors decades longer than first anticipated.

Driven by demand for cheap power, utilities are seeking to keep existing reactors operating until as late as 2040 and beyond. Regulators have approved license extensions for aging nuclear plants across the country, with more to come.

Which raises the question, how long can a nuclear plant run safely?

"There is nothing to stop them from operating safely" indefinitely, said Alex Marion, senior director of the Nuclear Energy Institute, who said utilities routinely replace aging components and upgrade facilities.

But critics argue that the older nuclear plants--and at nearly 35 years Oyster Creek is the country's oldest still in operation--need retirement to avoid the risk of a catastrophe. Some warn that the plants, which store decades worth of high-level nuclear waste, could cause a disaster on the scale of Chernobyl.

"The Nuclear Regulatory Commission has been doing a terrible job of ensuring that these plants are safe," said Anna Aurilio, legislative director for the national office of the Public Interest Research Group. "We think most of them should be shut down."

Originally licensed for 40 years, plants are now winning 20-year extensions from the NRC.

The relicensings are justified, the NRC says, because utilities are getting better at operating the older plants, a sign they are safe for the future.

"We are continuing to see performance improve," said Christopher Grimes, deputy director of engineering at the NRC.

The NRC has extended the licenses for 26 plants around the country, with 42 more applications pending or expected.

On a national scale, the relicensing means that nuclear facilities will remain an important source of electricity well past the first third of the century.

Extending the lives of reactors is particularly important for Chicago-based Exelon Corp., the nation's largest operator of nuclear plants.

Exelon is the corporate parent of Commonwealth Edison in Illinois and other utilities in Pennsylvania and New Jersey. The company says it plans to seek relicensing for most, if not all, of its 10 nuclear power plants across the country. Other utilities are expected to do the same, eventually extending the lives of nearly all the 103 nuclear plants now operating.

"With the right engineering, with the right inspection, these plants can safely operate another 20 years," said Christopher Crane, president of Exelon Nuclear.

Realities of aging

Some problems are generic to all nuclear plants as they age. Cracking and corrosion of vital components is always a risk, for example.

And neutrons issuing from the reactor core can eventually cause the reactor's steel vessel to become brittle. The vessel is essential to nuclear safety, and its structural integrity must never be compromised.

The nuclear industry says it guards against such problems, and will do so with relicensed plants in the decades ahead.

But two models of nuclear plants, the General Electric Mark 1 and 2, particularly worry some nuclear scientists because of their design.

The vast bulk of the nation's spent nuclear fuel, many thousands of tons of still-radioactive uranium, is stored near the reactors that consumed it. That's because local opposition has blocked federal plans to deposit high-level nuclear waste at the Yucca Mountain site in Nevada.

Most nuclear plants store their spent fuel in pools built into the earth. Water in the pools blocks radiation and cools the hot fuel rods after they are removed from the reactor.

The GE plants are different. Their spent fuel is stored in a pool of water located above the reactor, essentially on the roof.

So at 32 plants around the country, the spent fuel pools stand far above the ground. At Oyster Creek, for example, the pool is 119 feet in the air.

The pools, a bit smaller than a typical back yard pool but much deeper, have concrete walls at least a yard thick, strong enough to resist a heavy blow. They include systems for cooling the water so the fuel cannot boil it away.

The roofed room above the pools is made of heavy construction-grade steel, strong but not nearly as strong as the massive protective structures that surround reactors. The NRC acknowledges that a large enough plane could pierce the roof or metal walls above the pool.

"These spent fuel pools are basically pre-deployed nuclear weapons," said Deb Katz, executive director of the Citizens Awareness Network, which opposes relicensing of the GE-designed nuclear plants.

The fear is that terrorists or a natural disaster could drain the water from the pool or prevent it from being cooled. Should that happen, heat from the spent fuel rods would accumulate. Under some scenarios, nuclear engineers say, the fuel would ignite and send a plume of radiation high into the atmosphere, contaminating a wide area.

"When the temperature gets over 3,000 or 4,000 degrees, the metal tubing that holds the fuel rods catches on fire," said David Lochbaum, a nuclear safety engineer with the Union of Concerned Scientists.

"You could get a large radioactive cloud escaping from the plant. The cloud would contain radioactive isotopes of cesium, strontium and other elements ... and could cause harm out to 500 miles."

GE maintains its Mark 1 and 2 plants are safe. "The NRC has a very stringent process" in issuing licenses, said Andy White, chief executive of GE's nuclear business.

The NRC also says the plants, when properly maintained and inspected, are safe to operate well into the future. In recent days, it downplayed the risk from a plane crashing into a nuclear plant, saying radioactive releases are apt to be minimal.

There is a technique, called dry storage, for emptying the fuel pools and securing the radioactive material they contain. It involves placing the spent fuel in 2-foot-thick, concrete-and-steel casks nearly the size of a truck trailer. The massive dimensions of the casks are intended to protect the fuel within through almost any assault.

Exelon is placing spent fuel in casks at Oyster Creek and two other plants, but it is only doing so as it runs out of room in the fuel pools. The company says that because of the cost, it does not plan to empty the pools and will instead continue to use them for fuel storage.

"Let's not create unnecessary expense," said Wayne Romberg, a program manager for Exelon at the Oyster Creek plant who estimated it would cost $30 million to move all of his plant's spent fuel from its pool into casks.

Early this year, nuclear physicist Jan Beyea, along with other scientists concerned about nuclear safety, released a paper estimating the cost if spent nuclear fuel were to burn at selected plants.

"This would be a major disaster for a huge part of the country," Beyea said in an interview. "It is really unthinkable."

Among the sites Beyea studied was Exelon's two-reactor nuclear plant in LaSalle County. LaSalle has an elevated spent fuel pool, as do Illinois reactors at the Dresden 2 and 3 plant near Morris and the Quad Cities 1 and 2 plant near Cordova.

Under one scenario, Beyea concluded that a fire in the spent fuel at LaSalle could cause $270 billion in property damage and decontamination expense. He estimated 6,400 people would die of cancer.

"These figures are very optimistic in many ways," Beyea said.

Beyea isn't predicting disaster. But he does say the country should debate the issue of relicensing older reactors.

"This is a decision not for scientists but for the public," he said. "Experts tend to be overconfident in what could go wrong."

Financial incentive

Industry advocates point to what they say are compelling reasons, among them safety, for keeping older reactors in operation.

"These plants are running better than they ever have," said Don Kirchoffner, a spokesman for Exelon.

It's true the nuclear industry in general, and Exelon in particular, have sharply improved plant operations.

The NRC says safety equipment problems and other negative events have generally declined since 1990. Radiation exposure to workers, one sign of a utility's competence to operate a plant, has fallen for years. The cost of electricity generated by the plants is going down as well.

Exelon, whose Commonwealth Edison ran into a variety of problems trying to operate a nuclear plant in the 1990s, now is doing well. This summer, for example, Commonwealth Edison's Illinois plants operated at record electrical output.

The length of the original 40-year license for U.S. nuclear plants wasn't chosen for any engineering reason. Industry analysts say it was picked for accounting purposes, not as the actual life span of the plant.

And the nuclear plants' age comes with a dividend: They are paid for.

It is jarring to hear nuclear critics and proponents agree on anything, but both sides say there is a strong financial incentive to keep an old plant operating as long as possible.

"The rate payers have already paid off the mortgage on these plants," said Aurilio, of the Public Interest Research Group.

Because of that, the plants can produce electricity cheaper than any other source except hydroelectric. Even with more than a billion dollars' worth of upgrades over the years, Exelon says Oyster Creek is probably economically viable.

Richard Myers, a director of business and environmental policy at the Nuclear Energy Institute, said the price of nuclear fuel is stable and the plants produce large amounts of electricity at a time when no major sources of power are coming on line.

Looking at an operating nuclear plant from an economic standpoint, Myers said, "it's tough to imagine why you would want to shut it down."

And except for controversy surrounding the Oyster Creek plant in New Jersey, there is little public opposition to extending the lives of nuclear plants.

When the plants were first approved in the 1960s and '70s, there was fierce debate over nuclear energy. Opponents then feared there would be no permanent repository for nuclear waste, which is still the case today.

In New Jersey, Gov. James McGreevey opposes the relicensing of the Oyster Creek plant, saying "the 20-year extension is an unnecessary risk to communities across New Jersey." Local governments have condemned the relicensing, and several community groups are opposed.

But in Illinois, little protest was heard in May when the NRC extended the lives of the Dresden 2 and 3 reactors to the year 2029. Illinois has six GE Mark 1 or 2 reactors, the most of any state.

David Kraft, director of the Evanston-based Nuclear Energy Information Service, said anti-nuclear activists have become discouraged by the pro-nuclear attitude of regulators.

"So many of us have given up on the Nuclear Regulatory Commission being fair," Kraft said. "They are going to relicense everything."

The NRC denies it is lenient in allowing old nuclear plants to remain in service.

"We are a very tough regulator, and known to be a very tough regulator," said NRC spokeswoman Sue Gagner.

That may be the case, but the agency has yet to reject a relicensing request.

Article found at :
http://www.energybulletin.net/newswire.php?id=2178

Original article :
http://www.chicagotribune.com/business/chi-0409190464sep19,1,4584928.story?coll=chi-business-hed

News Releases

July 31, 2006 - Exelon Announces Strong Second Quarter Results; Nuclear Fleet Achieves Superior Operating Performance; ComEd Receives Disappointing Order in Rate Case

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CHICAGO (July 31, 2006) – Exelon Corporation's (Exelon) second quarter 2006 consolidated earnings prepared in accordance with GAAP were $644 million, or $0.95 per diluted share, compared with earnings of $514 million, or $0.76 per diluted share, in the second quarter of 2005.

Exelon's adjusted (non-GAAP) operating earnings for the second quarter of 2006 were $577 million, or $0.85 per diluted share, compared with $506 million, or $0.75 per diluted share, for the same period in 2005. The 13 percent increase in adjusted (non-GAAP) operating earnings per share was primarily the result of higher margins on wholesale market sales, increased output due to strong nuclear performance at Exelon Generation Company, LLC (Generation) and higher electric revenues associated with certain authorized rate increases at PECO Energy Company (PECO). These positive factors were partially offset by the effects of unfavorable weather conditions in the Commonwealth Edison Company (ComEd) and PECO service territories, increased depreciation and amortization, including the higher competitive transition charge (CTC) amortization scheduled at PECO, and increased operating and maintenance expense.

The Exelon Nuclear-operated plants achieved a 95.5 percent capacity factor for the second quarter of 2006, compared with 95.4 percent for the second quarter of 2005. In June alone, the Exelon fleet achieved a capacity factor of 99.1 percent, its highest ever for the June-August summer period. Year to date, Nuclear completed five refueling outages, continuing to lead the industry with a 23-day average duration per outage.

"We had a solid first half. Our strong performance in the second quarter more than offset a lackluster first quarter," said John W. Rowe, Exelon's chairman, president and CEO. "Our second quarter operating performance was first rate as shown by both a consistently high nuclear capacity factor and the availability of our fossil fleet. Generation margins continued to improve over last year, as did core growth in our delivery service business." Rowe continued, "Our agreement with DOJ last month was a major milestone in our efforts to complete our proposed merger with PSEG. We are working hard to obtain our last remaining regulatory approval from the New Jersey Board of Public Utilities. We are hopeful that we can reach a resolution in New Jersey soon and must do so if we are to be able to complete this transaction."

A non-GAAP financial measure, adjusted (non-GAAP) operating earnings for the second quarter of 2006 do not include the following items that are included in reported GAAP earnings (all after tax):

- Income of $89 million, or $0.13 per diluted share, resulting from decreases in decommissioning obligations primarily related to the AmerGen nuclear plants.
- A net charge of $55 million, or $0.08 per diluted share, for an impairment related to the write-off of the intangible asset associated with investments in synthetic fuel-producing facilities, net of earnings from the investments, including the impact of mark-to-market gains associated with the related derivatives.
- Mark-to-market gains of $38 million, or $0.06 per diluted share, primarily from Generation's non-trading activities.
- A net charge of $5 million, or $0.01 per diluted share, related to certain integration costs associated with the proposed merger with Public Service Enterprise Group Incorporated (PSEG) and Generation's prior investment in Sithe Energies, Inc. (Sithe), which is reflected as discontinued operations.

Adjusted (non-GAAP) operating earnings for the second quarter of 2005 did not include the following items that were included in reported GAAP earnings (all after tax):

- Earnings of $29 million, or $0.04 per diluted share, from investments in synthetic fuel-producing facilities, including the impact of mark-to-market gains associated with the related derivatives.
- Mark-to-market losses of $14 million, or $0.02 per diluted share, from non-trading activities.
- Charges of $7 million, or $0.01 per diluted share, related to certain integration costs associated with the proposed merger with PSEG, severance and severance-related costs and Generation's prior investment in Sithe, which is reflected as discontinued operations.

ComEd Receives Order in First General Rate Case since 1995

On August 31, 2005, ComEd filed a proposal with the Illinois Commerce Commission (ICC) seeking approval of its first general rate case since January 1995. The rate case filing sought to allocate the costs of supplying electricity and to adjust ComEd's rates for delivering electricity to users in its service area, effective January 2007, in order to reflect ComEd's rising costs and significant capital investment in its delivery system. ComEd proposed a revenue increase of $317 million. On June 8, 2006, the administrative law judges issued a proposed order, which included a revenue increase of $164 million, plus ComEd's request for recovery of several items which were previously recorded as expense. On July 26, 2006, the ICC issued its Final Order, which is subject to rehearing and appeal. The Order allows an $8.3 million revenue increase. ComEd believes that the disallowances contained in the Order are inappropriate and intends to vigorously pursue these issues on rehearing and appeal.

As part of the rate case, ComEd requested recovery of amounts which have previously been recorded as expense. Based on the ICC Order in the rate case, ComEd estimates that during the third quarter it will record regulatory assets and reverse the previously incurred expenses for the following items (all pre-tax): severance ($158 million), losses on the extinguishment of debt as part of ComEd's 2004 Accelerated Liability Management Plan ($86 million), manufactured gas plant costs ($40 million) and costs associated with ComEd's procurement case ($7 million). In addition, ComEd may incur an impairment charge associated with its goodwill in the third quarter due to the ICC Order. As of June 30, 2006, Exelon and ComEd have goodwill of approximately $3.5 billion. Under GAAP, goodwill is tested for impairment at least annually or more frequently if events or circumstances indicate that it is "more likely than not" that goodwill might be impaired. ComEd currently performs its annual test in the fourth quarter of each year. However, due to the significant negative impact of the ICC's Order to the cash flows and value of ComEd, it is required to complete an interim impairment test during the third quarter of this year. The interim test may lead to an impairment of goodwill at both ComEd and Exelon. The size of any potential impairment will not be known until ComEd completes its test in the third quarter, but the impairment could be material and could exceed the regulatory assets expected to be recorded in the third quarter based on the ICC Order.

"ComEd is deeply disappointed with the Illinois Commerce Commission's delivery rate order. We believe the facts and record supported a much different result and we will certainly appeal the ICC order and seek reconsideration," said Frank Clark, ComEd's chairman and CEO. "We must remember that the Illinois Commissioners have shown both foresight and courage in previous decisions relating to ComEd, and ComEd remains committed to working with the Commission to achieve positive solutions to difficult challenges in Illinois in the long run," Clark added. "The ICC's order confirms that ComEd will be allowed to recover its energy costs which will be incurred by the company through the upcoming competitive power procurement auction in Illinois," Clark noted.

2006 Earnings Outlook

"Given first half performance that was roughly in line with our expectations and our increasing confidence that we will hit our targets in the second half, we are reaffirming our 2006 operating earnings guidance range of $3.00 to $3.30 per share," said Rowe. Earnings guidance is based on the assumption of normal weather for the remainder of the year.

Exelon's outlook for 2006 adjusted (non-GAAP) operating earnings excludes the earnings impacts of the following:

- mark-to-market adjustments from non-trading activities;
- investments in synthetic fuel-producing facilities;
- certain costs associated with the proposed merger with PSEG;
- significant impairments of intangible assets, including a potential impairment of ComEd's goodwill in the third quarter;
- significant changes in decommissioning obligation estimates;
- certain amounts to be recovered by ComEd as approved in the July 26, 2006 ICC rate order, specifically, previously incurred severance costs and losses on extinguishments of long-term debt; and
- other unusual items, including any future changes to GAAP.

In consideration of these factors, and the need to further analyze the impacts of the ICC's rate order, Exelon is not updating its 2006 GAAP earnings guidance of $3.00 to $3.30 per share until its analyses are complete, which is expected in the third quarter.

Second Quarter Highlights

- **Proposed Merger with PSEG:** On May 30, 2006, the Nuclear Regulatory Commission approved the merger and transfer of the nuclear plant operating licenses from PSEG Nuclear to Generation. On June 22, 2006, Exelon and PSEG reached a comprehensive agreement with the Antitrust Division of the United States Department of Justice (DOJ), which resolves all competition issues reviewed by the DOJ in connection with the proposed merger of Exelon and PSEG. Under the terms of the DOJ agreement, Exelon and PSEG will divest fossil-fuel fired electric generating stations with a total capacity of approximately 5,600 megawatts, assuring that the merger will not adversely affect competition. No divestiture of nuclear capacity or nuclear plants is required by DOJ, as the increased fossil divestiture will resolve all competition issues. The fossil plant divestiture required by the settlement with DOJ will satisfy the requirements imposed by the Federal Energy Regulatory Commission (FERC) to divest fossil generation. The virtual nuclear divestiture approved by FERC in June 2005 continues to be a FERC requirement even though it is not required by DOJ. The divestitures will be required when the merger closes.

- The New Jersey Board of Public Utilities (NJBPU) is the only remaining regulatory authority whose approval is required to complete the merger. Settlement discussions are continuing with the NJBPU staff and other parties. Exelon and PSEG recently made an enhanced settlement proposal that includes concessions that are significantly greater than the concessions originally offered. Exelon and PSEG have also indicated that it is essential to reach a settlement promptly. If Exelon and PSEG are able to reach a settlement in New Jersey, the settlement would need to be reviewed by the Administrative Law Judge presiding over the case and would need to be approved by the NJBPU after public comment. Although it is possible that this process could be completed in time to allow the merger to close in the third quarter of 2006, there is currently no established timetable for NJBPU action on the merger. The final decision on whether to proceed with the merger will rest with the boards of both Exelon and PSEG after the terms and conditions of regulatory requirements are known.
- **ComEd Procurement Case:** On January 24, 2006, the ICC approved ComEd's procurement case, authorizing ComEd to procure power after 2006 through a "reverse-auction" competitive bidding process and to recover the costs from retail customers with no markup. The first auction is scheduled to take place beginning September 5, 2006, and a Web site (www.illinois-auction.com) provides bidder and general information about the Illinois auction process. For the initial auction, ComEd's entire load will be up for bid. In order to mitigate the effects of changes in future prices, the load for residential and commercial customers less than 400 kW will be served utilizing staggered three-year contracts. On June 1, 2006, the Attorney General filed a petition for review with the Illinois Supreme Court related to the ICC's order in the procurement case. The petition for review includes a request that the Supreme Court stay the ICC's order. The Supreme Court has not yet acted on the petition.
- **ComEd Residential Rate Stabilization Program:** On May 23, 2006, ComEd filed a residential rate stabilization proposal to ease residential customers' transition after 2006 to cost-based rates from frozen rates, which requires regulatory approval to implement. The proposal would limit the energy procurement costs that ComEd could pass through to its customers for a specified period of time and allow ComEd to collect any unrecovered procurement costs, including appropriate returns, in later years. The plan would terminate if a material adverse event occurs or if ComEd's senior unsecured credit rating for at least one of the three major credit rating agencies falls below investment grade. ComEd has requested an ICC ruling on the proposal by late November 2006. Hearings on the proposal are scheduled for September 7 and 8. ComEd is reviewing this initiative in light of the ICC order on the delivery rate case.
- **Nuclear Operations:** Generation's nuclear fleet, including its owned output from the Salem Generating Station operated by PSEG and co-owned by Generation, produced 35,442 GWhs in the second quarter of 2006, compared with 34,685 GWhs in the second quarter of 2005. The Exelon Nuclear-operated plants completed two scheduled refueling outages in both of the second quarters of 2006 and 2005, and refueling outage days totaled 35 and 36, respectively. Total non-refueling outage days for the Exelon Nuclear-operated plants in the second quarter of 2006 were 24 versus 26 in the second quarter of 2005.
- **Fossil and Hydro Operations:** Generation's fossil fleet commercial availability was 93.7 percent in the second quarter of 2006, compared with 94.8 percent in the second quarter of 2005, primarily due to unplanned maintenance outages. The equivalent availability factor for the hydro facilities was 95.2 percent, a 2.7 percent improvement over the second quarter 2005 performance, largely due to less planned outage work performed in the second quarter 2006.

BUSINESS UNIT RESULTS

ComEd consists of the retail and wholesale electricity transmission and distribution operations in northern Illinois.

ComEd's net income in the second quarter of 2006 was $127 million compared with net income of $109 million in the second quarter of 2005. The second quarter 2006 net income included (all after tax) mark-to-market gains of $2 million from one wholesale contract and expenses of $1 million related to certain integration costs associated with the proposed merger with PSEG. Second quarter 2005 net income included after-tax income of $2 million related to adjustments to previously recorded severance and severance-related charges. Excluding the impact of these items, ComEd's net income in the second quarter of 2006 increased $19 million compared with the same quarter last year, primarily due to lower purchased power expense attributable to a contractual decrease in prices associated with ComEd's power purchase agreement with Generation, core growth in customers and deliveries and favorable changes in customer mix and usage, partially offset by the impact of less favorable weather.

In the ComEd service territory, cooling degree-days were down 32 percent relative to the same period in 2005 and were 2 percent below normal. ComEd's total retail kWh deliveries decreased 2 percent in 2006 as compared with 2005, with a 2 percent decrease in deliveries to the residential customer class, largely due to less favorable weather. ComEd's second quarter 2006 revenues were $1,453 million, down 2 percent from $1,488 million in 2005, primarily due to decreased deliveries to residential and Power Purchase Option (PPO) customers. For ComEd, weather had an unfavorable after-tax impact of $20 million on second quarter 2006 earnings relative to 2005 and had an unfavorable after-tax impact of $4 million relative to the normal weather that was incorporated in earnings guidance.

The number of customers being served in the ComEd region has increased 1.1 percent since the second quarter of 2005, with weather-normalized kWh growth of 1.8 percent compared with the second quarter of 2005.

PECO consists of the retail electricity transmission and distribution operations and the retail natural gas distribution business in southeastern Pennsylvania.

PECO's net income in the second quarter of 2006 was $93 million compared with net income of $110 million in the second quarter of 2005. The second quarter 2006 net income included after-tax expenses of $3 million related to certain integration costs associated with the proposed merger with PSEG. Second quarter 2005 net income included after-tax charges of $4 million related to certain integration costs associated with the proposed merger with PSEG. Excluding the impact of these items, PECO's net income in the second quarter of 2006 decreased $18 million compared with the same quarter last year, primarily due to higher CTC amortization and higher operating and maintenance expense, partially offset by higher revenues, net of purchased power and fuel expense. Higher net revenues reflected certain authorized electric rate increases, including a scheduled CTC rate increase, partially offset by lower net electric and gas revenues as a result of unfavorable weather. The increases in CTC amortization expense and CTC rates are in accordance with PECO's 1998 restructuring settlement with the PAPUC. As expected, the increase in CTC amortization expense exceeded the increase in CTC revenues.

In the PECO service territory, cooling degree-days were the same as in 2005 and were 3 percent above normal, while heating degree days were 31 percent below 2005 and normal. PECO's total electric retail kWh deliveries increased less than 1 percent, with residential deliveries down 1 percent. Total gas deliveries were down 7 percent from the 2005 period. PECO's second quarter 2006 revenues were $1,148 million, up 10 percent from

$1,044 million in 2005, primarily due to the above-mentioned electric rate increases and a net increase in gas rates through PAPUC-approved changes to the purchased gas adjustment clause. For PECO, weather had an unfavorable after-tax impact of $6 million on second quarter 2006 earnings relative to 2005 and an unfavorable after-tax impact of $6 million relative to the normal weather that was incorporated in earnings guidance.

The number of electric customers being served in the PECO region has increased 0.7 percent since the second quarter of 2005, with weather-normalized kWh growth of 1.2 percent compared with the second quarter of 2005.

Exelon Generation consists of Exelon's electric generation operations, competitive retail sales and power marketing and trading functions.

Second quarter 2006 net income was $500 million compared with $296 million in the second quarter of 2005. Second quarter 2006 net income included (all after tax) income of $89 million resulting from decreases in decommissioning obligations primarily related to the AmerGen nuclear plants, mark-to-market gains of $36 million from non-trading activities, costs of $2 million related to certain integration costs associated with the proposed merger with PSEG and income of $2 million related to Generation's prior investment in Sithe, which is reflected as discontinued operations. Second quarter 2005 net income included (all after tax) mark-to-market losses of $14 million from non-trading activities, costs of $1 million related to the proposed merger with PSEG, severance and severance-related costs of $1 million and charges of $1 million related to Generation's prior investment in Sithe, which is reflected as discontinued operations. Excluding the impact of these items, Generation's net income in the second quarter of 2006 increased $62 million compared with the same quarter last year, primarily due to higher revenue, net of purchased power and fuel expense, partially offset by higher other operating and maintenance expense largely due to inflationary increases.

Generation's revenue, net of purchased power and fuel expense, increased by $131 million in the second quarter of 2006 compared with the second quarter of 2005 excluding the mark-to-market impact in both years. The quarter-over-quarter increase in revenue, net of purchased power and fuel expense, was driven by higher average margins on wholesale market sales due to having previously re-priced forward hedges at higher prices, combined with higher spot market prices and the impact of higher generation output, as well as the contractual increase in the prices associated with Generation's power sales agreement with PECO, partially offset by the contractual decrease in prices associated with Generation's power sales agreement with ComEd. Generation's average realized margin on all electric sales, including sales to affiliates and excluding trading activity, was $26.43 per MWh in the second quarter of 2006 compared with $23.06 per MWh in the second quarter of 2005.

Adjusted (non-GAAP) Operating Earnings

Adjusted (non-GAAP) operating earnings, which generally exclude significant one-time charges or credits that are not normally associated with ongoing operations and mark-to-market adjustments from non-trading activities, are provided as a supplement to results reported in accordance with GAAP. Management uses such adjusted (non-GAAP) operating earnings measures internally to evaluate the company's performance and manage its operations. Reconciliations of GAAP to adjusted (non-GAAP) operating earnings for historical periods are attached. Additional earnings release attachments, which include the reconciliations on pages 7 and 8, are posted on Exelon's Web site: www.exeloncorp.com and have been filed with the Securities and Exchange Commission on Form 8-K on July 31, 2006.

Conference call information: Exelon has scheduled a conference call for

11 AM ET (10 AM CT) on July 31, 2006. The call-in number in the U.S. is 888-603-6873, and the international call-in number is 973-582-2706. No password is required. Media representatives are invited to participate on a listen-only basis. The call will be web-cast and archived on Exelon's Web site: www.exeloncorp.com. (Please select the Investor Relations page.)

Telephone replays will be available until August 14. The U.S. call-in number for replays is 877-519-4471, and the international call-in number is 973-341-3080. The confirmation code is 7592439.

This news release includes forward-looking statements within the meaning of the Private Securities Litigation Reform Act of 1995, that are subject to risks and uncertainties. The factors that could cause actual results to differ materially from these forward-looking statements include those discussed herein as well as those discussed in (1) Exelon Corporation's 2005 Annual Report on Form 10-K in (a) ITEM 1A. Risk Factors and (b) ITEM 8. Financial Statements and Supplementary Data: Exelon-Note 20, ComEd-Note 17, PECO-Note 15 and Generation-Note 17 and (2) other factors discussed in filings with the Securities and Exchange Commission (SEC) by Exelon Corporation, Commonwealth Edison Company, PECO Energy Company and Exelon Generation Company, LLC (Companies). Readers are cautioned not to place undue reliance on these forward-looking statements, which apply only as of the date of this news release. None of the Companies undertakes any obligation to publicly release any revision to its forward-looking statements to reflect events or circumstances after the date of this news release.

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Exelon Corporation is one of the nation's largest electric utilities with approximately 5.2 million customers and more than $15 billion in annual revenues. The company has one of the industry's largest portfolios of electricity generation capacity, with a nationwide reach and strong positions in the Midwest and Mid-Atlantic. Exelon distributes electricity to approximately 5.2 million customers in Illinois and Pennsylvania and natural gas to more than 470,000 customers in southeastern Pennsylvania. Exelon is headquartered in Chicago and trades on the NYSE under the ticker EXC.

Division of Environmental Safety and Health
Radiation Protection and Release Prevention Element
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Trenton, NJ 08625-0415
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July 30, 2004

Mr. Hubert Miller
Regional Administrator
U.S. Nuclear Regulatory Commission
475 Allendale Rd.
King of Prussia, PA 19406-1415

Subject: Effects of Aircraft Impact on Spent Fuel Pools in New Jersey

Dear Mr. Miller:

Since the September 11, 2001 tragedy, nuclear power generation facilities have been the subject of numerous evaluations related to the prevention of and emergency response to possible terrorist actions, including the use of aircraft as a destructive device. The State of New Jersey through our Radiation Protection and Release Prevention Element – Bureau of Nuclear Engineering (BNE) has been studying developments in this area.

Recently, two technical studies related to the effects of aircraft impact on Spent Fuel Pools have been performed by private parties and were reviewed by the NRC. These two studies were the Nuclear Energy Institute (NEI)/Electric Power Research Institute (EPRI) Study: "Deterring Terrorism: Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant's Structural Strength," issued March 2003 (hereafter referred to as the NEI Study) and the paper, "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," April 21, 2003, Robert Alvarez, et al., published in Science and Global Security, Spring 2003 (hereafter referred to as the Alvarez Paper).

NEI considers the details of their study, submitted to the NRC for review, to be security sensitive. Accordingly, New Jersey did not have access to the complete report and could not conduct a detailed independent review as to the study's validity for nuclear facilities located in the state. However, NEI has made public sufficient information to conclude that the study was limited to the evaluation of the impact of a Boeing 767-400 airplane into containment buildings, used fuel storage pools, used fuel "Dry" storage facilities and used fuel transportation containers. The NEI Study does not appear to have taken into account the thermal and structural consequences and collateral damage of the explosion and resulting fire that would also occur from the impact of a commercial aircraft. In addition, it appears that the structural models used to evaluate impact damage were based on "representative" (not site-specific), structures, which were considered by NEI to be typical to those that exist across the nuclear power industry.

The Alvarez Paper was available to New Jersey as was the NRC staff's review and comments. This paper focused on the potential generic vulnerabilities of spent fuel pools to terrorist attack. The paper also details the possible public safety and environmental consequences should such attacks successfully occur. Included in this paper were conservative estimates of the radiological release should a spent fuel zircaloy cladding fire occur due to a significant breach of a spent fuel pool. The paper states, "The long-term land-contamination consequences of such an event could be significantly worse than those from Chernobyl". The paper further states (in reference to Chernobyl), "The total area of this radiation-control zone is huge: 10,000 km^2, equal to half the area of the State of New Jersey. During the following decade, the population of this area declined by almost half because of migration to areas of lower contamination".

As you are aware, New Jersey is the home to four operating nuclear power reactors located at two separate generating sites. Three power reactors, "Hope Creek", "Salem Unit 1" and "Salem 2", are located on the Delaware River at the PSE&G Artificial Island Site and the fourth reactor, "Oyster Creek", is located near Barnegat Bay and the Atlantic coastline at the AmerGen Oyster Creek Site.

New Jersey is especially concerned about the vulnerability of the Oyster Creek spent fuel pool (OCSFP) to a terrorist attack using a commercial aircraft. This concern is based, in part, on the structural design of the superstructure of the building which encloses the OCSFP (metal siding, concrete roof panels, high collapse potential for this scenario), the location of the pool in the building (high elevation, near an outside wall, pool surface open to superstructure), the relatively unimpeded flight path to the fuel pool location (located on an open coastal plane with minimal surrounding obstructions to fuel pool wall), and, most importantly, the lack of a comprehensive site-specific evaluation for this terrorist aircraft impact scenario which addresses the collective consequences of impact and resulting explosion, fire (including thermal gradients through fuel pool concrete), and probable structural collapse on the OCSFP and fuel assemblies.

Additionally, the site-specific radiological release (including a timeline for the expected release) resulting from this terrorist aircraft impact scenario needs to be quantified by the NRC and provided to New Jersey for emergency planning preparation to insure that the safety of the residents of New Jersey and first responders can be maintained. New Jersey requests this information be provided expediently.

Since New Jersey is not aware of any site-specific evaluation of the OCSFP that addresses these issues, it is requesting that the USNRC provide detailed technical assurance documenting the basis that the above mentioned concerns have been rigorously addressed and that the safety of residents of New Jersey and the environment can be maintained should a 9-11 style terrorist attack occur at Oyster Creek.

New Jersey is also requesting that some provision be made so that authorized representatives of the State of New Jersey, Bureau of Nuclear Engineering, can be granted access to review any and all documentation which is used by the NRC as the basis for concluding that terrorist threats to nuclear power facilities do not represent a risk to New Jersey residents.

If you need additional information, please contact Mr. Kent Tosch, Manager of the Bureau of Nuclear Engineering, at (609) 984-7701.

Sincerely,

Jill Lipoti, Ph.D., Assistant Director
Radiation Protection Program and Release Prevention

From: "Richard Webster" <rwebster@kinoy.rutgers.edu>
To: <OysterCreekEIS@nrc.gov>
Date: 09/11/2006 2:12:34 PM
Subject: Additional exhibits

Here are the additional exhibits.

Respectully submitted

Richard Webster
Staff Attorney
Rutgers Environmental Law Clinic
123 Washington Street
Newark, NJ 07102
Phone: 973-353-5695
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Mail Envelope Properties (4505A703.218 : 3 : 16920)

Subject:	Additional exhibits
Creation Date	09/11/2006 2:11:48 PM
From:	"Richard Webster" <rwebster@kinoy.rutgers.edu>
Created By:	rwebster@kinoy.rutgers.edu

Recipients
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Ex. SC 1 GT Thompson Report 5-25-06.pdf		271585
Mime.822	986366	

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Expiration Date:	None
Priority:	Standard
ReplyRequested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard

Junk Mail Handling Evaluation Results
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This message was not classified as Junk Mail

Junk Mail settings when this message was delivered
Junk Mail handling disabled by User
Junk Mail handling disabled by Administrator
Junk List is not enabled
Junk Mail using personal address books is not enabled
Block List is not enabled

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Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants

by
Gordon R. Thompson

25 May 2006

A report for
Office of the Attorney General
Commonwealth of Massachusetts

Abstract

This report addresses some of the risks associated with the future operation of the Pilgrim and Vermont Yankee nuclear power plants. The risks that are addressed here arise from the storage of spent nuclear fuel in a water-filled pool adjacent to the reactor at each plant. Both pools are now equipped with high-density, closed-form storage racks. Options are available to reduce spent-fuel-pool risks. The option that would achieve the largest risk reduction at each plant, during operation within a license extension period, would be to re-equip the pool with low-density, open-frame storage racks. That option would return the plant to its original design configuration. This report describes risks and risk-reducing options, and relevant analysis that is required from the licensee and the Nuclear Regulatory Commission in the context of license extension applications for the Pilgrim and Vermont Yankee plants.

About the Institute for Resource and Security Studies

The Institute for Resource and Security Studies (IRSS) is an independent, nonprofit, Massachusetts corporation, founded in 1984. Its objective is to promote sustainable use of natural resources and global human security. In pursuit of this mission, IRSS conducts technical and policy analysis, public education, and field programs. IRSS projects always reflect a concern for practical solutions to resource and security problems.

About the Author

Gordon R. Thompson is the executive director of IRSS and a research professor at Clark University, Worcester, Massachusetts. He studied and practiced engineering in Australia, and received a doctorate in applied mathematics from Oxford University in 1973, for analyses of plasma undergoing thermonuclear fusion. Dr. Thompson has been based in the USA since 1979. His professional interests encompass a range of technical and policy issues related to international security and protection of natural resources. He has conducted numerous studies on the environmental and security impacts of nuclear facilities and options for reducing these impacts.

Dr. Thompson independently identified the potential for a spent-fuel-pool fire, and articulated alternative options for lower-risk storage of spent fuel, during his work for the German state government of Lower Saxony in 1978-1979. His findings were accepted by that government after a public hearing. Since that time, Thompson has conducted several other studies on spent-fuel-storage risk, alone and with colleagues. Findings of these studies have been confirmed by a 2005 report by the National Academy of Sciences, prepared at the request of the US Congress.

Acknowledgements

This report was prepared by IRSS for the Office of the Attorney General, Commonwealth of Massachusetts. Gordon R. Thompson is solely responsible for the content of the report.

Contents

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(Tables are located at the end of the report.)

1. Introduction

Applications have been submitted for 20-year extensions of the operating licenses of the Pilgrim and Vermont Yankee nuclear power plants. These plants began operating in 1972, and their current operating licenses expire in 2012. The designs of the two plants are broadly similar, and both are operated by Entergy Nuclear Operations Inc. (Entergy). Each plant features a boiling-water reactor (BWR) with a Mark 1 containment. The US Nuclear Regulatory Commission (NRC) has announced that interested persons can petition to intervene in the license extension proceedings for these plants. In that context, the Office of the Attorney General, Commonwealth of Massachusetts, has requested the preparation of this report.

This report addresses a particular set of risks associated with the future operation of the Pilgrim and Vermont Yankee plants. These risks arise from the storage of spent nuclear fuel in water-filled pools. Each plant's nuclear reactor periodically discharges fuel that is "spent" in the sense that the fuel is no longer suitable for power generation. The spent fuel contains a large amount of radioactive material, and is stored in a water-filled pool adjacent to the reactor. In this report, the word "risk" applies to the potential for a release of radioactive material from nuclear fuel to the atmosphere. Other risks arise from the operation of nuclear power plants, but are not addressed here. The concept of risk encompasses both the consequences and probability of an event. However, risk is not simply the arithmetic product of consequence and probability numbers, as is sometimes assumed.

Although this report focuses on the risks arising from pool storage of spent fuel, the report necessarily considers some aspects of the risks arising from operation of the reactor at each plant. Such consideration is necessary because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. Thus, an incident involving a release of radioactive material from the pool could be initiated or exacerbated by an incident at the reactor, or vice versa, or parallel incidents at the pool and the reactor could have a common cause.

Scope of this analysis

This report does not purport to provide a comprehensive assessment of the risks arising from pool storage of spent fuel at the Pilgrim and Vermont Yankee plants. As discussed in Section 10, below, preparation of such an assessment is a duty of Entergy and the NRC. Neither party has performed this duty. In the absence of a comprehensive assessment, this report provides illustrative analysis of selected issues. Assumptions of the analysis are stated, and the author would be pleased to engage in open technical debate regarding his analysis. A companion report, prepared independently by Dr. Jan Beyea, examines the offsite consequences of releases of radioactive material. Findings in that report are consistent with scientific knowledge and experience in the field of radiological consequence assessment. Questions about the analysis in that report should be directed to Dr. Beyea.

Five major purposes are pursued in this report. The focus throughout is on the Pilgrim and Vermont Yankee plants and their license extension applications, but much of the report's discussion has wider application. First, the potential for a release of radioactive material from a spent-fuel pool is described. Second, options for reducing the probability and/or consequences of such a release are described. These descriptions provide a general picture of the risks and risk-reducing options associated with pool storage of spent fuel. Third, an integrated view of these risks and risk-reducing options is provided. Fourth, the state of knowledge about these risks and risk-reducing options is reviewed. Fifth, the technical analysis required from Entergy and the NRC to improve this state of knowledge is described.

Two classes of event could lead to a release of radioactive material from a spent-fuel pool. One class of events, typically described as "accidents", includes human error, equipment failure and/or natural forces such as earthquakes. A second class encompasses deliberate, malicious acts. Some events, which involve harmful acts by insane but cognitively functioning persons, fall into both classes. This report considers the full range of initiating events, including human error, equipment failure, natural forces, malice, and/or insanity.

Protection of sensitive information

Any responsible analyst who discusses potential acts of malice at nuclear power plants is careful about making statements in public settings. The author of this report exercises such care. The author has no access to classified information, and this report contains no such information. However, a higher standard of discretion is necessary. An analyst should not publish detailed information that will assist potential attackers, even if this information is publicly available from other sources. On the other hand, if a plant's design and operation leave the plant vulnerable to attack, and the vulnerability is not being addressed appropriately, then a responsible analyst is obliged to publicly describe the vulnerability in general terms.

This report exemplifies the balance of responsibility described in the preceding paragraph. Vulnerabilities of the Pilgrim and Vermont Yankee plants are described here in general terms. Detailed information relating to those vulnerabilities is withheld here, although that information has been published elsewhere or could be re-created by many persons with technical education and/or military experience. For example, this report does not provide cross-section drawings of the Pilgrim and Vermont Yankee plants, although such drawings have been published for many years and are archived around the world. NRC license proceedings provide potential forums at which sensitive information can be discussed without concern about disclosure to potential attackers. Rules and practices are available so that the parties to a license proceeding can discuss sensitive information in a protected setting.

Structure of this report

The remainder of this report has eleven sections. Section 2 outlines the hazard posed by storage of spent fuel in a high-density configuration in pools at nuclear power plants, and describes the history of attention to this issue. The hazard arises from the potential for a self-ignited fire in a spent-fuel pool if water is lost from the pool. Technical aspects of this hazard are discussed in greater detail in subsequent sections of the report. Characteristics of the Pilgrim and Vermont Yankee plants and their spent fuel are described in Section 3. National trends in the management of spent nuclear fuel are described in Section 4, providing evidence that spent fuel is likely to remain at the Pilgrim and Vermont Yankee sites for at least several decades, and potentially for more than a century. The risks of spent-fuel storage will continue to accumulate over that period.

Section 5 reviews the state of technical knowledge about potential spent-fuel-pool fires. Scenarios for such a fire at the Pilgrim or Vermont Yankee plants are discussed in the two following sections. Section 6 discusses scenarios initiated by accidents not involving malice, while Section 7 discusses scenarios initiated by malicious action. Options to reduce the risks of spent-fuel-pool fires at the Pilgrim and Vermont Yankee plants are described in Section 8. An integrated view of risks and risk-reducing options at these plants is set forth in Section 9.

In Section 5 and elsewhere, this report discusses the state of technical knowledge about risks and risk-reducing options associated with spent-fuel pools. There are substantial deficiencies in present knowledge. Section 10 describes the technical analysis required from Entergy and the NRC to correct these deficiencies in the context of license extension applications for Pilgrim and Vermont Yankee. Conclusions are set forth in Section 11, and a bibliography is provided in Section 12. All documents cited in the text of this report are listed in the bibliography.

2. Recognition of the Spent-Fuel Hazard

From the earliest years of the nuclear-technology era, analysis and experience have shown that a nuclear reactor can undergo an accident in which the reactor's fuel is damaged. This damage can lead to a release of radioactive material within the reactor and, potentially, from the reactor to the external environment. An early illustration of this accident potential occurred in the UK in 1957, when an air-cooled reactor at Windscale caught fire and released radioactive material to the atmosphere. At that time, spent fuel was not perceived as a significant hazard.

When the Pilgrim and Vermont Yankee plants began operating in 1972, there was limited technical understanding of the potential for severe accidents at commercial reactors. In this context, "severe" means that the reactor core is severely damaged, which typically involves melting of some fraction of the core materials. The environmental impact statements (EISs) related to the operation of Pilgrim and Vermont Yankee did not consider severe reactor accidents.[1] Knowledge about the potential for such accidents was improved by completion of the Reactor Safety Study (WASH-1400) in 1975.[2] More knowledge has accumulated from analysis and experience since that time.[3]

Until 1979 it was widely assumed that stored spent fuel did not pose risks comparable to those associated with reactors. This assumption arose because a spent fuel assembly does not contain short-lived radioactivity, and therefore produces less radioactive decay heat than does a similar fuel assembly in an operating reactor. However, that factor was counteracted by the introduction of high-density, closed-form storage racks into spent-fuel pools, beginning in the 1970s. Initially, pools were designed so that each held only a small inventory of spent fuel, with the expectation that spent fuel would be stored briefly and then taken away for reprocessing. Low-density, open-frame storage racks were used. Cooling fluid can circulate freely through such a rack. When reprocessing was abandoned in the United States, spent fuel began to accumulate in the pools. Excess spent fuel could have been offloaded to other storage facilities, allowing continued use of low-density racks. Instead, as a cost-saving measure, high-density racks were introduced, allowing much larger amounts of spent fuel to be stored in the pools.

The potential for a pool fire

Unfortunately, the closed-form configuration of the high-density racks would create a major problem if water were lost from a spent-fuel pool. The flow of air through the racks would be highly constrained, and would be almost completely cut off if residual water or debris were present in the base of the pool. As a result, removal of radioactive decay heat would be ineffective. Over a broad range of water-loss scenarios, the temperature of the zirconium fuel cladding would rise to the point (approximately 1,000 degrees C) where a self-sustaining, exothermic reaction of zirconium with air or steam would begin. Fuel discharged from the reactor for 1 month could ignite in less than 2 hours, and fuel discharged for 3 months could ignite in about 3 hours.[4] Once initiated, the fire would spread to adjacent fuel assemblies, and could ultimately involve all fuel in the pool. A large, atmospheric release of radioactive material would occur. For simplicity, this potential disaster can be described as a "pool fire".

Water could be lost from a spent-fuel pool through leakage, boiling, siphoning, pumping, displacement by objects falling into the pool, or overturning of the pool. These modes of water loss could arise from events, alone or in combination, that include: (i) acts of malice by persons within or outside the plant boundary; (ii) an accidental aircraft impact; (iii) an earthquake; (iv) dropping of a fuel cask; (v) accidental fires or explosions; and (vi) a severe accident at an adjacent reactor that, through the spread of radioactive

[1] AEC, 1972a; AEC, 1972b.
[2] NRC, 1975.
[3] Relevant experience includes the Three Mile Island reactor accident of 1979 and the Chernobyl reactor accident of 1986.
[4] This sentence assumes adiabatic conditions.

material and other influences, precludes the ongoing provision of cooling and/or water makeup to the pool.

These events have differing probabilities of occurrence. None of them is an everyday event. Nevertheless, they are similar to events that are now routinely considered in planning and policy decisions related to commercial nuclear reactors. To date, however, such events have not been given the same attention in the context of spent-fuel pools.

Some people have found it counter-intuitive that spent fuel, given its comparatively low decay heat and its storage under water, could pose a fire hazard. This perception has slowed recognition of the hazard. In this context, a simple analogy may be helpful. We all understand that a wooden house can stand safely for many years but be turned into an inferno by a match applied in an appropriate location. A spent-fuel pool equipped with high-density racks is roughly analogous, but in this case ignition would be accomplished by draining water from the pool. In both cases, a triggering event would unleash a large amount of latent chemical energy.

The sequence of studies related to pool fires

Two studies completed in March 1979 independently identified the potential for a fire in a drained spent-fuel pool equipped with high-density racks. One study was by members of a scientific panel assembled by the German state government of Lower Saxony to review a proposal for a nuclear fuel cycle center at Gorleben.[5] After a public hearing, the Lower Saxony government ruled in May 1979, as part of a broader decision, that high-density pool storage of spent fuel would not be acceptable at Gorleben. The second study was done by Sandia Laboratories for the NRC.[6] In light of knowledge that has accumulated since 1979, the Sandia report generally stands up well, provided that one reads the report in its entirety. However, the report's introduction contains an erroneous statement that complete drainage of the pool is the most severe situation. The body of the report clearly shows that partial drainage can be a more severe case, as was recognized in the Gorleben context. Unfortunately, the NRC continued, until October 2000, to employ the erroneous assumption that complete drainage is the most severe case.

The NRC has published various documents that discuss aspects of the potential for a spent-fuel-pool fire. Several of these documents are discussed in Section 5, below. Only three of the various documents are products of processes that provided an opportunity for formally structured public comment and, potentially, for in-depth analysis of risks and alternatives. One such document is the August 1979 Generic Environmental Impact Statement (GEIS) on handling and storage of spent fuel (NUREG-0575).[7] The second document is the May 1996 GEIS on license renewal (NUREG-1437).[8] These two documents purported to provide systematic analysis of the risks and relative costs and

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[5] Thompson et al, 1979.
[6] Benjamin et al, 1979.
[7] NRC, 1979.
[8] NRC, 1996.

benefits of alternative options. The third document is the NRC's September 1990 review (55 FR 38474) of its Waste Confidence Decision.[9] That document did not purport to provide an analysis of risks and alternatives.

NUREG-0575 addresses the potential for a spent-fuel-pool fire in a single sentence that cites the 1979 Sandia report. The sentence reads:[10]

> Assuming that the spent fuel stored at an independent spent fuel storage installation is at least one year old, calculations have been performed to show that loss of water should not result in fuel failure due to high temperatures if proper rack design is employed.

Although this sentence refers to pool storage of spent fuel at an independent spent fuel storage installation, NUREG-0575 regards at-reactor pool storage as having the same properties. This sentence misrepresents the findings of the Sandia report. The sentence does not define "proper rack design". It does not disclose Sandia's findings that high-density racks promote overheating of exposed fuel, and that overheating can cause fuel to self-ignite and burn. The NRC has never corrected this deficiency in NUREG-0575.

NUREG-1437 also addresses the potential for a spent-fuel-pool fire in a single sentence, which in this instance states:[11]

> NRC has also found that, even, under the worst probable cause of a loss of spent-fuel pool coolant (a severe seismic-generated accident causing a catastrophic failure of the pool), the likelihood of a fuel-cladding fire is highly remote (55 FR 38474).

The parenthetic citation is to the NRC's September 1990 review of its Waste Confidence Decision. Thus, NUREG-1437's examination of pool fires is totally dependent on the September 1990 review. In turn, that review bases its opinion about pool fires on the following four NRC documents:[12] (i) NUREG/CR-4982;[13] (ii) NUREG/CR-5176;[14] (iii) NUREG-1353;[15] and (iv) NUREG/CR-5281.[16] These documents are discussed in Section 5, below. That discussion reveals substantial deficiencies in the documents' analysis of the potential for a pool fire.

Thus, neither of the two GEISs (NUREG-0575 and NUREG-1437), nor the September 1990 review of the Waste Confidence Decision, provides a technically defensible

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9 NRC, 1990a.
10 NRC, 1979, page 4-21.
11 NRC, 1996, pp 6-72 to 6-75.
12 NRC, 1990a, page 38481.
13 Sailor et al, 1987.
14 Prassinos et al, 1989.
15 Throm, 1989.
16 Jo et al, 1989.

examination of spent-fuel-pool fires and the associated risks and alternatives. The statements in each document regarding pool fires are inconsistent with the findings of subsequent, more credible studies discussed below.

The most recent published NRC technical study on the potential for a pool fire is an NRC Staff study, originally released in October 2000 but formally published in February 2001, that addresses the risk of a pool fire at a nuclear power plant undergoing decommissioning.[17] This author submitted comments on the study to the NRC Commissioners in February 2001.[18] The study was in several respects an improvement on previous NRC documents that addressed pool fires. It reversed the NRC's longstanding, erroneous position that total, instantaneous drainage of a pool is the most severe case of drainage. However, it did not consider acts of malice. Nor did it add significantly to the weak base of technical knowledge regarding the propagation of a fire from one fuel assembly to another. Its focus was on a plant undergoing decommissioning. Therefore, it did not address potential interactions between pools and operating reactors, such as the interactions discussed in Section 6, below.

In 2003, eight authors, including the present author, published a paper on the risks of spent-fuel-pool fires and the options for reducing these risks.[19] That paper aroused vigorous comment, and its findings were disputed by NRC officials and others. Critical comment was also directed to a related report by this author.[20] In an effort to resolve this controversy, the US Congress requested the National Academy of Sciences (NAS) to conduct a study on the safety and security of spent-fuel storage. The NAS submitted a classified report to Congress in July 2004, and released an unclassified version in April 2005.[21] Press reports described considerable tension between the NAS and the NRC regarding the inclusion of material in the unclassified NAS report.[22]

Since September 2001, the NRC has not published any document that contains technical analysis related to the potential for a pool fire. The NRC claims that it is conducting further analysis in a classified setting. The scope of information treated as secret by the NRC is questionable. Much of the relevant analysis would address issues such as heat transfer and fire propagation. Calculations and experiments on such subjects should be performed and reviewed in the public domain. Classification is appropriate for other information, such as specific points of vulnerability of a spent-fuel pool to attack.

3. Characteristics of the Pilgrim and Vermont Yankee Plants and their Spent Fuel

Basic data about the Pilgrim and Vermont Yankee plants are set forth in Table 3-1. Data and estimates about storage of spent fuel at these plants are set forth in Tables 3-2

[17] Collins and Hubbard, 2001
[18] Thompson, 2001a.
[19] Alvarez et al, 2003.
[20] Thompson, 2003.
[21] NAS, 2006.
[22] Wald, 2005.

through 3-5. In regard to the latter tables, publicly available information is incomplete and inconsistent. Therefore, assumptions are made at various points in the tables, as is readily evident. In addition, the estimates set forth in Tables 3-3 through 3-5 involve a number of simplifying assumptions, which are also evident from the tables.

The scope and accuracy of Tables 3-1 through 3-5 could be improved using information that is held by Entergy and the NRC. Given this information, a more sophisticated analysis could be conducted to estimate the inventories and other characteristics of the Pilgrim and Vermont Yankee spent-fuel pools during the requested period of license extension. These improvements would not alter the basic findings of this report.

At the Pilgrim plant, the present configuration of the storage racks in the spent-fuel pool reflects a license amendment approved by the NRC in 1994. A report submitted by the licensee in support of that license amendment states that the existing racks in the pool and the proposed new racks had a center-to-center distance of about 6.3 inches in both directions. The new racks would, when fully installed, fill the pool tightly, wall-to-wall.[23] Equivalent detail is not available regarding the present configuration of racks in the Vermont Yankee pool. However, from the data provided in Table 3-2 regarding the capacities, inventories and dimensions of both pools, it is evident that the Vermont Yankee pool configuration is similar to that at Pilgrim.[24]

Entergy has announced its intention to establish an independent spent fuel storage installation (ISFSI) at the Vermont Yankee site, and for this purpose has requested a Certificate of Public Good from the Vermont Public Service Board. The ISFSI would store fuel in dry-storage modules. Entergy has described its planned schedule for transferring spent fuel from the pool to the ISFSI.[25] From this schedule, it is evident that Entergy plans to use the spent-fuel pool at nearly its full capacity, storing the overflow from that capacity in the ISFSI.

Extension of the Pilgrim operating license would imply the establishment of an ISFSI at the Pilgrim site. Entergy has not yet announced a plan to establish such an ISFSI. Given the continuing accumulation of spent fuel in the Pilgrim pool, and the time required to establish an ISFSI, it can reasonably be presumed that Entergy plans to use the Pilgrim spent-fuel pool at nearly its full capacity, storing the overflow from that capacity in a future ISFSI.

Inventories of cesium-137

The radioactive isotope cesium-137 provides a useful indicator of the hazard potential of the Pilgrim and Vermont Yankee spent-fuel pools. This isotope, which has a half-life of

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[23] Holtec, 1993.
[24] Hoffman, 2005, states that the present Vermont Yankee racks have a center-to-center distance of 6.2 inches.
[25] Hoffman, 2005.

30 years, is a volatile element that would be liberally released during a pool fire.[26] Table 3-4 shows the estimated inventory of cesium-137 in the Pilgrim and Vermont Yankee spent-fuel pools during the period of license extension. This table shows that the pools will hold about 1.6 million TBq (Pilgrim) and 1.4 million TBq (Vermont Yankee) of cesium-137. For comparison, Tables 3-3 and 3-5 provide licensee estimates showing that the Pilgrim and Vermont Yankee reactor cores will hold 190,000 TBq and 179,000 TBq, respectively, of cesium-137. Thus, each pool will hold about 8 times as much cesium-137 as will be present in the adjacent reactor.

4. Trends in Management of Spent Fuel

Risks arising from storage of spent fuel will accumulate over time. Thus, it is important to estimate the time period during which spent fuel will be stored at the Pilgrim or Vermont Yankee site, whether in a pool or an onsite ISFSI. In testimony before the Vermont Public Service Board, an Entergy witness has stated that the US Department of Energy (DOE) could begin accepting spent fuel from Vermont Yankee as early as 2015, for emplacement in the proposed repository in Yucca Mountain, Nevada.[27]

Some decision makers have advocated a revival of spent-fuel reprocessing as an alternative to placing intact spent fuel in a repository. Reprocessing was the national strategy for spent-fuel management when the Pilgrim and Vermont Yankee plants were built, but was abandoned in the 1970s. If reprocessing were to resume, it would provide an option for removal of spent fuel from reactor sites.

This author has testified before the Vermont Public Service Board regarding the prospects for the Yucca Mountain repository, reprocessing, and other options for removal of spent fuel from the Vermont Yankee site. He concluded that spent fuel is likely to remain at the site for at least several decades, and potentially for more than a century.[28] The same arguments apply to the Pilgrim site. Here, selected arguments are summarized, to illustrate the factors that will hinder removal of spent fuel from each site.

Current national policy for long-term management of spent fuel is to establish a repository inside Yucca Mountain. Progress with this project has been slow, and many observers believe that it will be cancelled. Even if the repository does open, there will be a delay before fuel can be shipped to Yucca Mountain and emplaced in the repository. Table 4-1 shows a schedule projection by DOE, indicating that the emplacement process could occupy five decades.

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[26] A study by the US Department of Energy (DOE, 1987) shows that cesium-137 accounts for most of the offsite radiation exposure that is attributable to the 1986 Chernobyl reactor accident, and for about half of the radiation exposure that is attributable to fallout from nuclear weapons tests in the atmosphere. Note that the particular mechanisms of the Chernobyl accident could not occur in the Pilgrim or Vermont Yankee pool.

[27] Hoffman, 2005.

[28] Thompson, 2006.

The US fleet of commercial reactors will probably produce more than 80,000 MgU of spent fuel if each reactor operates to the end of its initial 40-year license period. If each reactor received a 20-year license extension, the fleet could eventually produce a total of about 120,000 MgU of spent fuel. Yet, the capacity of Yucca Mountain is limited by federal statute to 63,000 MgU of spent fuel. DOE has investigated the option of placing 105,000 MgU of spent fuel in Yucca Mountain, which assumes a statute amendment. However, Table 4-2 shows that emplacement of 105,000 MgU of fuel could require an emplacement area of up to 3,800 acres if a lower-temperature operating mode is selected. Licensing considerations are likely to favor the selection of a lower-temperature operating mode, and there may not be enough space in the mountain to allow a total emplacement area of 3,800 acres. Thus, the physical capacity of Yucca Mountain could be less than 105,000 MgU of fuel.

As Table 4-3 shows, operation of the Yucca Mountain repository would involve a large number of spent-fuel shipments. This potential traffic poses a security concern, because there is evidence that shipping casks are more vulnerable to attack by sub-national groups than DOE has previously assumed.[29] Spent-fuel shipments could be comparatively attractive targets because they cannot be protected to the same extent as nuclear power plants.

A further impediment to shipping spent fuel to Yucca Mountain is that DOE has announced that it will receive fuel in standard canisters that are inserted, unopened, into waste packages prior to emplacement in the repository. Yet, as Table 4-4 shows, the concept of a standard canister is incompatible with the present configurations of dry-storage canisters and the proposed configurations of Yucca Mountain disposal packages. There is no clear path to resolution of this problem.

5. Technical Understanding of Spent-Fuel-Pool Fires

Section 2, above, introduces the concept of a pool fire and describes the history of analysis of pool-fire risks. There is a body of technical literature on these risks, containing documents of varying degrees of completeness and accuracy. Current opinions about the risks vary widely, but the differences of opinion may be more about the probabilities of pool-fire scenarios than about the physical characteristics of these scenarios. In turn, differing opinions about probabilities lead to differing support for risk-reducing options. This situation is captured in a comment by Allan Benjamin on a paper (Alvarez et al, 2003) by this author and seven colleagues.[30] Benjamin's comment is quoted in the unclassified NAS report as follows:[31]

[29] The term "sub-national group" is used in security analysis to describe a human group that is larger and more capable than an isolated individual, but is not an arm of a national government. This distinction has strategic significance because deterrence, a potentially effective means of influencing a national government, may not influence a sub-national group.
[30] Allan Benjamin was one of the authors of: Benjamin et al, 1979.
[31] NAS, 2006, page 45.

> In a nutshell, [Alvarez et al] correctly identify a problem that needs to be addressed, but they do not adequately demonstrate that the proposed solution is cost-effective or that it is optimal.

The "proposed solution" to which Benjamin refers is the re-equipment of spent-fuel pools with low-density, open-frame racks, transferring excess spent fuel to onsite dry storage. In fact, however, the [Alvarez et al] authors had not claimed to complete the level of analysis, especially site-specific analysis, that risk-reducing options should receive in an Environmental Report or EIS. These authors stated:[32]

> Finally, all of our proposals require further detailed analysis and some would involve risk tradeoffs that also would have to be further analyzed. Ideally, these analyses could be embedded in an open process in which both analysts and policy makers can be held accountable.

The paper by Alvarez et al is consistent with current knowledge of pool-fire phenomena, including the findings set forth in the unclassified NAS report. The same cannot be said for all of the NRC documents that were cited in the NRC's September 1990 review of its Waste Confidence Decision. As discussed in Section 2, above, four NRC documents were cited to support that review's finding regarding the risks of pool fires.[33] In turn, the May 1996 GEIS on license renewal (NUREG-1437) relied on the September 1990 review for its position on the risks of pool fires. The four NRC documents are discussed in the following paragraphs.

NUREG/CR-4982 was prepared at Brookhaven National Laboratory to provide "an assessment of the likelihood and consequences of a severe accident in a spent fuel storage pool".[34] The postulated accident involved complete, instantaneous loss of water from the pool, thereby excluding important phenomena from consideration. The Brookhaven authors employed a simplistic model to examine propagation of a fire from one fuel assembly to another. That model neglected important phenomena including slumping and burn-through of racks, slumping of fuel assemblies, and the accumulation of a debris bed at the base of the pool. Each of these neglected phenomena would promote fire propagation. The study ignored the potential for interactions between a pool fire and a reactor accident. It did not consider acts of malice. Overall, this study did not approach the completeness and quality needed to support consideration of a pool fire in an EIS.

NUREG/CR-5176 was prepared at Lawrence Livermore National Laboratory.[35] It examined the potential for earthquake-induced failure of the spent-fuel pool and the pool's support systems at the Vermont Yankee and Robinson Unit 2 plants. It also considered the effect of dropping a spent-fuel shipping cask on a pool wall. Overall, this study appears to have been a competent exercise within its stated assumptions. With

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[32] Alvarez et al, 2003, page 35.
[33] NRC, 1990a, page 38481.
[34] Sailor et al, 1987.
[35] Prassinos et al, 1989.

appropriate updating, NUREG/CR-5176 could contribute to the larger body of analysis that would be needed to support consideration of a pool fire in an EIS.

NUREG-1353 was prepared by a member of the NRC Staff to support resolution of NRC Generic Issue 82.[36] It postulated a pool accident involving complete, instantaneous loss of water from the pool, thereby excluding important phenomena from consideration. It relied on the fire-propagation analysis of NUREG/CR-4982. As discussed above, that analysis is inadequate. In considering heat transfer from BWR fuel after water loss, NUREG-1353 assumed that a high-density rack configuration would involve a 5-inch open space between each row of fuel assemblies. That assumption is inappropriate and non-conservative. Modern, high-density BWR racks have a center-to-center distance of about 6 inches in both directions. Thus, NUREG-1353 under-estimated the potential for ignition of BWR fuel. Overall, NUREG-1353 did not approach the completeness and quality needed to support consideration of a pool fire in an EIS.

NUREG/CR-5281 was prepared at Brookhaven National Laboratory to evaluate options for reducing the risks of pool fires.[37] It took NUREG/CR-4982 as its starting point, and therefore shared the deficiencies of that study.

Clearly, these four NRC documents do not provide an adequate technical basis for an EIS that addresses the risks of pool fires. The knowledge that they do provide could be supplemented from other documents, including the unclassified NAS report, the paper by Alvarez et al, and the NRC Staff study (NUREG-1738) on pool-fire risk at a plant undergoing decommissioning.[38] However, this combined body of information would be inadequate to support the preparation of an EIS. For that purpose, a comprehensive, integrated study would be required, involving analysis and experiment. The depth of investigation would be similar to that involved in preparing the NRC's December 1990 study on the risks of reactor accidents (NUREG-1150).[39]

A pool-fire "source term"

The incompleteness of the present knowledge base is evident when one needs a "source term" to estimate the radiological consequences of a pool fire. The concept of a source term encompasses the magnitude, timing and other characteristics of a release of radioactive material. Present knowledge does not allow theoretical or empirically-based prediction of the source term for a postulated pool-fire scenario. Instead, informed judgment must be used.

Table 5-1 provides two versions of a source term for a pool fire at Pilgrim or Vermont Yankee. Each version assumes that a high-density pool would be almost full of spent

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[36] Throm, 1989.
[37] Jo et al, 1989.
[38] Collins and Hubbard, 2001.
[39] NRC, 1990b.

fuel, which is the expected mode of operation of each plant during the period of license extension.

One version of the source term involves a release of 100 percent of the cesium-137 in a pool. That is an upper limit. In practice, the cesium-137 release fraction would be less than 100 percent, but there is no way to determine if the largest achievable release fraction would be 90 percent or 95 percent or some other number. In any event, this large source term implies that all or most of the zirconium in the pool would oxidize. Table 5-1 assumes that the oxidation occurs over a period of 5 hours. The second version of the source term involves a release of 10 percent of the cesium-137 in the pool, with oxidation of 10 percent of the zirconium over a period of 0.5 hours.

Given present knowledge, the approximately 100-percent release and the 10-percent release are equally probable for a typical pool fire. A prudent decision maker could, therefore, reasonably use the 100-percent release to assess risks and risk-reducing options.

6. Initiation of a Pool Fire by an Accident Not Involving Malice

Section 2, above, provides a general description of the potential for a spent-fuel-pool fire. Such a fire could be caused by a variety of events. Here, accidental events not involving malice are considered, with a focus on the Pilgrim and Vermont Yankee plants. Section 7, below, considers events that involve malicious action.

At Pilgrim or Vermont Yankee, non-malicious events at the plant that could lead to a pool fire include: (i) an accidental aircraft impact, with or without an accompanying fuel-air explosion or fire; (ii) an earthquake; (iii) dropping of a fuel transfer cask or shipping cask; (iv) a fire inside or outside the plant building; and (v) a severe accident at the adjacent reactor.

Given the major consequences of a pool fire, analysis should have been performed to examine pool-fire scenarios across a full range of initiating events. The NRC has devoted substantial attention and resources to the examination of reactor-core-melt scenarios, through studies such as NUREG-1150.[40] Neither the NRC nor the nuclear industry has conducted a comparable study of pool fires. In the absence of such a study, this report provides illustrative analysis.

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[40] NRC, 1990b.

A pool fire accompanied by a reactor accident

As mentioned in Section 1, above, at Pilgrim and Vermont Yankee the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. These plants are, therefore, comparatively likely to experience a pool fire that is accompanied by a reactor accident.

This combination of accidents is the focus of discussion here. The pool fire and the reactor accident might have a common cause. For example, a severe earthquake could cause leakage of water from the pool, while also damaging the reactor and its supporting systems to such an extent that a core-melt accident occurs. In some scenarios, the high radiation field produced by a pool fire could initiate or exacerbate an accident at the reactor by precluding the presence and functioning of operating personnel. In other scenarios, the high radiation field produced by a core-melt accident could initiate or exacerbate a pool-fire scenario, again by precluding the presence and functioning of operating personnel. Many core-melt scenarios would involve the interruption of cooling to the pool.

By focusing on a pool fire accompanied by a reactor accident, this report does not imply that other pool-fire scenarios make a smaller contribution to pool-fire risks at Pilgrim and Vermont Yankee. Such a conclusion could come only from a comprehensive assessment of pool-fire risks, and no such assessment has ever been performed.

Tables 6-1 and 6-2 provide licensee estimates of core-damage frequency (probability) and radioactive-release frequency for the Pilgrim and Vermont Yankee reactors.[41] Some of these estimates are from the Independent Plant Examination (IPE) and the Independent Plant Examination for External Events (IPEEE) that have been performed for each plant.[42] The remaining estimates are from the Environmental Report (Appendix E of the license renewal application) for each plant. In this report, the IPE and IPEEE estimates are used instead of the ER estimates, because the studies underlying the latter are not available for review.[43]

Estimates shown in Tables 6-1 and 6-2 that are of particular relevance to this report are the estimates of the probability (frequency) of an early release of radioactive material from the reactor. Table 6-3 provides a definition of "early" and other terms that are used to categorize potential radioactive releases. "High" and "medium" release scenarios, as defined in Table 6-3, are often "early" and vice versa.

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[41] For present purposes, core damage is equivalent to core melt.
[42] Boston Edison, 1992; Boston Edison, 1994; VYNPS, 1993; VYNPS, 1998.
[43] NRC Public Document Room staff informed Diane Curran that the recent reactor-accident studies referenced in the Environmental Reports for Pilgrim and Vermont Yankee could not be located within the NRC.

Lessons from a license-amendment proceeding for the Harris plant

This report assumes that the conditional probability of a spent-fuel-pool fire, given an early release from the adjacent reactor, is 50 percent. That assumption is reasonable – and not necessarily conservative – for the Pilgrim or Vermont Yankee plant because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. Support for this assumption is provided by technical studies and opinions submitted to the Atomic Safety and Licensing Board (ASLB) in a license-amendment proceeding in regard to the expansion of spent-fuel-pool capacity at the Harris nuclear power plant. All three parties to the proceeding – the NRC Staff, Carolina Power and Light (CP&L), and Orange County – reached the same conclusion on an issue that is relevant to the above-stated conditional probability of 50 percent.

The Harris plant has one reactor and four pools. The reactor – a PWR – is in a cylindrical, domed containment building. The four pools are in a separate, adjacent building that was originally intended to serve four reactors. Only one reactor was built. Two pools were in use at high density prior to the proceeding, and the proceeding addressed the activation of the two remaining pools, also at high density.

During the proceeding, the ASLB determined that the potential for a pool fire should be considered, and ordered the three parties to analyze a single scenario for such a fire.[44] In the postulated scenario, a severe accident at the Harris reactor would contaminate the Harris site with radioactive material to an extent that would preclude actions needed to supply cooling and makeup to the Harris pools. Thereafter, the pools would boil and dry out, and fuel within the pools would burn. Following the ALSB's order, Orange County submitted a report by this author.[45] The NRC Staff submitted an affidavit by members of the Staff.[46] CP&L – the licensee – submitted a document prepared by ERIN Engineering.[47]

Orange County's analysis found that the minimum value for the best estimate of a pool fire, for the ASLB's postulated scenario, is 1.6 per 100 thousand reactor-years. This estimate did not account for acts of malice, degraded standards of plant operation, or gross errors in design, construction or operation. The NRC Staff estimated, for the same scenario, that the probability of a pool fire is on the order of 2 per 10 million reactor-years. The ASLB accepted the Staff's estimate, thereby concluding that, for the particular configuration of the Harris plant, the postulated scenario is "remote and speculative"; the

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[44] ASLB, 2000.
[45] Thompson, 2000.
[46] Parry et al, 2000.
[47] ERIN, 2000.

ASLB then terminated the proceeding without conducting an evidentiary hearing.[48] Elsewhere, the author has described deficiencies in the ASLB's ruling.[49]

A major reason for the difference in the probability estimates proffered by Orange County and the NRC Staff was their differing assessments of the spread of radioactive material from the reactor containment building to the separate, adjacent pool building. However, the Staff agreed with Orange County on some other matters. For example, the Staff reversed its previous position that comparatively long-discharged fuel will not ignite in the event of water loss from a high-density pool. Staff members stated that loss of water from pools containing fuel aged less than 5 years "would almost certainly result in an exothermic reaction", and also stated: "Precisely how old the fuel has to be to prevent a fire is still not resolved."[50] Moreover, the Staff assumed that a fire would be inevitable if the water level fell to the top of the racks.

Most importantly for present purposes, the technical submissions of all three parties agreed that the onset of a pool fire in two of the pools in the Harris pool building would preclude the provision of cooling and water makeup to the other two pools. This effect would arise from the spread of hot gases and radioactive material throughout the pool building, which would preclude access by operating personnel. Thus, the pools not involved in the initial fire would boil and dry out, and their fuel would burn.

The Pilgrim and Vermont Yankee plants have a different configuration than the Harris plant, because at Pilgrim and Vermont Yankee the reactor and the pool are within the same building whereas at Harris they are in different buildings. Thus, the Pilgrim and Vermont Yankee plants are analogous to the Harris pool building. Given an early release from the Pilgrim or Vermont Yankee reactor as part of a core-melt accident, hot gases and radioactive material from the reactor would spread throughout the building that encloses both. Provision of cooling and water makeup to the pool would be precluded, the radiation field and the thermal environment being even more extreme than in the Harris situation. The pool would boil and dry out, and its fuel would burn.

Thus, the three parties' agreement in the Harris proceeding implies their agreement that a pool fire would inevitably follow an early release as part of a core-melt accident at Pilgrim or Vermont Yankee. Against that background, this report's assumption of a conditional probability of 50 percent for a pool fire, given an early release, is reasonable.

7. Initiation of a Pool Fire by Malicious Action

The NRC's August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575) considered potential sabotage events at a spent-fuel pool.[51] Table 7-1 describes the postulated events, which encompassed the detonation of

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[48] ASLB, 2001.
[49] Thompson, 2001b.
[50] Parry et al, 2000, paragraph 29.
[51] NRC, 1979, Section 5 and Appendix J.

explosive charges in the pool, breaching of the walls of the pool building and the pool floor by explosive charges or other means, and takeover of the central control room for one half-hour. Involvement of up to 80 adversaries was implied.

NUREG-0575 did not, however, recognize the potential for an attack with these attributes to cause a fire in the pool.[52] Technically-informed attackers operating within this envelope of attributes could cause a fire in a pool at Pilgrim, Vermont Yankee or other plants. Informed attackers could use explosives, and their command of the control room for one half-hour, to drain water from the pool and release radioactive material from the reactor.[53] The radiation field from the reactor release would preclude personnel access, thus precluding recovery actions if command of the plant were returned to the operators after one half-hour.

The potential for a maliciously-induced pool fire at Pilgrim or Vermont Yankee is influenced by several factors. Here, the following factors are considered: (i) the present level of protection of nuclear power plants and spent fuel; (ii) options for providing greater protection; (iii) available means of attack; and (iv) motives for attack. In the context of an EIS, the first, third and fourth of these factors relate to the probability of a successful attack, and the second factor relates to alternatives.

The present level of protection of nuclear power plants and spent fuel

Site-security measures mandated by the NRC have made access to a nuclear power plant more difficult for attackers approaching on foot or by land vehicle than was the case in 1979.[54] Nevertheless, as discussed below, a successful attack could be mounted today using resources of the scale assumed in NUREG-0575 or employed to attack the United States on 11 September 2001. In light of information now available, the NRC could prepare a supplement to NUREG-0575 that updates its sabotage analysis. This supplement could employ a classified appendix to prevent public disclosure of sensitive information.

The consideration of sabotage events in NUREG-0575 is an exception. As a general rule, the NRC does not consider malicious acts in the context of license proceedings or environmental impact statements. The NRC's policy on this matter is illustrated by a September 1982 ruling by the Atomic Safety and Licensing Board in the operating-license proceeding for the Harris nuclear power plant. An intervenor, Wells Eddleman, had proffered a contention alleging, in part, that the plant's safety analysis was deficient because it did not consider the "consequences of terrorists commandeering a very large airplane.....and diving it into the containment." In rejecting this contention the ASLB stated:[55]

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[52] The sabotage events postulated in NUREG-0575 yielded comparatively small radioactive releases.
[53] In some areas of the Pilgrim or Vermont Yankee reactor building, one explosive charge could potentially breach the pool wall, the reactor containment, and the reactor vessel.
[54] NRC, 2004; Thompson, 2004.
[55] ASLB, 1982.

> This part of the contention is barred by 10 CFR 50.13. This rule must be read *in pari materia* with 10 CFR 73.1(a)(1), which describes the "design basis threat" against which commercial power reactors *are* required to be protected. Under that provision, a plant's security plan must be designed to cope with a violent external assault by "several persons," equipped with light, portable weapons, such as hand-held automatic weapons, explosives, incapacitating agents, and the like. Read in the light of section 73.1, the principal thrust of section 50.13 is that military style attacks with heavier weapons are not a part of the design basis threat for commercial reactors. Reactors could not be effectively protected against such attacks without turning them into virtually impregnable fortresses at much higher cost. Thus Applicants are not required to design against such things as artillery bombardments, missiles with nuclear warheads, or kamikaze dives by large airplanes, despite the fact that such attacks would damage and may well destroy a commercial reactor.

As indicated by the ASLB, the NRC's basic policy on protecting nuclear facilities from attack is laid down in the regulation 10 CFR 50.13. This regulation was promulgated in September 1967 by the US Atomic Energy Commission (AEC) – which preceded the NRC – and was upheld by the US Court of Appeals in August 1968. It states:[56]

> An applicant for a license to construct and operate a production or utilization facility, or for an amendment to such license, is not required to provide for design features or other measures for the specific purpose of protection against the effects of (a) attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, whether a foreign government or other person, or (b) use or deployment of weapons incident to US defense activities.

Pursuant to 10 CFR 50.13, licensees are not required to design or operate nuclear facilities to resist enemy attack. However, events have obliged the NRC to progressively modify this position, so as to require greater protection against malicious or insane acts by sub-national groups. A series of events, including the 1993 bombing of the World Trade Center in New York, persuaded the NRC to introduce, in 1994, regulations requiring licensees to defend nuclear power plants against vehicle bombs. The attacks of 11 September 2001 led the NRC to require additional measures.

The NRC requires its licensees to defend against a design basis threat (DBT), a postulated attack that has become more severe over time. The present DBT was promulgated in April 2003. Prior to February 2002 the DBT was published, but not thereafter. The NRC has described the present DBT for nuclear power plants as follows:[57]

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[56] Federal Register, Vol. 32, 26 September 1967, page 13445.
[57] NRC Press Release No. 03-053, 29 April 2003.

> The Order that imposes revisions to the Design Basis Threat requires power plants to implement additional protective actions to protect against sabotage by terrorists and other adversaries. The details of the design basis threat are safeguards information pursuant to Section 147 of the Atomic Energy Act and will not be released to the public. This Order builds on the changes made by the Commission's February 25, 2002 Order. The Commission believes that this DBT represents the largest reasonable threat against which a regulated private security force should be expected to defend under existing law. It was arrived at after extensive deliberation and interaction with cleared stakeholders from other Federal agencies, State governments and industry.

From this statement, and from other published information, it is evident that the NRC requires a comparatively light defense for nuclear power plants and their spent fuel. The scope of the defense does not reflect a full spectrum of threats. Instead, it reflects a consensus about the level of threat that licensees can "reasonably" be expected to resist.[58]

A rationale for the present level of protection of nuclear facilities was articulated by the NRC chair, Richard Meserve, in 2002:[59]

> If we allow terrorist threats to determine what we build and what we operate, we will retreat into the past – back to an era without suspension bridges, harbor tunnels, stadiums, or hydroelectric dams, let alone skyscrapers, liquid-natural-gas terminals, chemical factories, or nuclear power plants. We cannot eliminate the terrorists' targets, but instead we must eliminate the terrorists themselves. A strategy of risk avoidance – the elimination of the threat by the elimination of potential targets – does not reflect a sound response.

Options for providing greater protection

Chairman Meserve's statement does not consider another approach – designing new infrastructure elements or modifying existing elements so that they are more robust against attack. It has been known for decades that nuclear power plants could be designed to be more robust against attack. For example, in the early 1980s the reactor vendor ASEA-Atom developed a preliminary design for an "intrinsically safe" commercial reactor known as the PIUS reactor. Passive-safety design principles were used. The design basis for the PIUS reactor included events such as equipment failures, operator errors and earthquakes, but also included: (i) takeover of the plant for one operating shift by knowledgeable saboteurs equipped with large amounts of explosives; (ii) aerial bombardment with 1,000-pound bombs; and (iii) abandonment of the plant by the operators for one week.[60]

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[58] Fertel, 2006; Wells, 2006; Brian, 2006.
[59] Meserve, 2002, page 22.
[60] Hannerz, 1983.

As explained in Section 8, below, the spent-fuel pools at the Pilgrim and Vermont Yankee plants would be more robust against attack if they were re-equipped with low-density, open-frame storage racks. This step would restore the pools to their original design configuration.

Available means of attack

In considering the potential for a future attack on the Pilgrim or Vermont Yankee spent-fuel pool, it is necessary to consider both means and motives. Table 7-2 provides some general information about means. This table shows that nuclear power plants are vulnerable to attack by means available to sub-national groups. For example, one of the potential instruments of attack shown in Table 7-2 is an explosive-laden smaller aircraft. In this connection, note that the US General Accounting Office (GAO) expressed concern, in September 2003 testimony to Congress, about the potential for malicious use of general-aviation aircraft. The testimony stated:[61]

> Since September 2001, TSA [the Transportation Security Administration] has taken limited action to improve general aviation security, leaving it far more open and potentially vulnerable than commercial aviation. General aviation is vulnerable because general aviation pilots are not screened before takeoff and the contents of general aviation planes are not screened at any point. General aviation includes more than 200,000 privately owned airplanes, which are located in every state at more than 19,000 airports. Over 550 of these airports also provide commercial service. In the last 5 years, about 70 aircraft have been stolen from general aviation airports, indicating a potential weakness that could be exploited by terrorists.

Sub-national groups could obtain explosive devices that would be effective instruments of attack on a nuclear power plant. [62] Assistance from a government or access to classified information would not be required. Designs for sophisticated explosive devices capable of exploiting the vulnerabilities of the Pilgrim or Vermont Yankee spent-fuel pools are publicly available from sources including the web. Means for delivery of such devices to the target are also readily available. [63]

Motives for attack

Understanding the factors that could motivate a sub-national group to attack a civilian nuclear facility in the USA is a difficult task. Multiple, competing factors will be in play, and will affect different groups in different ways. An attacking group might be foreign, as was the case in New York and Washington in September 2001, or domestic, as was the case in Oklahoma City in April 1995 and London in July 2005. As we try to understand

[61] Dillingham, 2003, page 14.
[62] Walters, 2003.
[63] For example: Raytheon, 2004; the website www.aircraftdealer.com, accessed 6 November 2004.

the complex issue of motives, one requirement is clear. We must set aside our own perspectives, and attempt to understand the perspectives of those who might attack us. That understanding will help us to assess risks and prepare countermeasures.

One insight from experience is that an attack by a sub-national group could be part of an action-reaction cycle.[64] Former CIA Director Stansfield Turner has recounted how the October 1983 truck bombing of a US Marine barracks in Beirut was part of such a cycle.[65] A high-level task force convened by the Council on Foreign Relations recognized the potential for an action-reaction effect in the context of US military operations with counterterrorism objectives. They recommended that this effect be offset by greater protection of domestic targets. An October 2002 report of the task force stated:[66]

> *Homeland security measures have deterrence value*:
> US counterterrorism initiatives abroad can be reinforced by making the US homeland a less tempting target. We can transform the calculations of would-be terrorists by elevating the risk that (1) an attack on the United States will fail, and (2) the disruptive consequences of a successful attack will be minimal. It is especially critical that we bolster this deterrent now since an inevitable consequence of the US government's stepped-up military and diplomatic exertions will be to elevate the incentive to strike back before these efforts have their desired effect.

Probability of attack

For policy and planning purposes, it would be useful to have an estimate of the probability of an attack-induced spent-fuel-pool fire. The record of experience does not allow a statistically valid estimate of this probability. A decision maker or risk analyst must, therefore, rely on prudent judgment.[67] In the case of an attack-induced spent-fuel-pool fire in the USA, prudent judgment indicates that a probability of at least one per century is a reasonable assumption for policy purposes.

8. Options to Reduce the Risks of Pool Fires

Various options are available to reduce the probability and/or magnitude of an atmospheric release from a spent-fuel-pool fire at Pilgrim or Vermont Yankee. A useful option must achieve one or more of the following five effects: (i) reduce the probability of a loss of water; (ii) reduce the potential for ignition of fuel following a loss of water; (iii) reduce the potential for fire propagation following ignition of one or more fuel

[64] Davis, 2006.
[65] Turner, 1991.
[66] Hart et al, 2002, pp 14-15.
[67] The NRC has used qualitative judgment about the probability of attack as a basis for the 1994 vehicle-bomb rule and the present design basis threat.

assemblies; (iv) reduce the inventory of spent fuel in the pool; or (v) suppress a fire in the pool.

The fifth effect – fire suppression – would be extremely difficult to achieve. Spraying water on a fire could feed a zirconium-steam reaction. In principle, an air-zirconium reaction in the pool could be smothered, perhaps by spreading large amounts of a non-reactive powder. In practice, the high radiation field surrounding the pool would preclude the approach of firefighters. Here, the focus is on the first four effects.

Table 8-1 describes selected risk-reducing options that could, to some degree, achieve one or more of the first four effects. This table does not purport to identify a comprehensive set of risk-reducing options, or to provide a complete assessment of the listed options. Instead, this table illustrates the range of options and their properties.

The option that would achieve the largest risk reduction, during plant operation within a license extension period, would be to re-equip the pool with low-density, open-frame storage racks. Implementation of this option would return the plant to its original design configuration. Excess spent fuel would be placed in dry storage at the plant site. This option would not reduce the probability of a loss of water. Instead, it would allow the pool to survive a loss of water without damage to the fuel. It would prevent ignition of fuel in almost all scenarios of water loss. For the few, unlikely scenarios that would remain, it would inhibit fire propagation across the pool. By reducing the inventory of radioactive material in the pool, this option would limit the magnitude of the greatest possible release.

Re-equipping a spent-fuel pool with low-density, open-frame racks would be an entirely passive measure of risk reduction. Successful functioning of this option would not require electricity, a water supply, the presence of personnel, or any other active function. Passive risk-reduction measures of this type represent good practice in nuclear engineering design. Reactor vendors are seeking to use passive-safety principles in the design of new commercial reactors.

Nuclear power plants are important elements of the nation's critical infrastructure. Other elements of that infrastructure also offer opportunities to use passive measures of risk reduction. Passive measures can be highly reliable and predictable in their effectiveness. They can substitute for other measures to protect critical infrastructure, as shown in Table 8-2, yielding monetary and non-monetary benefits.

Table 8-3 provides an estimated cost for offloading spent fuel from the Pilgrim or Vermont Yankee pool, to allow the pool to be re-equipped with low-density, open-frame racks. There would be an additional, smaller cost for replacing the racks, which is neglected here. Note that Table 8-3 does not purport to provide a definitive specification for re-equipment of the pools, or a final estimate of the cost of this option. The analysis presented in Table 8-3 is illustrative. A more sophisticated analysis would not alter the basic findings of this report.

From Table 8-3 one sees that the estimated cost of a transition to low-density, open-frame racks would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee. Approximately the same cost would otherwise be incurred during decommissioning of the plant, when spent fuel would be offloaded from the pool to dry storage. The net additional cost of the option would reflect the comparative present values of approximately equal expenditures now or two decades in the future.

9. An Integrated View of Risks and Risk-Reducing Options

Preceding sections of this report have discussed particular aspects of the risks and risk-reducing options associated with pool storage of spent nuclear fuel. To produce useful policy findings, these separate discussions must be integrated.

Section 6 of this report provides, in Tables 6-1 and 6-2, licensee estimates of the probability of an early release as part of a severe reactor accident – of non-malicious origin – at Pilgrim or Vermont Yankee. Also, Section 6 develops the reasonable assumption that the conditional probability of a spent-fuel-pool fire, given an early release from the reactor, is 50 percent. Section 7 sets forth a judgment that the probability of a successful, attack-induced spent-fuel-pool fire in the USA can be assumed, for policy purposes, to be at least one per century. Section 8 provides an estimate that the cost of a transition to low-density, open-frame racks in a spent-fuel pool would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee.

Table 9-1 combines the findings of Sections 6 and 7, yielding an estimate that the total probability of a pool fire at Pilgrim or Vermont Yankee is 1.2 per 10,000 years at each plant. A number of simplifying assumptions are employed in Table 9-1, as is evident from the table. A more sophisticated analysis would not alter the general findings of this report.

Entergy's Environmental Reports for Pilgrim and Vermont Yankee present a cost-versus-benefit analysis as a means of evaluating Severe Accident Mitigation Alternatives. Table 9-2 illustrates this type of analysis. The table shows that an investment of $110-200 million (depending on discount rate) is justified to prevent a radioactive release with a probability of one per 10,000 years and a consequence cost of $100 billion.

A companion report by Dr. Jan Beyea shows that the consequence cost attributable to a spent-fuel-pool fire at Pilgrim or Vermont Yankee would exceed $100 billion across a range of release scenarios.[68] This report estimates that the probability of a pool fire at Pilgrim or Vermont Yankee is more than one per 10,000 years at each plant. Re-equipping the Pilgrim or Vermont Yankee pool with low-density, open-frame racks would substantially reduce the probability of a pool fire and the magnitude of its

[68] The findings in Dr. Beyea's companion report are consistent with previous analysis provided in: Beyea et al, 2004.

consequences. To a first-order approximation, re-equipping a pool in this manner would eliminate the risk of a pool fire. The cost of re-equipping a pool would be less than $110 million. Thus, a SAMA-type analysis shows that re-equipping both pools with low-density, open-frame racks is justified.

The analysis underlying this conclusion does not purport to be comprehensive. This analysis is, however, sufficient to show that Entergy and the NRC are obliged to perform new studies, as described in Section 10, below.

Probabilistic analysis, of the type that is used in Table 9-1 and in Entergy's Environmental Reports, should not be the only means of evaluating Severe Accident Mitigation Alternatives. People who are unfamiliar with probabilistic risk assessment may place unwarranted faith in the numerical values that it generates. A closer look at probabilistic risk assessment for nuclear power plants shows that its findings are plagued by incompleteness and uncertainty.[69] These findings cannot substitute for prudent, informed judgment. In exercising that judgment, decision makers should be aware of strategic considerations, such as those addressed in Table 8-2.

10. Analysis Required From Entergy and the Nuclear Regulatory Commission

Entergy's Environmental Reports for the Pilgrim and Vermont Yankee plants do not examine the potential for a radioactive release from a fire in a spent-fuel pool. Nor do they consider SAMA-type options that could reduce the probability and/or magnitude of such a release. Similarly, the NRC does not consider such options in its GEIS for re-licensing of nuclear power plants.

Yet, the NRC has determined that the potential for a reactor core-melt accident must be considered in a re-licensing EIS. Moreover, a spent-fuel-pool fire at Pilgrim or Vermont Yankee has, according to this report, a probability comparable to the probability of a reactor core-melt accident. Finally, the offsite radiological impact of the pool fire could be substantially greater than the impact of the core-melt accident, because the pool has a larger inventory of cesium-137. Therefore, the potential for a pool fire should be considered in an Environmental Report or EIS for re-licensing. Such studies should use at least the depth of analysis that is employed to consider the potential for a core-melt accident.

Entergy should withdraw, revise and re-submit its Environmental Reports. In addressing the potential for pool fires, each revised ER should consider the full range of potential initiating events, including acts of malice. Options for reducing the risks of pool fires should be considered to at least the depth of analysis that is employed for SAMAs in the context of reactor accidents.

[69] Hirsch et al, 1989.

The NRC should prepare generic supplements to its August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and its May 1996 GEIS on license renewal (NUREG-1437). These supplements should address the risks of spent-fuel-pool fires to at least the depth of analysis and experiment that was conducted to prepare the NRC's December 1990 study on the risks of reactor accidents (NUREG-1150).[70] In addition, the supplements should identify a range of options to reduce the risks of pool fires, and should comprehensively assess the benefits and costs of these options. An EIS prepared for re-licensing of Pilgrim or Vermont Yankee should incorporate the findings of the new, generic supplements to NUREG-0575 and NUREG-1437.

11. Conclusions

Discussions in preceding sections of this report lead to the following major conclusions:

C1. At the Pilgrim and Vermont Yankee plants, large amounts of spent nuclear fuel are stored in water-filled pools equipped with high-density, closed-form storage racks. Entergy plans to continue this practice during the period of license extension, operating the pools at near to full capacity.

C2. The radioactive isotope cesium-137 provides a useful indicator of the hazard potential of the Pilgrim and Vermont Yankee spent-fuel pools. During the period of license extension, it is likely that these pools will hold about 1.6 million TBq (Pilgrim) and 1.4 million TBq (Vermont Yankee) of cesium-137. Each pool will hold about 8 times as much cesium-137 as will be present in the adjacent reactor.

C3. Various studies by the NRC and other bodies have shown that loss of water from a spent-fuel pool equipped with high-density, closed-form storage racks would, over a range of scenarios, lead to self-ignition of some of the fuel assemblies in the pool, leading to a fire that could propagate across the pool. Burning of fuel assemblies would lead to a large atmospheric release of cesium-137 and other radioactive isotopes. These findings have been confirmed by a 2005 report prepared by the National Academy of Sciences at the request of the US Congress.

C4. Entergy has submitted an Environmental Report (ER) as part of each license extension application. Each ER examines potential reactor accidents involving damage to the reactor core and release of radioactive material to the atmosphere. That examination supports the ER's evaluation of Severe Accident Mitigation Alternatives (SAMAs) – options that could reduce the probability and/or magnitude of a radioactive release from the reactor. Neither ER examines the potential for a radioactive release from a fire in a spent-fuel pool, or considers SAMA-type options that could reduce the probability and/or magnitude of such a release.

[70] NRC, 1990b.

C5. The NRC has published various documents that discuss aspects of the potential for a spent-fuel-pool fire. Only three of these documents are products of processes that provided an opportunity for formally structured public comment and, potentially, for in-depth analysis of risks and alternatives. One document is the August 1979 Generic Environmental Impact Statement (GEIS) on handling and storage of spent fuel (NUREG-0575). The second document is the May 1996 GEIS on license renewal (NUREG-1437). These two documents purported to provide systematic analysis of the risks and relative costs and benefits of alternative options. The third document is a September 1990 review (55 FR 38474) of the NRC's Waste Confidence Decision. That document did not purport to provide an analysis of risks and alternatives. None of the three documents provides a technically defensible examination of spent-fuel-pool fires and the associated risks and alternatives. The findings in each document are inconsistent with the more recent and more credible findings of the National Academy of Sciences, set forth in its 2005 report, and the findings of other studies conducted since 1996.

C6. The August 1979 GEIS (NUREG-0575) considered potential sabotage events at a spent-fuel pool. The GEIS did not recognize the potential for an attack with the postulated attributes to cause a fire in the pool. Technically-informed attackers operating within this envelope of attributes could, with high confidence, cause an unstoppable fire in a pool.

C7. Site-security measures mandated by the NRC have made access to a nuclear power plant more difficult for attackers approaching on foot or by land vehicle than was the case in 1979. Nevertheless, a successful attack could be mounted using resources of the scale assumed in NUREG-0575 or employed to attack the United States on 11 September 2001. The NRC has not prepared any environmental impact statement or comparable study that updates the sabotage analysis set forth in NUREG-0575.

C8. The record of experience does not allow a statistically valid estimate of the probability of an attack-induced spent-fuel-pool fire in the USA. Prudent judgment indicates that a probability of at least one per century is a reasonable assumption for policy purposes. This translates to a probability of one per 10,000 years at Pilgrim or Vermont Yankee, which is comparable to the estimated probability of a reactor core-melt accident according to probabilistic risk studies done for these plants.

C9. Probabilistic risk studies done by licensees for the Pilgrim and Vermont Yankee plants can support an estimate of the probability of a spent-fuel-pool fire that is caused by or accompanies a core-melt accident at the adjacent reactor. The connection between these events is particularly strong at these plants because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. A provisional estimate of the probability of a spent-fuel-pool fire associated with a core-melt accident, not involving malice, is about two per 100,000 years at each plant.

C10. Options are available to reduce the probability and/or magnitude of an atmospheric release from a spent-fuel-pool fire at Pilgrim or Vermont Yankee. The option that would achieve the largest risk reduction, during plant operation within a license extension period, would be to re-equip the pool with low-density, open-frame racks. This step would return the plant to its original design configuration. Excess spent fuel would be placed in dry storage at the plant site. The estimated cost of this option would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee. Approximately the same cost would otherwise be incurred during decommissioning of the plant, when spent fuel would be offloaded from the pool to dry storage. The net additional cost of the option would reflect the comparative present values of approximately equal expenditures now or two decades in the future.

C11. Re-equipping a spent-fuel pool with low-density, open-frame racks would be a passive measure that would eliminate most scenarios for a pool fire and greatly reduce the atmospheric release for the few, unlikely scenarios that would remain. Passive risk-reduction measures of this type represent good practice in nuclear engineering design. Substantial benefits, both monetary and non-monetary, could arise from the deployment of passive risk-reduction measures at nuclear power plants and other elements of critical infrastructure.

C12. Entergy's Environmental Reports present a cost-versus-benefit analysis as a means of evaluating Severe Accident Mitigation Alternatives. This type of analysis should not be the only basis for evaluating SAMAs, but can provide useful information. The analysis shows that an investment of $110-200 million (depending on discount rate) is justified to prevent a radioactive release with a probability of one per 10,000 years and a consequence cost of $100 billion. A companion report by Dr. Jan Beyea shows that the consequence cost attributable to a spent-fuel-pool fire at Pilgrim or Vermont Yankee would exceed $100 billion across a range of release scenarios. Given the pool-fire probability found in this report (at least one per 10,000 years), and the estimated cost of re-equipping the Pilgrim or Vermont Yankee pool with low-density, open-frame racks (less than $110 million), re-equipment of both pools in this manner is justified.

C13. The NRC has determined that the potential for a reactor core-melt accident must be considered in an environmental impact statement for the re-licensing of a nuclear power plant. Thus, the NRC has determined that such an accident is neither remote nor speculative. A spent-fuel-pool fire at Pilgrim or Vermont Yankee has, by estimation in this report, a probability comparable to the probability of a reactor core-melt accident. The offsite radiological impact of the pool fire could be substantially greater than the impact of the core-melt accident. Therefore, the potential for a pool fire should be considered in a re-licensing EIS to at least the depth accorded the consideration of a core-melt accident.

C14. Entergy should withdraw, revise and re-submit its Environmental Reports for Pilgrim and Vermont Yankee. The revised ERs should address the potential for pool fires to at least the depth of analysis that is employed for reactor accidents. The pool-fire analysis should consider the full range of potential initiating events, including acts of malice. Options for reducing the risks of pool fires should be considered to at least the depth of analysis that is employed for SAMAs in the context of reactor accidents.

C15. The NRC should prepare supplements to its August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and its May 1996 GEIS on license renewal (NUREG-1437). These supplements should address the risks of spent-fuel-pool fires to at least the depth of analysis and experiment that was conducted to prepare the NRC's December 1990 study on the risks of reactor accidents (NUREG-1150). Acts of malice should be considered. In addition, the supplements should identify a range of options to reduce the risks of pool fires, and should comprehensively assess the benefits and costs of these options.

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Table 3-1
Selected Characteristics of the Pilgrim and Vermont Yankee Plants

Characteristic	Pilgrim	Vermont Yankee
Reactor type	BWR Mark 3	BWR Mark 4
Containment type	Mark 1: Drywell and free-standing torus	Mark 1: Drywell and free-standing torus
Rated power	2,028 MWt	1,593 MWt; application pending for 20% uprate to 1,912 MWt
Number of fuel assemblies in reactor core	580	368
Date of first commercial operation	December 1972	November 1972
Date of expiration of present operating license	June 2012	March 2012
Heat sink	Ocean	Connecticut River and/or cooling towers
Inventory of cesium-137 in reactor core	1.90E+17 Bq (Assumed power: 2,028 MWt)	1.79E+17 Bq (Assumed power: 1,912 MWt)

Sources:
(a) Jay R. Larson, *System Analysis Handbook, NUREG/CR-4041*, USNRC, November 1985.
(b) License renewal application, Appendix E (for each plant).

Table 3-2
Selected Characteristics of the Spent-Fuel Pools at the Pilgrim and Vermont Yankee Plants

Characteristic	Pilgrim	Vermont Yankee
Licensed capacity	3,859 fuel assemblies	• In 1988: 2,870 fuel assemblies; unused floor space could hold racks with potential additional capacity of about 360 assemblies • At present: 3,355 fuel assemblies, incl. temporary, 266-cell rack in cask position
Inventory at end of 2002	2,274 fuel assemblies	2,671 fuel assemblies
Capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Floor dimensions	40 ft 4 in by 30 ft 6 in; 5 ft 8 in thick	40 ft 0 in by 26 ft 0 in; 5 ft 0 in thick including 11 in of grout
Depth	38 ft 9 in	38 ft 9 in
Wall thicknesses	Reactor shield wall forms one face; thicknesses of other walls range from 4 ft 1 in to 6 ft 1 in.	Reactor shield wall forms one face; thicknesses of other walls range from 4 ft 6 in to 6 ft 0 in.
Typical spent fuel assembly	General Electric 8x8; 210 kgU per assembly	General Electric 8x8; 210 kgU per assembly

Sources:
(a) USNRC documentation of Amendment No. 155, Pilgrim operating license.
(b) USNRC documentation of Amendment No. 104, Vermont Yankee operating license.
(c) P. G. Prassinos et al, *Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants, NUREG/CR-5176*, USNRC, January 1989.
(d) Vermont Yankee Nuclear Power Corporation, *Vermont Yankee Spent Fuel Storage Rack Replacement Report*, April 1986.
(e) Holtec International, *Pilgrim Nuclear Power Station Spent Fuel Storage Capacity Expansion*, 5 January 1993.
(f) USNRC, *Generic EIS on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575*, August 1979.
(g) Anthony Andrews, *Spent Nuclear Fuel Storage Locations and Inventory, CRS Report for Congress*, 21 December 2004.
(h) John Hoffman, pre-filed testimony to Vermont Public Service Board on behalf of Entergy Nuclear Vermont Yankee, LLC, 16 June 2005.

Table 3-3
Estimation of Cesium-137 Inventory in a Spent-Fuel Assembly and the Reactor Core, for the Pilgrim and Vermont Yankee Plants

Estimation Step	Pilgrim	Vermont Yankee
Fuel burnup at discharge	B MWt-days per kgU	B MWt-days per kgU
Discharge burnup assuming each fuel assembly has a mass of 210 kgU	210xB MWt-days per assembly	210xB MWt-days per assembly
Reactor characteristics	• Rated power: 2,028 MWt • 580 fuel assemblies	• Rated power: 1,912 MWt • 368 fuel assemblies
Av. rated power per assembly	2,028/580 = 3.50 MWt	1,912/368 = 5.20 MWt
Av. full-power days per assembly	210xB/3.50 = 60.0xB days	210xB/5.20 = 40.4xB days
Av. full-power days per assembly, assuming B = 30	1,800 days = 4.93 yr	1,212 days = 3.32 yr
Av. actual days of exposure per assembly, assuming plant capacity factor = 0.90	2,000 days = 5.48 yr	1,347 days = 3.69 yr
Cesium-137 inventory in av. fuel assembly at completion of exposure	7.24E+14 Bq	7.39E+14 Bq
Approx. core inventory of cesium-137	((7.24E+14)/2)x580 = 2.10E+17 Bq	((7.39E+14)/2)x368 = 1.36E+17 Bq
Core inventory of cesium-137 as reported in Appendix E of license renewal application	1.90E+17 Bq	1.79E+17 Bq

Notes:
Here, calculation of the cesium-137 inventory in an average fuel assembly assumes steady-state fission of uranium-235 with an energy yield of 200 MeV per fission and a cesium-137 fission yield of 6.2 percent, over the actual days of exposure with a constant power level of 0.90 times the rated power level.

Table 3-4
Estimated Future Inventory and Selected Characteristics of Spent Fuel in Pools at the Pilgrim and Vermont Yankee Plants

Estimation Step	Pilgrim	Vermont Yankee
Licensed capacity	3,859 fuel assemblies	3,089 fuel assemblies (Not including temporary, 266-cell rack in cask position)
Capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Assumed periodic offload of older fuel assemblies to onsite dry-storage modules	Offload to fill 3 modules, each of 68-assembly capacity: 204 assemblies	Offload to fill 3 modules, each of 68-assembly capacity: 204 assemblies
Average inventory of spent fuel, assuming pool used at near-full capacity	3,859 – 580 – 204/2 = 3,177 fuel assemblies	3,089 – 368 – 204/2 = 2,619 fuel assemblies
Av. period of exposure of assembly in core, assuming burnup of 30 MWt-days per kgU and plant capacity factor of 0.90	5.48 yr	3.69 yr
Av. age of fuel assemblies after discharge to pool	(3,177/(580/5.48))/2 = 15.0 yr	(2,619/(368/3.69))/2 = 13.1 yr
Cesium-137 in av. fuel assembly at discharge	7.24E+14 Bq	7.39E+14 Bq
Cesium-137 in pool, assuming all assemblies at average age	1.63E+18 Bq (44.1 MCi)	1.43E+18 Bq (38.6 MCi)
Mass of zirconium in pool, assuming 60 kg per fuel assembly	191,000 kg	157,000 kg

Notes:
Data on a General Electric 8x8 fuel assembly are provided in Table G.4 of: USNRC, *Generic EIS on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575*, August 1979. The total mass of an assembly is 275 kg and the mass of uranium is 210 kg. If all non-U mass were Zr, then the mass ratio of Zr to U would be 0.31. For comparison, masses of U and Zr in the core of the Peach Bottom BWR are provided in Table 4.7 of: M. Silberberg et al, *Reassessment of the Technical Bases for Estimating Source Terms, NUREG-0956*, USNRC, July 1986. The U mass is 138 Mg and the Zr mass is 64.1 Mg. Thus, the mass ratio of Zr to U in the core is 0.46. In the table above, it is assumed that each fuel assembly contains 60 kg of Zr, representing a Zr-to-U mass ratio of 0.29.

Table 3-5
Illustrative Inventories of Cesium-137

Case	Inventory of Cesium-137 (TBq)
Produced during detonation of a 10-kilotonne fission weapon	67
Released to atmosphere during Chernobyl reactor accident of 1986	89,000
Released to atmosphere during nuclear-weapon tests, primarily in the 1950s and 1960s (Fallout was non-uniformly distributed across the planet, mostly in the Northern hemisphere.)	740,000
In Pilgrim spent-fuel pool during period of license extension	1,630,000
In Vermont Yankee spent-fuel pool during period of license extension	1,430,000
In Pilgrim reactor core	190,000
In Vermont Yankee reactor core	179,000

Notes:
(a) 1 Tbq = 1.0E+12 Bq = 27.0 Ci
(b) Inventories in the first three rows are from Table 3-2 of: Gordon Thompson, *Reasonably Foreseeable Security Events: Potential threats to options for long-term management of UK radioactive waste*, A report for the UK government's Committee on Radioactive Waste Management, IRSS, 2 November 2005.
(c) Inventories in the fourth and fifth rows are author's estimates set forth in this report.
(d) Inventories in the sixth and seventh rows are from Appendix E of the license renewal application for each plant.

Table 4-1
Estimated Duration of Phases of Implementation of the Yucca Mountain Repository

Phase of Repository Implementation		**Duration of Phase (years)**	
		If Yucca Mountain Total Inventory of Commercial Spent Fuel = 63,000 MgU	**If Yucca Mountain Total Inventory of Commercial Spent Fuel = 105,000 MgU**
Construction phase		5	5
Operation and monitoring phases	Development	22	36
	Emplacement	24-50	38-51
	Monitoring	76-300	62-300
Closure phase		10-17	12-23

Notes:
(a) These estimates are from the Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, pages 8-8 and 2-18.
(b) The Development and Emplacement phases would begin on the same date. Other phases would be sequential.
(c) The Construction phase would begin with issuance of construction authorization, and end with issuance of a license to receive and dispose of radioactive waste.

Table 4-2
Potential Emplacement Area of the Yucca Mountain Repository for Differing Spent-Fuel Inventories and Operating Modes

Total Inventory of Commercial Spent Fuel in Repository (MgU)	Emplacement Area (acres)	
	Higher-Temperature Operating Mode	Lower-Temperature Operating Modes
63,000	1,150	1,600 to 2,570
105,000	1,790	2,480 to 3,810

Source: Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, page 8-9.

Table 4-3
Estimated Number of Radioactive-Waste Shipments to the Yucca Mountain Site

Category of Radioactive Waste	Total Number of Shipments			
	If Yucca Mountain Total Inventory of Commercial Spent Fuel = 63,000 MgU		If Yucca Mountain Total Inventory of Commercial Spent Fuel = 105,000 MgU	
	By Truck	By Rail	By Truck	By Rail
** *If shipment mostly by truck* **				
Commercial spent fuel	41,000	0	80,000	0
All wastes	53,000	300	109,000 to 110,000	300 to 360
** *If shipment mostly by rail* **				
Commercial spent fuel	1,100	7,200	3,100	13,000
All wastes	1,100	9,700	3,100	18,000 to 19,000

Source: Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, page 8-8.

Table 4-4
Characteristics of BWR-Spent-Fuel Storage Canisters or Disposal Packages Proposed for Use at the Monticello or Skull Valley ISFSIs, or at Yucca Mountain

Category	Characteristics of Storage Canister or Disposal Package		
	NUHOMS 61BT Storage Canister (proposed for Monticello ISFSI)	**HI-STORM 100 MPC-68 Storage Canister (proposed for Skull Valley)**	**Proposed Disposal Package for Emplacement in Yucca Mountain**
Vendor	Transnuclear West	Holtec	Unknown
Capacity (number of BWR fuel assemblies)	61	68	24 or 44
Wall thickness	0.5 in. (stainless steel)	0.5 in. (stainless steel)	2.0 in. (stainless steel) plus 0.8 in. outer layer (Alloy 22)
Length	196.0 in.	190.3 in.	201.0 in. (for 24 assemblies) or 203.3 in. (for 44 assemblies)
Diameter	67.2 in.	68.4 in.	51.9 in. (for 24 assemblies) or 65.9 in. (for 44 assemblies)
Neutron absorber material	Boral	Boral	Borated stainless steel
Fill gas	Helium	Helium	Helium
Presence of aluminum thermal shunts to transfer interior heat to wall of vessel ?	No	No	No for 24 assemblies, Yes for 44 assemblies

Notes:
(a) NUHOMS data are from: Xcel Energy's Application to the Minnesota PUC for a Certificate of Need to Establish an ISFSI at the Monticello Generating Plant, 18 January 2005, Section 3.7; and Transnuclear West's FSAR for the Standardized NUHOMS system, Revision 6, non-proprietary version, October 2001.
(b) HI-STORM data are from Holtec's FSAR for the HI-STORM 100 system, Holtec Report HI-2002444, Revision 1.
(c) Characteristics of the Yucca Mountain package are from the Yucca Mountain Science and Engineering Report, DOE/RW-0539, May 2001, Section 3.

Table 5-1
Estimated Source Term for Atmospheric Release from Spent-Fuel-Pool Fire at the Pilgrim or Vermont Yankee Plant

Indicator	Pilgrim	Vermont Yankee
	*** Large Release ***	
Release to atmosphere of 100% of cesium-137 in pool	1.63E+18 Bq	1.43E+18 Bq
Thermal power of fire, assuming oxidation of 100% of Zr over 5 hrs	191,000x12.1/(5x60x60) = 128 MW	157,000x12.1/(5x60x60) = 106 MW
	*** Smaller Release ***	
Release to atmosphere of 10% of cesium-137 in pool	1.63E+17 Bq	1.43E+17 Bq
Thermal power of fire, assuming oxidation of 10% of Zr over 0.5 hrs	19,100x12.1/(0.5x60x60) = 128 MW	15,700x12.1/(0.5x60x60) = 106 MW

Notes:
(a) Pool inventories of cesium-137 and zirconium are from Table 3-4.
(b) The heat of reaction of Zr with oxygen or water is provided in Table 3-1 of: Louis Baker Jr. and Robert C. Liimatainen, "Chemical Reactions", Chapter 17 in T. J. Thompson and J. G. Beckerley (editors), *The Technology of Nuclear Reactor Safety*, MIT Press, 1973. The heat of reaction with oxygen is 12.1 MJ/kg, and the heat of reaction with water (steam) is 6.53 MJ/kg. In the table above, it is assumed that Zr reacts with air (oxygen).

Table 6-1
Licensee Estimates of Core Damage Frequency and Radioactive Release Frequency, Pilgrim Plant

Indicator	Source of Estimate	Estimated Frequency	Est. Frequency Adjusted (by factor of 6) to Account for External Events & Uncertainty
Core damage freq. (internal events)	License renewal application, App. E	6.4E-06 per yr	3.8E-05 per yr
Core damage frequency (fires)	License renewal application, App. E	1.9E-05 per yr	Not relevant
Core damage freq. (earthquakes)	License renewal application, App. E	3.2E-05 per yr	Not relevant
Large, early release frequency (internal events)	License renewal application, App. E	1.1E-07 per yr	6.8E-07 per yr
Medium, early release frequency (internal events)	License renewal application, App. E	6.5E-08 per yr	3.9E-07 per yr
Core damage frequency (internal events)	IPE, September 1992	5.8E-05 per yr	This adjustment not used in this source
Core damage frequency (fires)	IPEEE, July 1994	2.2E-05 per yr	Not relevant
Core damage frequency (earthquakes)	IPEEE, July 1994	5.8E-05 per yr (EPRI) 9.4E-05 per yr (LLNL)	Not relevant
Early release frequency (internal events)	IPE, September 1992	1.3E-05 per yr	This adjustment not used in this source
Early release frequency (earthquakes)	IPEEE, July 1994	1.6E-05 per yr (EPRI) 3.2E-05 per yr (LLNL)	Not relevant

Table 6-2
Licensee Estimates of Core Damage Frequency and Radioactive Release Frequency, Vermont Yankee Plant

Indicator	Source of Estimate	Estimated Frequency	Est. Frequency Adjusted (by factor of 10) to Account for External Events & Uncertainty
Core damage frequency (internal events)	License renewal application, App. E	5.0E-06 per yr	5.0E-05 per yr
Core damage frequency (fires)	License renewal application, App. E	5.6E-05 per yr	Not relevant
Core damage frequency (earthquakes)	License renewal application, App. E	Not estimated in this source or in IPEEE of June 1998	Not relevant
Large, early release frequency (internal events)	License renewal application, App. E	1.6E-06 per yr	1.6E-05 per yr
Medium, early release frequency (internal events)	License renewal application, App. E	2.1E-06 per yr	2.1E-05 per yr
Core damage frequency (internal events except intl. floods)	IPE, December 1993	4.3E-06 per yr	This adjustment not used in this source
Core damage frequency (internal floods)	IPEEE, June 1998	9.0E-06 per yr	Not relevant
Core damage frequency (fires)	IPEEE, June 1998	3.8E-05 per yr	Not relevant
Large, early release frequency (internal events except intl. floods)	IPE, December 1993	9.4E-07 per yr	This adjustment not used in this source
Medium, early release frequency (internal events except intl. floods)	IPE, December 1993	8.0E-07 per yr	This adjustment not used in this source

Table 6-3
Categories of Release to Atmosphere by Core-Damage Accidents at Pilgrim and Vermont Yankee Nuclear Plants

Release Magnitude		Release Timing	
Category	**Release of Cesium from Reactor Core to Atmosphere**	**Category**	**Timing of Release Initiation After Accident Begins**
High	Greater than 10%	Early	Less than 6 hrs
Medium	1% to 10%		
Low	0.1% to 1%	Intermediate	6 hrs to 24 hrs
Low-Low	0.001% to 0.1%		
Negligible	Less than 0.001%	Late	Greater than 24 hrs

Notes:
These release categories are set forth in Appendix E of the license renewal application for Vermont Yankee. In the license renewal application for Pilgrim, the same categories are used except that: (i) the Early and Intermediate categories shown in the table above are combined into one category designated as 'Early'; and (ii) the Low and Low-Low categories are combined into one category designated as 'Low'.

Table 7-1
Potential Sabotage Events at a Spent-Fuel-Storage Pool, as Postulated in the NRC's August 1979 GEIS on Handling and Storage of Spent LWR Fuel

Event Designator	General Description of Event	Additional Details
Mode 1	• Between 1 and 1,000 fuel assemblies undergo extensive damage by high-explosive charges detonated under water • Adversaries commandeer the central control room and hold it for approx. 0.5 hr to prevent the ventilation fans from being turned off	• One adversary can carry 3 charges, each of which can damage 4 fuel assemblies • Damage to 1,000 assemblies (i.e., by 83 adversaries) is a "worst-case bounding estimate"
Mode 2	• Identical to Mode 1 except that, in addition, an adversary enters the ventilation building and removes or ruptures the HEPA filters	
Mode 3	• Identical to Mode 1 within the pool building except that, in addition, adversaries breach two opposite walls of the building by explosives or other means	• Adversaries enter the central control room or ventilation building and turn off or disable the ventilation fans
Mode 4	• Identical to Mode 1 except that, in addition, adversaries use an additional explosive charge or other means to breach the pool liner and 5-ft-thick concrete floor of the pool	

Notes:
(a) Information in this table is from Appendix J of: USNRC, *Generic EIS on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575*, August 1979.
(b) The postulated fuel damage ruptures the cladding of each rod in an affected fuel assembly, releasing "contained gases" (gap activity) to the pool water, whereupon the released gases bubble to the water surface and enter the air volume above that surface.

Table 7-2
Potential Modes and Instruments of Attack on a Nuclear Power Plant

Mode of Attack	Characteristics	Present Defense
Commando-style attack	• Could involve heavy weapons and sophisticated tactics • Successful attack would require substantial planning and resources	Alarms, fences and lightly-armed guards, with offsite backup
Land-vehicle bomb	• Readily obtainable • Highly destructive if detonated at target	Vehicle barriers at entry points to Protected Area
Anti-tank missile	• Readily obtainable • Highly destructive at point of impact	None if missile launched from offsite
Commercial aircraft	• More difficult to obtain than pre-9/11 • Can destroy larger, softer targets	None
Explosive-laden smaller aircraft	• Readily obtainable • Can destroy smaller, harder targets	None
10-kilotonne nuclear weapon	• Difficult to obtain • Assured destruction if detonated at target	None

Notes:
This table is adapted from a table, supported by analysis and citations, in: Gordon Thompson, *Robust Storage of Spent Nuclear Fuel: A Neglected Issue of Homeland Security*, IRSS, January 2003. Later sources confirming this table include:
(a) Gordon Thompson, testimony before the California Public Utilities Commission regarding Application No. 04-02-026, 13 December 2004.
(b) Jim Wells, US Government Accountability Office, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, 4 April 2006.
(c) Marvin Fertel, Nuclear Energy Institute, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, 4 April 2006.
(d) Danielle Brian, Project on Government Oversight, letter to NRC chair Nils J. Diaz, 22 February 2006.
(e) National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report*, National Academies Press, 2006.

Table 8-1
Selected Options to Reduce Risks of Spent-Fuel-Pool Fires at the Pilgrim and Vermont Yankee Plants

Option	Passive or Active?	Does Option Address Fire Scenarios Arising From:		Comments
		Malice?	Other Events?	
Re-equip pool with low-density, open-frame racks	Passive	Yes	Yes	• Will substantially reduce pool inventory of radioactive material • Will prevent auto-ignition of fuel in almost all cases
Install emergency water sprays above pool	Active	Yes	Yes	• Spray system must be highly robust • Spraying water on overheated fuel can feed Zr-steam reaction
Mix hotter (younger) and colder (older) fuel in pool	Passive	Yes	Yes	• Can delay or prevent auto-ignition in some cases • Will be ineffective if debris or residual water block air flow • Can promote fire propagation to older fuel
Minimize movement of spent-fuel cask over pool	Active	No (Most cases)	Yes	• Can conflict with adoption of low-density, open-frame racks
Deploy air-defense system (e.g., Sentinel and Phalanx) at plant	Active	Yes	No	• Implementation requires presence of US military at plant
Develop enhanced onsite capability for damage control	Active	Yes	Yes	• Requires new equipment, staff and training • Personnel must function in extreme environments

Table 8-2
Selected Approaches to Protecting US Critical Infrastructure From Attack by Sub-National Groups, and Some of the Strengths and Weaknesses of these Approaches

Approach	Strengths	Weaknesses
Offensive military operations internationally	• Can deter or prevent governments from supporting sub-national groups hostile to the USA	• Can promote growth of sub-national groups hostile to the USA, and build sympathy for these groups in foreign populations • Can be costly in terms of lives, money and national reputation
International police cooperation within a legal framework	• Can identify and intercept potential attackers	• Implementation can be slow and/or incomplete • Requires ongoing international cooperation
Surveillance and control of the domestic population	• Can identify and intercept potential attackers	• Can destroy civil liberties, leading to political, social and economic decline of the nation
Active defense of infrastructure elements	• Can stop attackers before they reach the target	• Can involve higher operating costs • Requires ongoing vigilance
Passive defense of infrastructure elements	• Can allow target to survive attack without damage • Can substitute for other approaches, avoiding their costs	• Can involve higher capital costs

Table 8-3
Estimation of Cost to Offload Spent Fuel from Pools at the Pilgrim and Vermont Yankee Plants After 5 Years of Decay

Estimation Step	Pilgrim	Vermont Yankee
Present licensed capacity of pool	3,859 fuel assemblies	3,089 fuel assemblies
Pool capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Anticipated av. pool inventory of spent fuel during period of license extension	3,177 fuel assemblies	2,619 fuel assemblies
Av. period of exposure of fuel assembly in core	5.48 yr	3.69 yr
Av. annual discharge of fuel from reactor	580/5.48 = 106 fuel assemblies	368/3.69 = 100 fuel assemblies
Pool capacity needed to store fuel for 5-yr decay, incl. 10% buffer	106x5x1.1 = 583 fuel assemblies	100x5x1.1 = 550 fuel assemblies
Total pool capacity needed for full-core discharge and 5-yr decay	580 + 583 = 1,163 fuel assemblies	368 + 550 = 918 fuel assemblies
Fuel requiring offload if pool storage is limited to fuel undergoing 5-yr decay	3,177 – 583 = 2,594 fuel assemblies	2,619 – 550 = 2,069 fuel assemblies
Capital cost to offload fuel, assuming 210 kgU per assembly and capital cost of $100-200 per kgU for dry storage	$54-109 million	$43-87 million

Notes:
A capital cost of $100-200 per kgU for dry storage of spent fuel is used by Robert Alvarez et al in their paper in *Science and Global Security*, Volume 11, 2003, pp 1-51.

Table 9-1
Provisional Estimate of the Probability of a Spent-Fuel-Pool Fire at the Pilgrim or Vermont Yankee Plant

Estimation Step	Pilgrim	Vermont Yankee
CDF (internal events)	2.8E-05 per yr	4.3E-06 + 9.0E-06 = 1.3E-05 per yr
CDF (fires + earthquakes)	2.2E-05 + (5.8E-05 + 9.4E-05)/2 = 9.8E-05 per yr	3.8E-05 + (5.8E-05 + 9.4E-05)/2 = 1.1E-04 per yr
CDF (internal events + fires + earthquakes)	1.3E-04 per yr	1.2E-04 per yr
Early release frequency (internal events + fires + earthquakes)	1.3E-05 + (1.3/5.8)x2.2E-05 + (1.6E-05 + 3.2E-05)/2 = 4.2E-05 per yr	1.7E-06 + (1.7/4.3)x(9.0E-06 + 3.8E-05) + (1.6E-05 + 3.2E-05)/2 = 4.4E-05 per yr
Conditional probability of a pool fire, given an early release from the reactor (internal events + fires + earthquakes)	0.5 (Author's assumption)	0.5 (Author's assumption)
Probability of a pool fire initiated by events not including malice	(4.2E-05)x0.5 = 2.1E-05 per yr	(4.4E-05)x0.5 = 2.2E-05 per yr
Probability of a maliciously-induced pool fire in the USA (99 pools)	1 per 100 yr (Author's assumption)	1 per 100 yr (Author's assumption)
Probability of a maliciously-induced pool fire at this plant	1.0E-04 per yr	1.0E-04 per yr
Total probability of a pool fire at this plant	2.1E-05 + 1.0E-04 = 1.2E-04 per yr	2.2E-05 + 1.0E-04 = 1.2E-04 per yr

Notes:
(a) CDF = core damage frequency
(b) Estimates in the first four rows are drawn from the IPEs and IPEEEs for each plant, except that the Pilgrim internal-events CDF is drawn from: Willard Thomas et al, *Pilgrim Technical Evaluation Report on the Individual Plant Examination Front End Analysis*, Science and Engineering Associates, prepared for the USNRC, 9 April 1996. Earthquake findings shown for Pilgrim are the average of the EPRI and LLNL values, and are used for both plants. The conditional probability of an early release, given core damage, is assumed to be the same for events initiated by fires and by internal events including internal flooding.
(c) The probability of a maliciously-induced pool fire in the USA is assumed to be uniformly distributed across all pools.

Table 9-2
Present Value of Cumulative (20-year) Economic Risk of a Potential Release of Radioactive Material

Selected Characteristics of the Potential Release		**Present (Initial) Value of Cumulative (20-year) Economic Risk, for various Discount Rates (D)**		
Economic Cost of the Release	**Probability of the Release**	**D = 7% per yr**	**D = 3% per yr**	**D = 0% per yr**
$100 billion	1.0E-03 per yr	$1.1 billion	$1.5 billion	$2 billion
	1.0E-04 per yr	$110 million	$150 million	$200 million
	1.0E-05 per yr	$11 million	$15 million	$20 million
	1.0E-06 per yr	$1.1 million	$1.5 million	$2 million

Notes:
(a) The discounted cumulative-value function is: (1-exp(-DT))/D, where T = 20.
(b) The present values shown in the table can be scaled linearly for alternative values of the economic cost or probability of the potential release.

Report To The Massachusetts Attorney General On The Potential Consequences Of A Spent-Fuel-Pool Fire At The Pilgrim Or Vermont Yankee Nuclear Plant.

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May 25, 2006

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Personal Background. I am a nuclear physicist who has studied the consequences of both real and hypothetical nuclear accidents, as well as strategies for mitigation. I am a regular member of panels and boards of the National Research Council of the National Academy of Sciences and an advisor to the Division of Engineering and Physical Sciences. After receiving my Ph.D. in nuclear physics from Columbia University, I taught environmental studies at Holy Cross College. Next, I did research at Princeton's Center For Energy and Environmental Studies modeling the consequences of nuclear accidents. I then spent 15 years at the National Audubon Society as Senior Policy Scientist, and ultimately as Chief Scientist and Vice President. Currently, I am senior scientist at Consulting in the Public Interest, providing scientific assistance to not-for-profits, universities, government, and injured plaintiffs.

I am the author of over 100 articles and reports that span a diverse range of topics. I am a regular peer reviewer of articles for scientific journals. One of my specialties is geographic exposure modeling of toxic releases (Beyea and Hatch 1999). My reconstruction of exposures following the TMI accident has been used in radiation epidemiologic studies (Hatch et al. 1990; Hatch et al. 1991). My reconstructions of historical exposures to traffic pollution (Beyea et al.; Beyea et al. 2005) are being used in two ongoing epidemiologic studies of breast cancer (Gammon et al. 2002), (Nie et al. 2005). I am a co-author of studies on risks and consequences of spent-fuel-pool fires (Alvarez et al. 2003a), (Beyea et al. 2004a), (Beyea 1979). I presented a briefing on this work to a committee of the National Research Council that was studying risks of spent fuel.

Introduction I have been asked by the Office of the Attorney General, Commonwealth of Massachusetts, to consider the consequences of releases of radioactivity from spent-fuel-pool fires at the Pilgrim and Vermont Yankee nuclear plants, as part of a relicensing proceeding. In my report I consider important new information on the consequences of releases of radioactivity, in general, and spent-fuel-pool fires, in particular, that was not available to the analysts who prepared earlier documents that are relevant to these proceedings. For example, this new information, which deals with damage costs and radiation risks, was not available prior to the publication of the Environmental Reports for Pilgrim and Vermont Yankee; it was not available prior to the publication of the generic relicensing environmental impact statement (NUREG 1996); and, some of it was not available prior to the filing of Entergy's license renewal application. Consequently, these earlier documents are incomplete from the scientific perspective.

I have addressed the consequences of releases from spent-fuel pools prior to these proceedings (Alvarez et al. 2003a), (Beyea et al. 2004a), (Beyea 1979), in some cases in collaboration with Gordon Thompson, Ph.D., who is filing a separate report in these proceedings. The work we have done has led to a study of the National Research Council[1] and has generated considerable debate and commentary (Alvarez et al. 2003b; Alvarez et al. 2003c; Beyea et al. 2004b)). We have revised our calculations to account for criticisms we thought were valid and easily addressable. In particular, Edwin Lyman, Frank von Hippel and I, in our most recent published work (Beyea et al. 2004a), which forms the backbone of this report on Pilgrim and Vermont Yankee, have specifically responded to criticisms by NRC staff concerning the use of constant population densities around nuclear plants (Alvarez et al. 2003c). In this report, I have addressed additional limitations that raised concerns about our earlier work in some circles. Although critiques of our independent work indicate that there are differences among analysts on the quantity of radioactivity that might be released in a spent-fuel-pool fire and the probability of such releases, there is a consensus among the technical community that this problem needs to be addressed.[2, 3]

For my report, I have considered releases of 10% and 100% of the pool inventory, using methodologies outlined in (Alvarez et al. 2003a) and (Beyea et al. 2004a). I have also provided

1 For a discussion of the relationship between our study and the National Research Council's report (NatRC 2005), see remarks of Kevin Crowley before the Council on Foreign Relations (Crowley 2005).

2 Allan Benjamin, lead author of the original 1979 spent-fuel paper from Sandia Laboratory, was a reviewer of our 2003 paper in SG&S. He provided a public commentary on it, in which he stated, "In summary, the authors are to be commended for identifying a problem that needs to be addressed, and for scoping the boundaries of that problem. However, they fall short of demonstrating that their proposed solution is cost effective or that it is optimal." (Benjamin 2003). Whether or not we "fell short" in demonstrating cost effectiveness or optimality is not the issue at this stage in the relicensing proceedings.

3 It was in 2005, after the relicensing GEIS was completed, that the National Research Council (NatRC) released its study on risks of spent-fuel-pool fires.

"The committee judges that successful terrorist attacks on spent fuel pools, though difficult, are possible.

... If an attack leads to a propagating zirconium cladding fire, it could result in the release of large amounts of radioactive material.
... Additional analyses are needed to understand more fully the vulnerabilities and consequences of events that could lead to propagating zirconium cladding fires.
... it appears to be feasible to reduce the likelihood of a zirconium cladding fire by rearranging spent fuel assemblies in the pool and making provision for water-spray systems that would be able to cool the fuel, even it the pool or overlying building were severely damaged.
...Dry cask storage has inherent security advantages over spent fuel pool storage, but it can only be used to store older spent fuel.

The committee judges, however, that further engineering analyses and cost-benefit studies would be needed before decisions on this and other mitigative measures are taken." (NatRC 2005)

I note that such engineering analyses and cost-benefit studies have not been published by the applicants.

additional calculations that a) fill in some gaps left in earlier work, and b) take into account new information that has recently become available. 10% and 100% are the release fractions recommended for consideration by Gordon Thompson in his report. I have read his report and find it consistent with my knowledge of this field. These release fractions match earlier published work by Thompson, myself, and co-authors (Alvarez et al. 2003a), (Beyea et al. 2004a). They also are consistent in order of magnitude with values considered appropriate by the analyst who did the original work on releases from spent-fuel pools.[4] In addition to a 10% and 100% release fraction, I have also considered (briefly) a smaller release. I have presented general formulas that can be used to estimate consequences for a wide range of releases, other than 10% or 100%.

Thompson finds the inventory of Cesium-137 to be somewhat higher at Pilgrim and Vermont Yankee than the default inventory for a generic reactor considered in (Alvarez et al. 2003a). The differences are not major. I have reviewed Thompson's analysis and find his values reasonable for me to use.

Thompson has estimated the heat rate of a spent-fuel-pool fire to be higher at Pilgrim and Vermont Yankee than estimated for a generic spent-fuel pool in (Alvarez et al. 2003a). The difference in resulting plume rise is within one standard deviation for plume rise, using standard formulas, so it has not been necessary for me to modify my calculations with respect to plume rise.

Before submitting a report on consequences of a 10% and 100% release, I have made an independent assessment to assure myself that such releases are probable enough to be more than a mathematical exercise. I have already noted that many analysts have found that the generic, spent-fuel-pool problem needs to be addressed. In addition, I have reviewed the treatment of release probabilities in the companion report of Gordon Thompson, Ph.D. I find his analysis reasonable and conservative. I am certainly comfortable relying on his plant-specific probability numbers for this proceeding. I note that his estimate of the probability of a release caused by a malicious act increases his total probability estimate by only a factor of 6. A factor of 6 increase is modest, given the ingenuity that terrorists have shown in the past. Thompson's plant-specific numbers are consistent with generic probability analyses that were part of a scoping cost-benefit analysis that my colleagues and I made in 2003 (Alvarez et al.

[4] Allan Benjamin, lead author of the original 1979 paper from Sandia Laboratory, was a reviewer of our 2003 paper in SG&S. He provided a public commentary on it, in which he stated,. "Although there is clear evidence that some of the fuel would melt in such a situation, we don't know how much. Since we don't, it is conservative and appropriate to assume that a large fraction of the fission product inventory could become released to the environment. Whether that fraction is 0.20 or 1.00 doesn't change the fact that the release would be unacceptable." (Benjamin 2003)

2003a). Our analysis suggests that even using older probability numbers, and without considering threats of terrorism or new data on radiation risks to be discussed later, moving older fuel to dry cask storage is nearly cost-effective.[5] The Nuclear Regulatory Commission's response to the issues raised by the report of the National Research Council (NatRC 2005) and our paper in *Science and Global Security* (SG&S)(Alvarez et al. 2003a) is discussed in (Dorman 2005). The NRC does not appear to be addressing the scenarios of most concern to me, such as those addressed by Thompson in his report for Pilgrim and Vermont Yankee. The Commission essentially sees the spent-fuel pool problem as a non-issue that is diverting resources from more important areas. However, the basis for the Commission's overall judgment is secret, presenting a challenge in relicensing proceedings to independent scientists like myself, who are not allowed to review the secret analysis. Should I simply accept the Commission's judgment without review and remain silent to avoid any chance of providing useful information to terrorists? The problem with such a stance is that I do not believe the Commission (or any government agency) can best protect the public against terrorism in the absence of vigorous pressure from, and critical analysis by, a range of stakeholders. It would be irresponsible to say nothing, but equally irresponsible to say too much. I hope the balance I have struck in this report is the right one. I certainly conclude from all of the analysis carried out, both by me, Thompson, and others, and the lack of response by the NRC to date, that computing the consequences of large releases of Cesium-137 in regulatory proceedings is responsible and in the public interest.

Another reason that I find it important to make consequence calculations in these proceedings is that the NRC's own Inspector General has observed that the NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem (IG 2003). Considerable evidence is available that a correspondingly high barrier has been set for alternatives to pool storage at reactors, based on comments by NRC staff on our 2003 paper and by my reading of (Dorman 2005). Thus, independent analysts may be the only vehicle for computing state-of-the-art consequences, if the NRC is reluctant to commission such calculations or require applicants to make them.

Consequences of a release. The first realistic study of the economic and land use consequences of

[5] The approach I took for our 2003 report, when it came to dealing with terrorism, was to think of scenarios that a terrorist group might come up with using the technical means I thought would be reasonably available to them. Since at least one of those generic scenarios I came up with seemed plausible, I considered at the time, and still do, that we need to understand the consequences of spent-fuel-pool fires.

releases of long-lived radioactivity that tried to go beyond bounding calculations was published in 1996 (Chanin and Murfin 1996). This work appeared in the same year of publication of the relicensing GEIS (NUREG 1996), so would not likely have been considered in the GEIS. More recently, in 2003 and 2004, estimates of the long-term health consequences of releases from spent-fuel fires were published by our group of independent analysts, as noted above. Some NRC Commissioners have referred to staff analyses refuting our published results, but such analyses have never been made public, as far as I am aware. If the new staff analysis does exist, it was also prepared after the GEIS and so should be incorporated into the EIS for Pilgrim and Vermont Yankee. The staff analysis that has been published is sobering and only applies specifically to decommissioning (Collins and Hubbard 2001).

For this report, components of damage costs not previously considered at other sites have been included. For instance, new damage cost and latent cancer calculations have been made to extend the work by Beyea, Lyman, and von Hippel to areas contaminated by resuspension. Results from "wedge model" calculations (discussed below) have been used for this purpose. Loss of property value outside remediated areas have also been considered, again with reliance on the wedge model. Approximate correction has been made for wind-rose effects, something that was not done in (Beyea et al. 2004a). In addition, I have made cost and latent cancer estimates, assuming that the latest radiation mortality studies are used in the calculations. As for the standard components of damage calculations, I have scaled, interpolated or extrapolated from values computed for other sites as reported in (Beyea et al. 2004a). Since the MACCS2 model was run in the paper by Beyea, Lyman, and von Hippel, with the parameter values listed there, the results in this report on Pilgrim and Vermont Yankee are based on the MACCS2 model.

The models included in the MACCS2 code are based largely on methodologies originally developed for the 1975 Reactor Safety Study (NUREG 1975), as refined in the CRAC2 code (Kocher et al. 1987; Ritchie et al. 1984). See (Young and Chanin 1996). A simpler approach to consequence analysis (wedge model) was developed by an American Physical Society group that reviewed the Reactor Safety Study (APS 1975). The wedge-model provides quick estimates of consequences that usually gives similar results to more detailed models, such as MACCS2, provided one uses appropriate effective parameters. The wedge model may underestimate acute consequences in situations where changing weather classes dominates health effects, but that is not a major issue for releases of cesium-137, where the risk is from long-term exposure.

Details of the calculations made for this report are given in Appendix I. Tables with quantitative results appear in a subsequent section. Reliance on output from the MACCS2 computer code or the wedge model to estimate consequences from releases of Cesium-137 in this report does not necessarily imply endorsement of the use of these methodologies in other contexts, nor endorsements of the parameter sets that applicants or others may use with them. All models have strengths and weaknesses that must not be forgotten by modelers. MACCS2 does not appear to have undergone extensive field validation (Young and Chanin 1997), but sensitivity studies have been undertaken (Helton et al. 1995; McKay and Beckman 1994), (Neymotin 1994) and a large number of expert elicitations have been carried out that provide uncertainty distribution for input parameters (Goossens et al. 1997; Harper et al. 1993; Little et al. 1997; USNRC 1995). The model has been used in a limited number of peer-reviewed publications. Edwin Lyman, who ran the MACCS2 code for (Beyea et al. 2004a) has probably the greatest number of peer-reviewed papers using MACCS2.

For late health effects, which are of interest in this report, the deposition velocity has been found to be a major parameter affecting MACCS results (Helton et al. 1995). Because the uncertainty distribution for deposition velocity is quite broad (USNRC 1995), the variance in the MACCS2 predictions for cancers (and damage costs) could be large. When possible, I prefer to rely on exposure models that have been tested against field data, such as those I have developed in recent years (Beyea et al.). However, by relying on results from MACCS2 in these proceedings with respect to consequences from releases of Cesium-137, I hope to avoid distracting debate over models.

In the next section, I present results of consequence calculations using standard cancer risk coefficients. In subsequent sections, I discuss major new studies on cancer risks from radiation that suggest the risk coefficients used in most versions of MACCS2 are way too low. I then present consequence calculations using higher cancer coefficients and discuss some of the implications for cost benefit analyses. Finally, I discuss some new developments in dispersion modeling at coastal sites. I suggest that the applicant at Pilgrim should undertake sensitivity studies using appropriate computer codes to see if this new knowledge of meteorology modifies cost-benefit computations.

Quantitative damage estimates for releases from Pilgrim and Vermont Yankee, assuming standard cancer risk coefficients:

This section presents a subset of consequence estimates for hypothetical releases of Cesium-137 from spent-fuel pools at Pilgrim and Vermont Yankee. Estimates are presented for economic costs and latent cancers. Variance in the estimates are not considered for the contention phase. Details of the estimates are given in the Table footnotes and in Appendix I. Political, psychological, and social impacts of hypothetical releases are not considered, although they could obviously be significant. For instance, there appears to exist a "radiation syndrome" that affects a subset of exposed populations, causing debilitating psychiatric symptoms (Vyner 1983). Psychological effects of radiation disasters are expected to be most serious for children (CEH 2003).

Releases of 10% and ~100% of the radiocesium in the spent-fuel pools at both Pilgrim and Vermont Yankee are considered. Results are presented in this section using the standard risk coefficients assumed in (Beyea et al. 2004a). Releases lower than 10% of the Cesium-137 inventory, even releases too low to justify remediation, could have costs associated with loss in property value in the range of 10 to 100 billion dollars.

The damage estimates shown in the Tables are much less than the GDP of the US, which is about 12 trillion per year. However, some of the numbers exceed the annual payment on the national debt, which is about 350 billion dollars per year, indicating that government borrowing to cover the damage payments from a spent-fuel-pool fire could represent a major perturbation on the economy. Thus, significant macroeconomic effects could be expected depending on the state of the economy at the time of any hypothetical release. The regional impacts would be expected to be the most serious. Estimating such effects are beyond the scope of this report.

The Tables include numbers in some cells to 3-significant figures. This does not imply any comparable level of accuracy.

Table 1. Cost estimates for a release of 10% of spent-fuel pool inventory of radioactive Cesium-137 assuming no change in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	49	39	
Indirect administrative costs[b)]	49	39	
Loss in property values adjacent to treated areas[c)]	7-74	9-87	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 105-171	> 87-165	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). Reduction by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset any economies of scale.
c) Assumes 5% loss in property value for an area surrounding the plume that includes 1 to 10 times as many persons as are in the (0.24 radian) plume extending out to 250 miles (see Appendix I). A similar 5% loss in property value is assumed in the plume from 250-1000 miles. $132,000 in property value assumed per capita (Beyea et al. 2004a). Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Table 2. Cost estimates for a release of ~100% of spent-fuel pool inventory of Cs-137 assuming no increase in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	163	173	
Indirect administrative costs[b)]	163	173	
Loss in property values adjacent to treated areas[c)]	16-162	17-172	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 342-488	> 364-518	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). Figures reduced by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.
c) Assumes 5% loss in property value for an area including 1 to 10 times as many persons as are in a 0.24 radian plume extending out to 700 miles (see text). A similar 5% loss in property value is assumed in the plume from 700-1000 miles. $132,000 in property value assumed per capita (Beyea et al. 2004a). Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Note that the latent cancer estimates in Table 3, below, are lower limits, because they only include the cancers from Cesium-137. This approximation ignores shorter isotopes in the fresh fuel in the pool, especially Cesium-134 (Benjamin 2003).

Table 3. Estimates for latent cancers following releases from the spent-fuel pools at either Pilgrim or Vermont Yankee (assuming no increase in cancer risk number)

Category	10% release	~100% release
Latent cancers in main plume path from residual contamination[a)]	1300	4000
Latent cancers from deposited resuspension[b)]	1300	4000
Total	2,700	8,000

a) Based on typical numbers for plants analyzed in (Beyea et al. 2004a). Figures reduced by 1/3rd to account for wind rose effects. Cancers in the direct plume are reduced by more than a factor of ten from decontamination and deconstruction.
b) Assumes 10% resuspension and redistribution of deposited Cesium-137 resulting from a) wind removal in the first few weeks, and b) remediation/demolition efforts over successive years. It is possible that even the resuspended Cesium would produce concentrations high enough to justify remediation, with a corresponding reduction in projected cancers. However, clean-up costs would be increased.

I have not been able to incorporate new understanding of the flow of air over and around the New England Coastline that has been achieved in recent years. Still, this new knowledge should be taken into account in EISs for coastal facilities. Releases from Pilgrim headed initially out to sea will remain tightly concentrated due to reduced turbulence until winds blow the puffs back over land (Zagar et al.), (Angevine et al. 2006). This can lead to hot spots of radioactivity in unexpected locations (Angevine et al. 2004). Dismissing radioactivity blowing out to sea is inappropriate. Reduction of turbulence on transport from Pilgrim across the water to Boston should also be studied. Although incorporating such meteorological understanding into a PSA or equivalent at Pilgrim would not be likely to make more that a factor of two difference in risk, the change could bring more SAMAs into play and would be significant in an absolute sense, when combined with the increase arising from incorporation of new values of radiation dose conversion coefficients (discussed below). The program

CALPUFF (Scire et al. 2000) has the capability to account for reduced turbulence over ocean water and could be used in sensitivity studies to see how important the phenomenon is at Pilgrim.

New cancer risk coefficients There have been increases in the value of the cancer risk assigned to low doses of radiation that should be taken into account in EISs. These increases have been steady since 1972,[6] which makes the original EISs out of date. In addition, there has been a marked increase in the value of the cancer mortality risk per unit of radiation at low doses (2-to-3 rem average) as a result of recent studies published on a) radiation workers (Cardis et al. 2005) and b) the Techa River cohort (Krestinina et al. 2005). Both studies give similar values for low dose, protracted exposure, namely about 1 cancer death per Sievert (100 rem).

Worker study: The average dose for the workers was 2-rem. The authors of this large, international study of radiation workers included major figures in the field of radiation studies. The authors state, "On the basis of these estimates, 1-2% of deaths from cancer among workers in this cohort may be attributable to radiation." Although it can be misleading to interpret epidemiologic data in this way (Beyea and Greenland 1999), because it implies to non-experts a single-cause model of cancer, there is no doubt that a 1-2% increase in cancer mortality for a worker population is unusually high.

Techa River Cohort: The results for the Techa River cohort are equally striking, showing a strong linear effect down to a few rads. The average dose was 3 rads. The authors, who once again include major figures in the field of radiation studies, state: "It is estimated that about 2.5% of the solid cancer deaths...are associated with the radiation exposure." As in the worker population, an increase in solid cancer deaths of 2.5% from a dose of 3 rads is extraordinarily high compared to past estimates.

Such high risk coefficients imply that background radiation itself must increase cancer mortality by 3-5%.[7] (It has long been known that background radon concentrations may well increase lung cancer rates by 10% or more (Lubin et al. 1995), (Darby et al. 2005).) Critics of studies like those by

[6] For instance, there was a large increase in the risk coefficients estimated between the 1980 BEIR III report and the 1990 BEIR V report. See Table 4-4 of (National Research Council 1990), where the lifetime risk estimates increased by a factor of 4.6-19, depending on the risk model.

7 Assuming 0.1 rem per year background, which ignores the "equivalent" dose to the lung from radon. It is more difficult to compare rates of lung cancer, because the interaction of smoking and radiation has been found to lie between a linear and relative model. Therefore, such interactions must be taken into account, before drawing conclusions about area-wide differences, or lack of differences, in lung cancer rates.

Cardis et al. and by Krestinina et al. argue that such big effects, if they were real, should show up in cancer statistics in places like Colorado, where background radiation is high, when compared to areas of the country where background radiation is lower. However, crude statistical analysis that does not adjust for covariates at an individual level is unlikely to be very reliable (Lubin 1998). Also, there is an issue of the confounding effect of hypoxia (Weinberg et al. 1987). Hypoxia also varies with altitude.

Because the average dose in these two new studies is so low and so close to background radiation dose, there is no way to escape the linear non-threshold model. Even were a hypothetical hormesis effect to lead to a minimum risk at background levels (5 rem lifetime dose), the risk has to rise again after another 2-3 rem dose, based on the studies by Cardis et al. and Krestinina et al.

Could the increased risk numbers be due to a systematic underestimate or underreporting of doses? Random errors in doses would tend, in most cases, to reduce the strength of associations (Carroll et al. 1998), (Thomas et al. 1993). On the other hand, if dose errors were not random, but were proportionately underestimated or proportionately underreported in the worker studies and the Techa River cohort, then the risk coefficients could be inflated. For this to happen in both studies would be a coincidence. And in the radiation worker study, the results for Hanford do not support the missing-dose hypothesis, even though we know the neutron doses were likely underreported at Hanford (CohenAssociates 2005). In fact, the cancer risk numbers at Hanford were lower than average, not higher (Cardis et al. 2005). Finally, should the Techa River cohort dose estimates be too low that would mean that modern dose reconstruction techniques are underestimating doses, suggesting that other modern dose estimation techniques, such as those used in MACCS2 (Chanin and Young 1997), the standard NRC consequence code, could well be too low. In that case, an upward adjustment of doses would be required, if the risk coefficients were kept the same. Certainly, from a public health point of view, the arguments are strong for making use of the new risk coefficients, one way or another, with programs like MACCS2 and other consequence codes.

Recent press reports around the anniversary of the Chernobyl accident seemed to suggest that effects of radiation doses were lower than expected. Not at all. The "new" estimates of 4,000 projected fatalities were merely a re-interpretation of a study from the 1990s. No longer were 5,000 projected cancers outside the most highly contaminated regions counted. Also, another 7,000 cancers projected to occur in Europe were not noted by the press (Cardis et al. 2006). A summary of all of these estimates can be found in (Cardis et al. 2006). Were the new risk coefficients discussed earlier applied to the population dose estimates, the projected numbers of fatalities from the Chernobyl releases would climb much higher.

The confusion over the Chernobyl numbers appears to be traceable to a typo in a highly publicized IAEA report (Forum 2005) that relied on a WHO report for its cancer numbers (WHO 2005). The WHO report stated that the "Expert Group" concluded that there may be up to 4 000 additional cancer deaths among the three *highest* exposed groups over their lifetime (emphasis added). This was translated in the IAEA report to, "The total number of people that could have died or could die in the future due to Chornobyl originated exposure over the lifetime of emergency workers and residents of *most* contaminated areas is estimated to be around 4 000." (Emphasis added.) In fact, in my view, the last clause should have referred to "residents of *the* most contaminated areas..."[8]

Impact of new cancer risks. As a result of these two radiation studies, all probabilistic safety analyses prepared prior to them need to be revisited. These new studies should change the threshold for adoption of severe accident mitigation alternatives (SAMA). For instance, the current Environmental Report for Pilgrim assigns a value of $2,000 per person rem in deciding whether a proposed SAMA is cost effective. According to the results of the study by Cardis et al., $2,000 per rem implies a valuation of $200,000 per cancer death before discounting, which is way to low.[9] The same low valuation of life would arise from use of the risk numbers derived from the Techa River cohort (Krestinina et al. 2005). As a result, the SAMA analyses prepared for the Pilgrim and Vermont Yankee facilities need to be redone, even without inclusion of spent-fuel-pool fires as a risk to be addressed. Presumably, a number of additional SAMAs that were previously rejected by the applicant's methodology will now become cost effective. In addition to affecting the existing SAMA calculations, the new cancer risk coefficients make the consideration in an EIS of mitigation measures for spent-fuel-pool fires especially important.

In addition to providing motivation for a reanalysis of past PSAs and SAMA thresholds, the results of these new epidemiologic studies throw into doubt the entire basis of the NRC culture, which maintains that the linear non-threshold theory (LNT) is conservative, providing a margin of safety. Although it has always been known that the dose-response at doses below the 25-rad average dose of the Atomic Bomb survivors could be supralinear, as opposed to sublinear, the possibility has not been

8 Note that the IAEA stands by its original wording, not accepting it as a typo. Personal Communication, 2006, D. Kinley, IAEA public information, Vienna.

9 $50,000 net present value for a cancer death occurring 20 years from now, based on the 7% per year discount rate assumed in rhe Pilgrim Environmental Report, which leads to a factor of 4 reduction in present value for a cancer induced 20 years from now.

given much attention in the radiation protection community until now.[10] This is not the time for *pro forma* treatment of licensing applications. Whereas it would be unreasonable to require an applicant to redo analysis after every new paper is published in the scientific literature, the increase at low doses is very dramatic in this case. It represents a 5-fold increase over the risk estimated in BEIR VII (NRC 2005). Based on information in (Little 1998), it appears to represent a factor of 10 over the standard value used in the MACCS2 computer code, which is the code on which the applicants' analyses are based. With such a high reported increase, public health considerations have to take precedence over applicant convenience. The paper by Cardis et al., at the very minimum, demands that a thorough analysis be made of mitigation and alternatives to spent-fuel pool storage.

For example, application of the new risk coefficients would drive the risk of spent-fuel-pool accidents during decommissioning (without even considering terrorist threats) above the NRC's safety goal. See Figures ES-1, ES-2 of (Collins and Hubbard 2001).

Quantitative damage estimates for releases from Pilgrim and Vermont Yankee, assuming cancer risk coefficients are increased to accommodate the new epidemiologic studies:

This section presents a subset of consequence estimates for hypothetical releases of Cesium-137 from spent-fuel pools at Pilgrim and Vermont Yankee, assuming a 3-fold increase in cancer risk coefficients to conservatively account for the latest studies on radiation risk at low dose. To account for some weighting of other studies, I have chosen a value lower than the factor of 5-to-10 increase that is suggested by the study of (Cardis et al. 2005).[11]

As with earlier Tables, estimates are presented for economic costs and latent cancers. Variance in the estimates are not considered for the contention phase. See the Table footnotes and Appendix I for details. Political, psychological, and social impacts of hypothetical releases are not considered, although they could obviously be significant. As stated earlier, there appears to exist a "radiation syndrome" that affects a subset of exposed populations, causing debilitating psychiatric symptoms (Vyner 1983). Psychological effects of radiation disasters are expected to be most serious for children (CEH 2003).

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[10] There has been some discussion, however, that the A-Bomb survivor data produces low risk coefficients due to a healthy survivor effect (Stewart and Kneale 1993; Stewart and Kneale 1999). In addition, I have always wondered about the lowest dose data in Pierce, which seems to show a supralinear effect below 5 rem (Pierce et al. 1996), page 9.

11 Part of the factor of 5 comes from the use of a dose and dose rate effectiveness factor, which is commonly used with the MACCS2 code, as in (Beyea et al. 2004a).

Once again, releases lower than 10% of the Cesium-137 inventory, even releases too low to justify remediation, could have costs associated with loss in property value in the range of 10 to 100 billion dollars.

The damage estimates shown in the Tables are much less than the GDP of the US, which is about 12 trillion per year. However, some of the numbers are considerably larger than the annual payment on the national debt, which is about 350 billion dollars per year, indicating that government borrowing to cover the damage payments from a spent-fuel-pool fire could represent a major perturbation on the economy. Thus, once again, significant macroeconomic effects could be expected depending on the state of the economy at the time of any hypothetical release. The regional impacts would be expected to be the most serious. Estimating such effects are beyond the scope of this report.

The Tables include numbers in some cells to 3-significant figures. This does not imply any comparable level of accuracy.

Table 4. Cost estimates for a release of 10% of spent-fuel-pool inventory of Cs-137 assuming 3-fold increase in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	89	79	
Indirect administrative costs[b)]	89	79	
Loss in property values adjacent to treated areas[c)]	> 7-74	> 9-87	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 186-253	> 167-245	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). An increase in the cancer risk numbers is mathematically equivalent to an increase in release magnitude, which is how the numbers in the Table were computed. Figures reduced by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.
c) Assumed to be at least as great as the figures calculated in Table 1, where the cancer risk coefficient was left unchanged. Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Table 5. Cost estimates for a release of ~100% of spent-fuel-pool inventory of Cs-137 assuming a three-fold increase in cancer risk coefficient (billions of dollars)

Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	283	353	
Indirect administrative costs[b)]	283	353	
Loss in property values adjacent to treated areas[c)]	16-162	17-172	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Costs due to delays in implementing remediation and deconstruction[d)]	??	???	
Total	> 582-728	> 723-878	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). An increase in the cancer risk numbers is mathematically equivalent to an increase in release magnitude, which is how the numbers in the Table were computed. Figures reduced by $1/3^{rd}$ to account for wind rose effects.

b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.

c) Assumed to be at least as great as the figures calculated in Table 2, where the cancer risk coefficient was left unchanged. Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.

d) We have not attempted an estimate for this category in the contention phase.

Note that the latent cancer estimates in Table 6, below, are lower limits, because they only include the cancers from Cesium-137. This approximation ignores shorter isotopes in the fresh fuel in the pool, especially Cesium-134 (Benjamin 2003).

Table 6. Estimates for latent cancers following releases from the spent-fuel pools at either Pilgrim or Vermont Yankee (assuming a 3-fold increase in cancer risk number)

Category	10% release	~100% release
Latent cancers in main plume path from residual contamination[a)]	4,000	12,000
Latent cancers from deposited resuspension[b)]	4,000	12,000
Total	8,000	24,000

a) Based on typical numbers for plants analyzed in (Beyea et al. 2004a) multiplied by a factor of 3. Figures reduced by 1/3rd to account for wind rose effects. Cancers in the direct plume are reduced by more than a factor of ten from decontamination and deconstruction.
b) Assumes 10% resuspension and redistribution of deposited Cesium-137 resulting from a) wind removal in the first few weeks, and b) remediation/deconstruction efforts over successive years. It is possible that even the resuspended Cesium would produce concentrations high enough to justify remediation, with a corresponding reduction in projected cancers. However, clean-up costs would be increased.

Regulatory implications. The results in Tables 1-6, along with the discussion in the text suggest that: The applicant should withdraw and revise its Environmental Reports for Pilgrim and Vermont Yankee. The NRC should prepare supplements to the August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and the May 1996 GEIS on license renewal (NUREG-1437). The revised documents should consider the new cancer risk coefficients published by Cardis et al. and Kristinina et al. For both reactor accidents and spent-fuel-pool fires, when relevant, the documents should consider loss of property value outside remediated areas. They should consider wind-driven resuspension, especially from remediation activities, that carries radioactivity to new areas in the immediate weeks and years following the release. Although MACCS2 does not directly account for such refinements, it may be possible to mimic their effects in the program.[12] In their economic calculations, the revised documents should include administrative and litigation costs associated with clean up and demolition. The ER for Pilgrim should consider the reduced turbulence over ocean water, including transport directly over water to the Boston area. The NUREG supplements should consider the impacts of coastal meteorology for reactors on the East and West Coasts. The program CALPUFF can be used to deal with dispersion over coastal waters.

[12] This might be done by adding on extra plume segments to the end of a standard run, with varying delay times, and a total added release equal to the assumed resuspension fraction times the initial release. This will tend to produce the mathematical equivalent of resuspended material being carried in directions different from the main plume.

Appendix I.

Variance in estimates are not considered in this report for the contention phase.

Based on the report of Gordon Thompson, the inventories at Pilgrim and Vermont Yankee are somewhat higher than the 35 MCi considered in (Beyea et al. 2004a). For Pilgrim, Dr. Thompson estimates 44 MCi; for Vermont Yankee, 39 MCi.

Thompson has also estimated a hotter heat rate for releases at Pilgrim and Vermont Yankee than was assumed in the calculations in (Beyea et al. 2004a). 106-128 MW vs 40 MW. Plume rise varies as the 1/3rd power of the heat rate in the standard "Briggs" formula for plume rise (Parks 1997), which implies a 50% greater rise than would have been calculated in the MACCS2 program that was used in the paper by Beyea, Lyman and von Hippel. For the contention phase of these proceedings, this difference has been ignored, since a 50% increase in plume rise is within 1-standard deviation of the value predicted by the formula (Irwin and Hanna 2004).

Rather than make new MACCS2 calculations for the contention phase of these proceedings, the azimuthally-averaged radial population distributions for both Pilgrim and Vermont Yankee have been compared as a function of distance with those for which economic and latent cancer consequences have been calculated in (Beyea et al. 2004a). It is the radial population numbers that drive the economic damage costs and cancer numbers. Figures 1 and 2 show the azimuthally-averaged radial population distributions for Pilgrim and Vermont Yankee for two different maximum distances. The CensusCD computer program (Geolytics 2002) was used to generate these population distributions. The same program was used in (Beyea et al. 2004a) for the five reactors, Catawba, Indian Point, LaSalle, Palo Verde, and TMI.

The effect of variation in wind direction at Pilgrim is to reduce the average damages and latent fatalities. Wind rose data taken from the Pilgrim FSAR shown in Figure 5 for the 300 foot tower suggest a reduction factor of 0.666 for that facility. See caption for Figure 5. I did not find similar data for a high tower in the FSAR for Vermont Yankee, so I have used the 0.666 factor determined for Pilgrim. Wind flows at the surface given in the Vermont Yankee FSAR are not particularly relevant to a hot release during a fire, since the plume will be elevated. The variance with angle appears to be quite large, because the population figures change with release angle, as shown in Figures 3 and 4.

For economic damages from the 10% releases, we are interested in populations out to 250 miles (based on wedge model calculations). For the ~100% releases, the corresponding distance is 700 miles. The Pilgrim population figures best match Catawba out to 250 miles. For Vermont Yankee the population figures best match Lasalle out to 250 miles. Out to 700 miles, both Pilgrim and Vermont Yankee are most similar to Lasalle, although I discount the Lasalle cost figures to account for the lower population values of Pilgrim and Vermont Yankee.

Table 7, shows the relevant costs extracted from Table 3 of (Beyea et al. 2004a) and adjusted as indicated in the Table footnotes. These numbers were then fit to a power law function of release magnitude. The corresponding functions were used to generate costs estimates for the Pilgrim and Vermont Yankee releases estimated by Thompson, which differ somewhat from the releases assumed for a spent-fuel fire in (Beyea et al. 2004a).

Table 7. Assigning damage cost estimates in billions of dollars based on Table 3 of (Beyea et al. 2004a)

Release magnitude	Pilgrim	Vermont Yankee
3.5 MCi	71[a)]	54[b)]
35 MCi	219[c)]	243[d)]

a) Cost figure for Catawba for a 3.5 MCi release.
b) Cost figure for Lasalle for a 3.5 MCi release.
c) Cost figure for Lasalle for a 35 MCi release reduced by 20%
d) Cost figure for Lasalle for a 35 MCi release reduced by 10%

Extrapolated and interpolated direct damage costs for Pilgrim and Vermont Yankee were computed from the following formulas:

Pilgrim: Damages = $0.66 * 35 * (\text{release in Mci})^{0.5}$

Vermont Yankee: Damages = $0.66 * 24 * (\text{release in MCi})^{0.65}$

The factor of 0.66 comes from wind-rose effects.

Administrative costs are taken equal to direct costs, following the suggestion of (Chanin and Murfin 1996). Property loss estimates are discussed below.

Estimates of losses in property value. It is assumed that an area exists around the "main portion" of the plume, where potential property buyers would be concerned about residual risk. (The main portion of the plume is defined as the area where remediation or demolition takes place.) Outside the main plume, contamination would still be measurable. Lack of trust in statements by government would translate into loss in property values. All things being equal, persons would wish to live as far away from contaminated areas as possible.

Note that radioactive deposition would extend into these non-remediated areas, both from the immediate release and from resuspension in the weeks and years after the release and from subsequent demolition and remediation efforts. People would be accumulating long-term radiation doses, which government sources would say are too trivial to worry about. Expert opinion would differ on the seriousness of the long-term exposures. Confidence in government would likely drop over time based on revelations of government failings. If past patterns are followed, government leaders would early on feel compelled to downplay the true situation to prevent panic. Although it is hard to see how they could act otherwise, it is also hard to see how citizens enthusiasm for purchasing property in the vicinity of the main plume would not be weakened.

How much would property values decline? Based on expert reports filed in litigation concerning the Rocky Flats nuclear weapons facility, and the jury decision favorable to plaintiffs in that litigation (2006), I assume a 5% loss in property value for property lying within measurable contours of contamination. This is quite conservative, since the jury accepted Plaintiffs' expert assessment that residential values dropped by 7%,[13] vacant land by 30%, and commercial land by 53%. For the calculations in this report, I define the main, remediated plume as a 0.24 wedge extending out to 250 miles for the 10% release and 700 miles for the ~100% release.

Areas where property damage loss is assumed to take place extends outward from the plume to 1000 miles, which is where the damage calculations stop in (Beyea et al. 2004a). In addition, property in areas to the side of the plume are also expected to suffer a 5% loss in value. Because I have no firm basis for determining the distance to which property loss would extend, I have picked a ten-fold range. At the low end, as many people outside the main plume are assume to be affected as live in the main plume. At the high end, I pick ten times as many persons.

13 The "residential" figure appears to be some sort of compromise. It's within a range reported by expert Radke's year-by-year multiple regressions for 1988-95, but it's less than the 10% that expert Hunsperger ultimately estimated. Personal commuication, 2006, Peter Nordberg, Berger and Montague.

MACCS2 accounts for inhalation of resuspended material at the location where radioactivity is deposited (Chanin et al. 2004), Section 2, page 6-14. However, MACCS2 does not allow for redistribution of resuspended material to new locations. Yet, 10% of radioactivity deposited on vegetation may be blown off in the first few weeks,[14] with additional resuspension over decades,[15] increased dramatically by anthropogenic activity during clean up and remediation (Schershakov 1997). I adopt a net resuspension factor for Cesium-137 of 10% over the long term, which should be a conservative choice in this context.[16] To account for the latent cancers that would be caused by this redistribution of radioactivity, I have made the approximation that no such re-deposited material would be high enough to generate remediation. (If this assumption is violated, the number of latent cancers from redistributed radioactivity would go down, but it would then be necessary to increase clean-up costs.)

Based on wedge model calculations, I know that remediation reduces latent cancers by a factor of 10 or more. Thus, the contribution from redistributed radiation to total cancers, under the assumptions I have made, should be more than the direct contribution from the remediated plume (10% X 10 = 100%). A more precise calculation could be obtained by running MACCS2 in a special way, even though MACCS2 does not directly handle redistributed radioactivity. (MACCS2 only allows straight-line plume segments and does not allow wind trajectories (Chanin et al. 2004), Section 5, page 1-4.) However, MACCS2 does allow multiple straight-line segments with different starting times (Chanin et al. 2004), Section 2, page 6-14. If MACCS2 was run with extra plume segments added on to the end of a standard release sequence, with varying delay times, and a total added release equal to

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[14] (NUREG 1975), Appendix VI. Radioiodine after weapons fallout shows very rapid decline over periods of days, some of which must be due to wind action (NCI 1997), Table 4.8. The half-life for small particles is longer, about 14 days (Prohl et al. 1995). Resuspension *factors* in the early days after the Chernobyl accident have shown very high values, including 2.4 E-04 m^{-1} at one day after deposition (Schershakov 1997). Such a high rate could not be maintained without completely exhausting the surface concentration in a very short time. The resuspension factor has been estimated to drop as an inverse power of time in days, with an exponent of 0.5-to-1.67 (Schershakov 1997). At issue is the size of the resuspended material, because some radioactivity might deposit on relatively large particles on vegetation that are easily removed by wind.

[15] Resuspension *rates* measured for Chernobyl radiocesium are also high (1E-08 s^{-1}) (Schershakov 1997). When such a high uplift rate is totaled for periods of years, a 10% net loss is quite reasonable, although resuspension rates were measured to decrease by an order of magnitude over time (Schershakov 1997). Studies by my colleagues and I have indicated that underground material is brought to the surface by animal burrowing (Morrison et al. 1997; Smallwood et al. 1998), where it is subject to wind resuspension. Thus, movement into the soil of radiocesium does not keep it away from the surface forever. Smallwood has estimated from his measurements in California and Colorado that about 0.5 % of underground radioactivity should be brought to the surface each year by animal burrowing, including ant burrowing (Smallwood, personal communication, 1998). How relevant this number is to the East Coast is not known.

[16] Because of lack of data on particle sizes, analysts may differ as to how much resuspended material would be in particle sizes large enough to travel outside the main plume before remediation. However, most land area would not be remediated. In any case, it will be important for the field of contamination consequence analysis to have debates on this subject.

the assumed resuspension fraction times the initial release, then MACCS2 will produce as output the mathematical equivalent of resuspended material being carried in directions different from the main plume.

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Figure 1.

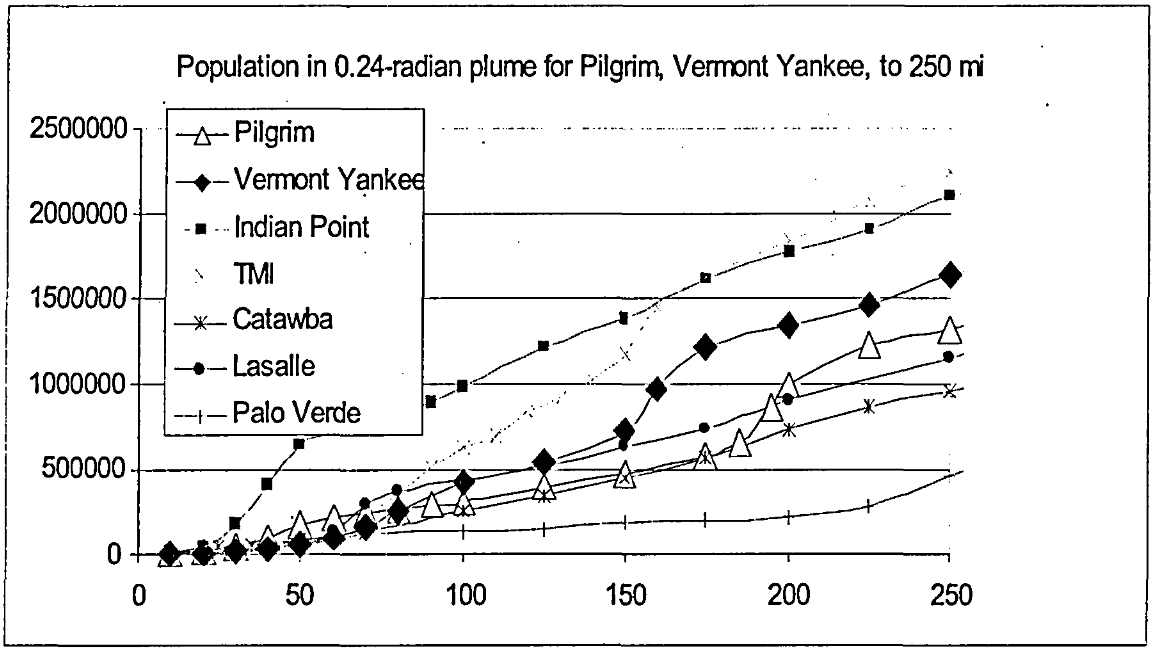
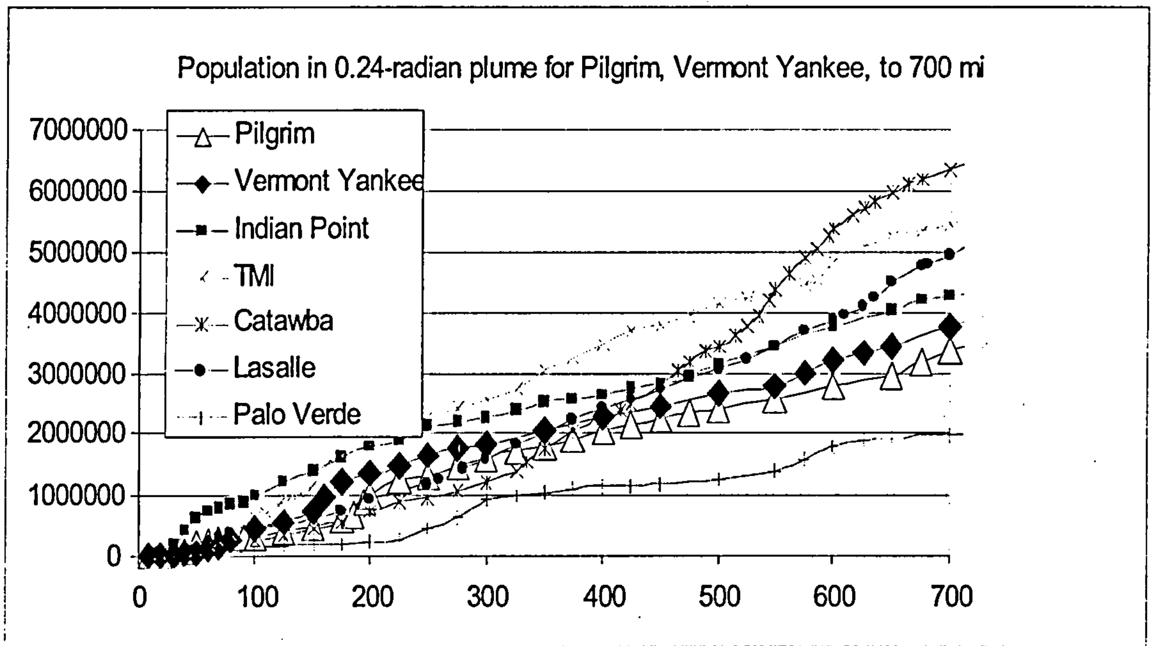

Population in 0.24-radian plume for Pilgrim, Vermont Yankee, to 250 mi
2500000
2000000
1500000
1000000
500000
0
0
50
100
150
200
250
Pilgrim
Vermont Yankee
Indian Point
TMI
Catawba
Lasalle
Palo Verde

Figure 2.



Population in 0.24-radian plume for Pilgrim, Vermont Yankee, to 700 mi
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
100
200
300
400
500
600
700
Pilgrim
Vermont Yankee
Indian Point
TMI
Catawba
Lasalle
Palo Verde

Figure 3. Calculated with the SECPOP 2000 computer code (Bixler et al. 2003).

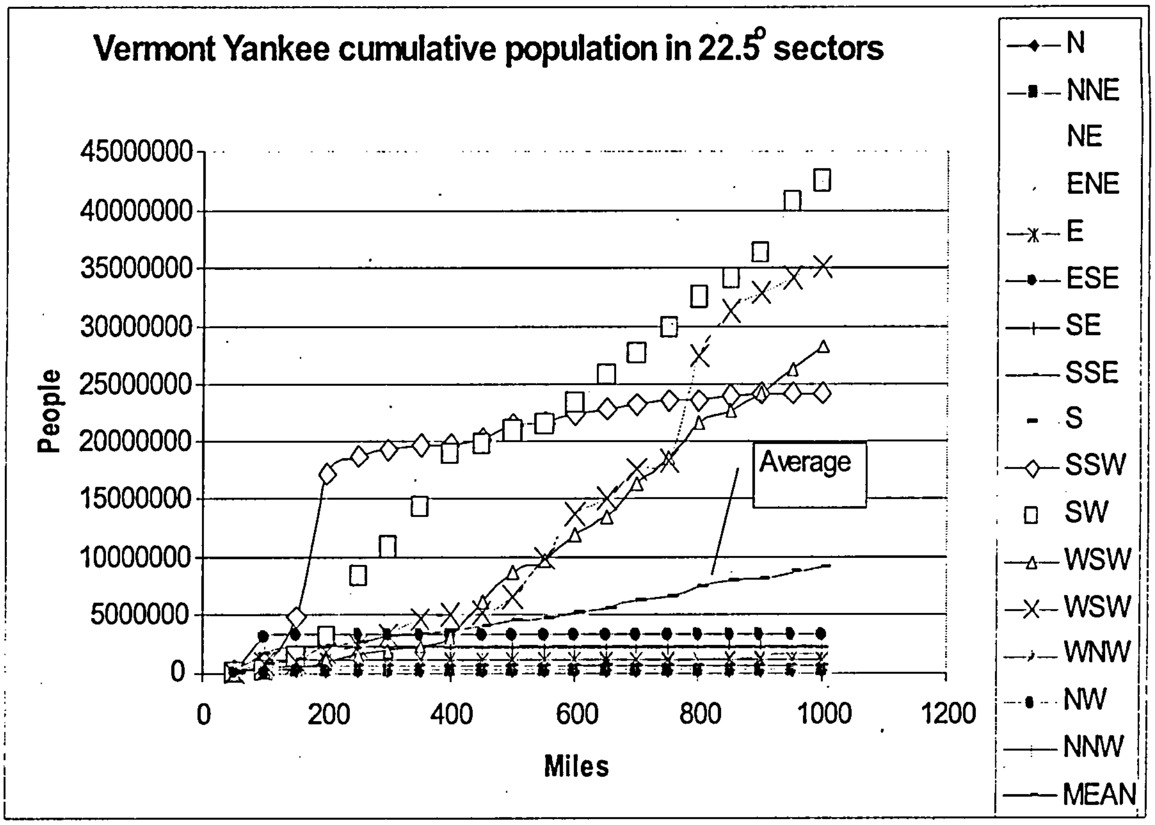


Figure 4. Calculated with the SECPOP 2000 computer code (Bixler et al. 2003).

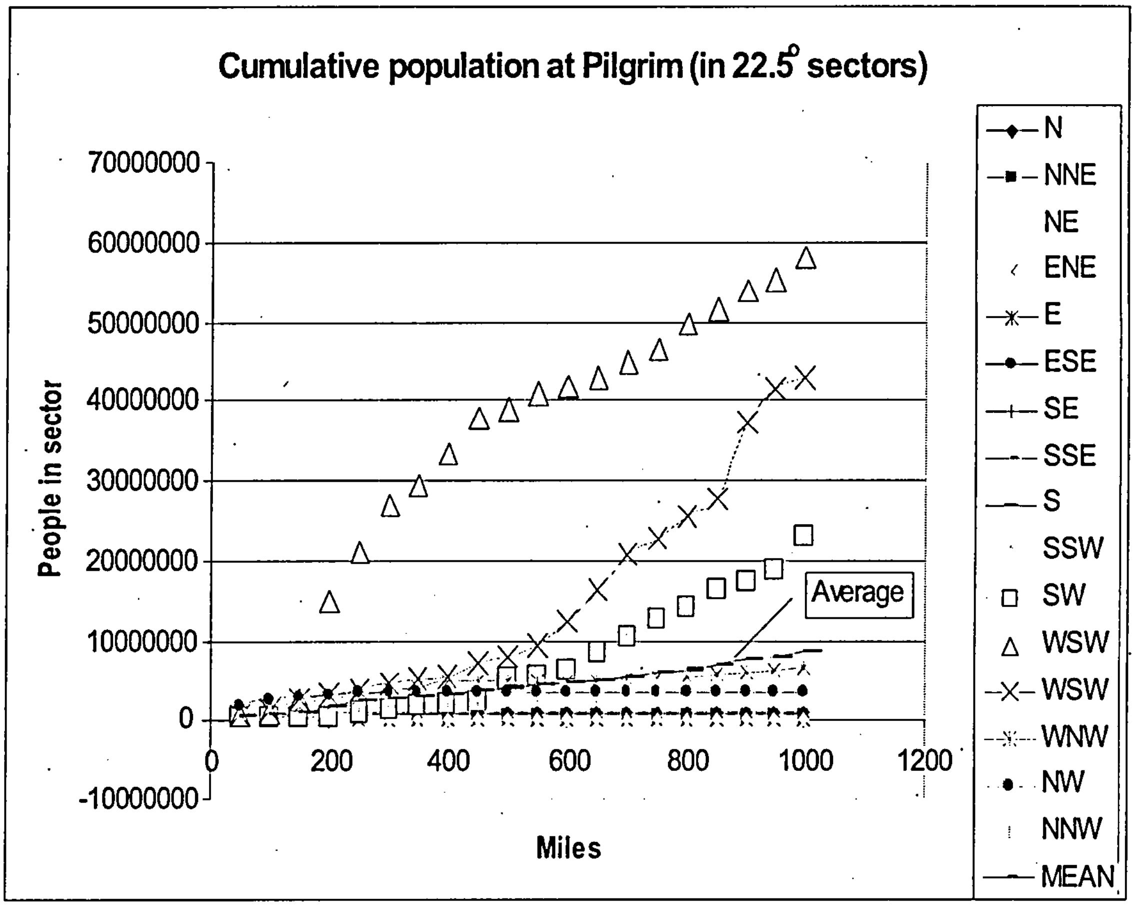


Figure 5: In the wind rose below for Pilgrim, an excess frequency beyond the 4% circle is shown for winds coming from the Southwest, which would blow out over the ocean. Ignoring return flows, such excess flows would not contribute to damage. The excess beyond the 4% circles is about 33% of the total year. Removing this excess leaves a roughly axially-symmetric flow, which matches the assumptions used in the paper by Beyea, Lyman, and von Hippel.

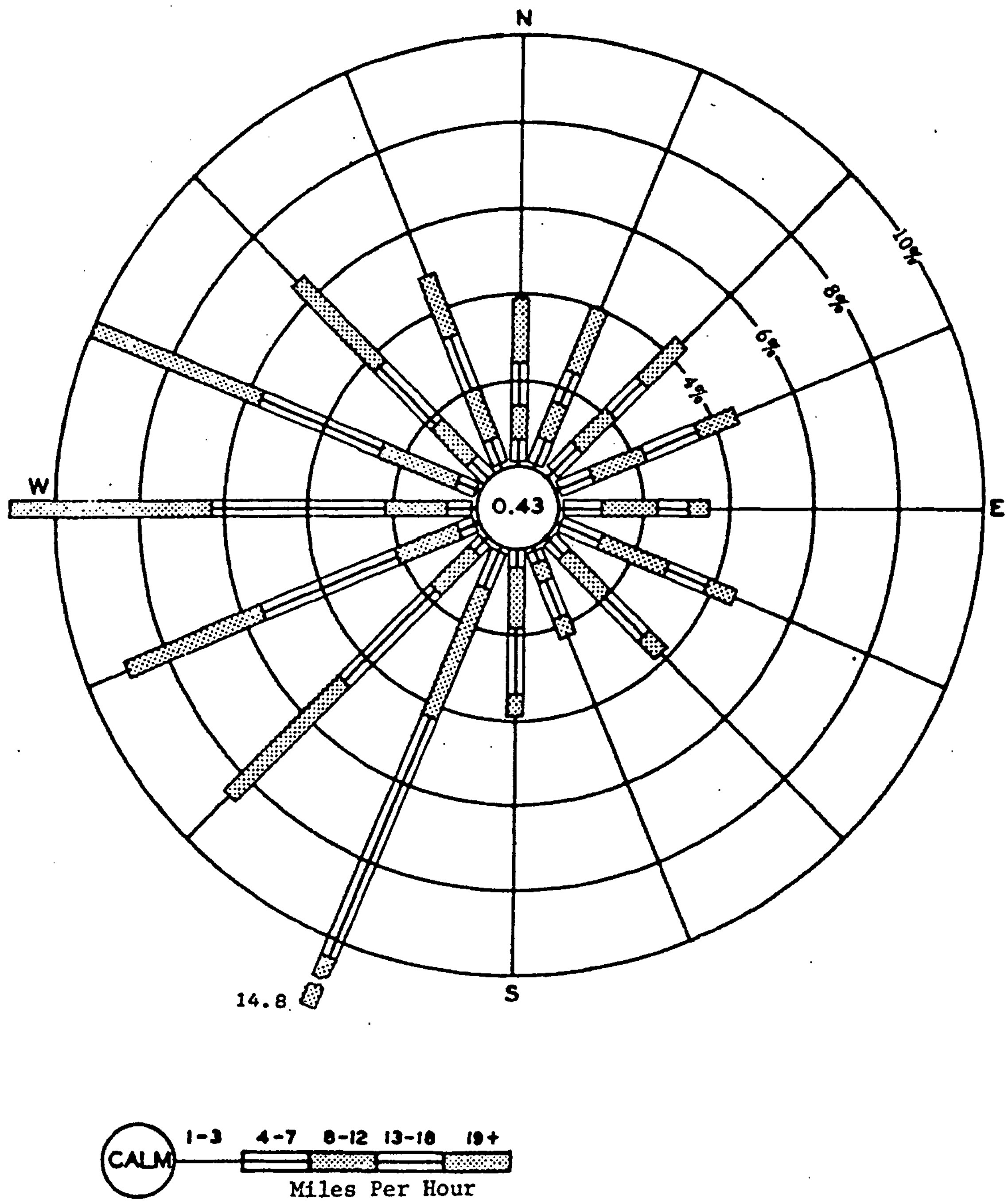


FIGURE 2.3-6
ELEVATION 300 FT. MSL
WIND ROSE ANNUAL
PILGRIM SITE
PILGRIM NUCLEAR POWER STATION
FINAL SAFETY ANALYSIS REPORT