NOTE: This document is being released in draft form to support the Advisory Committee on Reactor Safeguards Full Committee Meeting scheduled for October 2, 2013

MEMORANDUM TO: Chairman Macfarlane
Commissioner Svinicki
Commissioner Apostolakis
Commissioner Magwood
Commissioner Ostendorff

FROM: Michael R. Johnson
Deputy Executive Director for Reactors
and Preparedness Programs
Office of the Executive Director for Operations

SUBJECT: STAFF EVALUATION AND RECOMMENDATION FOR JAPAN LESSONS-LEARNED TIER 3 ISSUE ON EXPEDITED TRANSFER OF SPENT FUEL

PURPOSE:

The purpose of this memorandum is to provide the Commission with information and a recommendation from the staff regarding whether regulatory action is warranted for the expedited transfer of spent fuel to dry cask storage. The staff's assessment, as documented in this memorandum, concludes that the expedited transfer of spent fuel to dry cask storage would neither provide a substantial increase in the overall protection of public health and safety nor sufficient safety benefit to warrant the expected implementation costs. Therefore, the staff recommends that no further generic assessments be pursued related to possible regulatory actions to require the expedited transfer of spent fuel to dry cask storage and that this Tier 3 Japan lessons learned activity be closed.

SUMMARY:

In evaluating whether regulatory action might be warranted to require expedited transfer of spent fuel to dry cask storage, the staff has considered a broad history of NRC oversight of spent fuel storage, spent fuel pool (SFP) operating experience (domestic and international), past studies of SFP safety, and the recent SFP study. To determine whether regulatory action might be warranted, the staff has conducted a regulatory analysis of expedited transfer of spent fuel to dry cask storage in accordance with the NRC's normal decisionmaking process, which is provided in the enclosure. The staff's assessment concludes that the expedited transfer of spent fuel to dry cask storage would neither provide a substantial increase in the overall protection of public health and safety, nor sufficient safety benefit to warrant the expected implementation costs.

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BACKGROUND:

There are a variety of postulated events or conditions that can challenge the ability of a SFP to provide adequate cooling to spent fuel assemblies. A loss of heat removal from the SFP, which might be caused by a loss of electrical power, produces a slowly evolving event that could be mitigated with a high probability of success by plant staff and available equipment. Potentially more serious events involve possible coolant inventory loss resulting from events that cause a loss of pool integrity. These events could be initiated by low likelihood events, such as a large earthquake producing ground accelerations well above those considered in the design of the facility or other mechanisms that result in damage to SFP structures and systems, and could potentially lead to large radiological releases. Common to all event scenarios, significant radiological releases can only result if spent fuel heat loads exceed heat removal such that fuel cladding temperatures are sufficient to cause an ignition of zirconium cladding and resultant fire. This outcome evolves relatively slowly, with time for mitigative and/or protective actions to prevent a release or otherwise ensure public health and safety.

On March 11, 2011, a 9.0-magnitude earthquake struck Japan and was followed by a 45-foot tsunami, which resulted in extensive damage to the nuclear power reactors at the Fukushima Dai-ichi facility. After the onset of core damage in some units, there were significant concerns about the integrity of SFPs and the possible release of radioactive materials from the spent fuel assemblies. However, subsequent inspections determined that pool integrity had been maintained, the integrity of the spent fuel cladding had not been challenged, and equipment to restore coolant inventory was successfully deployed, despite radiological hazards and extensive damage to the surrounding structures from the tsunami and hydrogen explosions. While the SFPs and the spent fuel assemblies at the site remained intact, the event led to questions about the safe storage of spent fuel and whether the NRC should undertake a regulatory action to require expedited transfer of spent fuel to dry cask storage at U.S. nuclear power plants.

In the summer of 2011, the staff initiated a research project entitled, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor." The draft version of this study[1], dated June 2013, can be accessed in the Agencywide Documents Access and Management System (ADAMS) under Accession No. ML13133A132. The purpose of the study—commonly referred to as the SFP study—was to provide additional information to determine if accelerated transfer of spent fuel from the SFP to dry cask storage significantly reduces risks to public health and safety. The study was intended to provide consequence estimates of a hypothetical SFP accident initiated by a low likelihood seismic event at a reference plant for both a fully loaded (high-density) and minimally loaded (low-density) SFP. The SFP study contributed to the resolution of this Tier 3 issue by providing a measure of the change in potential consequences resulting from a change in spent fuel storage density.

In SECY-11-0137, "Prioritization of Recommended Actions To Be Taken in Response to Fukushima Lessons Learned," dated October 3, 2011 (ADAMS Accession No. ML11272A111),

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[1] The recent SFP study will be completed and provided to the Commission on or around the same date as this memorandum. The staff is coordinating these activities such that assessments provided by this memorandum are reflected in the final study.

the staff identified six additional issues that may warrant regulatory action but were not included with the Near-Term Task Force (NTTF) recommendations. One additional issue was the expedited transfer of spent fuel to dry cask storage. The staff judged this issue to warrant further consideration and potential prioritization based on potential safety significance, nexus to NTTF recommendations, and other ongoing staff activities. As directed by a staff requirements memorandum (SRM), SRM-SECY-11-0137, dated December 15, 2011 (ADAMS Accession No. ML113490055), the staff conducted an assessment of whether this issue should be included with the Japan lessons-learned activities and whether any regulatory action is recommended or necessary. The staff applied the same prioritization process described in SECY-11-0137. In SECY-12-0025, "Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami," dated February 17, 2012 (ADAMS Accession No. ML12039A103), the staff prioritized this issue in the Tier 3 category and said it requires further staff study to determine if regulatory action is warranted.

In SECY-12-0095, "Tier 3 Program Plans and 6-Month Status Update in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Subsequent Tsunami," dated July 13, 2012 (ADAMS Accession No. ML12165A092), the staff provided a five-step plan to evaluate whether regulatory action is warranted for the expedited transfer of spent fuel from SFPs into dry cask storage. After submitting the Tier 3 program plan, the staff received direction in several SRMs:

- In SRM M120607C, "Staff Requirements—Meeting with the Advisory Committee on Reactor Safeguards, 9:30 A.M., Thursday, June 7, 2012, Commissioners' Conference Room, One White Flint North, Rockville, Maryland (Open to Public Attendance)," dated July 16, 2012 (ADAMS Accession No. ML121980043), the Commission provided the staff with direction on several topics on additional research activities (e.g., human reliability analysis and comparative assessment to previous SFP studies) that the SFP study should address.

- In SRM-M120807B, "Staff Requirements—Briefing on the Status of Lessons Learned from the Fukushima Dai-ichi Accident, 9:00 A.M., Tuesday, August 7, 2012, Commissioners' Conference Room, One White Flint North, Rockville, Maryland (Open to Public Attendance)," dated August 24, 2012 (ADAMS Accession No. ML122400033), the Commission directed the staff to address international practices related to spent fuel management as part of the Tier 3 program plan for expedited transfer of spent fuel.

In a memorandum to the Commission entitled, "Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," dated May 7, 2013 (ADAMS Accession No. ML13105A122), the staff outlined updated plans for evaluating whether regulatory action is warranted to require licensees to expedite transfer of spent fuel from SFPs to dry cask storage. The staff aligned the ongoing research activities related to the SFP study with the previously established Tier 3 program plan while considering the schedule to support the agency's ongoing waste confidence efforts. The staff's objective with this integration was to facilitate the public's involvement in these activities and related policy issues.

Subsequent to providing the updated schedule and plans to the Commission, the staff determined that the Tier 3 analysis would include a regulatory analysis to help in the decisionmaking process. This paper assesses whether additional studies should be pursued to determine if regulatory action is warranted to expedite transfer of spent fuel to dry cask storage. The staff evaluated a variety of initiating events and their estimated frequencies drawn from previous studies or developed from other existing information using expert judgment. The worst-case outcome is a runaway zirconium oxidation reaction, which was fully considered in the recent SFP study and the enclosed regulatory analysis. The NRC staff used insights from the recent SFP study, along with other references, to estimate the consequences of accidents, which become the averted costs or benefits of possible actions in the regulatory analysis.

DISCUSSION:

In evaluating whether regulatory action might be warranted to require expedited transfer of spent fuel to dry cask storage, the staff has considered a broad history of NRC oversight of spent fuel storage, SFP operating experience (domestic and international), past studies of SFP safety, and the recent SFP study. The NRC's regulatory activities and past studies have shown that SFPs are designed to prevent accidents that could affect the safe storage of spent fuel. The past studies of SFP safety and the SFP study have offered detailed assessments, which provide a structured method for consideration of information in making a regulatory decision. Operating experience has shown that SFPs have safely withstood challenging events, while continuing to maintain structural integrity and a large inventory of coolant to protect the stored fuel.

Design and Licensing

The SFPs at operating U.S. reactors have been designed and licensed to maintain a large inventory of coolant to protect and cool the fuel under accident conditions, including earthquakes. SFPs have been constructed to be robust structures with very thick steel-reinforced concrete walls and floors. The pools' thick walls, floors, and stainless steel liner helps maintain the coolant inventory and protects the fuel from the effects of natural phenomena and accidents. SFPs have generally been configured to protect against a substantial loss of coolant inventory by locating penetrations in the SFP wall above the top of the stored fuel and providing anti-siphon features for piping that extend below the top of the fuel within the pool. Through the NRC's regulatory oversight for all SFPs, the staff has determined that they provide adequate protection against drain-down events and otherwise satisfy regulatory requirements.

Operating Experience

Operating experience with spent fuel storage in pools confirms that SFPs have provided adequate protection of public health and safety. The staff previously completed a detailed review of SFP operating experience in NUREG-1275, Volume 12, "Operating Experience Feedback Report, Assessment of Spent Fuel Cooling," dated February 1997 (ADAMS Accession No. ML010670175), and the staff performs annual reviews of U.S. and international operating experience with spent fuel storage and handling. Early problems with seal leakage around large penetrations above the elevation of the stored fuel have been resolved by seal design changes. Operational issues affecting configuration control of SFP cooling and purification systems also have decreased in frequency. Operating experience reviews have indicated that events involving loss of coolant inventory or loss of forced cooling have had no more than a minor effect on spent fuel storage conditions. The staff is currently in the process of gaining additional perspective on SFP operational experience by participating in international activities such as a Nuclear Energy Agency SFP operating experience working group.

The staff has reviewed information on the effect of large earthquakes on the integrity of SFPs and has determined that the response of the pools maintains safe storage of spent fuel. The staff has reviewed information on SFP performance during the March 11, 2011, Great Tohoku earthquake and the July 16, 2007, Niigataken Chuetsu-Oki earthquake, which affected 20 operating reactors in Japan, including Fukushima Dai-ichi and Kashiwazaki-Kariwa. Of the SFPs at these 20 reactors, there was no observed damage of the SFP structure or any penetrations, and any water loss caused by sloshing resulted in only a minor loss of inventory. A complete discussion of this evaluation is provided in Section 4.3 of the recent SFP study. Additionally, the Mineral, Virginia, earthquake of August 23, 2011, which occurred near the North Anna nuclear power plant and produced ground motions near the design basis for that plant, resulted in neither damage nor loss of water from that plant's SFP.

Recent Regulatory Actions To Enhance Safety

In response to the Fukushima Dai-ichi accident, the staff is currently implementing regulatory actions, which originated from the NTTF recommendations, to further enhance reactor and SFP safety. On March 12, 2012, the staff issued Order EA-12-051, "Issuance of Order To Modify Licenses with Regard to Reliable Spent Fuel Pool Instrumentation," (ADAMS Accession No. ML12054A679), which requires that licensees install reliable means of remotely monitoring wide-range SFP levels to support effective prioritization of event mitigation and recovery actions in the event of a beyond-design-basis external event. Although the primary purpose of the order was to ensure that operators were not distracted by uncertainties related to SFP conditions during the accident response, the improved monitoring capabilities will help in the diagnosis and response to any losses of SFP integrity. In addition, on March 12, 2012, the staff issued Order EA-12-049, "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" (ADAMS Accession No. ML12054A735), which requires licensees to develop, implement, and maintain guidance and strategies to maintain or restore SFP cooling capabilities, independent of alternating current power, following a beyond-design-basis external event. These requirements ensure a more reliable and robust mitigation capability is in place to address degrading conditions in SFPs than was assumed in the recent SFP study. For the purpose of evaluating the potential benefits of expedited transfer of spent fuel to dry cask storage, the enclosed regulatory analysis used a conservative approach to mitigation by crediting successful mitigation to the low-density SFP storage alternative and assuming no successful mitigation for the high-density SFP storage regulatory baseline.

Evaluation of Expedited Transfer of Spent Fuel to Dry Cask Storage

The staff has conducted a regulatory analysis of expedited transfer of spent fuel to dry cask storage, in accordance with the NRC's normal decisionmaking process, using the current agency policies and guidance, which are provided in the enclosure. A regulatory analysis is an analytical tool to help determine if a proposed regulatory action should be implemented. The regulatory analysis provides information to the Commission on whether there is a substantial increase in the overall protection of the public health and safety and whether the direct and indirect costs of implementation are justified in view of that increase in protection. The staff uses the quantitative health objectives (QHO) for the screening criteria in accordance with the "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission" (NUREG/BR-0058), to determine if there is a substantial increase in the overall protection of the public health and safety. The quantitative health objectives are used as a surrogate for the safety goal as outlined in the Commission's policy statement on safety goals for the operation of nuclear power plants. The regulatory analysis also contains estimates of benefits and costs, which are quantified, when possible, together with a conclusion as to whether the proposed regulatory action is cost-beneficial. "Cost-beneficial" means that the benefits of the proposed action are equal to, or exceed, the costs of the proposed action.

To determine if the proposed regulatory action constitutes a substantial increase in the overall protection of the public health and safety, the staff relied on past studies and the recently completed SFP study to inform the regulatory analysis. The staff used bounding or conservative values in the regulatory analysis for several parameters, particularly in the high estimate, to ensure that design, operational, and other site variations among the new and operating reactor fleet were encompassed. These bounding or conservative values were important to encompass the significant variation in the detailed construction of SFPs and the progression of zirconium oxidation in configurations that differ from those considered in the SFP study. Sensitivity studies were also conducted on key factors such as the dollars per person-rem conversion factor and consideration of consequences beyond 50 miles to measure each attribute's effect upon the overall result. The sensitivity of the dollars per person-rem conversion factor is important to consider as it is currently being updated. The sensitivity of consequences beyond 50 miles is important to consider for accidents involving SFP fires as the spread of radioactive materials could extend over long distances. The regulatory analysis uses key insights from operating experience and the recent SFP study, such as the plant damage state for seismic events, probability of a release for specific pool damage states, and the expected amount and type of radioactive material release.

In past SFP studies and the recent SFP study, the staff has evaluated seismic events because they have been identified as the largest risk contributor to SFP safety. Based on the latest seismic hazard curves developed for nuclear power plant sites in the central and eastern United States, the overall estimated frequency of significant spent fuel damage continues to be very low for those facilities. At this time, updated structural and seismic hazard information for operating reactors in the western United States are being developed, as part of NTTF Recommendation 2.1 activities. Considering the robust designs of SFPs, especially in more seismically active areas in the western United States, the staff concludes that public health and safety are adequately protected. At the completion of the NTTF Recommendation 2.1 seismic reevaluation, the staff will confirm that the seismic risk for SFPs are consistent with that considered in the enclosed regulatory analysis. The staff also has not included malevolent acts in this analysis because various studies and regulatory changes implemented following the terrorist attacks of September 11, 2001, have thoroughly considered security issues associated with SFPs. The details of the staff's review of security issues involve sensitive and classified information and are therefore not available to the public.

The outcome of the Tier 3 regulatory analysis indicates that undertaking additional study of the low-density SFP storage alternative is not justified. Except in those cases where action is needed to ensure adequate protection of public health and safety, the process used by the NRC is to consider additional regulatory requirements to assess the potential benefits from such regulations against the costs of implementing new requirements. The potential benefits of a requirement to expedite the transfer of spent fuel to dry cask storage could be to reduce the risk to the public from possible accidents involving SFPs. Assessments of risk and changes in risk from possible actions involve identifying what can go wrong, the possible consequences, and how likely problems are to occur. In the case of hypothetical accidents involving SFPs, the assessments have shown that impacts on public health and safety can, for the most part, be avoided but that the potential economic consequences can be very large. However, the assessments also show that based on the design and construction of SFPs, the characteristics of the spent fuel assemblies, and the availability of mitigating systems, the likelihood of a release of radioactive materials because of an accident affecting an SFP is low. This evaluation of a low probability, high consequence event is similar to previous NRC risk assessments and related regulatory analyses for potential issues related to nuclear reactors and SFPs.

For the NRC to meet its mission to protect public health and safety, provide for the common defense and security, and protect the environment, while also serving as an efficient and predictable regulator, the NRC evaluates proposed regulatory actions in accordance with process and criteria defined in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.109, "Backfitting." As previously discussed, the staff used insights from the recent SFP study and previous studies in an assessment of the potential reductions in risk to public health and safety associated with expediting transfer of spent fuel to dry cask storage. The staff has included in the enclosed analysis an evaluation of the costs and safety benefits associated with expedited transfer of spent fuel (i.e., a backfit analysis) and determined that the proposed regulatory action would not meet existing standards for a cost-justified, substantial safety improvement.

The regulatory analysis also considers not only safety benefits, but wider societal measures, such as averted offsite property damage. The regulatory analysis determines if direct and indirect costs of implementation might be justified in view of any increased protection of public health and safety. As discussed in more detail in the enclosure, the added costs involved with expedited transfer of spent fuel to dry cask storage to achieve the low-density fuel pool storage alternative are not warranted in light of the benefits from such an action. The regulatory analysis includes sensitivity studies and some combinations of high estimates for important parameters resulting in large economic consequences such that, in a few cases, the benefits from expedited transfer of spent fuel to dry cask storage appear to be cost beneficial. However, even in these cases, there is not a substantial safety improvement in terms of public health and safety. In the staff's judgement, it is unlikely that individual plants would meet or exceed the most conservative assumptions made in these sensitivity cases within the regulatory analysis. The staff concludes, therefore, that the expedited transfer of spent fuel to dry cask storage would neither provide a substantial increase in the overall protection of public health and safety, nor sufficient safety benefit to warrant the expected implementation costs.

In addition to assessing whether further studies of expedited transfer of spent fuel to dry cask storage are warranted, the recent SFP study and staff's interactions with stakeholders identified other possible improvements to the storage of spent fuel. Examples include the possible investigation of alternate loading patterns (e.g., the 1 x 8 high-density loading pattern assessed in the SFP study, in addition to the standard 1 x 4 high-density loading pattern), capability of licensees to directly offload fuel into more coolable patterns, and the possible enhancement of mitigation strategies during identified periods when the heat load from recently discharged fuel assemblies is especially high. As described in the enclosure, the staff has taken note of these possible improvements, but determined that they do not provide a substantial safety enhancement such that it could recommend pursuing generic regulatory action.

International Practices and Public Involvement

As directed in SRM-M120807B, the staff assessed international practices related to spent fuel storage and determined that current U.S. fuel storage practices are consistent with international practices. Although commercial U.S. operating reactor sites typically have greater inventories of fuel stored on site than otherwise comparable foreign reactors, this principally reflects the longer period of operation and the high capacity factors that U.S. operators have achieved. Countries with options for centralized storage, either in preparation for disposal (e.g., Sweden) or reprocessing (e.g., England, France, and Japan), have nevertheless adopted high-density storage at reactor sites. The staff's review did not identify any country with an explicit policy for early transfer of fuel to dry or centralized storage to maintain low density storage in the onsite SFPs.

To provide additional insights on the need for regulatory action, the staff interacted with various stakeholders. The nuclear industry provided insights to the staff through various interactions and also through reports prepared by the Electric Power Research Institute. Several nongovernmental organizations and individuals provided correspondence and attended public meetings to give information to the staff. Public meetings were held on August 22, 2013 (meeting summary in ADAMS under Accession No. ML13253A162), and September 18, 2013 (meeting summary to be added to ADAMS) to provide stakeholders a forum for discussing and asking questions about the recent SFP study, provide an overview of the regulatory analysis conducted in this paper, and solicit feedback. Most of the individuals and organizations participating in the meetings said they favored expedited transfer of spent fuel to dry cask storage. The industry provided its views that spent fuel is continuing to be stored safely in SFPs. A transcript of the September 18, 2013, public meeting will be added to ADAMS. The staff considered this stakeholder feedback in the development of this paper. Additionally, on October 2, 2013, the staff briefed *the Office of the Advisory Committee on Reactor Safeguards (ACRS)* on the results of its assessments and evaluations, as well as the resulting conclusions and recommendations. In their letter (to be added to ADAMS), the ACRS provided its own recommendations and views on the staff's recommendations.

The staff has undertaken this activity with thorough consideration of the agency's activities on the waste confidence generic environmental impact statement (GEIS) and rulemaking, and it has ensured that the availability of these documents and interactions with stakeholders are coordinated to facilitate the public's involvement in these activities. Although this Tier 3 analysis was not specifically referenced in the draft GEIS, the staff is aware of the conclusions in this analysis and has coordinated the preparation of the relevant sections of the draft GEIS. To ensure that the public is aware of these activities, the recent SFP study was released for public review and comment on July 1, 2013, and the evaluation of this Tier 3 issue is being publicly released before the conclusion of the draft GEIS public comment period.

Staff Recommendation

The staff's assessment concludes that the expedited transfer of spent fuel to dry cask storage would neither provide a substantial increase in the overall protection of public health and safety nor sufficient safety benefit to warrant the expected implementation costs. Therefore, the staff recommends that no further generic assessments[2] be pursued related to possible regulatory actions to require the expedited transfer of spent fuel to dry cask storage and that this Tier 3 Japan lessons learned activity be closed.

SECY, please track.

Enclosure:
Regulatory and Backfitting Analysis
for Expedited Transfer of Spent Fuel

cc: SECY
OCA
OGC
OPA
CFO

[2] The staff will confirm that the seismic risk for western nuclear power plant spent fuel pools are consistent with that considered in the enclosed regulatory analysis at the completion of the NTTF Recommendation 2.1 seismic reevaluation activity.

REGULATORY AND BACKFITTING ANALYSIS FOR JAPAN LESSONS LEARNED TIER 3 ISSUE ON EXPEDITED TRANSFER OF SPENT FUEL

U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation

FOREWORD

On March 11, 2011, the Tohoku earthquake and subsequent tsunami in Japan resulted in significant damage to the site of the Fukushima Dai-ichi nuclear power station. Although the spent fuel pools and the used fuel assemblies stored in the pools remained intact at the plant, the event led to questions about the safe storage of spent fuel and whether the U.S. Nuclear Regulatory Commission (NRC) should require the expedited transfer of spent fuel from pools to dry cask storage containers at U.S. nuclear power plants.

This regulatory analysis evaluates whether regulatory action is needed to require expedited transfer of spent fuel to dry cask storage. This analysis was undertaken to support development of a technical basis for the program plan described in a memorandum to the Commission, "Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," dated May 7, 2013.

The results of this analysis are consistent with the conclusions of past studies that the risk at spent fuel pools is low and well within the Commission's Quantitative Health Objectives. The NRC continues to believe, based on this analysis and previous studies, that spent fuel pools protect public health and safety.

EXECUTIVE SUMMARY

This report evaluates whether regulatory action is needed to require expedited transfer of spent fuel to dry cask storage. This analysis was undertaken to support development of a technical basis for the program plan described in a memorandum to the Commission, “Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel,” dated May 7, 2013 (Ref. 76).

The staff published a draft study in June 2013 (Ref. 2) for public comment that continued its examination of the risks and consequences of postulated spent fuel pool accidents. The purpose of this consequence study was to determine if accelerated transfer of older, colder spent fuel from the spent fuel at a reference plant to dry cask storage significantly reduces risks to public health and safety. The specific reference plant used for this study is a General Electric (GE) Type 4 boiling-water reactor (BWR) with a Mark I containment.

This draft study’s results are consistent with earlier research conducted over the last several decades and summarized in NUREG-1353, “Regulatory Analysis for the Resolution of Generic Issue 82, Beyond-Design-Basis Accidents in Spent Fuel Pools,” dated April 1989; in NUREG/CR-6451, “A Safety and Regulatory Assessment of Generic BWR and PWR [pressurized-water reactor] Permanently Shutdown Nuclear Power Plants,” dated April 1997, and in NUREG-1738, “Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants,” dated February 2001.

The risk estimates contained in this analysis are based on accidents initiated by random equipment failures, human errors, or external events. The risk from the storage of spent fuel in the spent fuel pool is dominated by the beyond-design-basis earthquake accident scenario with peak ground accelerations greater than 0.7g (the acceleration due to Earth’s gravity, or g-force). The seismic event contributes a significant majority to the BWR and PWR spent fuel damage frequency. Western plants (including Columbia, Diablo Canyon, Palo Verde, and San Onofre) were not included in the Generic Safety Issue (GSI)-199 seismic hazard studies, which focused on the central and eastern United States, and were not evaluated by this analysis. Based on the latest hazard characterization, seismic hazard curves developed for nuclear power plant sites in the central and eastern United States show that the overall estimated frequency of significant spent fuel damage continues to be very low for those facilities. At this time, updated structural and seismic hazard information for operating reactors in the western United States are being developed, as part of the Near-Term Task Force (NTTF) recommendation 2.1 activities. By contrast, this analysis and the supporting references, in general, do not include events caused by sabotage. No established method exists for estimating the likelihood of a sabotage event, nor for analyzing the effect of security provisions on that likelihood. Security regulations are designed and structured to prevent sabotage on the assumption that the design basis threat could occur at commercial nuclear power plants without assessing the actual probability or consequences. As such, no information in this analysis bears on the level of security necessary to limit the risk from sabotage events. Those decisions will continue to be made by an analytical assessment of the level of threat and the difficulty of protecting a specific facility.

The source term for the spent fuel pool accident is not the same as the source term associated with core damage accidents. The consequences of a spent fuel pool accident, which results in the loss of cooling or the loss of pool water inventory and a radiological release, are dominated by the long-lived isotopes, such as cesium. The health consequences are dominated by the risk of latent cancer fatalities caused by long-term exposure.

Operator diagnosis and recovery are important factors considered in the development of the event frequencies for the successful mitigation of accident events. Success is premised on licensees having taken appropriate actions to understand the potential consequences of spent fuel pool accident events and develop appropriate procedures and mitigating strategies to respond and mitigate the consequences. The June 2012 draft study evaluated the potential benefits of mitigation measures required under Title 10 of the *Code of Federal Regulations* (10 CFR) 50.54(hh)(2), which were implemented following the September 11, 2001 attacks. Additionally, the post-Fukushima mitigation required by U.S. Nuclear Regulatory Commission (NRC) in Orders EA-12-051 and EA-12-049 and currently being implemented by all U.S. nuclear power plants should serve to further reduce spent fuel pool accident risk by increasing the capability of nuclear power plants to mitigate beyond-design-basis external events further reducing the frequency of a spent fuel pool accident release. This regulatory analysis used a conservative approach to mitigation by crediting successful mitigation to the low-density spent fuel pool storage alternative and assuming no successful mitigation for the high-density spent fuel pool storage regulatory baseline.

The risks associated with a severe spent fuel pool accident are compared to the objectives and guidance in the Safety Goal policy Statement. Despite the fairly large releases for the spent fuel pool accident progressions analyzed, the consequence analysis for the Spent Fuel Pool Study indicates there is little potential for offsite early fatalities from acute radiation effects. The results also showed that the risk of an individual dying from cancer from the radioactive release is very low. When including the very low likelihood of a release, the risk in the analyzed scenarios that an average individual within 16 kilometers (10 miles) receives a fatal latent cancer is about two in a billion per year. The risks are similar between different loading or mitigation scenarios because of modeled offsite protective actions that include evacuation, sheltering, relocation, and decontamination. Additionally, these individual risks are dominated by long-term exposures to very lightly contaminated areas for which doses are small enough for the areas to be considered habitable

In order to determine whether the proposed regulatory action might constitute a cost--justified substantial safety improvement, the staff relied on past studies and the recently completed SFPS to inform the regulatory analysis. The staff generally used bounding or conservative values in the regulatory analysis for several parameters, particularly in the high estimates, to ensure that design, operational and other site variations among the new and operating reactor fleet were encompassed. The staff's use of conservative estimates and assumptions is considered appropriate for this assessment because the decision being supported is whether or not additional studies are warranted to further explore possible regulatory actions to require expedited transfer of spent fuel (i.e., Phase 2 of the program plan as described in the memorandum to the Commission dated May 7, 2013). If the Commission were to direct additional study of possible regulatory actions related to spent fuel storage alternatives, the staff would revisit and likely revise the conservative assumptions used in this analysis.

Therefore, the staff has determined that the criteria that a substantial increase in the overall protection of the public health and safety is achieved contained within 10 CFR 50.109, "Backfitting," is not met, and Alternative 1—Regulatory Baseline is recommended.

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ABBREVIATIONS AND ACRONYMS

ADAMS	Agencywide Documents Access and Management System
Bq	becquerel
BLS	Bureau of Labor Statistics
BWR	boiling-water reactor
CDF	core damage frequency
CEUS	central and eastern United States
CFR	*Code of Federal Regulations*
CoC	certificate of compliance
CPI-U	consumer price index—all urban consumer inflator
Cs	cesium
DOE	U.S. Department of Energy
DSC	dry storage cask systems
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FR	*Federal Register*
FTE	full-time equivalent
GMPE	ground motion prediction equation
GWd	gigawatt-day
ISFSI	independent spent fuel storage installation
LCF	latent cancer fatality
LERF	large early release frequency
LNT	linear no-threshold
LOOP	loss of offsite power
MACCS2	MELCOR Accident Consequence Code System, Version 2
MELCOR	(not an acronym)
MTU	metric ton heavy metal or metric ton uranium
MW_t	megawatt thermal
NPV	net present value
NRC	Nuclear Regulatory Commission
NTTF	Near-Term Task Force
OCP	operating cycle phase
OMB	Office of Management and Budget
ORIGEN	(not an acronym)
PAG	protective action guides
PGA	peak ground acceleration
PRM	petition for rulemaking
PSHA	probabilistic seismic hazard assessment
RA	regulatory analysis
SCALE	(not an acronym)

SFP	spent fuel pool
SRM	staff requirements memorandum
USGS	U.S. Geological Survey
VSL	value of a statistical life

1. INTRODUCTION

This document, which is organized into six sections, presents the regulatory analysis and backfitting discussion to determine the safety benefit of expedited transfer of spent fuel from spent fuel pools to dry storage facilities at any U.S. nuclear power plant.

- Section 1 describes the nature of the problem and provides a clear statement of the objective of the proposed analysis.
- Section 2 describes and clearly explains the alternative approaches considered.
- Section 3 describes spent fuel pool characteristics, design differences, and operational strategies employed for the population of spent fuel pools covered by this analysis, which affects the alternatives evaluated.
- Section 4 describes the attributes affected, the methodology used to evaluate benefits and costs, the analysis model, key data and assumptions, and results for the alternatives evaluated.
- Section 5 presents the analytical results and findings including discussion of supplemental considerations, uncertainties in estimates, and results of sensitivity analyses on the overall costs and benefits.
- Section 6 presents the preferred alternative and the basis for selection, discusses any decision criteria used, identifies and discusses the regulatory instrument to be used (as applicable), and explains the statutory basis for the action.

1.1 Statement of the Problem

United States nuclear power plants store spent fuel in pools for varying periods of time using a high-density configuration. Various risk studies (such as NUREG-1738, “Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants,” February 2001 (Ref. 54)) have shown that storage of spent fuel in a high-density configuration in spent fuel pools is safe and that the risk of accidental release of a significant amount of radioactive material to the environment is appropriately low. These studies used simplified and sometimes bounding assumptions and models to characterize the likelihood and consequences of beyond-design-basis spent fuel pool accidents.[3] As part of the U.S. Nuclear Regulatory Commission’s (NRC’s) post-9/11 security assessments, spent fuel pool modeling using detailed thermal-hydraulic and severe accident progression models integrated into the MELCOR code were developed and applied to assess the realistic heatup of spent fuel under various pool draining conditions. Moreover, in conjunction with these post-9/11 security assessments, the NRC issued a new regulation in 2009, Title 10 of the *Code of Federal Regulations* (10 CFR) 50.54(hh)(2) (Ref. 33), that requires reactor licensees to develop and implement guidance and strategies intended, in part, to maintain or restore spent fuel pool cooling capabilities following certain beyond-design-basis events.

[3] An overview of previous studies is provided in section 10.2 to the Spent Fuel Pool Study (Ref. 2).

Recently, the agency has restated its views on the safety of spent fuel stored in high-density configurations in a response to Petition for Rulemaking (PRM)-51-10 (Ref. 25) and PRM—51-12 (Ref. 27) (73 FR 46204, August 8, 2008) as well as the revision to NUREG-1437, “Generic Environmental Impact Statement for License Renewal, Draft Report for Comment” (Ref. 44). However, this position relies, in part, on the findings of the aforementioned security assessments, which are not publicly available. The Federal Government’s decision to stop work on a deep geologic repository at Yucca Mountain and the events in Japan following the March 2011 earthquake have rekindled public and industry interest in understanding the consequences from postulated accidents associated with high-density spent fuel pool storage and the relative benefits of low-density spent fuel pool storage. This analysis quantifies the health and safety benefits, if any, from moving from high-density to low-density spent fuel pool storage and then assesses whether the benefits are cost-justified and substantial enough to justify a backfit to impose new requirements on any licensee.

In response to these recent events, the staff has determined that it should confirm that high-density spent fuel pool configurations continue to provide adequate protection and assess whether any safety benefits (or detriments) would occur from expedited transfer of spent fuel to dry cask storage, as described in a memorandum to the Commission, “Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel,” (Ref. 77).

The purpose of this regulatory analysis is to help ensure that:

- Appropriate alternatives to accomplish regulatory objectives are identified and analyzed.
- No clearly preferable alternative is available to the recommended action.
- The costs of implementation of any recommended action are justified by its effect on overall protection of the public health and safety.

1.1.1 Objective of Proposed Action

The Fukushima Dai-ichi accident, in Japan, was the result of a tsunami that exceeded the plant’s design basis and flooded the site’s emergency power supplies and electrical distribution system. This extended loss of power severely compromised the key safety functions of core cooling and containment integrity and ultimately led to core damage in three reactors. While the loss of power also impaired the spent fuel pool cooling function, sufficient water inventory was maintained in the spent fuel pools to preclude fuel damage from loss of cooling.

The size of a tsunami that hit Fukushima Dai-ichi was being evaluated by Tokyo Electric Power Company before 2011, and was not currently addressed in that plant’s design basis (Ref. 13). Although the ability to predict the magnitude and frequency of beyond-design-basis external events such as earthquakes and floods may be improving, and design bases for plants include some margin, some probability will always remain for a beyond-design-basis external event. As a result, though unlikely, external events could exceed the assumptions used in the design and licensing of a plant, as demonstrated by the events at Fukushima.

Following the March 2011 accident at the Fukushima Dai-ichi nuclear power plant in Japan that resulted after the Tohoku earthquake and subsequent tsunami, several stakeholders submitted comments to the Commission and staff requesting that regulatory action be taken to require the expedited transfer of spent fuel stored in spent fuel pools to dry cask storage. The rationale was that transferring the spent fuel to dry storage would lessen the potential consequences associated with a loss of spent fuel pool water inventory by decreasing the amount of spent fuel stored in these pools and, thereby, decreasing the heat generation rate and radionuclide source term associated with the spent fuel in pool storage. Furthermore, certain stakeholders have requested regulatory action to change the design of the fuel storage racks to an open-frame design that would not interfere with horizontal cooling flow, unlike current rack designs.

As directed by the Commission in SRM-SECY-12-0025, dated March 9, 2012 (Ref. 32), the staff has undertaken regulatory actions that originated from the NRC Near Term Task Force (NTTF) recommendations to enhance reactor and spent fuel pool safety. On March 12, 2012, the staff issued Order EA-12-051 (Ref. 74), which requires that licensees install reliable means of remotely monitoring wide-range spent fuel pool levels to support effective prioritization of event mitigation and recovery actions in the event of a beyond-design-basis external event. Although the primary purpose of the order was to ensure that operators were not distracted by uncertainties related to spent fuel pool conditions during the accident response, the improved monitoring capabilities will help in the diagnosis and response to any losses of spent fuel pool integrity. In addition, the staff issued Order EA-12-049 (Ref. 73), which requires that licensees develop, implement, and maintain guidance and strategies to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities following a beyond-design-basis external event. These requirements ensure a more reliable and robust mitigation capability is in place to address degrading conditions in spent fuel pools than was assumed in the Spent Fuel Pool Study (SFPS). For the purpose of evaluating the potential benefits of reducing the amount of spent fuel stored in storage pools, the enclosed regulatory analysis used a conservative approach to mitigation by crediting successful mitigation to the low-density spent fuel pool storage alternative and assuming no successful mitigation for the high-density spent fuel pool storage regulatory baseline.

This analysis uses information contained within the “Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor” (SFPS) for its structural analysis and related damage characterization, its accident progression analysis, and it offsite consequences analysis. These results are supplemented with results from previous studies to broaden the assessment to generically address the spent fuel pool risk at multiple facilities.

This analysis calculates the potential benefit per reactor year resulting from expedited fuel transfer by comparing the safety of high-density fuel pool storage relative to low-density fuel pool storage and related alternatives. The comparison uses the initiating frequency and consequences from the SFPS as an indicator of any changes in the NRC’s understanding of safe storage of spent fuel following a beyond-design-basis seismic event. The staff also used calculated results from previous spent fuel pool studies (i.e., NUREG-1353 and NUREG-1738) to extend the applicability of this evaluation to include other initiators, which could challenge spent fuel pool cooling or integrity and incorporated inputs representing the range of U.S. spent fuel pool characteristics to extend the analysis applicability to spent fuel pools within other U.S. reactor designs.

2. IDENTIFICATION AND PRELIMINARY ANALYSIS OF ALTERNATIVE APPROACHES

This section presents the analysis of the alternatives that the U.S. Nuclear Regulatory Commission (NRC) considered to address the problem identified in the previous section.

The alternatives considered may be classified into one of two categories, reflecting the fashion in which the alternative affects risk. A preventive option is one intended to reduce the frequency of conditions potentially conducive to the release of fission products from the spent fuel assemblies. Therefore, an alternative intended to reduce the likelihood of the loss of spent fuel pool integrity following a seismic event, or to reduce the unavailability of the spent fuel pool cooling systems is a preventive alternative. An alternative intended to reduce the magnitude of the consequences that would result from a selected set of accident sequences is a mitigative alternative, which is generally achieved through reduction of radioactive material susceptibility for environmental radiological release.

Given the occurrence of a spent fuel pool accident initiator, there exists the potential to arrest the progression of the accident at various stages of its development. For example, in the event of loss of spent fuel pool cooling and the gradual boil-off of pool water inventory, accident preventive measures taken to increase the reliability of inventory makeup will have direct impact upon the risk profile of such a sequence.

Given a loss of spent fuel pool water inventory and the uncovery of spent fuel assemblies, measures taken to reduce the likelihood of the subsequent initiation of self-sustaining clad oxidation will reduce the risk profile of pool draindown events. The placement of the spent fuel into a lower density storage pattern is assessed in this regulatory analysis. This change in the fuel storage pattern may require a reduction in the amount of fuel stored in the pool, but the change allows the fuel to be air-cooled under a substantially greater spectrum of conditions as a result of the enhanced air flow. Similarly, application of spray flow can provide direct water cooling of the fuel and prevent a release under a broad range of conditions that expose the fuel.

Finally, given the loss of water inventory with the possibility of spent fuel uncovery and the onset of clad degradation, accident mitigative measures may be taken to minimize the subsequent release of radioactive fission products. These accident mitigative measures include changes in the configuration of the stored fuel to reduce the release of radioactive materials when air cooling is not adequate and implementation of spent fuel pool spray capabilities in a manner that removes radioactive aerosols from the air.

The NRC considered the regulatory baseline and one alternative to change this baseline as discussed below.

2.1 Alternative 1—Regulatory Baseline—Maintain the Existing Spent Fuel Storage Requirements

This proposed alternative reflects a Commission decision not to expedite the storage of spent fuel to dry cask storage, but to continue with the NRC's existing licensing requirements for spent fuel storage. Under this alternative, spent fuel is moved into dry cask storage only as necessary to accommodate fuel assemblies being removed from the core during refueling operations. Spent fuel pool capacity specifications are to allow sufficient empty space in the pool for removal of one full core of reactor fuel in case of emergencies (referred to as full core discharge) or other operational contingencies. It also assumes that all applicable requirements and guidance to date have been implemented, there are no unevaluated degraded or nonconforming conditions, and no implementation is assumed for related generic issues or other staff requirements or guidance that is unresolved or still under review.

The condition represented by this alternative is the storage of spent fuel in high-density racks[4] in the spent fuel pool, a relatively full spent fuel pool, and compliance with all current regulatory requirements. The regulatory requirements include design features intended to prevent a substantial loss in water inventory under accident conditions and those requirements for emergency abnormal conditions associated with the following:

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.54(hh)(2) (Ref. 33) with respect to spent fuel configuration and spent fuel pool preventive and mitigative capabilities

- Order EA-12-049 (Ref. 73), which requires licensees to develop, implement, and maintain guidance and strategies to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities following a beyond-design-basis external event

- Order EA-12-051 (Ref. 74), which requires licensees to install reliable means of remotely monitoring wide-range spent fuel pool levels to support effective prioritization of event mitigation and recovery actions in the occurance of a beyond-design-basis external event

Furthermore, because spent fuel pools have a limited amount of available storage, even after licensees expanded their storage capacity using high-density storage racks, the current practice of transferring spent fuel to dry storage in accordance with 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste" (Ref. 36) is assumed to continue.[5] This alternative represents the baseline for estimating the incremental costs of the other alternatives considered.

2.2 <u>Alternative 2—Low-Density Spent Fuel Pool Storage</u>

This proposed alternative would require older spent fuel assemblies[6] to be expeditiously moved from spent fuel pool storage to dry cask storage beginning in year 2014 to achieve and maintain

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[4] Most nuclear power plant spent fuel pools were originally designed for temporary storage of spent fuel. Starting in the 1980s, most pools were "re-racked" to use hardware that stores the assemblies in a more closely spaced arrangement, thus allowing the storage of more assemblies in a high-density configuration.

[5] Maintenance of the existing spent fuel pool storage requirements would not limit the Commission's authority to add new requirements or update regulatory guidelines, as necessary. These actions and activities are a part of the regulatory baseline. However, these activities would be pursued as separate regulatory actions to resolve particular technical issues. Under this alternative, the NRC would take no action to require facilities to expedite the movement of spent fuel to achieve low-density loading in the spent fuel pool.

[6] Older spent fuel assemblies are those that have been placed in the spent fuel pool to cool for at least 5 years after discharge from the reactor core.

a low-density loading of spent fuel in the existing high-density racks as a preventive measure. Because of the low-density spent fuel pool loading, this alternative has less long-lived radionuclide inventory in the spent fuel pool, a lower overall heat load in the pool, and a slight increase in the initial water inventory that displaces the removed spent fuel assemblies.

Because of the uncertainty associated with the schedule for the availability of a spent fuel repository, many plants have plans to have sufficient onsite storage capacity (in-pool capacity and dry storage) to store all of the spent fuel discharged over the operating life of the plant until sufficient repository capacity becomes available. As of early 2013, all but five of the 65 U.S. sites with operating nuclear power reactors had either built or were seeking licenses to build dry storage facilities (Ref. 62).

As a result, the analyzed incremental increase in costs result primarily from the increase in net present value cost for the early transfer of spent fuel into dry storage resulting from the earlier capital costs for new casks and for a dry storage facility.

An additional seven storage facilities are located at sites where reactors are no longer operating, and one independent storage pool is located in Morris, IL, at a reprocessing plant that never operated.

Recently, U.S. citizens groups concerned about the hazards of nuclear power have indicated that they prefer onsite storage to the reprocessing of spent fuel and, in most cases, to central storage, which involves transport. They have called for spent fuel to be placed in onsite dry casks after, at most, 5 years of cooling in spent-fuel pools.

The staff recognizes that there are cost and risk impacts associated with the transfer of spent fuel from the spent fuel pool to cask storage and during long-term cask storage.[7] These cost and risk impacts, if included, would reduce the overall net benefit of this alternative in relation to the regulatory baseline. These effects (e.g., the added risks of handling and moving casks) were conservatively ignored to calculate the potential benefit per reactor year by only comparing the safety of high-density fuel pool storage relative to low-density fuel pool storage and its implementation costs. If the Commission were to direct additional study of possible regulatory actions related to spent fuel storage alternatives (i.e., Phase 2 of program plan described in memorandum to Commission dated May 7, 2013), the staff would address these and other conservatisms used in this analysis.

3. SPENT FUEL POOL CHARACTERISTICS AND OPERATION STRATEGIES

3.1 Spent Fuel Pools

3.1.1 Spent Fuel Pool Configurations

[7] EPRI report TR-1021049 (Ref. 9) assesses the cost and risk impacts (from a worker dose perspective) associated with transfer of spent nuclear fuel from spent fuel pools to dry storage after 5 years of cooling. The report concludes that expedited fuel movement would result in an increase cost to the U.S. nuclear industry of $3.6 billion, with the increase primarily related to the additional capital costs for new casks and construction costs for the dry storage facilities.

The configuration of spent fuel storage pools is similar for most nuclear reactor and away-from-reactor storage facilities. The pools are rectangular in cross section and approximately 12 meters (40 feet) deep. Fuel assemblies are placed vertically in storage racks that maintain an adequate spacing to prevent criticality and to promote natural convective cooling in a water medium. The pools themselves are constructed of reinforced concrete with sufficient thickness to meet radiation shielding and structural requirements, and are lined with stainless steel plates of approximately 2.5-center (1/4-inch) thickness to ensure a leak-tight system.

3.1.1.1 Boiling-Water Reactors with Mark I and Mark II Containments

Boiling-water reactors (BWRs) with Mark I and Mark II containments are designed with the spent fuel pool located within the reactor building as shown in Figure 1. The bottom of the spent fuel pool is usually elevated approximately 15 meters (50 feet) above grade, which places the top of the pool at the level of the operating floor. The enclosing superstructure above the pool is typically a low-leakage steel, industrial-type building designed to house cranes that are used to move reactor components, spent fuel, and spent fuel casks. For a few reactor buildings, the enclosing superstructure is a reinforced concrete structure with strength similar to the lower portions of the reactor building, as depicted in Figure 1.

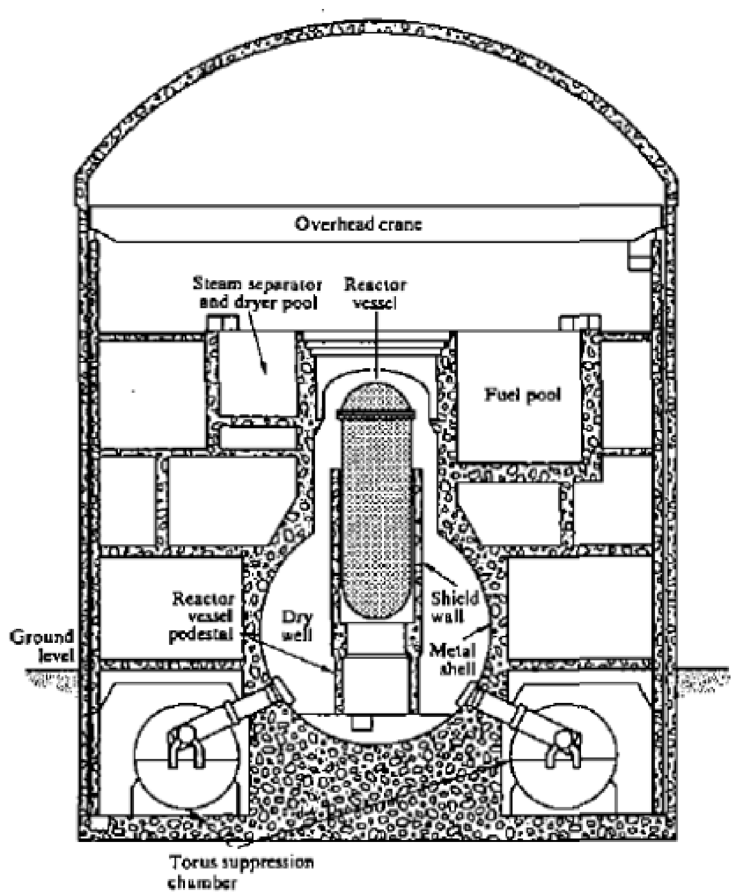

Figure 1 Schematic of a GE BWR Mark I reactor layout

Source: Lamarsh, Figure 11.3 (Ref. 18).

3.1.1.2 Pressurized-Water Reactors and Boiling-Water Reactors with Mark III Containments

Figure 2 shows the location of the spent fuel pool for the newer BWR Mark III design, which call for a ground-level storage pool to reduce seismic loads. The fuel building is located adjacent to the reactor building and is accessible for fuel servicing during plant operation. A lined fuel pool is used for the storage and servicing of spent fuel and the preparation of new fuel for insertion into the reactor. An area of the pool, separated by gates, is used for transfer of fuel to the reactor servicing pools located in the reactor building, and the receiving of spent fuel discharged from the reactor using a transfer tube. Another area of the fuel storage pool, also separated by gates, is used for the loading and decontamination of equipment and its containers for offsite shipping. Some of these spent fuel pools are located below grade.

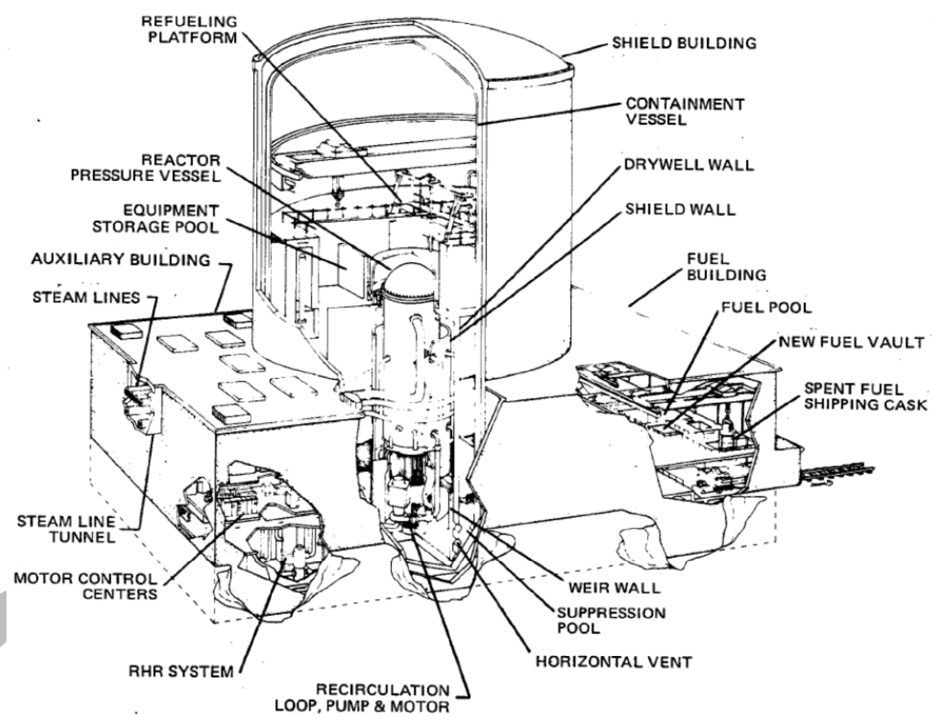

Figure 2 Schematic of a BWR Mark III reactor layout

Source: BWR/6 General Description of a Boiling Water Reactor, Figure 7-1 (Ref 1).

Pressurized-water reactor (PWR) designs have spent fuel pools that are located close to grade level within the auxiliary building as shown in Figure 3. This design is typical of the fuel pool arrangement for PWRs.

Nuclear power plant sites that contain two PWR reactors are usually arranged in a mirror image fashion, with the two spent fuel pools (or a shared pool) located in a common area adjoining both reactor buildings or contained within the seismic Category I auxiliary building around or adjacent to the containment building. For single plant or two-plant arrangements, the building covering the spent fuel pool and crane structures is typically an ordinary steel industrial building.

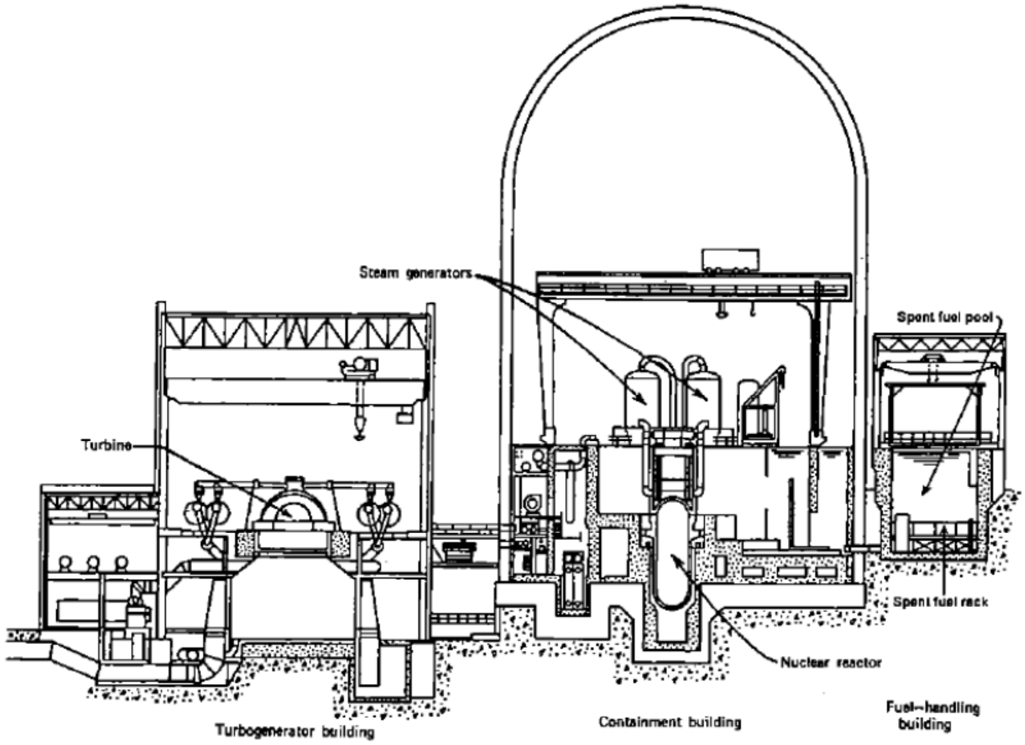

Figure 3 Schematic of a PWR layout

Source: Duderstadt and Hamilton, Figure 3-4 (Ref. 5).

3.1.1.3 New Reactors

For the new reactors, the spent fuel storage facility is located within the seismic Category I auxiliary building fuel handling area. The walls of the spent fuel pool are an integral part of the seismic Category I auxiliary building structure as shown in Figure 4. The facility is protected from the effects of natural phenomena, such as earthquakes, wind and tornados, floods, and external missiles.

Figure 4 Schematic of an AP1000 reactor layout

Source: Nuclear Street (Ref. 23).

3.1.1.4   Spent Fuel Pools at Non-Operating Plants

A spent fuel pool at non-operating plants is a special situation in which the reactor unit is no longer operating and spent fuel is stored in the unit's spent fuel pool for safe storage until it is placed in an ISFSI or shipped to a long-term Federal repository.

Based on the characteristics of the spent fuel pools in this grouping, analysis performed for the operating nuclear power plant pools bound the consequences from this grouping of pools. No further analysis is performed in this regulatory analysis for this grouping.

3.1.1.5   Decommissioned Plant Spent Fuel

A decommissioned plant spent fuel is a special situation in which the licensee requested a license for an independent spent fuel storage installation (ISFSI) to store the reactor unit's spent fuel. The spent fuel was relocated from wet storage in a spent fuel pool to dry storage containers at the ISFSI. The spent fuel will be held at the ISFSI until the U.S. Department of Energy is prepared to take possession of the spent fuel and transport it to a long-term repository.

This grouping also includes the GE–Hitachi Morris ISFSI, which is a wet pool storage design and is the only wet ''away from reactor'' ISFSI of its kind in the United States. The major components of the Morris ISFSI I include the stainless steel lined concrete storage basins, the pool structure, the spent fuel storage grid structure and fuel storage baskets that can store BWR spent fuel assemblies or PWR spent fuel assemblies, ancillary equipment necessary for the movement of spent nuclear fuel, e.g., cranes and basket grappling devices, and equipment necessary for the maintenance of the pool water quality and level (Ref.44). Because of the length of time that the discharged spent fuel stored at the Morris ISFSI has cooled, the licensee estimates that, based on evaporation rates, it will take approximately 140 days for the water level to expose the top of the stored fuel bundles (Ref. 41). Furthermore, there is not sufficient energy in the stored fuel assemblies to ignite the fuel from either a partial or total loss of water.

Based on the characteristics of the spent fuel storage in this grouping, no further analysis is performed in this regulatory analysis for this grouping.

3.1.2 Spent Fuel Storage Options

The technologies available for spent fuel storage fall broadly into two categories—wet and dry—distinguished according to the cooling medium used. The wet option has historically been used for temporary storage in anticipation of the next step in the fuel cycle. More recently, a variety of dry storage options have been developed and applied in the U.S. and international markets.

3.1.2.1 Wet Storage

The majority of U.S. nuclear power plant spent fuel is stored in water pool storage (i.e., spent fuel pools). Spent fuel pools have been used for storage of spent fuel as an established practice since the early days of nuclear power, due among other things, to the excellent properties of water for heat removal and shielding. The majority of reactor spent fuel pools have been re-racked once, and some several times, to increase in-pool storage capacity. These pools are designed to the following principles as discussed in NUREG-0800, "Standard Review Plan," Section 9.1.2, "New and Spent Fuel Storage," (Ref. 44):

- the capability to withstand and protect against natural phenomena (e.g., safe shutdown earthquake, design-basis tornado)
- the effectiveness of natural circulation of water through the spent fuel storage racks
- the ability to retain water and minimize leakage, which should be detectable, collectable, and quantifiable
- the configuration of the new fuel vault, the spent fuel storage pool, and their handling areas to preclude accidental falls of heavy objects on the new and spent fuel
- the ability to provide both radiological shielding for personnel by maintaining adequate water levels in the spent fuel pool
- the use of design features to maintain an adequate water inventory in the spent fuel pool under accident condition (e.g., weirs and gates, absence of unnecessary drains, proper piping penetration levels, etc.)
- the use of appropriate monitoring systems to detect spent fuel pool water levels, pool temperature, building radiation levels, and to ensure an adequate degree of subcriticality
- safety implications related to sharing (for multiunit) facilities

While there are many common features between spent fuel pools, there are design differences.

3.1.2.1.1 Location

At-reactor pool located above grade

For boiling water reactor (BWR) Mark I and II designs, the spent fuel pool structures are located in the reactor building at an elevation several stories above grade.

At-reactor pool located near or below grade

The spent fuel pools at pressurized water reactors (PWRs) and BWR Mark III operating reactors in the United States are located with the bottom of the pool at or below plant grade level. Because of the lower elevation, the seismic response is relatively low in comparison to the elevated pools in the BWR Mark I and Mark II plants. Some pools are located below grade, often in bedrock, such that even if a hole in the pool formed, it cannot rapidly drain this pool.

Away-from reactor or non-operating reactor pool

Away-from-reactor pools are used to provide interim spent fuel storage. Typically, they are divided into pools at the reactor site and pools away from the reactor site or offsite although this distinction is not important to this analysis. True away-from-reactor pools are independent of the reactor and all its services and can continue to operate after the reactor has been finally shut down and decommissioned. There are pools, however, that are located at reactors that are shut down but rely extensively on reactor services such as cooling water and water treatment, ventilation and electrical supplies. When reactors are shut down, special arrangements are usually taken because it could be impractical or uneconomic to continue to operate costly reactor-derived services if the spent fuel must remain in storage onsite for long periods. Dry storage facilities generally remove decay heat by passive cooling and have lower operating costs.

3.1.2.1.2 Functional Configuration

Dedicated pool

This is the simplest layout adopted for nuclear power plants in which a spent fuel pool supports a single nuclear power plant unit.

Shared pool

There are cases in which nuclear power plant units may be connected by water gates to share a spent fuel pool.

3.1.2.2 Dry Storage

Numerous companies supply dry storage technologies to U.S. commercial nuclear power plants, as shown in Table 81 located in Appendix A to this document. These dry storage cask systems[8] (DSCs) are certified by the NRC for storage of high burnup spent fuel (i.e., burnups

8 The term dry storage cask system (DSC) includes dual-purpose canister based systems, dual-purpose casks, and storage-only dry storage casks and canister systems.

greater than 45 GWd/MTU), using both regional and uniform loading of spent fuel in the packages. Although the dry storage design differs in design details, capacity, and loading steps, the scope of this analysis is limited to generic dry storage technologies, in order to develop a context for the cost-benefit analysis described in subsequent sections of this document.

3.1.3 Rack Designs

The design of storage racks and fuel element holder configurations varies considerably from facility to facility, both in general appearance and in details. In March 1979, the NRC issued NUREG/CR-0649, "Spent Fuel Heatup following Loss of Water during Storage" (Ref. 59), which provided an analysis of spent fuel heatup following a hypothetical accident involving drainage of the storage pool. The report included analysis to assess the effect of decay time, fuel element design, storage rack design, packing density, room ventilation, drainage level, and other variables on the heatup characteristics of spent fuel stored in a spent fuel pool to predict the conditions under which clad failure would occur. The report concluded that the likelihood of clad failure caused by rupture or melting following a complete drainage is extremely dependent on the storage configuration and the spent fuel decay period. Furthermore, the minimum prerequisite decay time to preclude clad failures may vary from less than 10 days for some storage configurations to several years for others. The potential for reducing this critical decay time either by making reasonable design modifications or by providing effective emergency countermeasures was found to be significant. The NUREG/CR-0649 analysis assumed in most cases that a 41-centimeter (16-inch) open space is maintained between the baseplate and the bottom of the pool and between the sidewalls and the outermost basket or holder. The rack designs evaluated had center-to-center fuel element spacing that ranged from 21.6 centimeters (8.5 inches) to 53 centimeters (21 inches).

NUREG-1353, "Regulatory Analysis for the Resolution of Generic Issue 82, Beyond-Design-Basis Accidents in Spent Fuel Pools," which draws from the preceding report, concludes that if the decay heat level is high enough to heat the fuel rod cladding to about 900 degrees Celsius (C), the oxidation becomes self-sustaining, resulting in a Zircaloy cladding fire. NUREG-1353 used a conservative and bounding conditional probability of a Zircaloy cladding fire given a complete loss of water. The conservative and bounding values used were 1.0 for PWRs and 0.25 for BWRs in high-density configurations based on differences in assumed rack geometry.

NUREG/CR-6441, "Analysis of Spent Fuel Heatup following Loss of Water in a Spent Fuel Pool: A Users' Manual for the Computer Code SHARP" (Ref. 64), was issued in 2002. This report included an analysis of spent fuel heatup, using representative design parameters and fuel loading assumptions. Sensitivity calculations were also performed in this NUREG to study the effect of fuel burnup, building ventilation rate, baseplate hole size, partial filling of the racks, and the amount of available space to the edge of the pool. The spent fuel heatup was found to be strongly affected by the total decay heat production in the pool, the availability of open spaces for airflow, and the building ventilation rate. Spent fuel pool analyses performed by the NRC after this time do not use the SHARP computer code. Rather, the NRC uses the MELCOR computer code (owing to its mechanistic treatment of severe accident phenomena), with supporting analysis using the COBRA-SFS, FLOW3D, and Fluent codes, along with confirmatory experiments at Sandia National Laboratories.

The Spent Fuel Pool Study (draft) evaluated a BWR reference plant rack geometry with a cell pitch of 16 centimeters (6.28 inches); a closed rack design that inhibited or prevented cross-flow, while being relatively open at the top and bottom for axial flow; and a distance between the pool floor liner and the bottom of the rack baseplate of approximately 26 centimeters (10.25 inches) on average.

3.1.4 Spent Fuel Pool Groupings

Based on the discussed variation in spent fuel pool configurations, rack designs, and spent fuel pool capacities, the following grouping were created for use in this regulatory analysis.

Table 1 Average Reactor Operation Expectancy by Grouping

SFP Group No.	Description	No. of reactor units	No. of spent fuel pools	Average Year when the Reactor Operating License Expires
1	BWR Mark I and Mark II with nonshared spent fuel pool	31	31	2037
2	PWR and Mark III with nonshared spent fuel pool	48	48	2040
3	AP1000 spent fuel pools	4	4	2078
4	Reactor units with shared spent fuel pools	21	11	2038
5	Spent fuel pools located below grade	--	--	--
6	Decommissioned plants with spent fuel stored in pool	6	6	N/A
7	Decommissioned plants with fuel stored in an ISFSI using dry casks	21	N/A	N/A

1. Group 5 is a special set of currently operating PWRs where damage to the pool structure would not result in a rapid loss of water inventory.
2. The GE-Hitachi Morris wet ISFSI site is included in Group 6.

This regulatory analysis will focus on the first four groups identified in Table 1. Group 5 spent fuel pools are a special case of the Group 1, 2, 3, and 4 spent fuel pools because they are less susceptible to the formation of small or medium leaks. The spent fuel in Groups 6 spent fuel pools have cooled for 5 years or more because of extended plant outages and have insufficient energy to cause the cladding to burn if the fuel is no longer covered by water. The spent fuel in Group 7 is already in dry cask storage with the exception of the wet ISFSI site. For this site, the spent fuel has cooled for several years and has insufficient energy to cause the cladding to burn if cooling is lost.

3.2 Interim Storage Options To Expand Onsite Storage

The delay in the construction of the geologic repository mandated by Congress has forced nuclear power plants to store used fuel on site for longer than originally intended. The result is that many nuclear plants are running out of existing storage capacity. When a plant’s used fuel pool nears its designed capacity, a company has two options:

- **Re-racking**. The first choice is to re-rack the used spent fuel pool, moving the fuel assemblies closer together. Eventually, even re-racked pools reach their capacity.

- **Dry Containers**. Many U.S. nuclear power plants are storing used spent fuel in large, rugged containers made of steel or steel-reinforced concrete. Depending on the design, a container can hold up to 37 PWR fuel assemblies or 87 BWR fuel assemblies. The containers have a 20-year license. After 20 years, with NRC approval, the license could be extended for up to 40 years.

Building a dry storage facility at a plant site requires an initial investment of approximately $10 million to $20 million. Once the facility is operational, it may cost $5 million to $7 million a year for the maintenance and security of the facility and for adding more containers as storage needs grow (Ref. 22).

While re-racking is the most used method for expanding at-reactor spent fuel storage capacity over the past 40 years, utility experience with dry storage applications has grown significantly. In addition to the implementation and continued operation of dry storage at operating plant sites, numerous nuclear power plants that have permanently ceased operation have offloaded spent fuel from storage pools to at-reactor ISFSIs to facilitate decommissioning of the spent fuel pools.

3.3 Cask Loading Strategies

Two cask loading strategies used to manage cask loading are 1) full core reserve (FCR) margin, and 2) spent fuel pool inventories. The first strategy is just-in-time cask loading, in which casks are loaded with a goal of maintaining FCR in the spent fuel pool. The second type of cask loading strategy employs larger loading campaigns with a goal of achieving additional space above that required for FCR in order to space cask loading campaigns further apart. When implementing this cask loading strategy, a plant might load 10 to 12 casks following every other refueling rather than 5 to 6 casks following every refueling outage.

The benefits of just-in-time cask loading are that:

- It minimizes near-term capital and operating expenditures since only enough casks to maintain FCR are loaded.

- Cask loading crews also do not have long periods of time between cask loading campaigns and may result in shorter learning curves for the next cask loading campaign.

The risks associated with a just-in-time loading strategy include:

- unexpected maintenance that requires offloading the reactor core at a time when the spent fuel pool has less than one FCR

- unexpected delays in delivery of storage casks caused by licensing issues or fabrication delays that might affect FCR capability

- increased outage times because of space limitations in the spent fuel pool

Benefits associated with larger loading campaigns include:

- There are fewer cask loading campaigns over the life of the plant (although the same number of casks would be loaded over the life of the plant) resulting in cost savings associated with mobilization/demobilization for cask loading, training, and dry runs.

- If a company owns multiple sites with operating ISFSIs and cask loading equipment is shared between sites, this results in fewer shipments of cask handling equipment between sites and possible cost savings.

- Larger loading campaigns would also provide more margin in SNF storage pools over FCR, such that unexpected maintenance requiring off-loading of the reactor core can be accomplished and unexpected delays in delivery of storage casks are more likely to be accommodated.

- A negative benefit is that costs associated with large loading campaigns include increases in near-term capital and operating budgets because of purchasing and loading casks sooner than in a just-in-time loading scenario.

Risks associated with larger loading campaigns include:

- Longer cask loading cycles (months rather than weeks) to complete a loading campaign and possible impacts on plant maintenance activities or other spent fuel pool activities.

- Impacts on workers involved in cask loading operations. Shutdown nuclear operating plants have loaded between 15 and 60 casks in extended campaigns with reasonable schedules.

4. ESTIMATION AND EVALUATION OF VALUES AND IMPACTS

This section discusses the benefits and costs of each action alternative relative to the baseline. Ideally, all costs and benefits are converted into monetary values. The total of benefits and costs are then algebraically summed to determine for which alternative the difference between the values and impacts was greatest. However, in some cases the assignment of monetary values to benefits is not provided because meaningful quantification is not possible.

4.1 Identification of Affected Attributes

This section identifies the factors within the public and private sectors that the regulatory alternatives (discussed in Section 2) are expected to affect. These factors are classified as attributes using the list of potential attributes provided by the U.S. Nuclear Regulatory Commission (NRC) in Chapter 5 of its Regulatory Analysis Technical Evaluation Handbook. The basis for selecting each attribute is presented below.

Affected attributes are the following:

- Public Health (Accident). This attribute measures expected changes in radiation exposure to the public caused by changes in accident frequencies or accident consequences associated with the proposed action. The expected changes in radiation exposure are measured over a 50-mile (80-kilometer) radius from the plant site. The dose to the public is from reoccupation of the land and other activities following a severe accident. In addition, the dose to the public includes the occupational dose to workers for cleanup and decontamination of the contaminated land not onsite. The calculation for each alternative is made by subtracting the alternative from the regulatory baseline.

- Occupational Health (Accident). This attribute measures occupational health effects, for both immediate and long-term, associated with site workers because of changes in accident frequency or accident mitigation. Within the regulatory baseline, the short-term occupational exposure related to the accident occurs at the time of the accident and during the immediate management of the emergency and during decontamination and decommissioning of the onsite property. The radiological occupational exposure resulting from cleanup and refurbishment or decommissioning activities of the damaged facility to occupational workers are found within the long-term occupational exposure.

- Occupational Health (Routine). This attribute accounts for radiological exposures to workers during normal facility operations (i.e., nonaccident situations). These occupational exposures occur during dry storage cask (DSC) loading and handling activities; independent spent fuel storage installation (ISFSI) operations, maintenance, and surveillance activities; and preparing to ship the spent fuel offsite.

  This attribute represents an estimate of health effects incurred during normal facility operations so accident probabilities are not relevant. As is true of other types of exposures, a net decrease in worker exposures is taken as positive; a net increase in worker exposures is taken as negative. This exposure is also subject to the dollar per person-rem conversion factor.

- Offsite Property. This attribute measures the expected total monetary effects on offsite property resulting from the proposed action. Changes to offsite property can take various forms, both direct, (e.g. land, food, and water) and indirect (e.g. tourism). This attribute is typically the product of the change in accident frequency and the property consequences from the occurrence of an accident.

  For the regulatory baseline, the offsite property costs are any property consequences resulting from any radiological release from the occurrence of an accident. Normal operational releases and those releases before severe accident are outside the scope of this regulatory analysis.

- Onsite Property. This attribute measures the expected monetary effects on onsite property, including replacement power costs, decontamination, and refurbishment costs, from the proposed action. There are two forms of onsite property costs that are evaluated. The first type is the cleanup and decontamination costs for the unit. The second type is the cost to replace the energy from the damaged or shutdown units.

- Industry Implementation. This attribute accounts for the projected net economic effect on the affected licensees to implement the mandated changes. Costs include procedural and administrative activities. Additional costs above the regulatory baseline are considered negative and cost savings are considered positive.

- Industry Operation. This attribute accounts for the projected net economic effect caused by routine and recurring activities required by the proposed alternative on all affected licensees.

- NRC Implementation. This attribute accounts for the projected net economic effect on the NRC to place the proposed alternative into operation. NRC implementation costs and benefits incurred in addition to those expected under the regulatory baseline are included. Additional rulemaking, policy statements, new or expedited revision of guidance documents, and inspection procedures are examples of such costs.

- NRC Operation. This attribute accounts for the projected net economic effect on the NRC after the proposed action is implemented. Additional inspections, evaluations, or enforcement activities are examples of such costs.

Attributes that are not expected to be affected under any of the alternatives include the following: public health (routine), other government, general public, antitrust considerations, safeguards and security considerations, regulatory efficiency, improvements in knowledge, and environmental considerations.

4.2 Methodology Overview

This section describes the process used to evaluate benefits and costs associated with the proposed alternatives. The benefits (values) include desirable changes in affected attributes (e.g., monetary savings and improved security and safety). The costs (impacts or burdens) include undesirable changes in affected attributes (e.g., increased monetary costs and decreased security and safety).

The regulatory analysis methodology is specified by various guidance documents. The two documents that govern the NRC's voluntary regulatory analysis process are NUREG/BR-0058, Revision 4, "Regulatory Analysis (RA) Guidelines of the U.S. Nuclear Regulatory Commission," dated September 2004 (RA Guidelines), and NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook," dated January 1997 (RA Handbook). The regulatory analysis identifies all attributes impacted by the proposed alternative and analyzes them either quantitatively or qualitatively as described in the previous section.

For the quantified regulatory analysis, the NRC staff develops expected values for each cost and benefit. The expected value is the product of the probability of the cost or benefit occurring and the consequences that would occur assuming the event actually happens. For each alternative, the staff first determines the probabilities and consequences for each cost and benefit, including the year the consequence is incurred. The NRC staff then discounts the consequences in future years to the current year of the regulatory action. Finally, the NRC staff sums the costs and the benefits for each alternative and compares them.

After performing a quantitative regulatory analysis, the NRC staff adds attributes that could only be qualified.[9] Based on the qualification of each attribute, uncertainties, sensitivities, and the

9 See the NRC's Regulatory Analysis Technical Evaluation Handbook, Section 4.3, "Estimation and Evaluation of Values and Impacts" (Ref. 65).

quantified costs and benefits, the staff makes a recommendation for each alternative. If the benefits, both quantified and qualified, are greater than the quantified and qualified costs, then the staff recommends the alternative should be implemented. If the benefits, both quantified and qualified, are less than the quantified and qualified costs, then the staff recommends the alternative should not be implemented.[10]

4.3 Assumptions

This section provides an overview of the assumptions made in order to estimate the impacts associated with the accelerated transfer of spent fuel pool inventories to dry storage to achieve low-density storage, high-density spent fuel pool storage with more beneficial spent fuel loading pattern, and enhanced mitigation. This section describes:

- Assumptions associated with economic modeling, the definition of representative plants, projection of future spent fuel discharges, and requirements for dry storage. This includes assumptions regarding fuel burnup, decay heat, and cesium-137 source term, as well as wet and dry storage technology capacity and heat load capability;

- Assumptions associated with spent fuel pool accident modeling and evaluation. This includes assumptions regarding the likelihood of initiating events challenging spent fuel pool integrity and spent fuel cooling, radiological release source term, atmospheric modeling and meteorology, post-accident radiological doses, population demographics and surrounding area economic data, long-term habitability criteria, and emergency response modeling;

- Assumptions associated with time periods required to load dry storage cask systems (DSCs) and occupational dose received during cask loading operations;

- Assumptions regarding the costs associated with construction and operation of an at-reactor ISFSI; possible cost increases associated with accelerated transfer of spent fuel to dry storage, possible cost increases associated with the need for a short-term increase in DSC fabrication capacity, costs to load additional DSCs, the need to increase shielding capability of DSCs to store spent fuel with shorter cooling times, costs associated with implementing more beneficial spent fuel pool loading patterns, and costs associated with achieving enhanced mitigation.

4.3.1 Economic Modeling and Representative Plant Assumptions

4.3.1.1 Compliance with Existing NRC Requirements

The regulatory baseline assumes full compliance with existing NRC requirements, including current regulations and relevant orders. This is consistent with NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," Rev. 4 (Ref. 55), which states

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10 See the NRC's Regulatory Analysis Technical Evaluation Handbook, Section 4.5, "Decision Rationale" (Ref. 65). Nonquantifiable attributes can only be factored into the decision in a judgmental way; the experience of the decisionmaker will strongly influence the weight that they are given. Qualitative attributes may be significant factors in regulatory decisions and should be considered, if appropriate.

that “in evaluating a new requirement…, the staff should assume that all existing NRC and Agreement State requirements have been implemented.”

The data and assumptions used in analyzing the quantifiable impacts associated with each proposed alternative are discussed in this section. Information on attributes affected by the proposed regulatory framework alternatives are obtained from experienced NRC staff and other sources as referenced. The NRC considers the potential differences between the new requirements and the current requirements and incorporates the proposed incremental changes into this regulatory analysis.

4.3.1.2 Base Year

All monetized costs are expressed in 2012 dollars. Ongoing costs of operation related to the alternatives are assumed to begin in 2014 unless otherwise stated, and are modeled on an annual cost basis.

Estimates are made for one-time implementation costs. The NRC assumes that these costs will be incurred in the first year of the analysis unless otherwise noted.

Estimates are made for recurring annual operating expenses. The values for annual operating expenses are modeled as a constant expense for each year of the analysis horizon. An annuity calculation was performed to discount these annual expenses to 2012 dollar values.

4.3.1.3 Discount Rates

In accordance with guidance from the Office of Management and Budget (OMB) Circular No. A-4 (Ref. 23) and NUREG/BR-0058, Revision 4 (Ref. 55), present-worth calculations are used to determine how much society would need to invest today to ensure that the designated dollar amount is available in a given year in the future. By using present-worth, costs and benefits, regardless of when the cost or benefit is incurred in time, are valued to a reference year for comparison. The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the Federal government. Based on OMB Circular No. A-4, present-worth calculations are presented using 3 percent and 7 percent real discount rates. A 3 percent discount rate approximates the real rate of return on long-term government debt, which serves as a proxy for the real rate of return on savings to reflect reliance on a social rate of time preference discounting concept. A 7 percent rate approximates the marginal pretax real rate of return on an average investment in the private sector, and is the appropriate discount rate whenever the main effect of a regulation is to displace or alter the use of capital in the private sector. A 7 percent rate is consistent with an opportunity cost of capital concept to reflect the time value of resources directed to meet regulatory requirements.

4.3.1.4 Cost/Benefit Inflators

The consequences for some attributes are estimated based on the values published in the NRC Regulatory Analysis Handbook. Within the NRC Regulatory Analysis Handbook, the information in relation to severe reactor accident consequences is provided in previous year dollars. To evaluate the costs and benefits consistently, the consequences are inflated. The most common inflator is the Consumer Price Index for all urban consumers (CPI-U), developed by the U.S. Department of Labor, Bureau of Labor Statistics. Using the CPI-U, the previous year dollars were converted to the year 2012. The formula to determine the amount in 2012 dollars is

$$\frac{\text{CPIU}_{2012}}{\text{CPIU}_{\text{Base Year}}} * \text{Consequence}_{\text{Base Year}} = \text{Consequence}_{2012}$$

Values of CPI-U used in this regulatory analysis are summarized in Table 2.

Table 2 Consumer Price Index—All Urban Consumers Inflator

Base Year	CPI-U Inflator for Year 2012
2005	1.1756
2006	1.1389
2007	1.1073
2008	1.0664
2009	1.0702
2010	1.0529
2011	1.0207

Source: U.S. Department of Labor, Bureau of Labor Statistics, "Databases, Tables & Calculators by Subject: CPI Inflation Calculator (Ref. 38).

4.3.1.5 Description of Representative Plants

Representative BWR Mark I and Mark II (Group 1)

The representative Group 1 plant is a single unit boiling-water reactor (BWR) Mark I or Mark II reactor with a rated capacity of approximately 3,500 megawatts thermal (MW_t) and a unit dedicated spent fuel pool. The representative BWR reactor began operating in the 1970s and will reach the end of its extended operating license by year 2037. The NRC assumes the reactor core contains 764 assemblies and the spent fuel pool has a capacity of approximately 3,055 assemblies in a high-density 1x4 loading configuration. This number is based on a pool capacity of 3,819 assemblies, reduced by 764 assemblies to accommodate a full core offload capability using the existing high-density racking. In a low density configuration, the spent fuel pool stores 852 assemblies in which the newly discharged spent fuel is arranged in a 1x4 configuration and the remaining fuel assemblies arranged in a checkerboard pattern. The unit operates on 24-month cycles, discharging approximately 284 assemblies per cycle. The representative BWR has already implemented dry storage

Representative PWR or BWR Mark III (Group 2)

The representative Group 2 plant is a single unit pressurized-water reactor (PWR) with a rated capacity of approximately 3,400 MW_t and a unit dedicated spent fuel pool. The representative Group 2 reactor began operating in the 1970s and will reach the end of its extended operating license by year 2040. The NRC assumes the reactor core contains 193 assemblies and the spent fuel pool has a capacity of approximately 1,220 assemblies in a high-density 1x4 loading configuration. This number is based on a pool capacity of 1,414 assemblies, reduced by 193 assemblies to accommodate a full core offload capability using the existing high-density racking. In a low density 1x4 with empties configuration, the spent fuel pool stores 312 assemblies. The unit operates on 18-month cycles, discharging approximately 78–84 assemblies per cycle. The representative PWR has already implemented dry storage.

Representative New Nuclear Plant (Group 3)

The representative new plant is an AP1000 PWR with a rated capacity of approximately 3,400 MW_t and a unit dedicated spent fuel pool. The representative Group 3 reactor begins operating in the year 2018 and will reach the end of its extended operating license by year 2078. The NRC assumes the reactor core contains 157 assemblies and the spent fuel pool has a capacity of approximately 1,000 assemblies in a high-density 1x4 loading configuration. This number is based on a pool capacity of 1,160 assemblies, reduced by 157 assemblies to accommodate a full core offload capability using the existing high-density racking. In a low density 1x4 with empties configuration, the spent fuel pool stores 340 assemblies. The unit operates on either 18-month or 24-month cycles, discharging an estimated 69 assemblies per 18-month cycle or 77 assemblies per 24-month cycle (Ref. 79, Section 9.1). The representative new nuclear plant is expected to begin dry storage in 2038 if high-density pool storage is allowed and will load a sufficient number of casks to maintain its full core offload capability.

Representative Spent Fuel Pool Shared Between Units (Group 4)

This representative spent fuel pool is shared between two PWR units, each with a rated capacity of approximately 3,400 MW_t. The spent fuel pool, designed in two halves, is located outside the containment in the Auxiliary Building and provides underwater storage of spent fuel assemblies after their removal from the reactor vessel of either reactor unit. The associated Group 4 reactor unit began operating in the 1970s and will reach the end of its extended operating license by year 2038. The NRC assumes each reactor core contains 193 assemblies and the spent fuel pool has a capacity of 1637 assemblies in a high-density 1x4 loading configuration. This number is based on a pool capacity of 1,830 assemblies, reduced by 193 assemblies to accommodate one unit's full core offload capability using the existing high-density racking. In a low density 1x4 with empties configuration, the spent fuel pool stores 468 assemblies. The units operate on 24-month cycles, discharging approximately 78–84 assemblies per cycle on a 1-year staggered cycle. The representative shared spent fuel pool has already implemented dry storage.

4.3.1.6 Projected Number of Outages and Spent Fuel Assemblies

The spent fuel assembly inventory at a spent fuel pool is plant specific based on initial inventory, projected spent fuel discharged during each refueling outage, and operating cycle length. Additional spent fuel storage requirements are calculated using the spent fuel pool capacity and the cumulative spent fuel discharges. The cumulative number of fuel assemblies discharged is subtracted from the spent fuel pool capacity, assuming that each spent fuel pool retains space in the spent fuel pool to discharge one full core of fuel. During years in which no spent fuel is discharged at plants operating on 18-month or 24-month operating cycles, there would be no change in the spent fuel pool inventory. If there are more assemblies requiring storage than there is space in the spent fuel pool (including space to discharge one full core of fuel), these additional storage needs are assumed to be met using at-reactor dry storage rather than expansion of spent fuel pool capacity. The number of spent fuel assemblies required up to operating license expiration is calculated for each group based on the existing high-density spent fuel pool inventory, the number added from refueling outages, and the full reactor core inventory. These results are provided in Table 3

Table 3 Number of Spent Fuel Assemblies Remaining through Operating License Expiration

Group No.	Category	Inventory	Number of Inventories	No. of spent fuel assemblies	Total
1	Current spent fuel pool inventory	3,055	1	3,055	
	refueling	284	12	3,408	
	reactor core	764	1	764	7,227
2	Current spent fuel pool inventory	1,220	1	1,220	
	refueling	78	18	1,404	
	reactor core	193	1	193	2,817
3a	Current spent fuel pool inventory	0	1	0	
	Refueling (18-month cycle)	69	40	2,760	
	reactor core	157	1	157	2,917
3b	Current spent fuel pool inventory	0	1	0	
	Refueling (24-month cycle)	77	30	2,310	
	reactor core	157	1	157	2,467
4	Current spent fuel pool inventory	1,637	1	1,637	
	refueling	78	24	1,872	
	reactor core	193	2	386	3,895

4.3.1.7 Dry Storage Capacity

Three companies supply most of the dry storage technologies to U.S. commercial nuclear power plants. These companies are Holtec International, Inc. (Holtec), NAC International, Inc. (NAC), and Transnuclear, Inc. (Transnuclear). The dry storage cask systems[11] (DSCs) for all three companies are certified by the NRC for storage of high burnup spent fuel (i.e., burnups greater than 45 GWd/MTU), using both regional and uniform loading of spent fuel in the packages. A summary of a representative sampling of dry storage canisters commercially available for spent fuel storage is provided in Table 4.

11 The term dry storage cask system (DSC) includes dual-purpose canister based systems, dual-purpose casks, and storage-only dry storage casks and canister systems.

Table 4 Representative Sampling of Commercially Available BWR Spent Fuel Dry Storage Technology

Vendor Package	Fuel Type	Canister Type	Capacity (Assemblies)	Maximum Decay Heat Per Package[1] (kW)
Holtec HI-STORM 100	PWR	MPC-24	24	34
	PWR	MPC-32	32	34
Holtec HI-STORM FW	PWR	MPC-37	37	47
NAC UMS	PWR	24P	24	23
NAC MAGNASTOR	PWR	37P	37	35.5
Transnuclear NUHOMS	PWR	24PTH	24	40.8
	PWR	32PTH1	32	40.8
Transnuclear TN-40HT	PWR	Bolted	40	32
Holtec HI-STORM	BWR	MPC-68	68	34
Holtec HI-STORM FW	BWR	MPC-89	89	46.36
NAC MAGNASTOR	BWR	87B	87	33
Transnuclear NUHOMS	BWR	61BTH	61	31.2
Transnuclear TN-68	BWR	Bolted	68	30

The maximum decay heat per assembly for uniform loading is estimated by dividing the package decay heat by the number of assemblies. The maximum decay heat per assembly under regional loading schemes will generally be higher than the maximum decay heat per assembly assuming uniform loading for a smaller number of assemblies. Cask certificates of compliance provide the specific maximum assembly decay heat limits for each storage location in the basket.
Source: EPRI TR-1025206, p. 2-11 (Ref. 10).

4.3.1.8 Discharged Spent Fuel Assemblies

The number of spent fuel assemblies in units of million tons of uranium (MTU) that is discharged by a reactor unit during each refueling outage is estimated based on the unit's licensed thermal rating (megawatts thermal, MW_t, discharge burnup (BUP in MWd/MTU), capacity factor (CF in percent), and operating cycle length (CYL in years) as shown below.

$$MTU = \frac{MW_t \ x \ CYL \ x \ \frac{CF}{100} \ x \ \frac{365 \ days}{year}}{BUP}$$

Using the above formula, a 3,514 MW_t BWR reactor with a 24-month operating cycle operating at a 90 percent capacity factor and an average spent fuel assembly burnup of 45,000 MWd/MTU would discharge 51.3 MTU during each refueling cycle. The number of discharged assemblies (ASSY) is estimated by dividing the MTU discharge value by the fuel assembly unit weight. Based on an average BWR fuel assembly unit weight of 0.18 MTU per assembly the equation yields approximately 285 assemblies.

4.3.1.9 Spent Fuel Assembly Decay Heat as a Function of Burnup and Cooling Time

As fuel assembly burnups increase, the decay heat of the fuel assembly (watts per assembly) and the Cesium-137 inventory in the spent fuel increase. Decay heat also can vary significantly with initial enrichment and assembly irradiation parameters. Spent fuel burnups have gradually increased since the 1990s with average BWR burnups about 43 GWd/MTU and range between 40 and 53 GWd/MTU and with average PWR burnups range between 40 and 55 GWd/MTU.

Average decay heat for a 40 GWd/MTU PWR spent fuel assembly that has cooled for 5 years is approximately 1,100 watts per assembly based on approximately 2.3 kW/MTU (from Figure 5) times 0.45 MTU per assembly and a Cesium-137 inventory of approximately 6.8x10^4 Ci per assembly. The average decay heat for a 55 GWd/MTU assembly that has cooled for 5 years is approximately 1,500 watts per assembly with a Cesium-137 inventory of 9.6x10^4 Ci per assembly (Ref. 10, p. 2-6). In comparison, a 40 GWd/MTU PWR spent fuel assembly that has cooled for 10 year has a decay heat of approximately 700 watts per assembly and a 55 GWd/MTU PWR spent fuel assembly has a decay heat of approximately 1,000 watts per assembly.

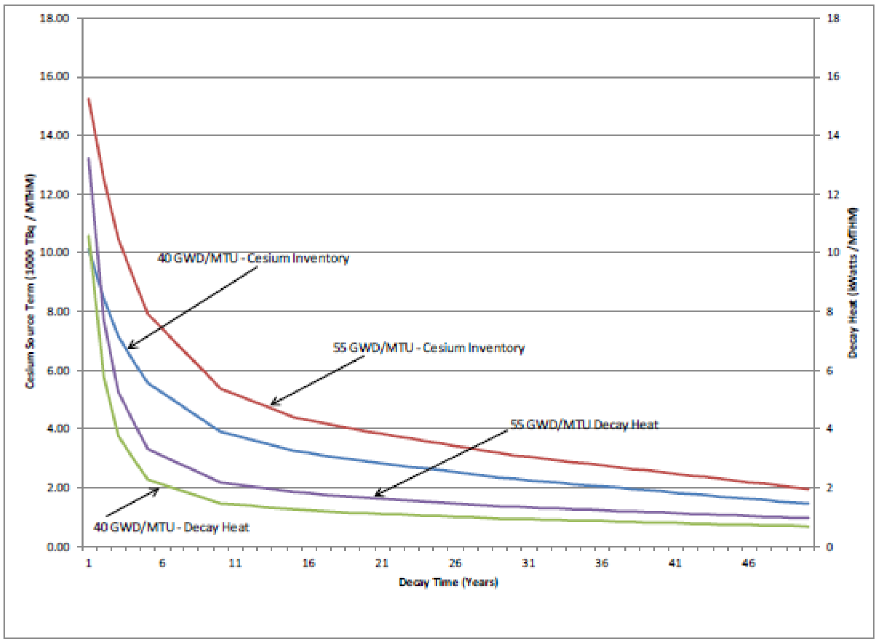


Figure 5 PWR spent fuel assembly decay heat and cesium inventory as a function of burnup and cooling time

Source: EPRI TR-1025206, p. 2-6 (Ref. 10).

Average decay heat for a 40 GWd/MTU BWR spent fuel assembly that has cooled for 5 years is approximately 360 watts/assembly based on approximately 2.0 kW/MTU (from Figure 6) times 0.18 MTU per BWR assembly and a Cesium-137 inventory of approximately 3.0x10^4 curies per assembly. The average decay heat for a 50 GWd/MTU assembly that has cooled for 5 years is approximately 520 watts per assembly with a Cesium-137 inventory of 3.4x10^4 curies per assembly (Ref. 10, p. 2-8). In comparison, a 40 GWd/MTU BWR spent fuel assembly that has cooled for 10 years has a decay heat of approximately 250 watts per assembly and a 50 GWd/MTU BWR spent fuel assembly has a decay heat of approximately 350 watts per assembly.

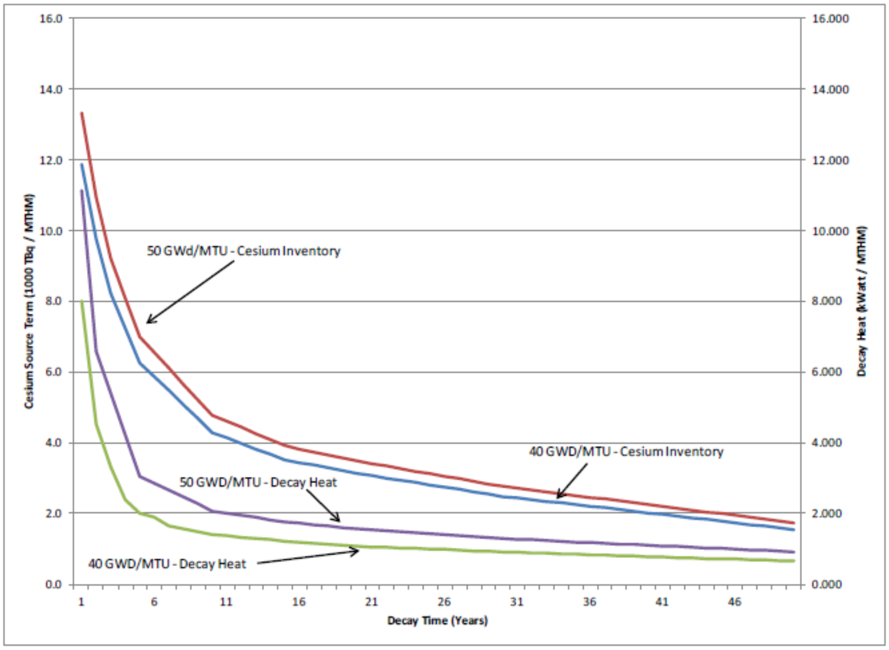


Figure 6 BWR spent fuel assembly decay heat and cesium inventory as a function of burnup and cooling time

Source: EPRI TR-1025206, p. 2-9 (Ref. 10).

Based on an average PWR spent fuel assembly that emits 1,100 watts or an average BWR spent fuel assembly that emits 360 watts, Table 5 shows the number of spent fuel assemblies that could be stored assuming uniform fuel assembly burnup of 40 GWd/MTU and a 5-year decay time. Table cells that are not shaded identify those dry storage canisters that can be filled to capacity without exceeding the maximum decay heat per package rating, subject to restrictions on loading pattern. Shaded table cells identify those casks whose capacity loading is limited by the spent fuel assembly decay heat. For 55 GWd/MTU PWR assemblies that emit approximately 1,500 watts after they have cooled for 5 years or 50 GWD/MTU BWR assemblies that emit approximately 520 watts, fewer assemblies after they have cooled for 5 years, most cask capacity must be limited to ensure that it does not exceed the maximum decay heat rating. The number of additional dry storage casks that would be required for spent fuel cooled for 5 years depends on the vendor package selected and ranges between no additional canisters to almost twice as many additional canisters. Additional DSCs, which are required because of high heat load, are estimated in this regulatory analysis. For a sensitivity analysis, the maximum capacity based on decay heat limitations was also calculated if the spent fuel was allowed to cool for 10 years. As shown in Table 5, all of the lower heat rate fuel and most of the higher heat rate fuel could be loaded into casks without any decay heat limitations.

For this regulatory analysis, the Transnuclear TN-68 dry casks are selected as representative DSCs for the BWR spent fuel for Group 1. For Groups 2, 3, and 4, the Holtec Hi-Storm FW DSC is modeled as representative DSCs for the PWR spent fuel.

Table 5 Canister Storage Capacity Based on Decay Heat Limitations

Vendor Package	Fuel Type	Capacity (Assemblies)	Maximum Decay Heat Per Package (kW)	Maximum capacity based on decay heat			
				5 year cooling		10 year cooling	
				1100w (PWR) 360w (BWR) per assembly	1500w (PWR) 520w (BWR) per assembly	700w (PWR) 250w (BWR) per assembly	1000w (PWR) 350w (BWR) per assembly
Holtec HI-STORM 100	PWR	24	34	24.00	22.67	24.00	24.00
	PWR	32	34	30.91	22.67	32.00	32.00
Holtec HI-STORM FW	PWR	37	47	37.00	31.33	37.00	37.00
NAC UMS	PWR	24	23	20.91	15.33	24.00	23.00
NAC MAGNASTOR	PWR	37	35.5	32.27	23.67	37.00	35.50
Transnuclear NUHOMS	PWR	24	40.8	24.00	24.00	24.00	24.00
	PWR	32	40.8	32.00	27.20	32.00	32.00
Transnuclear TN-40HT	PWR	40	32	29.09	21.33	40.00	32.00
Holtec HI-STORM	BWR	68	34	68.00	65.38	68.00	68.00
Holtec HI-STORM FW	BWR	89	46.36	89.00	89.00	89.00	89.00
NAC MAGNASTOR	BWR	87	33	87.00	63.46	87.00	87.00
Transnuclear NUHOMS	BWR	61	31.2	61.00	60.00	61.00	61.00
Transnuclear TN-68	BWR	68	30	68.00	57.69	68.00	68.00

1. Shaded values identify where cask loading capacity is limited by the spent fuel decay heat.

The currently approved minimum cooling time for fuel stored in dry casks is 7 years (10 years for some fuel types). Cask vendors would need to demonstrate, in an amendment request, that spent fuel that was cooled for a shorter period can be stored safely. The costs to prepare such an amendment request and for the NRC review are not included in this regulatory analysis. Furthermore, fuel selected must meet cask design specific fuel selection parameters that limit the maximum enrichment, maximum burnup, minimum cooling time, and maximum decay heat. The methodology used to estimate the capacity of the DSCs for spent fuel is subject to uncertainties resulting from decay heat and loading pattern restrictions. As a result, the actual DSC capacity may be higher or lower than those estimated.

4.3.1.10 Facility Life Cycle

Spent fuel storage involves a series of phases over the life cycle of the nuclear power plant for which it supports. The plant operational phases will have variable time requirements depending on the plant's refueling schedule, the capacity of the spent fuel pool, the term of the operating license, and the forecast schedule of removal of spent fuel from the spent fuel pool to the ISFSI.

At the expiration of a nuclear power plant's operating license, the full core is offloaded into the spent fuel pool. The licensee continues to store spent fuel in the pool following commercial operation[12] to allow the spent fuel to cool sufficiently before placing into dry storage.

[12] Decommissioning of the unit must be completed within 60 years of permanent cessation of operations under 10 CFR 50.82, "Termination of License" (Ref. 64). Completion of decommissioning beyond 60 years will be approved by the Commission only when necessary to protect public health and safety.

4.3.1.11 Spent Fuel Pool Capacities

Spent fuel pools for all reactor types typically range from 9 to 18 meters (30 to 60 feet) in length and 6 to 12 meters (20 to 40 feet) in width, with a spent fuel capacity that ranges from 544 to 4,117 spent fuel assemblies for dedicated spent fuel pools as shown in Table 83. Spent fuel pools that are shared between units have capacities up to 4,628 fuel assemblies. This regulatory analysis assumes that plants with spent fuel pools that are shared by multiple units reserve space for only one full core in the spent fuel pool.

For new reactors, spent fuel is stored in high density racks which include integral neutron absorbing material to maintain the required degree of subcriticality. The spent fuel pool rack layout contains both Region 1 rack modules and Region 2 rack modules. The racks are designed to store fuel of the maximum design basis enrichment. Each rack in the spent fuel pool consists of an array of cells interconnected to each other at several elevations and to a thick base plate at the bottom elevation. These rack modules are free-standing, neither anchored to the pool floor nor braced to the pool wall. For the AP1000 reactors, the spent fuel storage racks include storage locations for 884 fuel assemblies and five defective fuel assemblies.

4.3.1.12 Spent Fuel Pool Cesium Inventory

The amount of cesium inventory in a spent fuel pool varies based on the number of spent fuel assemblies, the type of fuel stored, the discharge burnup, and the amount of time since the fuel was removed from the reactor core. The specific activity, $\frac{A}{M}$, in megacuries per metric tons of uranium (MCi/MTU) is relatively invariant and the assembly mass (in initial MTUs) is a reasonable scaling factor account for variations between different spent fuel pools. This scaling factor is derived as follows assuming the two pools have similar distributions of burnup and cooling periods:

$$\frac{A_1}{M_1} \sim \frac{A_2}{M_2}$$

Where A_x is the absolute activity in megacuries (MCi) of spent fuel pool x and M_x is the total amount of uranium in metric tons (MTU) stored in spent fuel pool x. The total amount of uranium, M_x, is estimated based on the number of spent fuel assemblies, N, and the average fuel assembly unit weight, m in MTU per assembly in the pool. A burnup scaling factor (BUP in MWd/MTU) can also be used in the above equation to yield:

$$\frac{A_1}{N_1\ x\ BUP_1\ x\ m_1} = \frac{A_2}{N_2\ x\ BUP_2\ x\ m_2}$$

Solving for the spent fuel pool absolute activity of the second pool yields:

$$A_2 = \frac{A_1\ x\ N_2\ x\ BUP_2\ x\ m_2}{N_1\ x\ BUP_1\ x\ m_1}$$

Using the above formula, a 3,514 MW_t BWR reactor with a spent fuel pool with absolute activity of 60 MCi from the storage of 3,055 BWR fuel assemblies with an average spent fuel assembly burnup of 45,000 MWd/MTU and with an average BWR fuel assembly unit weight of 0.18 MTU per assembly can be equated to a 3,400 MW_t PWR reactor with a spent fuel pool with an unknown absolute activity from the storage of 1,220 PWR fuel assemblies with an average spent fuel assembly burnup of 45,000 MWd/MTU and with an average PWR fuel assembly unit weight of 0.46 MTU per assembly as shown below.

$$A_{PWR} = \frac{59\ x\ 1220\ x\ 45000\ x\ 0.46}{3055\ x\ 45000\ x\ 0.18} = \frac{1.49\ x\ 10^9}{2.47\ x\ 10^7} = 60.2\ MCi$$

To test the accuracy of this estimate for high density spent fuel pool scaling, the high density Peach Bottom, Unit 3 spent fuel pool cesium inventories from 2001 and 2011 were used. The results showed that there is less than 1 percent error by using the scaling method described above.

Error is introduced when attempting to estimate a pool with a significantly different average cooling period for the spent fuel. To eliminate this source of error, the low density loaded spent fuel pool inventory is estimated based on the low density spent fuel pool characteristics evaluated in the SFPS and using the actual Cs-137 inventory of 22 MCi for all low density spent fuel pools and the formula above.

Table 83 located in Appendix A provides the estimated Cs-137 inventory for each spent fuel pool in a high-density loading configuration using the scaling factor discussed above. Cesium inventories used to analyze each spent fuel pool group are summarized in Table 6.

Table 6 Spent Fuel Pool Group Cesium Inventory

SFP Group	Pool Storage Case	Pool Cesium Inventory (MCi)		
		Sensitivity (Low Estimate)	Base Case	Sensitivity (High Estimate)
1	High-density	40.6	52.7	63.3
	Low-density	19.8	22.0	26.4
2	High-density	57.4	67.9	78.2
	Low-density	15.7	17.4	20.9
3	High-density	33.7	44.4	54.2
	Low-density	15.7	17.4	20.9
4	High-density	63.6	101.1	142.2
	Low-density	31.4	34.8	41.8

4.3.2 Spent fuel Pool Accident Modeling and Evaluation Assumptions

4.3.2.1 Seismic Hazard Model

This regulatory analysis uses the existing U.S. Geological Survey (USGS) 2008 model to evaluate seismic hazards at central and eastern United States (CEUS) nuclear power plants. A new probabilistic seismic hazard model is currently being developed and will consist of two parts: (1) a seismic source zone characterization and (2) a ground motion prediction equation (GMPE) model. Although part (1) is now complete (Ref. 56), the GMPE update is still in progress. Furthermore, the NRC is currently developing an independent probabilistic seismic hazard assessment (PSHA) computer code to incorporate part (1) and part (2) when complete. While the USGS (2008) hazard model is not sufficiently detailed for regulatory decisions, it is used for this regulatory analysis because it is the most recent and readily available hazard model and was used in the Spent Fuel Pool Study (Ref. 2). Although the USGS 2008 model considers western U.S. sites (e.g., Columbia, Diablo Canyon, Palo Verde, and San Onofre), these sites are not addressed in Generic Issue 199 (Ref. 76), which focused on the CEUS and, therefore, are not included in this analysis. Western sites will be considered on a site-specific basis in response to licensee requested information related to Recommendations 2.1 (Seismic Hazards Evaluations) and 2.3 (Seismic Walkdowns) of the Post-Fukushima Near-Term Task Force.

A comparison of the annual frequency of exceeding a given PGA for BWR Mark I and II sites (Figure 7) shows that Peach Bottom (i.e., the reference plant) falls close to the upper end of the group located in the CEUS in terms of hazard estimates.

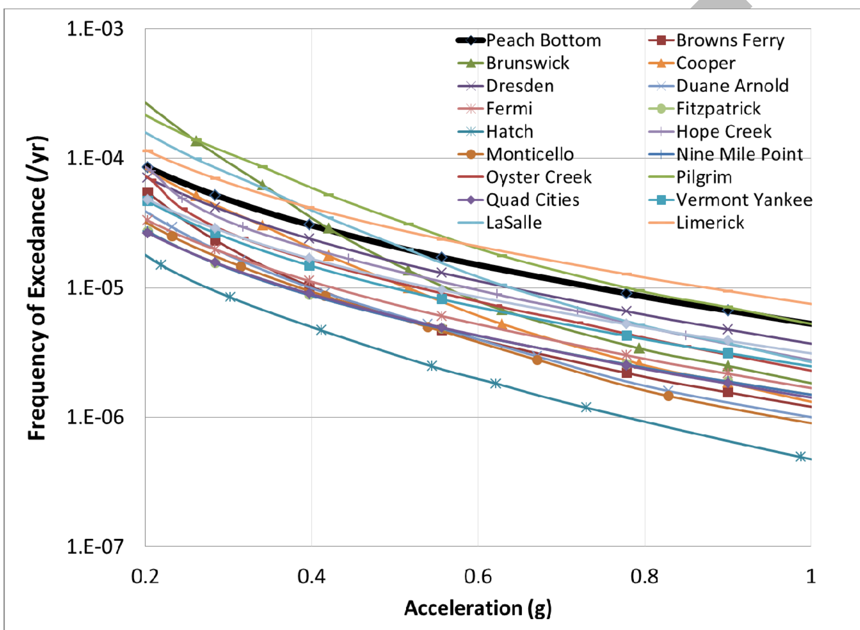


Figure 7 Comparison of annual PGA exceedance frequencies for U.S. BWR Mark I and Mark II reactors (USGS 2008 model)

A similar comparison of the annual frequency of exceeding a given PGA for PWR and BWR Mark III sites (Figure 8), for new reactors (Figure 9), and for reactors units with a shared spent fuel pool (Figure 9) show that Peach Bottom falls close to the upper end of the group in terms of hazard estimates.

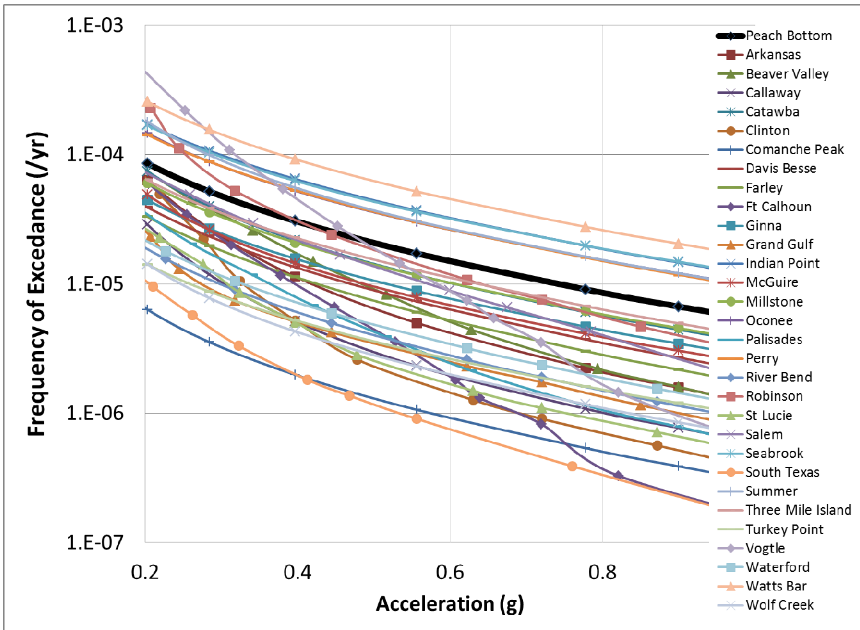


Figure 8 Comparison of annual PGA exceedance frequencies for U.S. PWR and BWR Mark III reactors (USGS 2008 model)

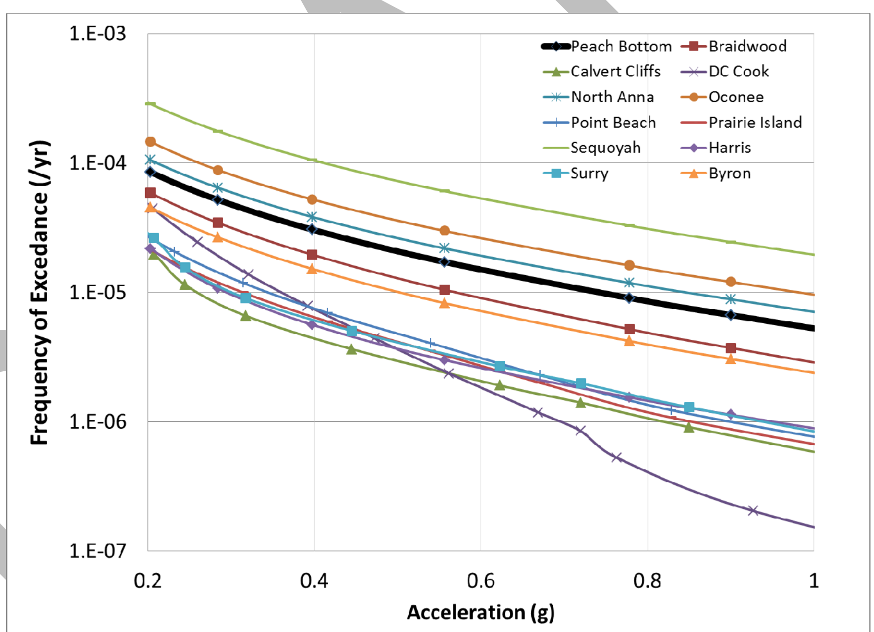


Figure 9 Comparison of annual PGA exceedance frequencies for new U.S. reactors (USGS 2008 model)

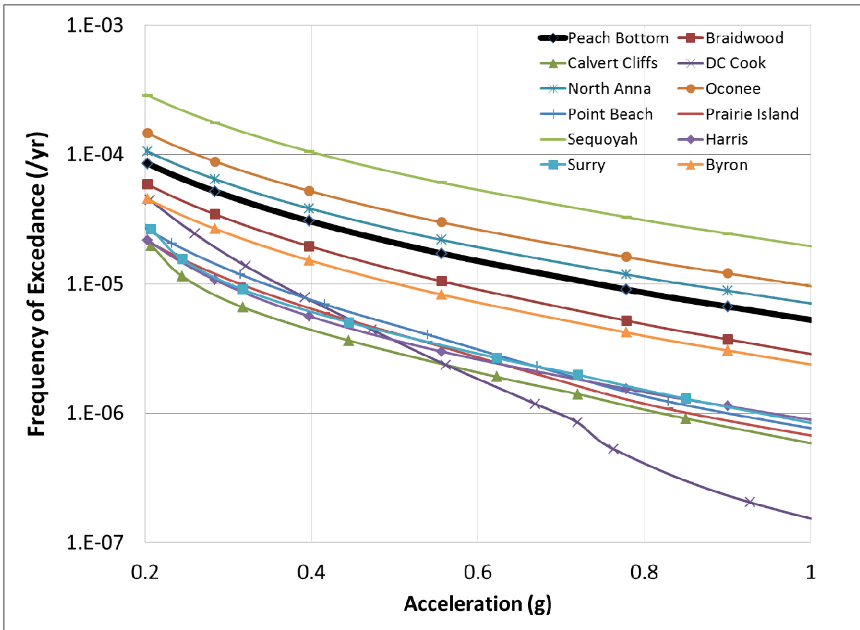


Figure 10 Comparison of annual PGA exceedance frequencies for U.S. reactors with a shared spent fuel pool (USGS 2008 model)

4.3.2.2 Characterization of Seismic Event Likelihood

As described in Section 3.2 of the Spent Fuel Pool Study (Ref. 2), the hazard exceedance frequencies can be translated into initiating event frequencies by partitioning the PGA range into a number of discrete categories (bins) defined in terms of PGA intervals. These bins define a discrete number of seismic event scenarios with increasing intensity (PGA). Revision 1.01 of the NRC handbook entitled, “Risk Assessment of Operational Events, Volume 2—External Events,” issued January 2008 (Ref. 44), recommends the use of at least three bins unless plant-specific considerations require more bins. The SFPS used four bins.

Table 4 of the Spent Fuel Pool Study, reproduced in this analysis as Table 7, shows the resulting bins, along with the tabulated frequencies for various spectral and peak accelerations for Peach Bottom, the reference plant evaluated in that study. Note that for bin 4, the representative bin PGA has been set to 1.2g by convention, whereas for the other bins, it is the geometric mean of the interval endpoints.

Table 7 Seismic Bin Initiating Event Frequencies (Base Case)

Bin No.	Bin Range (g)	Bin PGA (g)	Approximate Initiating Event Frequency (USGS 2008 model) (/yr)
1	0.05 - 0.3	0.12	5.2×10^{-4}
2	0.3 - 0.5	0.4	2.7×10^{-5}
3	0.5 - 1.0	0.7	1.7×10^{-5}
4	> 1.0	1.2[1]	4.9×10^{-6}

1. Assumed based on PRA modeling convention.

Although the Peach Bottom hazard exceedance frequencies curves shown in Figures 7 through 10 fall close to the upper end of each group in terms of hazard estimates, there are some CEUS sites that exceed those estimates. For each SFP group, the site with the highest plant hazard exceedance frequency for peak ground accelerations greater than 0.6g was selected to produce the high estimate seismic bins and initiating event frequencies provided in Table 8.

Table 8 Seismic Bin Initiating Event Frequencies (High Estimate sensitivity)

SFP Group (Site Name)	Bin No.	Bin Range (g)	Bin PGA (g)	Approximate Initiating Event Frequency (USGS 2008 model) (/yr)
SFP Group 1 (Limerick)	1	0.05 - 0.3	0.12	6.8E-04
	2	0.3 - 0.5	0.4	3.6E-05
	3	0.5 - 1.0	0.7	2.2E-05
	4	> 1.0	1.2	7.1E-06
SFP Group 2 (Watts Bar)	1	0.05 - 0.3	0.12	1.7E-03
	2	0.3 - 0.5	0.4	8.1E-05
	3	0.5 - 1.0	0.7	4.9E-05
	4	> 1.0	1.2	1.5E-05
SFP Group 3 (Summer)	1	0.05 - 0.3	0.12	1.8E-03
	2	0.3 - 0.5	0.4	5.4E-05
	3	0.5 - 1.0	0.7	2.9E-05
	4	> 1.0	1.2	9.1E-06
SFP Group 4 (Sequoyah)	1	0.05 - 0.3	0.12	1.79E-03
	2	0.3 - 0.5	0.4	8.98E-05
	3	0.5 - 1.0	0.7	5.64E-05
	4	> 1.0	1.2	2.00E-05

The information above coupled with the review of previous studies (Ref. 54) suggests that the base case frequency of a seismic event that could challenge the integrity of a spent fuel pool is on the order of 1.7×10^{-5} per year (i.e., approximately one event in 60,000 years) or less. Table 9 contrasts this frequency against other sources of information.

Table 9 Comparison of Seismic Frequencies from Various Sources

Source	Estimated initiating event frequency of a large seismic event	Notes
USGS 2008—Regulatory analysis base case	1.7×10^{-5} /year (one event in 60,000 years)	Frequency of seismic bin 3 (0.5 to 1.0 g) of 4 bins
USGS 2008—Regulatory analysis high estimate sensitivity	5.6×10^{-5}/year (one event in 18,000 years)	
NUREG-1738[1]	1.1×10^{-5}/year (one event in 90,000 years)	Frequency of seismic hazard between 0.51g to 1.02g

1. Initiating event frequency reported is based on the LLNL models (Ref. 51).

4.3.2.3 Spent Fuel Pool Initiator Release Frequency

Section 1.5 of the SFPS (Ref. 2) provides an overview of contributors to spent fuel pool risk. The majority of spent fuel pool risk emanates from a loss of water from a sizeable leak in the spent fuel pool or a boil off in which operator action to inject water into the pool for an extended period is precluded. The release frequency from the spent fuel pool can then be characterized as the frequency of the initiator causing fuel uncovery multiplied by the probability of a release given fuel uncovery for the specific initiating event. The total release frequency is the sum of the frequency of releases from cask drops, seismic events, and other initiators. This value is given by:

$$F_{release} = \sum_{i} F_{initiator_i} \, x \, P_{release_i}$$

Where $F_{initiator}$ includes:

Fdrop	=	frequency of spent fuel uncovery from cask drops
Fseismic-bin 3	=	frequency of spent fuel uncovery from seismic bin 3 event
Fseismic-bin 4	=	frequency of spent fuel uncovery from seismic bin 4 event
Fother	=	frequency of spent fuel uncovery from sources other than cask drops and seismic
Prelease	=	probability of release given spent fuel uncovery for specific initiators

Source: Derived from Spent Fuel Pool Study, Section B.4 (Ref. 2).

The SFPS provides a detailed analysis of the consequences, for a particular site and a calculation of $F_{seismic}$ for seismic bin 3, a hazard exceedance frequency range provided in Table 7.

The SFPS did not analyze initiators that contribute to spent fuel pool risk other than for seismic events defined by seismic bin no. 3. However past studies, such as NUREG-1353 (Ref. 48) and NUREG-1738 (Ref. 54), evaluated additional events that could contribute to risk and consequences from spent fuel pool fires. Table 13 summarizes these initiating-event-class fuel uncovery frequencies. Uncovery frequencies taken from past studies depend on the assumptions stated in those studies. Additionally, seismic bin no. 4 is included by extrapolating the results of the SFPS. For seismic bin no. 3 and bin no. 4 events, the uncovery frequency is the product of the initiating event frequency, ac power fragility, and the liner fragility.

The Spent Fuel Pool Study (Ref. 2) uses an alternating current (ac) power fragility value of 0.84 taken from NUREG-1150 (Ref. 47) as a surrogate for the conditional probability of normal spent fuel pool cooling and makeup not being available following a 0.7g earthquake. This simplifying assumption was made in light of the fact that the SFPS is not a probabilistic risk assessment but rather a consequence analysis with probabilistic considerations.

In reality, the availability of normal spent fuel pool cooling and makeup would be a combination of the ac power fragility, the fragility of the actual equipment and its support equipment, and operator actions to recover spent fuel pool cooling capabilities using additional mitigation equipment and strategies implemented in response to Order EA-12-049 (Ref. 73). The modeling and consideration of these guidance and strategies to maintain or restore spent fuel pool cooling capabilities following a beyond-design-basis external event on a plant-specific basis may result in a value for spent fuel pool cooling and makeup failure conditional probability that may differ from the NUREG-1150. Because a documented ac power fragility analysis that covers all U.S. spent fuel pools is not readily available, a conservative bounding value of 1.0 is used in this regulatory analysis.

Section 4.1.5 of the Spent Fuel Pool Study (Ref. 2) describes the results from the nonlinear finite element analysis to estimate the likelihood of leakage from concrete cracking and related spent fuel pool liner failure for the 0.7g earthquake. Figure 27 from this study shows that the maximum membrane effective strain is about 3.7 percent. Based on this calculated liner strain for the 0.7g earthquake, a structural analysis of the pool estimates that the spent fuel pool in this study has a 90 percent probability of surviving the 0.7g earthquake with no liner leakage (or conversely, a 10 percent probability of damaging the liner such that leakage will occur). As a result, a liner fragility value of 0.1 is used in the SFPS for the seismic bin No. 3 initiating event. NUREG/CR-5176 (Ref. 63) provides the fragility for the walls of a PWR located in the Central and Eastern United States as having a 98 percent probability of surviving the 0.7g earthquake with no liner leakage (or conversely, a 2 percent probability of damaging the liner such that leakage will occur).

For the seismic bin 4 initiating event (i.e., 1.2g earthquake), a comparable structural analysis is not performed in the SFPS to determine the liner fragility value for the reference BWR Mark I plant. As a result, a bounding value of 1.00 for the seismic bin no. 4 earthquake is used in this regulatory analysis for Group 1 liner fragility high estimate, even though a detailed analysis may be able to justify a value a factor of 2 or more lower. NUREG/CR-5176 provides the fragility for the walls of a PWR located in the Central and Eastern United States as having an 84 percent probability of surviving the 1.2g earthquake with no liner leakage (or conversely, a 16 percent probability of damaging the liner such that leakage will occur).. As a result, a value of 0.16 is used for the seismic bin no. 4 earthquake low estimate in this regulatory analysis for Groups 2, 3, and 4 liner fragility. A summary of these liner fragility values are provided in Table 10.

Table 10 Liner Fragility Values as a Function of Spent Fuel Pool Group and Seismic Bin

SFP Group	Seismic Bin	Liner Fragility		
		Low Est.	Base Case	High Est.
1	Bin 3	10%	10%	100%
	Bin 4	50%	100%	100%
2, 3, & 4	Bin 3	2%	5%	25%
	Bin 4	16%	50%	100%

Past studies have reached generally similar conclusions about the relative contribution to risk from the seismic initiating events considered. Table 11 summarizes the impact of the above modeling assumptions when comparing the seismic initiating event fuel uncovery frequencies from previous spent fuel pool accident regulatory analyses.

Table 11 Frequency of Spent Fuel Pool Fuel Uncovery for Seismic Events

Reference	Reactor Type / SFP Grouping	Seismic Event Contribution to Spent Fuel Pool Fuel Uncovery (per 10^6 reactor-years)	
		Base case	High estimate sensitivity
NUREG-1353 (Ref. 48) (best estimate)	BWR[1]	6.7	N/A
	PWR	1.8	N/A
NUREG-1738[2] (Ref. 54)	All	2.0	N/A
This regulatory analysis[3]	SFP Group 1	6.6	29
	SFP Group 2	3.3	27
	SFP Group 3	3.3	16
	SFP Group 4	3.3	34

1. The NUREG-1353 BWR seismic structural failure value was not multiplied by the stated conditional probability of having a zirconium fire of 0.25.
2. NUREG-1738 presented results for the two different seismic hazard models in wide use at the time (the Electric Power Research Institute and Lawrence Livermore National Labs models). The larger of the two values is listed above.
3. The base case initiating event frequency value is from Table 7. The high estimate sensitivity initiating event frequency value is from Table 8. The likelihood of fuel uncovery is a product of initiating event frequency, ac power fragility (1.0), and liner fragility (value depends on case being evaluated). A value of 1.0 for ac power or pool liner failure mean represents a 100 percent likelihood of failure.

The SFPS evaluated a specific BWR Mark I reference site for a specific initiating event. When spent fuel in a pool becomes uncovered, it may still be coolable from natural circulation of air once the water level clears the baseplate of the racks, depending on the amount of decay heat during the operating cycle. In Section 12.1 of the Spent Fuel Pool Study, the fuel is estimated to be air coolable for all but roughly 10 percent of the operating cycle. Factors affecting this value include the amount of fuel in the pool, its configuration, geometry of the fuel racks, etc. A partial draindown event with channeled fuel or solid-walled high-density racks could impede airflow. In this case with no natural circulation of air through the racks, the fuel could only be cooled by steam generated by the fuel itself or through the application of water spray. For these mechanisms to be effective, a substantial fraction of the decay heat must be absorbed by the remaining water to generate adequate steam flow or adequate spray flow must be applied. Distributed fuel assemblies late in the operating cycle may lose a significant portion of the remaining decay heat to radiation heat transfer and limited convective heat transfer at temperatures below the runaway oxidation threshold, and therefore, the assemblies would not reach a self-sustaining oxidation condition.

The spent fuel is expected to retain an air coolable geometry following a seismic event that causes a moderate to large crack in the pool, and information provided in NUREG/CR-5176 (Ref. 62), which concludes that there is high confidence that spent fuel pool racks are sufficiently robust to remain generally intact with their fuel channels open supports this assumption. Furthermore, prior studies conclude that severe earthquakes are not expected to result in catastrophic failure of spent fuel pool structural walls and floor or fuel racks. However, there is considerable variability in U.S. spent fuel pool size, capacity, rack type, and geometry as well as the amount and age of the fuel in the pool and its burnup. Because plant-specific analyses is not available to verify that all Unites States spent fuel pools and racks retain their structural integrity and air-coolable geometry following a beyond-design basis seismic event for all U.S. spent fuel pools, a bounding approach was used to evaluate the sensitivity of assuming the spent fuel is not air-coolable following a seismic bin 3 or seismic bin 4 earthquake. For bin 3 this modeling represents the scenario in which the seismic event results in a partial draindown condition (i.e., liner tearing at the walls) with some water remaining at the bottom of the spent fuel pool. This was done by assuming a bounding value of 100 percent for the conditional probability of release for certain cases as shown in Table 12.

Table 12 Fraction of Time Either Excessive Heat or a Partial Spent Fuel Pool Draindown Prevents Natural Circulation Cooling of the Spent Fuel

SFP Group	Seismic Bin	Inadequate Spent Fuel Cooling Fraction		
		Low Est.	Base Case	High Est.
1	Bin 3	10%	10%	100%
	Bin 4	30%	100%	
2, 3, & 4	Bin 3	10%	100%	100%
	Bin 4	30%		

For the postulated cask drop event, the spent fuel is expected to retain an air coolable geometry because a cask drop accident would most likely affect the fuel pool floor in the cask loading area. Typically overhead cranes used to move casks are designed to meet single failure proof criteria, and have interlocks and administrative controls that limit the motion of the crane over the spent fuel pool to the cask loading area, where no fuel is stored. Although improbable, crane failure is more likely to occur during hoisting operations when many components contribute to holding the cask than during translational motion when the hoist holding brakes are set. The hoisting activities occur over the cask loading area, and, in that location, the cask, if dropped, could have sufficient potential energy to damage the spent fuel pool floor. However, a structural analysis to evaluate all U.S. spent fuel pools was not performed to verify that spent fuel and racks retain their structural integrity and air-coolable geometry following a cask drop event. Given the uncertainties and plant-specific variabilities involved, a bounding approach was used by assuming the spent fuel is not air-coolable following a cask drop accident. This was done by assigning a bounding value of 1.0 for the conditional probability of release for the cask drop unsuccessful mitigation event.

To calculate the total release frequency, the uncovery frequencies are multiplied by the conditional probability of release for each initiating event class. The conditional probability of release depends on the fraction of the operating cycle where the fuel is not air coolable. As previously discussed in this section, given the uncertainties and plant-specific variability involved, a bounding approach was used. For all spent fuel pool draindown events (e.g., seismic events and cask drops) the bounding approach used in this regulatory analysis assumes these events are not air-coolable. For the nonseismic and noncask drop events taken from previous studies, the nature of the events may lead to a situation similar to a partial draindown where the rack baseplate is not cleared and airflow is impeded. For these events, the spent fuel is not air-coolable and the conditional release probability is assumed to be 100 percent.

When mitigation is credited, the SFPS found that successful deployment of mitigation decreased the conditional probability by a factor of 19 for the seismic bin no. 3 event analyzed at the reference plant using mitigation measures required under 10 CFR 50.54 (hh)(2) (Ref. 33).

The SFPS does not consider the post-Fukushima spent fuel pool instrumentation required under Order EA-12-051 (Ref. 74) and severe accident mitigation equipment and mitigation strategies (Ref. 21) required under Order EA-12-049 (Ref. 73), which is being implemented by the plants and is intended to increase the likelihood of restoring or maintaining power and mitigation capability during severe accidents. In reality, the effectiveness of post-Fukushima improvements to severe accident mitigation measures will depend on a variety of factors, which the SFPS did not consider but are expected to increase the likelihood that deployment of mitigation measures is successful. Each plant has developed a plant-specific analysis and strategies for coping with the effects of the beyond-design-basis natural events that may challenge its spent fuel pool cooling and makeup capabilities. For the purposes of this regulatory analysis, it was estimated that mitigation if successfully deployed in time decreased the conditional probability by a factor of 19 for all initiating events as determined in the SFPS. Because of uncertainty and variability in designs and strategies between plants, this assumption was only used in the evaluation of Alternative 2 for low-density spent fuel pool storage.

Table 13 summarizes the non-seismic initiating event fuel uncovery frequencies, the conditional probability of release, and the total release frequency with mitigation.

Table 13 Release Frequencies for Spent Fuel Pool Initiators for Nonseismic Events

Initiating Event Class	Initiating Event Fuel Uncovery Frequency (per r-yr)	Conditional Probability of Release (Unsuccessful mitigation)	Release Frequency (Unsuccessful mitigation) (per r-yr)
Cask / heavy load drop	$2x10^{-7}$ [2]	8.2% - 100%	$1.64x10^{-8}$ – $2.00x10^{-7}$
LOOP – severe weather	$1x10^{-7}$ [2]	100%	$1.00x10^{-7}$
LOOP – other	$3x10^{-8}$ [2]	100%	$3.00x10^{-8}$
Internal fire	$2x10^{-8}$ [2]	100%	$2.00x10^{-8}$
Loss of pool cooling	$6x10^{-8}$ [1]	100%	$6.00x10^{-8}$
Loss of water inventory	$1x10^{-8}$ [2]	100%	$1.00x10^{-8}$
Inadvertent aircraft impacts	$6x10^{-9}$ [2]	100%	$6.00x10^{-9}$
Missiles – general	$1x10^{-8}$ [1]	100%	$1.00x10^{-8}$
Missiles - tornado	$1x10^{-9}$ [2]	100%	$1.00x10^{-9}$
Pneumatic seal failures	0 – $3x10^{-8}$ [1,4]	100%	0 – $3.00x10^{-8}$
Total			$2.53x10^{-7}$ – $4.37x10^{-7}$

1. Values from NUREG-1353 (Ref. 48). These numbers are applicable to all reactors and were not adjusted by the stated conditional probability of having a zirconium fire of 0.25 for BWR reactors.
2. Values from NUREG-1738 (Ref. 54).
3. The operating cycle phase is equal to 8.2% (e.g., 60/730) for 2-year refueling cycles and 11.0% (e.g., 60/547.5) for 18-month refueling cycles.
4. Although many plants use gates with mechanical seals that are kept under pressure by passive mechanical means (i.e., do not depend on air pressure, ac power, or dc power) to prevent leakage, there may be some plants that continue to use pneumatic seals. This regulatory analysis conservatively includes the pneumatic seal failures as an initiating event for U.S. PWR spent fuel pools.

Table 14 provides the total release frequency by spent fuel pool group for all spent fuel pool event initiators.

Table 14 Total Release Frequency by Spent Fuel Pool Group

SFP Group	Seismic Bin	Bin Frequency (per year)	Liner Fragility	Fraction Not Air Coolable	Seismic Release Frequency (per year)	Non-Seismic Release Frequency (per year)	Total Release Frequency per Group (per year)
Low Estimate							
1	3	1.65×10^{-5}	10%	8%	1.35×10^{-7}	2.53×10^{-7}	1.12×10^{-6}
	4	4.90×10^{-6}	50%	30%	7.35×10^{-7}		
2,3,4	3	1.65×10^{-5}	2%	8%	3.30×10^{-8}	2.83×10^{-7}	5.51×10^{-7}
	4	4.90×10^{-6}	16%	30%	2.35×10^{-7}		
Base Case							
1	3	1.65×10^{-5}	10%	8%	1.35×10^{-7}	4.37×10^{-7}	5.47×10^{-6}
	4	4.90×10^{-6}	100%	100%	4.90×10^{-6}		
2,3,4	3	1.65×10^{-5}	5%	100%	8.25×10^{-7}	4.67×10^{-7}	3.74×10^{-6}
	4	4.90×10^{-6}	50%	100%	2.45×10^{-6}		
High Estimate							
1	3	2.24×10^{-5}	100%	100%	2.24×10^{-5}	4.37×10^{-7}	2.99×10^{-5}
	4	7.09×10^{-6}	100%	100%	7.09×10^{-6}		
2	3	4.92×10^{-5}	25%	100%	1.23×10^{-5}	4.67×10^{-7}	2.79×10^{-5}
	4	1.51×10^{-5}	100%	100%	1.51×10^{-5}		
3	3	2.95×10^{-5}	25%	100%	7.38×10^{-6}	4.67×10^{-7}	1.69×10^{-5}
	4	9.10×10^{-6}	100%	100%	9.10×10^{-6}		
4	3	5.64×10^{-5}	25%	100%	1.41×10^{-5}	4.67×10^{-7}	3.46×10^{-5}
	4	2.00×10^{-5}	100%	100%	2.00×10^{-5}		

4.3.2.4 Duration of Onsite Spent Fuel Storage Risk

For this regulatory analysis, it is assumed that the each nuclear power plant operates through the term of its operating license and that the licensee continues to store spent fuel in the plant's spent fuel pool following commercial operation[13] to allow the spent fuel to cool sufficiently before placing into dry storage. Other than for operating reactors that have indicated they would not seek a license renewal, this regulatory analysis assumes that remaining operating reactors' operation expectancy will include a 20-year license extension, unless stated otherwise.[14] As a result, the average license will expire in 2039. Table 1 summarizes the average reactor operation expectancy by the identified spent fuel pool groupings.

13 Decommissioning of the unit must be completed within 60 years of permanent cessation of operations under 10 CFR 50.82, "Termination of License." Completion of decommissioning beyond 60 years will be approved by the Commission only when necessary to protect public health and safety.

14 Six U.S. nuclear power plant units that have announced early retirements (with year of closure in parentheses) are Crystal River 3 (2013), Kewaunee (2013), San Onofre Units 2 and 3 (2013), Vermont Yankee (2014), and Oyster Creek (2019).

4.3.2.5 Dollar per Person-Rem Conversion Factor

Using the dollar value of the health detriment and a risk factor that establishes the nominal probability for stochastic health effects attributable to radiological exposure (fatal and nonfatal cancers and hereditary effects) provides a dollar per person-rem of $2,000, rounded to the nearest thousand, according to NUREG-1530, “Reassessment of NRC’s Dollar per Person-Rem Conversion Factor Policy,” dated December 1995 (Ref. 51).

The NRC currently uses a value of statistical life (VSL)[15] of $3 million based on NUREG-1530, and a cancer risk factor of 7.0×10^{-4}, which is a reduction to the closest significant digit of a recommendation by the International Commission on Radiation Protection (ICRP) in Publication No. 60. Therefore, the dollar per person-rem is equal to $3 million times 7.0×10^{-4} rounded to the nearest thousand (because of uncertainties) or $2,000.

4.3.2.6 Onsite Property Decontamination, Repair, and Refurbishment Costs

Spent fuel pool accident risks have significant contributions from onsite property monetary losses (e.g., repair and refurbishment) and plant decontamination. The risk dominant accident sequences involve the failure of the pool because of seismic or load drop events resulting in the loss of pool integrity. This scenario results in loss of spent fuel pool water inventory, Zircaloy cladding fire initiation with propagation through the spent fuel assemblies stored in the pool, and an uncontrolled radiological release from the reactor building. The NRC assumes that, based on the current regulatory framework, with insights from the Fukushima Dai-ichi accident, that onsite property would be radiologically affected in the following way. The consequences of a spent fuel fire are expected to be similar to the Category II accident as defined in NUREG/CR-5281, Section 3.2.4 (Ref. 64). Based on this reference, the cleanup and decontamination costs are estimated to be approximately $165 million (1983 dollars) and the cost for permanent disposal of the damaged fuel is $26 million (1983 dollars). Using Table C.95 from the RA Handbook (Ref. 58), the pool repair is expected to cost $72 million (1983 dollars). Adjusting these estimated costs using the CPI-U inflator formula and using a multiplier of three to model the high estimate and a divider of two to model the low estimate results in the values provided in Table 15.

Table 15 Onsite Property Decontamination, Repair, and Refurbishment Costs

	1983 dollars			2012 dollars		
Onsite Property Cost Element	Best Estimate	High Estimate	Low Estimate	Best Estimate	High Estimate	Low Estimate
Cleanup and decontamination	$165,000,000	$495,000,000	$82,500,000	$380,358,000	$1,141,074,000	$190,179,000
Repair Pool	$72,000,000	$216,000,000	$36,000,000	$165,974,000	$497,922,000	$82,987,000
Disposal of damaged fuel	$26,000,000	$78,000,000	$13,000,000	$59,935,000	$179,805,000	$29,968,000
Total	$263,000,000	$789,000,000	$131,500,000	$606,267,000	$1,818,801,000	$303,134,000

15 The value of a statistical life (VSL) is the monetary value of a mortality risk reduction that would prevent one statistical (as opposed to an identified) death (Ref. 16). The VSL is a key component in the calculation of the dollar per person-rem value, which is the product of the VSL multiplied by a risk coefficient.

4.3.2.7 Replacement Energy Costs

Replacement energy costs are the costs for replacing the energy from the nuclear power plant because of a plant shutdown to install required equipment or because of an accident.[16] The NRC assumes that replacement energy costs would be required until onsite decontamination and repair efforts are completed or the unit is retired.

The NRC assumes that licensees engage in power purchase agreements (PPA)[17] to economically purchase replacement power. A PPA is a legal contract between an electricity generator (licensee) and a power purchaser. The NRC assumes that a licensee will not be able to replace the power through other generation for 7 years and would have to buy power from the market. Although not all licensees may have PPAs, the licensee will still replace the lost energy any time that the nuclear power plant is not operating to meet its electrical power supply obligations. The NRC assumes that after 7 years, the onsite decontamination and repair efforts are completed or the unit is retired and other power sources will be developed to replace the unit's lost electrical generation capability.

4.3.2.8 Occupational Worker Exposure (Accident)

There are two types of occupational exposure related to accidents: short-term and long-term. The first occurs at the time of the accident and during the immediate management of the emergency. The second is a long-term exposure, presumably at significantly lower individual rates, associated with the cleanup and refurbishment or decommissioning of the damaged facility. The value gained in the avoidance of both types of exposure is conditioned on the change in frequency of the accident's occurrence.

The experiences at the Three Mile Island Unit 2 (TMI-2), the Chernobyl, and the Fukushima nuclear power plants illustrated that significant occupational exposures could result from performing activities outside the control room during a power reactor accident. At TMI-2, the average occupational exposure related to the incident was approximately 1.0 rem, with a collective dose of 1,000 person-rem occurring over a 4-month span, after which time occupational exposure approached pre-accident levels. For Chernobyl, the average dose for persons closest to the plant was 3.3 person-rem (Ref. 58, p. 5.30), yielding an average value of 3,300 person-rem.

The accident at Fukushima involved release of both short-lived and long-lived radionuclides from the reactor cores within Units 1, 2, and 3, and no release from the fuel stored in the spent fuel pools. Significant changes in the release of radioactivity occurred following changes in the status of the core, primary containment, and secondary containment. After the Fukushima unit 1 building explosion on March 12, 2011, the unit 3 building explosion on March 14, and the unit 4 building explosion, which released radioactivity from Unit 3 because of a shared

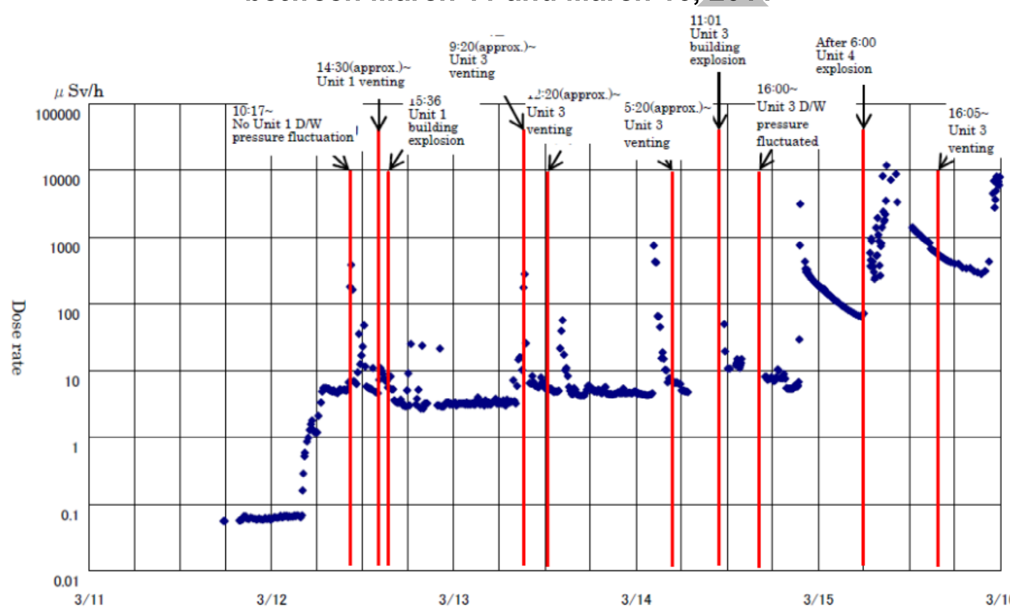
16 The replacement energy cost is only the cost to buy the energy for production on the market. Therefore, the cost would be the cost of buying the cheapest energy. These estimates do not include transmission or distribution costs.

17 A power purchase agreement is a contract between two parties, one who generates electricity for the purpose of sale (the seller) and one who is looking to purchase electricity (the buyer). The PPA defines all of the commercial terms for the sale of electricity between the two parties, including when the project will begin commercial operation, schedule for delivery of electricity, penalties for under delivery, payment terms, and termination.

ventilation system, and the exposure of the unit 2 reactor fuel rods on March 15, radioactive materials were released into the environment and surrounding areas of the Fukushima Dai-ichi nuclear power plant. Measurement and evaluation of radiation exposure levels for workers engaged in emergency work at the Fukushima Dai-ichi NPS have been implemented continuously since the Tohoku earthquake.

As shown in Figure 11, the dose rate in the vicinity of the main gate at the Fukushima Dai-ichi site near the time of the Unit 4 explosion varied between 20 mrem and 1.0 rem per hour (between 200 and 10,000 μSv per hour).

Figure 11: Dose rate in vicinity of Fukushima Dai-ichi nuclear plant site main gate between March 11 and March 16, 2011



Source: Fukushima Nuclear Accident Analysis Report p. 371 (Ref. 17).

On March 22 and 23, surveys of the airborne radioactivity and dose rates around the Fukushima Dai-ichi site were collected and documented. The dose rates are shown on Figure 12.

Figure 12: Fukushima Dai-ichi site dose rates between March 22 and March 23, 2011

Source: INPO 11-005, p 41 (Ref. 11).

The distribution of total monthly exposure for workers engaged in radiation work at the Fukushima Dai-ichi nuclear plant site for the first 3 months following the March 2011 accident is provided in Table 16.

Table 16 Average Accident Occupational Exposure at Fukushima Dai-ichi Nuclear Power Plant from March to May 2011

Total Radiation Exposure (mSv)	Number of Plant Workers Exposed		
	March 2011[1]	April 2011[2]	May 2011[3]
≥ 250	6	0	0
200 - 249	2	0	0
150 - 199	14	0	0
100 - 149	77	0	0
50 - 99	309	3	0
20 - 49	859	81	19
10 - 19	1041	310	144
< 10	1434	3214	2854
Total number of workers	3742	3608	3017

Notes:
1. Maximum March 2011 occupational exposure was 670.4 mSv.
2. Maximum April 2011 occupational exposure was 69.3 mSv.
3. Maximum May 2011 occupational exposure was 41.6 mSv.
4. One mSv is equal to 0.1 rem.

Source: Wada et al, Occupational and Environmental Medicine, 2012 August; 69(8): p. 600 (Ref. 76).

To estimate the monthly total occupational radiation exposure received by all workers, a high estimate, base case, and low estimate were calculated based on the maximum category value, the midpoint category value, and the first quartile category value. The results are tabulated in Table 17.

Table 17 Estimated Immediate Accident Occupational Monthly Exposure at Fukushima

Radiation Exposure (mSv)	Best Estimate Category Radiation Exposure (mSv)			High Estimate Category Radiation Exposure (mSv)			Low Estimate Category Radiation Exposure (mSv)		
	March 2011	April 2011	May 2011	March 2011	April 2011	May 2011	March 2011	April 2011	May 2011
≥ 250	460.2			670.4			355.1		
200 - 249	224.5			249			212.25		
150 - 199	174.5			199			162.25		
100 - 149	124.5			149			112.25		
50 - 99	74.5	69.3		99	69.3		62.25	62.25	
20 - 49	34.5	34.5	34.5	49	49	41.6	27.25	27.25	27.25
10 - 19	14.5	14.5	14.5	19	19	19	12.25	12.25	12.25
< 10	5	5	5	10	10	10	2.5	2.5	2.5
Total Monthly Dose	90,200	23,600	17,000	125,600	42,200	32,100	72,500	14,200	9,400
Avg Worker Dose	24.1	6.5	5.6	33.6	11.7	10.6	19.4	3.9	3.1

The immediate accident occupational exposure for a spent fuel pool accident shown in Table 18 is estimated based on the Fukushima data and the following assumptions:

- The immediate accident period lasts for 1 year.
- The workforce during the immediate accident period is 3,700 workers.
- The average worker radiation exposure remains constant at the May 2011 value from May 2011 through February 2012.

Table 18 Immediate Accident Occupational Exposure for a Spent Fuel Pool Fire

Case	Immediate Accident Occupational Exposure (averted person-rem)
Low Estimate	18,070
Best Estimate	28,380
High Estimate	48,880

After the immediate response to a spent fuel pool fire, a long process of cleanup and refurbishment or decommissioning will follow. The Fukushima Nuclear Accident Analysis Report states, “The average value for 5,128 people in April of 2012 was 1.07 mSv per worker because of decreasing trends in environment dose rates (Ref. 17, p 415). The NRC assumes that the process of cleanup and refurbishment or decommissioning will begin 1 year after the accident and will take 7 years to complete. During those 7 years, the NRC assumes that each occupational worker at the damaged reactor site will be exposed to 1.07 mSv per month (0.107 rem per month) for the duration of the cleanup and refurbishment or decommissioning. Assuming the average value for 5,128 workers would remain for the duration yields a cumulative long-term occupational dose of 46,000 person-rem.

In NUREG/CR-5281 (Ref. 64), Jo et al. (1989) conducted what essentially amounted to a regulatory analysis of a non-reactor nuclear fuel cycle facility using Heaberlin, et al 1983 Handbook (Ref. 60) as guidance. The accidental occupational exposure was assumed to be similar to that from TMI-2, which is 4,580 person-rem.

As described in the RA Handbook (Ref. 58, p 5.30), the DOE (1987) summarized results on the collective dose received by the populace surrounding the Chernobyl accident. Average dose equivalents of 3.3 rem per person, 45 rem per person, and 5.3 rem per person were estimated for residents within 3 km, between 3 km and 15 km, and between 15 km and 30 km of Chernobyl, respectively (Ref. 65, p. A-5). Assuming 1,000 workers and a 4.2 multiplier, an estimate radiation exposure of 14,000 person-rem results.

Site worker exposures following a spent fuel pool accident could be greater than that of a reactor core melt accident. This is because a spent fuel pool stores significantly more fuel assemblies than a reactor core. Given the uncertainties in existing data and variability in severe accident parameters and worker response, Table 19 provides the long-term occupational dose used in this regulatory analysis to analyze spent fuel pool fires.

Table 19 Long-Term Accident Occupational Exposure for a Spent Fuel Pool Fire

Case	Long-Term Accident Occupational Exposure (averted person-rem)
Low Estimate	4,580
Best Estimate	14,000
High Estimate	46,000

4.3.2.9 Spent Fuel Pool Release Fractions

The spent fuel pool release fractions used in this regulatory analysis is based on the results of the Spent Fuel Pool Study for Group 1 as well as previous spent fuel pool studies. Table 20 shows a comparison of the release fractions between the Spent Fuel Pool Study and previous studies that demonstrates that cesium release fractions are generally less in the Spent Fuel Pool Study when compared to previous studies, and the timing of the release is generally longer.

The range of release fractions for this regulatory analysis is shown in Table 21. For the alternative 1 in Group 1, the release fractions are based on the high density cases in the Spent Fuel Pool Study with the low estimate representing cases where the reactor building remains intact, while the base case reflects cases with significant air oxidation as a result of substantial damage to the refueling bay. The high estimate represents a bounding case with large scale damage and relocation of the spent fuel assemblies and subsequent interaction of the fuel debris with the concrete floor. Alternative 2 in Group 1 represent the low density cases from the SFPS. For alternative 1 in the other groups, the range of release fractions is consistent with past studies (see Table 20), but the high estimate is 90 percent based on insights from the SFPS regarding molten core concrete interaction sensitivity study. The release fractions for Alternative 2 in Groups 2, 3, & 4 are assumed the same as in Group 1 since the releases are dominated by the recently discharged fuel.

Table 20 Comparison of Release Fractions from Current and Previous Spent Fuel Pool Analyses

Resolution of GI-82: NUREG-1353 (Ref. 48), NUREG/CR-4982 (Ref. 62), NUREG/CR-5281 (Ref. 64)	NUREG-1738 (Ref. 54)	Spent Fuel Pool Study (Ref. 2)
• 10 to 100% cesium release (100% assumed for cases 1 and 2) • Release over 8 hours for a propagating spent fuel pool zirconium fire (assumed) • 0.25 (BWR) or 1.0 (PWR) conditional probability if fuel becomes uncovered	• 75% cesium release (assumed from NUREG-1465 (Ref. 51) • Instantaneous draindown for large seismic event • 2 to 14 hour heatup depending on fuel age (see Ref. 54, Table A1-1)	• Less than 1% to 49% cesium release • Draindown to uncovery ranges from 2.5 to 43 hours (when leak exists) • Start of release ranges between 8 hours to greater than 72 hours

Table 21 Estimated Cumulative Cesium Inventory Release Fraction Given a Spent Fuel Pool Fire

SFP Group	Alternative	Low Est.	Base Case	High Est.
Group 1	1	3%	40%	90%
	2	0.5%	3%	5%
Group 2, 3 & 4	1	10%	75%	90%
	2	0.5%	3%	5%

4.3.2.10 Atmospheric Modeling and Meteorology

The atmospheric transport and dispersion model used in this regulatory analysis are based on the Peach Bottom MACCS2 results described in Section 7.1.2 of the Spent Fuel Pool Study (Ref.2), which uses a straight-line Gaussian plume segment dispersion model. As described in this study, the atmospheric release of radionuclides is discretized into (at longest) 1-hour plume segments. This accounts for variations in the release rate, as well as for changes in wind direction. More plume segments increase the resolution of the dispersion modeling to the point the resolution corresponds to the time resolution of the weather data, because each segment can travel in a compass direction representative of the actual weather data at the time the plume segment is released.

Two important parameters and variables required to model a spent fuel pool site are 1) the population density and distribution and 2) the site meteorology. The radionuclide inventory, source term (i.e., release fraction, release start time, and release duration), initial plume dimensions (related to the system geometry), and plume heat content were described.

4.3.2.11 Population and Economic Data

Population distributions characteristics for spent fuel pool sites are examined to provide perspective on site demographic characteristics important to this regulatory analysis. Based on the review performed, site population densities near spent fuel pools have the following statistical characteristics:

Table 22 Population Density within a 50 Mile Radius of U.S. Nuclear Power Plant Sites

Case	Statistical Parameter	Average Population Density within 50 miles (No. of people per square mile)	Representative Site Demographics
High estimate	90th percentile	688	Peach Bottom
Mean estimate	Mean	317	Surry
Median estimate	Median	169	Palisades
Low estimate	20th percentile	93	Point Beach

Source: 2010 census. Population density calculations do not correct the area within the radius that is water

Representative site demographics were selected to represent the 90th percentile, the mean, the median, and the 20th percentiles. For each representative site, the site population and economic data was created for 16 compass sectors and then interpolated onto a 64 compass-sector grid for better spatial resolution for the consequence analysis. Site population data is projected to the year 2011 using the latest version of the computer code SECPOP2000 (Ref. 67). SECPOP2000 uses 2000 census data and applies a multiplier to account for population growth and an economic multiplier to account for the value of the dollar to create site data for the MELCOR Accident Consequence Code System (MACCS2). A multiplier value of 1.1051 from the U.S. Census Bureau was used to account for the average population growth in the United States from 2000 to 2011. Consistent with the approach used in the SFPS, the economic values from the database in SECPOP2000 (which uses an economic database based on the year 2002) were scaled to account for price escalation between the years 2002 and 2011. A scaling factor of 1.250 was derived based on the Consumer Price Index.

4.3.2.12 Long-Term Habitability Criteria

The long-term phase is the period following the 7-day emergency phase and is modeled for 50 years to calculate consequences from exposure of the average person. Radiation exposure during this phase is mainly from external radiation from trace contaminants that remain after the land is decontaminated, or in lightly contaminated areas where no decontamination was required. Internal radiation exposures may also occur during this period, including inhalation of resuspended radionuclides and ingestion of food and water with trace contaminants. Depending on the relevant protective action guides (PAGs) and the level of radiation, food, and water below a certain limit could be considered adequately safe for ingestion, and lightly contaminated areas could be considered habitable.

A long-term cleanup policy for recovery after a severe nuclear power plant accident does not currently exist. The actual decisions regarding how land would be recovered and populations relocated after an accident would be made by a number of local, State, and Federal jurisdictions and would most likely be based on a long-term cleanup strategy, which is currently being developed by the NRC, U.S. Environmental Protection Agency (EPA), and other Federal agencies. Furthermore, a cleanup standard may not have an explicit dose level for cleanup. Instead, the cleanup strategy may give local jurisdictions the ability to develop localized cleanup goals after an accident, to allow for a number of factors that include sociopolitical, technical, and economic considerations.

Site-specific values are used to determine long-term habitability. For habitability, most States adhere to EPA intermediate phase protective action guides that allow a dose of 2 rem in the first year and 500 mrem each year thereafter (Ref. 39). This habitability criterion was used in previous spent fuel pool studies, which used 4 rem in 5 years to represent these PAG levels (e.g., 2 rem in year one, followed by 0.5 rem each successive year). The nationally and internationally recommended upper bound for dose in a single year from man-made sources, excluding medical radiation, is 500 mrem per year to the whole body of individuals in the general population. The EPA states “these recommendations were not developed for nuclear incidents … [and] also not appropriate for chronic exposure” (Ref. 39, p. E-12). However, some States, such as the State of Pennsylvania, has adopted a habitability criterion of 500 mrem beginning in the first year (and each following year) as determined by the Pennsylvania Code Title 25 Section 219.51 (Ref. 37). The use of this long-term habitability criterion reduces the predicted long-term population doses and health effects and increases the costs associated with interdiction, decontamination, and condemnation.[18]

Given the uncertainties in which long-term habitability criterion would be used, Table 23 provides the long-term phase habitability criterion used in this analysis to analyze the consequences of spent fuel pool fires on public health (accident).

Table 23 Long-Term Habitability Criterion

Case[19]	Long-Term Habitability Criterion	Protective Action Basis
Low Estimate	500 mrem annually	Pennsylvania dose limit to the public
Base Case	2 rem in the first year and 500 mrem each year thereafter	EPA intermediate phase PAGs
High Estimate	2 rem annually	EPA intermediate phase PAG: first year

MACCS2 computer runs were run for each of the protective action levels listed in Table 23 to calculate averted dose and offsite property damage using the representative plant site demographics listed in Table 22.

The use of these habitability criteria also affects the values of offsite property damage used in this analysis. Certain metrics such as offsite property damage, the number of displaced individuals (either temporarily or permanently) and the extents to which such actions may be needed are inversely proportional to changes in collective dose resulting from changes in habitability criteria.

These criteria provide a benchmark for understanding the nature and the extent of the relationship between collective dose, economic consequences, and habitability criteria following a severe spent fuel pool accident. These measures are subject to large uncertainties, as it is difficult to model the impact of disruptions to many different aspects of local economies, the loss of infrastructure on the general U.S. economy, or the details of how long-term protective actions would be performed.

18 Interdiction and condemnation refer to the relocation of people from contaminated areas according to the habitability criterion. Interdiction is the temporary relocation of the affected population while decontamination, natural weathering, and radioactive decay reduce the contamination levels. Condemnation is the permanent relocation of the affected population if decontamination, natural weathering, and radioactive decay cannot adequately reduce contamination levels to habitability limits within 30 years.

19 Cases are defined as low and high estimate based on the affect that different long-term habitability criteria have on averted radiation exposure.

4.3.2.13 Emergency Response Modeling

This regulatory analysis uses the emergency response model contained in the Reference Plant-specific MACCS2 results described in Section 7.1.2 and Appendix A of the SFPS. The extended loss of ac power is assumed to be limited to the plume exposure pathway emergency planning zone (EPZ) (approximately 16 kilometers or 10 miles) because of the assumption that the strength of the seismic event is from the proximity of the seismic event to the site, rather than being a wider impact from a larger magnitude. See Section 7.1.4 of the Spent Fuel Pool Study for additional details.

A summary of the evacuation timing and speeds for each cohort modeled in the SFPS and reproduced here is provided in Table 24. This evacuation timing and speeds is used to produce the consequence analyses results for this regulatory analysis.

Table 24 Evacuation Model 1: Plume Exposure Pathway EPZ Evacuation

Population			Response Delays (hours)				Phase Duration (hours)		Evacuation Travel Speeds (mph)		
Cohort		Population Fraction	Siren (OALARM)	Delay to Shelter	Delay to Evacuation	Total (Depart time)	Early (DURBEG)	Middle (DURMID)	Early (ESPEED)	Middle (ESPEED)	Late (ESPEED)
1	0 to 10 miles Early Evacuees	0.3	1	0	0	1	1	0.5	20	15	5
	10 to 20 miles Shadow			2	1	4					
2	0 to 10 miles General Public	0.417	1	1	1	3	0.25	3	5	2	20
3	0 to 10 miles Special Facilities	0.006	1	0	4	5	0.5	0.5	2	15	20
4	0 to 10 miles Evacuation Tail	0.1	1	2	3	6	0.5	0.5	2	15	20
5	0 to 10 miles Schools	0.172	1	0	0.5	1.5	1	0.5	20	15	20
6	0 to 10 miles Nonevacuating Public	0.005	1	-	-	-	-	-	-	-	-

Meteorological data used to calculate offsite consequences for this regulatory analysis consisted of 1 year of hourly meteorological data (8,760 data points for each meteorological parameter) for the Peach Bottom site evaluated in the Spent Fuel Pool Study (Ref. 2) and in NUREG-1935 (Ref. 55). The Peach Bottom site provided 2 years of weather data, including directly measured hourly precipitation data. Stability class data were derived from temperature measurements at two elevations on the site meteorological towers. The specific year of meteorological data chosen for the Peach Bottom site was 2006, which was based on data recovery (greater than 99 percent being desirable) as documented in NUREG/CR-7009 (Ref. 70). Different trends (e.g., wind rose pattern and hours of precipitation) between the years were estimated to have a relatively minor (less than 25 percent) effect on the results. More specific details of the weather data can be found in NUREG/CR-7009.

The wind rose shown in Figure 13 shows the Peach Bottom site wind direction (direction the wind blows toward) data that were used in the consequence analyses for this regulatory analysis. The wind rose in the figure below suggests that the predominant wind direction is to the south and east and a secondary direction in terms of likelihood is to the northwest to north.

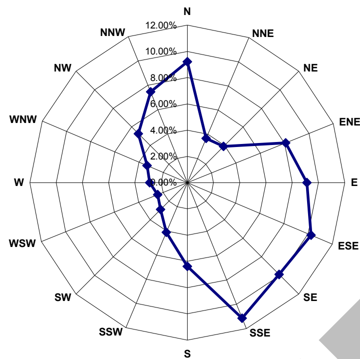


Figure 13 Reference plant wind rose
Source: Spent Fuel Pool Study (Ref. 2, p. A-3)

Although using a single plant's emergency response modeling and consequence analyses introduce uncertainty, the conditional individual risk measures near the site are expected to be relatively insensitive to site-specific characteristics (i.e., emergency response measures). This is because the relatively delayed and prolonged releases as predicted by the SFPS and the lack of short-lived radionuclides allow time for effective protective actions, in both the early and long term phases, to limit exposures to the public particularly in the event of large releases. This is consistent with previous studies in which individual early and latent fatality risks were projected to be low. Therefore, the resulting individual risk measures near the site can used for comparisons to the quantitative health objectives represent risk to the average individual within 1.6 and 16 kilometers (1 and 10 miles) of the plant.

4.3.3 Implementation Assumptions

4.3.3.1 Dry Storage Occupational Exposure (Routine)

Routine occupational exposure associated with dry storage of spent fuel includes worker dose associated with additional DSC loading, unloading and handling activities; additional ISFSI operations, maintenance, and surveillance activities; additional DSC storage at an ISFSI; and additional transportation cask loading, unloading, and handling activities.

Worker dose associated with DSC loading operations vary depending upon the cask technology being loaded, the characteristics of the fuel being loaded (e.g., fuel age and burnup), and fuel loading patterns in the DSC (e.g., the location of short-cooled, high burnup spent fuel or colder spent fuel within DSC baskets using regional loading). For the regulatory baseline, a worker dose of 400 person-mrem per DSC loaded was assumed. This radiation dose is consistent with the exposure value used in EPRI TR-1021049 (Ref. 9) and in EPRI TR-1018058 (Ref. 5), which analyzed worker impacts associated with loading spent fuel for transport to the proposed Yucca Mountain repository. Some sites achieve per package dose ranges in the range of 200 to 300 person-mrem per package loaded, while other sites experience higher per package dose rates. For the low-density storage case, each cask loaded in addition to the number required by the regulatory baseline is estimated to result in an incremental 400 person-mrem dose.

There is routine occupational dose associated with ISFSI annual operation and maintenance activities (i.e., inspection, surveillance, and security operations). The regulatory baseline assumes an annual dose of 120 person-mrem per site per year for inspection, surveillance, and security activities and 1,500 person-mrem per site per year for ISFSI operations and maintenance. These estimated radiation doses are consistent with assumptions used by EPRI in EPRI TR-1021049 (Ref. 9) and TR-1018058 (Ref. 5). Because additional shielding is assumed to be provided by concrete overpacks, the worker dose associated with ISFSI operations and maintenance is not expected to increase. Therefore, no incremental occupational dose is predicted for performing annual ISFSI operation and maintenance.

There is routine occupational dose associated with the storage of each DSC at an operational ISFSI. The regulatory baseline assumes a worker dose of 170 person-mrem for each additional DSC loaded at an ISFSI site. This estimated radiation dose is consistent with assumptions used by EPRI in EPRI TR-1021049 (Ref. 9) and TR-1018058 (Ref. 5). Because additional shielding is assumed to be provided by concrete overpacks, the worker dose associated with each DSC stored at an operational ISFSI is not expected to increase. For the low-density spent fuel pool storage case, each cask stored in addition to the number required by the regulatory baseline is estimated to result in an incremental 170 person-mrem dose.

Table 25 summarizes the occupational dose estimates for each activity.

Table 25 Incremental Occupational Dose (Routine) Estimates

Activity	Incremental Occupational Dose (Routine) (person-mrem per activity)
Load a DSC	400
ISFSI Operation and maintenance	0
Loading a DSC at an ISFSI	170
Total	570

4.3.3.2 Number of Dry Storage Casks

In 2013, the representative Group 1 plant has 3,055 fuel assemblies stored in the spent fuel pool in a high-density 1x4 loading configuration. During each refueling outage, 284 assemblies are offloaded from the reactor vessel to the spent fuel pool. For the regulatory baseline, the plant is expected to load the required number of DSCs with a 68-assembly capacity each refueling outage to retain sufficient space in the spent fuel pool to discharge one full core of fuel (full core reserve). The estimated DSC inventory is shown in Figure 14.

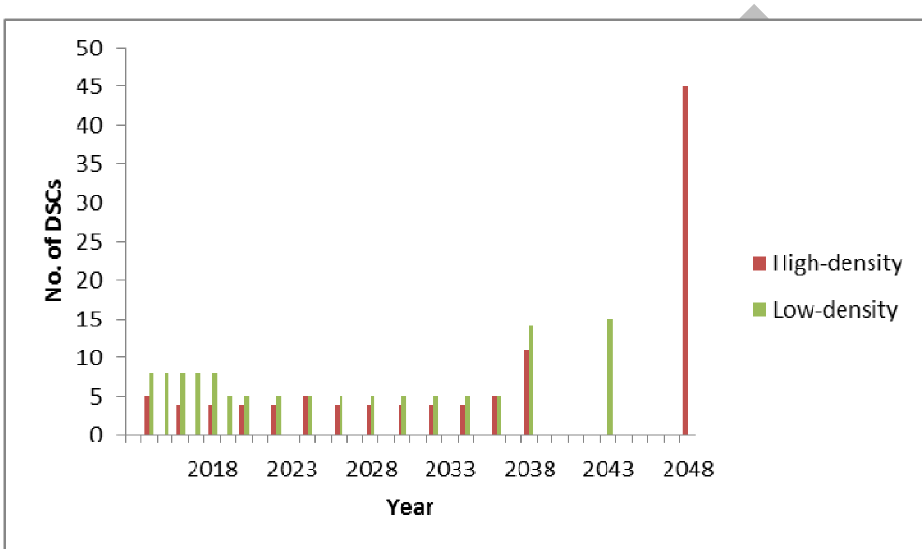


Figure 14 Timing of dry storage cask loading for the representative Group 1 plant

At the expiration of the operating license in 2038, the full core is offloaded into the spent fuel pool. The analysis further assumes that the entire spent fuel pool inventory will be placed into dry storage by 2048, 10 years after termination of unit commercial operation.

For the low-density spent fuel pool storage case, it is assumed that there is an NRC policy decision that requires licensees to offload the spent fuel inventory to dry storage to obtain a low-density configuration within 5 years (e.g., by end of 2019). In this configuration, the representative Group 1 plant spent fuel pool stores 852 assemblies, which is equivalent to the discharge from the last three refueling outages. Using the same initial conditions as above, and using the DSC with a 57-assembly derated capacity beginning in year 2020, the inventory model is provided as the low-density chart in Figure 14.

At the expiration of the operating license in 2034, the full core is offloaded into the spent fuel pool. The analysis further assumes that the entire spent fuel pool inventory will be placed into dry storage by 2048. Additionally, in year 2048, the spent fuel has cooled for a sufficient length of time that the DSC is no longer derated.

Similar calculations were performed for Groups 2, 3 and 4 using the Holtec Hi-Storm FW DSC system for PWR spent fuel. The dry storage cask loading for the representative Group 2 plant is shown in Figure 15.

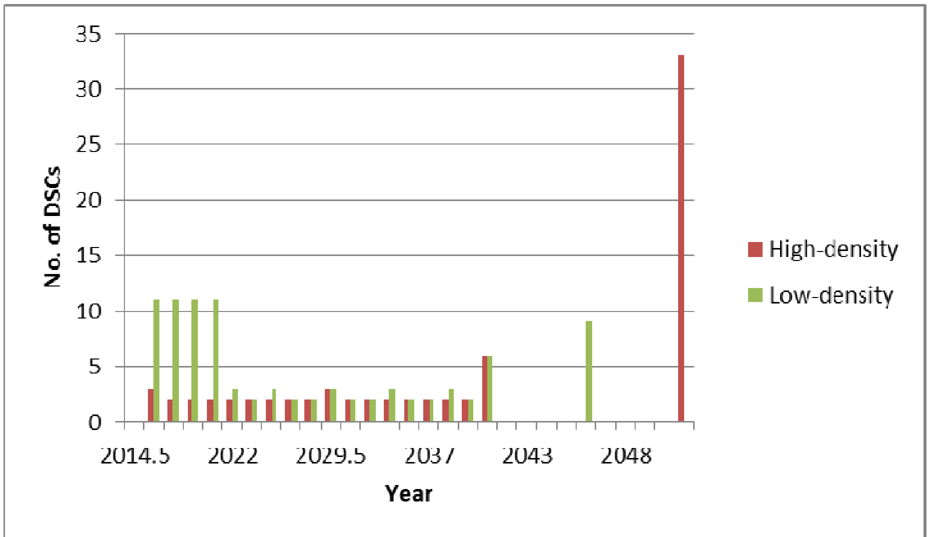


Figure 15 Timing of dry storage cask loading for the representative Group 2 plant

In 2018, the representative Group 3 plant is assumed to begin commercial operation. At this time, there is no spent fuel assemblies stored in the spent fuel pool. The unit is assumed to operate on an 18 month refueling cycle, discharging an estimated 69 assemblies per cycle (Ref. 79, Section 9.1). For the regulatory baseline, the representative new nuclear plant is expected to begin dry storage in 2038 and will load a sufficient number of Holtec Hi-Storm FW casks to maintain its full core offload capability. The estimated timing for DSC loading is shown in Figure 16.

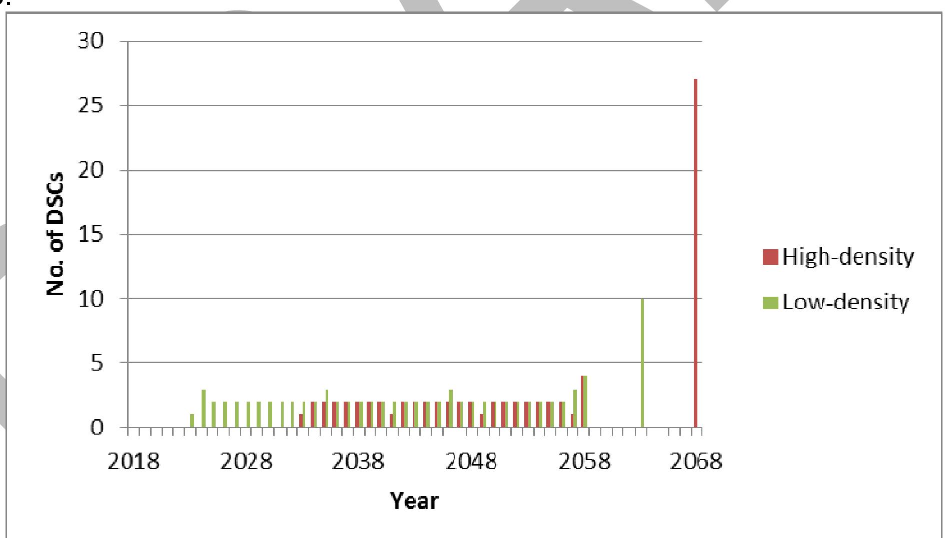


Figure 16 Timing of dry storage cask loading for the representative Group 3 plant

The representative Group 4 spent fuel pool which is shared between two PWR units is assumed to have 1,637 fuel assemblies stored in the spent fuel pool in a high-density 1x4 loading configuration. Each reactor unit operates on a 24-month refueling cycle and discharges 84 assemblies on a 1-year staggered cycle. The representative shared spent fuel pool has already implemented dry storage.

For the regulatory baseline, the Group 4 spent fuel pool is expected to load the required number of DSCs with a 37-assembly capacity each refueling outage to retain sufficient space in the spent fuel pool to discharge one full core of fuel (full core reserve). For the low-density case, the DSC has a 33- assembly capacity because of the higher heat load of the spent fuel. At the expiration of the operating license in 2038, the full core is offloaded into the spent fuel pool. The analysis further assumes that the entire spent fuel pool inventory will be placed into dry storage beginning in 2038 and completed by 2048. The estimated timing for DSC loading for the representative Group 4 spent fuel pool is shown in Figure 17.

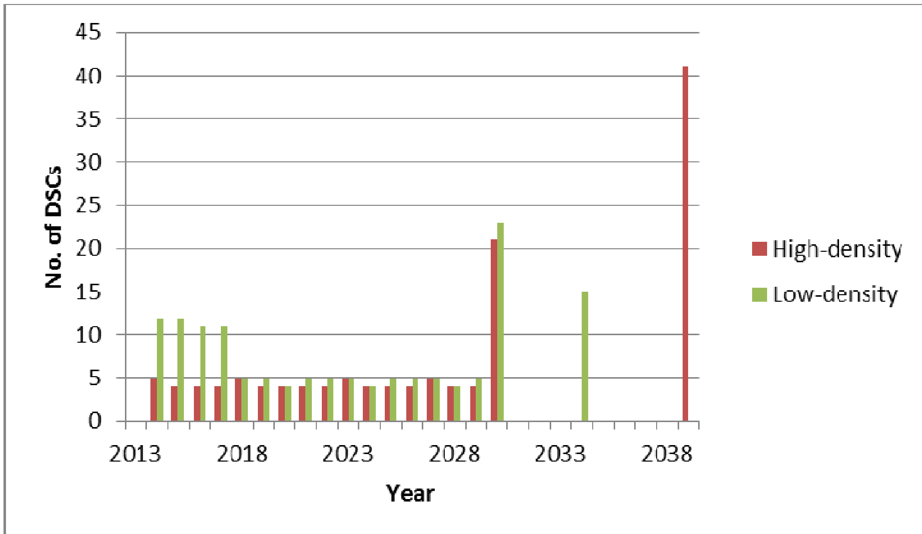


Figure 17 Timing of dry storage cask loading for the representative Group 4 plant

4.3.4 Cost Assumptions

4.3.4.1 Generic Costs

Costs presented in this regulatory analysis are based on estimates by the author or cited documents. This is a generic cost estimate and should be used accordingly. Site-specific features may result in higher or lower costs than those estimated.

4.3.4.2 Dry Storage Upfront Costs

Upfront costs include engineering, design, and licensing costs; equipment costs; construction costs; and start up and testing costs. Each of these cost components are further described in EPRI TR-1021048, “Industry Spent Fuel Storage Handbook” (Ref. 8). As noted in EPRI TR-1025206, “Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage after Five Years of Cooling, Revision 1” (Ref. 10), the independent spent fuel storage installation (ISFSI) upfront costs vary widely from site to site and the upfront costs for those in operation vary from several million to tens of millions of dollars (Ref. 10, p. 2-23). Values for upfront costs were estimated based on two publically available cost estimates that identified the specified number of DSC to be stored. The estimate amortized upfront costs for each site is provided in Table 26.

Table 26 Amortized DSC Upfront Costs

ISFSI Facility	Upfront Cost Estimate (base year)	Upfront Cost Estimate (2012 $)	DSC Storage Capacity	Attributed Upfront Cost per DSC (2012 $)
Monticello	$21.5 million (2005 $)	$25,275,400	30	$842,500
Pilgrim	$22 million (2006$)	$25,055,800	53	$472,800
Average (Best Estimate)		$25,165,600		$657,700

4.3.4.3 Incremental Costs Associated with Earlier DSC Purchase and Loading

Incremental costs are the costs associated with the purchase and loading of DSCs on a periodic basis. These costs include the capital costs for the DSC and the loading costs for the storage systems. The unit cost estimates used in this analysis are provided in Table 27. These cost estimates are based on the DSC unit costs that EPRI used for a generic interim storage facility (Ref. 7) and documented in EPRI TR-1025206 (Ref. 10). Nuclear power plant licensees may experience incremental DSC purchase and loading costs that are higher or lower than the amount assumed in this regulatory analysis.

Table 27 Incremental Unit Cost Estimates

Item	Base Case Unit Cost (Constant $2012)	Adders to load 5-year cooled fuel (Constant $2012)	5-Year cooled fuel Unit Cost (Constant $2012)
Canister	$780,000	$62,400[(1)]	$842,400
Concrete overpack	$208,000	$41,600[(2)]	$249,600
Loading of canister-based storage	$312,000	$62,400	$374,400
Total	$1,300,000		$1,466,400

1. The canister cost adder is the product of $780,000 x 40% x 20%.
2. The concrete overpack adder is the sum of the labor adder and the concrete shielding adder (e.g., $208,000 x 40% x 20% + $208,000 x 30% x 40%).

When only 5-year cooled, high burnup spent fuel is available for loading into dry storage, there are several potential cost adders to address increased fabrication costs, additional shielding capability in concrete storage overpacks; and higher loading costs because of increased worker dose and work rules that result in longer cask loading durations or the need to utilize additional crews.

Labor costs are approximately 40 percent of the cost of DSCs (Ref 10). Assuming that the labor portion of canister and concrete overpack cost increase by 20 percent, this results in a fabrication cost adder of $79,040 per DSC (e.g., 40 percent x $988,000 x 20 percent). This fabrication adder is applied to dry storage incremental costs when 5-year cooled inventories are transferred to dry storage.

Concrete shielding costs are approximately 30 percent of the concrete overpack cost (Ref. 10). Assuming that shielding costs increase by 40 percent, this results in a concrete overpack shielding cost adder of $24,960 per overpack ($208,000 x 30 percent x 40 percent). This shielding adder is applied to dry storage incremental costs when 5-year cooled inventories are transferred to dry storage.

There may be other additional costs associated with amending existing certificates of compliance (CoCs), certifying new designs, or may result from high demand for DSCs in short supply. These costs may be passed on to nuclear plant operators through the price of the DSC systems or may be directly billed to nuclear plant operators if the amended or new designs are specific only to that ISFSI. These additional costs were not estimated given the possibility for a wide range of costs for implementing CoC changes and the possible price swings, which could occur for DSCs if there is limited supply.

Because of the increased costs associated with increased worker dose, longer loading times to comply with work rules, and the need to load more DSCs, and the application of fatigue rules during cask loading operations, the NRC estimates that DSC loading costs increase by 20 percent. This loading cost adder of $62,400 per DSC (e.g., 20 percent times $312,000) is applied when 5-year cooled spent fuel assemblies are loaded into dry storage casks.

4.3.4.4 Incremental Annual ISFSI Operating Costs

Annual operating costs for an ISFSI during reactor operation include the costs associated with NRC inspections; security; radiation monitoring; ISFSI operational monitoring; technical specification and regulatory compliance, including implementation of new CoC amendments; personnel cost and code maintenance associated with fuel selection for dry storage; personnel costs for spent fuel management and fabrication surveillance activities; electric power usage for lighting and security systems; road maintenance to the ISFSI site; and miscellaneous expenses associated with ISFSI maintenance. NRC license fees for dry storage are included as part of the 10 CFR Part 50 ("Domestic Licensing of Production and Utilization Facilities") operating license fees and, therefore, are not an incremental cost.

Because most operating nuclear power plants have already implemented dry storage, no incremental annual ISFSI operating costs to implement dry storage at an earlier date is estimated for Group 1, 2, or 4 spent fuel pool sites if a policy decision is made to accelerate the transfer of spent fuel stored in spent fuel pools to dry storage.

For the Group 3 spent fuel pools for which the associated reactor is not expected to begin commercial operation until 2018, the NRC estimates that the site would begin transferring fuel to dry storage in 2040. For Alternative 2, it is expected that the unit would begin transferring fuel to dry storage in 2025 and, therefore, Group 3 sites would incur incremental annual ISFSI operating cost for the earlier ISFSI operating period from 2025 to 2040. EPRI reports a wide variability in published estimates of annual ISFSI operating costs that range from $212,000 to $2 million per year in 2012 dollars and reported their estimate of $1.1 million per year for an ISFSI at an operating nuclear power plant site (Ref. 10, p. 2–28). This estimate provided in Table 28 is used as the incremental annual Group 3 ISFSI operating cost in this regulatory analysis. ISFSIs located at nuclear operating plant sites may experience annual ISFSI operating costs that are higher or lower than this estimated value.

Table 28 Incremental ISFSI Annual Operating Costs

SFP Group	Activity	Incremental ISFSI Annual Operating Cost (2012 dollars)
All	ISFSI operation and maintenance costs	Negligible
3	Early ISFSI operation and maintenance costs	$1,100,00

4.4 <u>Sensitivity Analysis</u>

4.4.1 Present Value Calculations

The choice of a discount rate, over long periods of time, raises questions of science, economics, philosophy, and law. Although the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context.

The NRC traditionally uses constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.”

The 3 percent rate is consistent with estimates provided in the economics literature and approximates the real rate of return on long-term government debt which serves as a proxy for the real rate of return on savings. A low discount rate value of 2.0 percent is included, which represents the lower bound for the certainty-equivalency rate in 100 years using the random walk model approach (Ref. 19) to address the concern that interest rates are highly uncertain over time.

4.4.2 Dollar per Person-Rem Conversion Factor

The NRC is currently revising the dollar per person-rem averted conversion factor based on recent information regarding the value of a statistical life (VSL). However, until the NRC completes the update and publishes the appropriate guidance documents, the NRC will perform sensitivity analysis to estimate the impact on the calculated results when more current VSL and cancer risk factor are used. The NRC used the EPA’s VSL as an interim value in the sensitivity analysis. The EPA’s VSL was developed through a rigorous process, reviewing many published academic papers, and includes review from the Scientific Advisory Board, an independent review board.

The EPA’s VSL in 2009 dollars is approximately $7.2 million (Ref. 40, p. 41). The VSL is derived from “using a mixed effects model (random intercept with fixed effects for study characteristics), the authors regressed the VSL estimates on average income, probability of death, and several study design variables” (Ref. 40, p. 41). Therefore, using the CPI-U based inflator to adjust from 2009 dollars to 2012 dollars yields a VSL of approximately $7.7 million. The International Commission on Radiation Protection (ICRP) updated the mortality risk factor in ICRP Publication No. 103 (Ref. 15); the updated risk coefficient is 5×10^{-4}. Using the updated ICRP risk coefficient and escalated EPA-based VSL, the dollar per person-rem conversion, rounded to the nearest thousand, is $4,000 per person-rem.

Therefore, the NRC will provide the $2,000 per person-rem conversion value for the recommendation and the $4,000 per person-rem conversion value as a sensitivity analysis for this regulatory analysis.

4.4.3 Replacement Energy Costs

The NRC is currently updating its estimates for replacement energy costs based on a U.S. competitive electricity market area model. The updated model provides the replacement energy costs by day, week, and year, based on market area, in 2010 dollars. For each U.S. power market area, a lowest cost and highest cost replacement energy cost estimate was calculated, normalizing for reactor megawatt rating differences. The estimated replacement energy cost per reactor per year ranges from a high estimate of $54.4 million to a low estimate of $692,000 across all U.S. power markets. The average estimated cost per reactor per year across all United States power markets is $9.6 million and the median estimated cost is $6.4 million in 2010 dollars. Using the CPI-U inflator formula and the 2010 CPI-U inflator value from Table 2, the estimated replacement energy costs range from $57.3 million to $729,000 in 2012 dollars. The average estimated cost per reactor per year across all United States power markets is $10.1 million and the median estimated cost is $6.7 million in 2012 dollars.

4.4.4 Consequences Extending Beyond 50 Miles

NUREG/BR-0184 states that in the case of nuclear power plants, changes in public health and safety from radiation exposure and offsite property impacts should be examined over a 50-mile (80-kilometer) distance from the plant site. However, in this circumstance it is beneficial for the analysis to include supplemental information (e.g., analyses and results) that go beyond the guidance provided in this document. The SFPS uses a plume release model that predicts slow deposition of aerosols containing long-lived (i.e., slowly decaying) isotopes. This results in public health consequences that extend beyond 50 miles from the postulated accident site. While the accuracy of the model decreases with distance, the amount of public exposure beyond 50 miles in the event of a release is expected to be significant. To capture effects beyond 50 miles, this regulatory analysis evaluates the public health and safety and economic consequences estimated by the plume model beyond the 50-mile distance from the plant site as a sensitivity analysis.

4.4.5 Sensitivity to a Uniform Fuel Pattern during an Outage

The base case of this regulatory analysis assumes that the licensee has prearranged the spent fuel pool such that discharged assemblies can be placed directly into a 1x4 arrangement for the discharges of the last two outages. This approach is consistent with the requirements discussed in Section 9.3 of the SFPS. However, those requirements do allow for the fuel to be stored in a less favorable configuration for some time following discharge if other considerations prevent prearrangement. A requirement is associated with the time window by which the 1x4 arrangement must be achieved; however, the specific time requirement is not publicly available information. To capture the effects of nonbeneficial arrangement of discharged fuel, this regulatory analysis evaluates the situation in which the discharged spent fuel is uniformly arranged during the outage to evaluate the effect of this aspect on the results.

4.5 <u>Alternative 2—Low-Density Spent Fuel Pool Storage</u>

4.5.1 Public Health (Accident)

This attribute measures expected changes in radiation exposure to the public caused by change in accident frequencies or accident consequences associated with the proposed action. The expected changes in radiation exposure are predicted over a 50-mile radius from the plant site. The calculated radiation dose to the public is primarily from reoccupation of the land and other activities following the spent fuel pool accident. In addition, the calculated radiation dose to the public includes the occupational dose to workers for cleanup and decontamination of contaminated land not onsite. The incremental radiation doses are calculated by subtracting the values for the alternative from those of the regulatory baseline. The difference (delta) is the averted dose benefit of this alternative in units of person-rem. The quantitative results for public health (accident) that could affect spent fuel pool risk are provided for each spent fuel pool grouping. These values are based on MACCS2 analyses and probabilistic considerations described in further detail in this analysis, the SFPS, and other referenced documents as discussed in previous sections. The assumptions with regard to the base case seismic event frequencies are discussed in Section 4.3.2.2 and with regard to release frequencies are found in Section 4.3.2.3 of this regulatory analysis.

As Table 29 shows, the base case of the delta benefit for averted public health (accident) radiation exposure from a spent fuel pool accident resulting in spent fuel damage is approximately 360 person-rem for the Group 1 spent fuel pool and varies for each grouping. This dose represents the reduction of public health risk that results from a policy decision to transfer spent fuel from the spent fuel pool to dry storage in order to achieve low-density spent fuel loading in the pool. For a single BWR Mark I or Mark II reactor with a non-shared spent fuel pool (Group 1), the averted delta dose exposure is approximately 14.3 person-rem per year over a remaining licensed commercial operation of the reactor of 24-years (until year 2037). The value assumes a United States reactor site average population density of approximately 345 people per square mile within a 50-mile radius from the site. The calculated dose is the difference between an uncontrolled release of radionuclides from a full high-density spent fuel pool with no credit for successful mitigation to a full low-density spent fuel pool with credit for successful mitigation. The averted doses reflects the calculated health benefits that result if adherence to the EPA intermediate phase protective action guides that allow a dose of 2 rem in the first year and 500 mrem each year thereafter are used.

Table 29 Summary of Public Health (Accident) for Low-density Spent Fuel Pool Storage (Base case with $2,000 and $4,000 per person-rem)

SFP Group	Case	Dose conversion factor ($/person-rem)	Dose (averted person-rem per pool	Benefits (2012 million dollars)		
				2% NPV	3% NPV	7% NPV
1	Alternative 2 - Low-density storage	$2,000	360	$0.56	$0.50	$0.33
		$4,000		$1.12	$1.00	$0.67
2	Alternative 2 - Low-density storage	$2,000	1,630	$2.45	$2.15	$1.38
		$4,000		$4.90	$4.30	$2.75
3	Alternative 2 - Low-density storage	$2,000	3,020	$3.14	$2.37	$0.99
		$4,000		$6.28	$4.75	$1.98
4	Alternative 2 - Low-density storage	$2,000	1,690	$2.62	$2.33	$1.54
		$4,000		$5.25	$4.66	$3.08

An evaluation of the sensitivity of the results to a change in the dollar per person-rem conversion value from $2,000 to $4,000 per person-rem averted was performed and the results are also provided in Table 29.

4.5.1.1 Population Demographic Sensitivity

Population densities and distributions characteristics for spent fuel pool sites are examined to provide perspective on how important changes to these site demographic characteristics are for this regulatory analysis. The base case and the three additional site population densities and distributions near spent fuel pool locations are discussed in Section 4.3.2.11. These population distributions were used as additional inputs into the MACCS2 calculations that otherwise still used the Spent Fuel Pool Study reference plant specific values. Although the results provided in Table 30 provides insight into the analysis sensitivity to site population demographics in the United States, the results are not representative of any specific site because site specific meteorology for these additional sites is not used.

Table 30 Sensitivity of Public Health (Accident) Base Case Results to Population Demographics within 50 Miles

SFP Group	Site Population	Dose (averted person-rem per pool)	Benefits (2012 million dollars)		
			2% NPV	3% NPV	7% NPV
1	Low	99	$0.15	$0.14	$0.09
	Median	231	$0.36	$0.32	$0.22
	Average (base case)	367	$0.57	$0.51	$0.34
	High	458	$0.72	$0.64	$0.43
2	Low	113	$0.17	$0.15	$0.10
	Median	246	$0.37	$0.33	$0.21
	Average (base case)	365	$0.55	$0.48	$0.31
	High	465	$0.70	$0.61	$0.39
3	Low	181	$0.19	$0.14	$0.06
	Median	409	$0.43	$0.32	$0.13
	Average (base case)	626	$0.65	$0.49	$0.21
	High	789	$0.82	$0.62	$0.26
4	Low	130	$0.20	$0.18	$0.12
	Median	275	$0.43	$0.38	$0.25
	Average (base case)	395	$0.61	$0.54	$0.36
	High	508	$0.79	$0.70	$0.46

Variations in population densities given the underlying assumptions stated above has the following net change on the averted public health (accident) attribute as summarized in Table 31.

Table 31 Net Percent Change in Public Health (Accident) Base Case Results for Variations in Population Densities within 50 Miles

Site Population Case	Statistical Parameter	Average Population Density within 50 miles (No. of people per square mile)	Net Percent Change in Public Health (Accident) Base Case (within 50 miles)
High estimate	90th percentile	688	25% – 28%increase
Mean estimate	Mean	317	No change
Median estimate	Median	169	21% - 37% decrease
Low estimate	20th percentile	93	67% - 73% decrease

4.5.1.2 Public Health (Accident) Consequences Beyond 50 Miles Sensitivity

Because a spent fuel pool fire could result in impacts to public health that extend beyond 50 miles, this case evaluates the sensitivity of averted public health exposures extending beyond 50 miles from the site, using the base case assumptions and the standard $2,000 per person-rem conversion factor.

Table 32 shows the sensitivity on public health (accident) benefits of extending the consequence analysis beyond 50 miles for the base case.

Table 32 Sensitivity of Public Health (Accident) Benefits for Low-density Spent Fuel Pool Storage extending beyond 50 miles (Base case with $2,000 and $4,000 per person-rem)

SFP Group	Case	Dose conversion factor ($/person-rem)	Dose (averted person-rem per pool	Benefits (2012 million dollars)		
				2% NPV	3% NPV	7% NPV
1	Alternative 2 - Low-density storage	$2,000	3,000	$4.69	$4.18	$2.80
		$4,000		$9.38	$8.37	$5.60
2	Alternative 2 - Low-density storage	$2,000	13,680	$20.61	$18.10	$11.58
		$4,000		$41.22	$36.21	$23.17
3	Alternative 2 - Low-density storage	$2,000	22,730	$23.67	$17.90	$7.47
		$4,000		$47.33	$35.80	$14.94
4	Alternative 2 - Low-density storage	$2,000	15,880	$24.57	$21.83	$14.44
		$4,000		$49.14	$43.66	$28.88

4.5.1.3 Habitability Criteria Sensitivity

A long-term cleanup policy for recovery after a severe nuclear power plant accident does not currently exist. The actual decisions regarding how land would be recovered and populations relocated after an accident would be made by a number of local, State, and Federal jurisdictions and would most likely be based on a long-term cleanup strategy, which is currently being developed by the NRC, EPA, and other Federal agencies. Furthermore, a cleanup standard may not have an explicit dose level for cleanup. Instead, the cleanup strategy may give local jurisdictions the ability to develop localized cleanup goals after an accident, to allow for a number of factors that include sociopolitical, technical, and economic considerations.

For habitability, most States adhere to EPA intermediate phase protective action guides that allow a dose of 2 rem in the first year and 500 mrem each year thereafter. This habitability criterion was used in previous spent fuel pool studies, which used 4 rem in 5 years to represent these PAG levels (e.g., 2 rem in year one, followed by 0.5 rem each successive year).

Given the uncertainties in which long-term habitability criterion would be used, Table 33 provides a low and high value for the long-term phase habitability criterion for use in a sensitivity analysis to analyze the effect on the public health (accident) attribute.

Table 33: Sensitivity of Public Health (Accident) Benefits to Habitability Criteria (within 50 Miles)

SFP Group	Habitability Criteria	Dose (averted person-rem per pool)	Benefits (2012 million dollars)		
			2% NPV	3% NPV	7% NPV
1	Low (500 mrem annually)	163	$0.25	$0.23	$0.15
	Base Case (4rem / 5years)	367	$0.57	$0.51	$0.34
	High (2 rem annually)	417	$0.65	$0.58	$0.39
2	Low (500 mrem annually)	157	$0.24	$0.21	$0.13
	Base Case (4rem / 5years)	365	$0.55	$0.48	$0.31
	High (2 rem annually)	430	$0.65	$0.57	$0.36
3	Low (500 mrem annually)	273	$0.28	$0.21	$0.09
	Base Case (4rem / 5years)	626	$0.65	$0.49	$0.21
	High (2 rem annually)	724	$0.75	$0.57	$0.24
4	Low (500 mrem annually)	167	$0.26	$0.23	$0.15
	Base Case (4rem / 5years)	395	$0.61	$0.54	$0.36
	High (2 rem annually)	473	$0.73	$0.65	$0.43

Different habitability criteria given the underlying assumptions stated above has the following net change on the averted public health (accident) attribute as summarized in Table 34.

Table 34 Net Percent Change in Public Health (Accident) Base Case Results for Variations in Population Densities within 50 Miles

Habitability Criterion Case	Habitability Criterion	Net Percent Change in Public Health (Accident) Base Case (within 50 miles)
High estimate	2 rem annually	14% – 20% increase
Base case	2 rem first year, 500 mrem thereafter (4 rem / 5 years)	No change
Low estimate	500 mrem annually	56% – 58% decrease

4.5.1.4 Seismic Initiator Frequency Assumptions Sensitivity

Although the Spent Fuel Pool Study reference plant hazard exceedance frequencies curves discussed in 4.3.2.1 of this regulatory analysis falls close to the upper end of each group in terms of hazard estimates, there are some CEUS sites that exceed those estimates.
To analyze the seismic risk hazard for these CEUS sites, a high estimate using the Sequoyah site hazard exceedance frequency curve is used to in this sensitivity study. The seismic frequencies are provided in Table 8. Several other bounding assumptions are also made to arrive at the bounding spent fuel pool release frequency provided in Table 13. These bounding assumptions include the loss of all ac power for all spent fuel pool initiators, a conservative liner fragility value (provided in Table 10) even though a detailed analysis may be able to justify a value of factor of 2 or more lower, and assuming a bounding value of 1.0 for the conditional

probability of failure to successfully mitigate the high-density storage spent fuel accident. These conservative (bounding) assumptions were used in order to calculate a high value estimate for the seismic initiating frequency sensitivity analysis in order to analyze the effect on the public health (accident) attribute provided in Table 35. Further discussion of this approach is provided in Section 4.3.2.3 of this analysis.

Table 35 Sensitivity of Public Health (Accident) Benefits within 50 Miles to Changes in Seismic Initiator Frequency Assumptions

SFP Group	Seismic Initiator Case	Dose (averted person-rem per pool)	Benefits (2012 million dollars)		
			2% NPV	3% NPV	7% NPV
1	Base Case	370	$0.57	$0.51	$0.34
	High Estimate	1,700	$2.72	$2.42	$1.62
2	Base Case	370	$0.55	$0.48	$0.31
	High Estimate	5,300	$8.06	$7.08	$4.53
3	Base Case	630	$0.65	$0.49	$0.21
	High Estimate	9,200	$9.55	$7.22	$3.01
4	Base Case	130	$0.20	$0.18	$0.12
	High Estimate	5,800	$8.97	$7.97	$5.27

As illustrated in Table 35, the combination of conservative seismic initiator modeling assumptions with the bounding seismic source zone characterization for any spent fuel pool located in the central and eastern United States results in public health (accident) benefit values increasing by a factor between 4 and 44 times the averted public health (accident) dose calculated for the base case.

4.5.1.5 Sensitivity to a Uniform Fuel Pattern during an Outage

The base case of this regulatory analysis assumes that each licensee has prearranged the spent fuel pool such that discharged assemblies can be placed directly into a 1x4 arrangement for the discharges of the last two outages. This approach is consistent with the requirements discussed in Section 9.3 of the SFPS. However, those requirements do allow for the fuel to be stored in a less favorable configuration for some time following discharge if other considerations prevent prearrangement. To capture the effects of nonbeneficial arrangement of discharged fuel, this regulatory analysis evaluates the situation in which the discharged spent fuel is uniformly arranged during the outage to evaluate the effect of this aspect on public health (accident) attribute.

For the offsite consequence analysis, the sequences with recently discharged fuel in a uniform configuration were binned in a similar manner to the low-density and high-density (1x4) loading scenarios. Because licensees are required to move their recently discharged fuel to a more favorable configuration after a certain amount of time, this sensitivity assumes that the high-density uniform case becomes identical to the high-density (1x4) case by the end of operating cycle phase 2 (OCP 2) or within 25 days. While the uniform case has different release categories, the situations that lead to release are largely the same as the low-density and high-density (1x4) base cases.

Table 36 provides a comparison of the effect on the public health (accident) attribute if a plant operator initially places discharged spent fuel in a uniform pattern and achieves the 1x4 pattern by the end of OCP 2 (i.e., within 25 days) versus placing the fuel directly into the 1x4 pattern.

Table 36: Sensitivity of Public Health (Accident) Benefits (within 50 Miles) to Initial Loading Pattern of Discharged Fuel

SFP Group	Initial Loading Pattern of Discharged Fuel	Dose (averted person-rem per pool)	Benefits (2012 million dollars)		
			2% NPV	3% NPV	7% NPV
1	Base Case - 1x4	360	$0.56	$0.50	$0.33
	Uniform fuel pattern	420	$0.65	$0.58	$0.39
2	Base Case - 1x4	1,630	$2.45	$2.15	$1.38
	Uniform fuel pattern	2,470	$3.72	$3.27	$2.09
3	Base Case - 1x4	3,020	$3.14	$2.37	$0.99
	Uniform fuel pattern	4,240	$4.41	$3.34	$1.39
4	Base Case - 1x4	1,690	$2.62	$2.33	$1.54
	Uniform fuel pattern	2,680	$4.14	$3.68	$2.43

As shown in Table 36, the placement of the discharged fuel directly into a beneficial 1x4 pattern reduces the estimated averted dose within 50 miles of the site between 14 percent and 37 percent compared to the cases when achieving this fuel pattern is delayed for up to 25 days, the end of OPC 2.

4.5.2 Occupational Health (Accident)

Occupational health measures both short-term and long-term health effects associated with site workers as a result of changes in accident frequency or accident mitigation. Within the regulatory baseline, the short-term occupational exposure related to the accident occurs at the time of the accident and during the immediate management of the emergency and during decontamination and decommissioning of the onsite property. The radiological occupational exposure resulting from cleanup and refurbishment or decommissioning activities of the damaged facility to occupational workers are estimated within the long-term occupational exposure. The quantitative results for occupational health (accident) considering the contribution of all initiators that could affect spent fuel pool risk is provided in Table 37 and is based on the release frequencies discussed in Section 4.3.2.1 and the occupational health (accident) assumptions found in Section 4.3.2.8. The high estimate also incorporates the seismic initiator frequency assumptions described in Section 4.5.1.4.

Table 37 Summary of Occupational Health (Accident) Benefits for Low-density Spent Fuel Pool Storage (Base case with $2,000 and $4,000 per person-rem and with Low and High Estimates)

SFP Group	Case	Dose conversion factor ($/person-rem)	Dose averted per pool (person-rem)	Benefits (2012 dollars) 2% NPV	3% NPV	7% NPV
1	Low Estimate	$2,000	0.60	$942	$840	$562
		$4,000		$1,884	$1,730	$1,203
	Base Case	$2,000	1.13	$1,762	$1,572	$1,052
		$4,000		$3,524	$3,238	$2,251
	High Estimate	$2,000	12	$19,208	$17,132	$11,465
		$4,000		$38,415	$35,291	$24,535
2	Low Estimate	$2,000	0.34	$500	$400	$300
		$4,000		$1,000	$900	$600
	Base Case	$2,000	4.36	$6,600	$5,800	$3,700
		$4,000		$13,100	$11,500	$7,400
	High Estimate	$2,000	25	$37,300	$32,700	$21,000
		$4,000		$74,600	$65,500	$41,900
3	Low Estimate	$2,000	0.71	$700	$600	$200
		$4,000		$1,500	$1,100	$500
	Base Case	$2,000	9.16	$9,500	$7,200	$3,000
		$4,000		$19,100	$14,400	$6,000
	High Estimate	$2,000	52	$54,200	$41,000	$17,100
		$4,000		$108,400	$82,000	$34,200
4	Low Estimate	$2,000	0.30	$500	$400	$300
		$4,000		$900	$800	$600
	Base Case	$2,000	3.91	$6,000	$5,400	$3,600
		$4,000		$12,100	$10,700	$7,100
	High Estimate	$2,000	22	$34,300	$30,500	$20,200
		$4,000		$68,700	$61,000	$40,400

As Table 37 shows, the total delta benefit for short- and long-term occupational health (accident) range between 1.13 and 9.16 person-rem averted per spent fuel pool for the base case. The estimated total benefit of the occupational health (accident) attribute for low-density spent fuel pool storage relative to the regulatory baseline, using the $2,000 per person-rem averted conversion factor, net present value ranges are insignificant for the base case and do not warrant further sensitivity analysis. The high estimate includes the conservative inputs and assumptions for the seismic initiator frequency sensitivity analysis discussed in Section 4.5.1.4 of this regulatory analysis.

4.5.3 Occupational Health (Routine)

Occupational health (routine) accounts for radiological exposures to workers during normal facility operations (i.e., non-accident situations). These occupational exposures occur during DSC loading and handling activities, ISFSI operations, and maintenance and surveillance activities. The assumptions in relation to the exposures for occupational health (routine) are found in Section 4.3.3.1 of this regulatory analysis.

Table 38 Summary of Occupational Health (Routine) Costs for Low-Density Spent Fuel Pool Storage (Base Case with $2,000 and $4,000 per Person-rem)

SFP Group	No. of DSCs required through end of operation		Delta Dose (p-rem)	Dose conversion factor ($/p-	Costs (2012 dollars)		
	High-density storage (Alternative 1)	Low-density storage (Alternative 2)			2% NPV	3% NPV	7% NPV
1	107	119	6.84	$2,000	$25,400	$27,800	$28,200
				$4,000	$50,800	$55,600	$56,300
2	75	90	8.55	$2,000	$27,200	$29,100	$28,900
				$4,000	$54,500	$58,300	$57,700
3	77	87	5.70	$2,000	$14,500	$12,900	$6,400
				$4,000	$29,000	$25,800	$12,800
4	130	141	6.27	$2,000	$22,700	$24,700	$24,800
				$4,000	$45,400	$49,400	$49,700

As Table 38 shows, the delta benefit for occupational health (routine) is an increase of between 5.70 and 8.55 person-rem in worker exposure resulting from DSC loading and handling activities; ISFSI operations; and maintenance and surveillance activities depending on the spent fuel pool grouping. The estimated cost to the occupational health (routine) for low-density spent fuel storage relative to the regulatory baseline for all spent fuel pool groups and calculated in accordance with the current regulatory framework, ranges from $14,500 to $27,200 (2 percent net present value), $12,900 to $29,100 (3 percent net present value), and $6,400 to $28,900 (7 percent net present value) using the $2,000 per person-rem averted conversion factor. These ranges are insignificant for this analysis and do not warrant further sensitivity analysis.

4.5.4 Offsite Property

The offsite property attribute measures the expected total monetary effects on offsite property resulting from the proposed action. Changes to offsite property can take various forms, both direct, (e.g. land, food, and water) and indirect (e.g. tourism). This attribute is the product of the change in accident frequency and the property consequences from the occurrence of a spent fuel pool accident.

For the regulatory baseline, the offsite property costs are any property consequences resulting from any radiological release from the occurrence of an accident. Normal operational releases and any plant releases not related to the severe accident analyzed are outside the scope of this regulatory analysis.

The cost offsets for the analyzed spent fuel pool accident are quantified relative to the regulatory baseline based on the MACCS2 calculation results and probabilistic considerations. The results for the consequences from a low-density spent pool accident are compared to those from the regulatory baseline spent fuel pool accident. The calculation is the difference between the calculated consequences resulting from a low-density and a high-density spent fuel pool accident. The results are provided in Table 39. The assumptions with regard to the base case seismic event frequencies are discussed in Section 4.3.2.2 and with regard to release frequencies are found in Section 4.3.2.3 of this regulatory analysis.

Table 39 Summary of Offsite Property Cost Offsets for Low-Density Spent Fuel Pool Storage within 50 Miles (Base Case)

SFP Group	Case	Offsite Property Cost Offsets (2012 million dollars)		
		2% NPV	3% NPV	7% NPV
1	Alternative 2 - Low-density storage	$1.84	$1.64	$1.10
2	Alternative 2 - Low-density storage	$9.03	$7.93	$5.08
3	Alternative 2 - Low-density storage	$11.45	$8.66	$3.61
4	Alternative 2 - Low-density storage	$9.81	$8.71	$5.76

As Table 39 shows the estimate of offsite property damage from a spent fuel pool accident resulting in spent fuel damage, ranges from $1.84 million (2 percent net present value) to $1.10 million (7 percent net present value) for Group 1 spent fuel pools and varies for each grouping. This value assumes a U.S. reactor site average population density of approximately 345 people per square mile within a 50-mile radius from the site and is representative of the associated property values found near the Surry power plant site. This base case uses the EPA intermediate phase PAG level of 2 rem in the first year and 500 mrem annually to evaluate post-accident collective dose and offsite property costs as discussed in Section 4.3.2.12 of this regulatory analysis.

4.5.4.1 Population Demographic Sensitivity

Certain metrics such as property use, the number of displaced individuals (either temporarily or permanently), and the extent to which such actions may be needed are affected by the population size and the amount of economic activity in the vicinity of the postulated accident.

This section provides a basis for understanding the nature and the extent of the relationship between population densities, distributions characteristics, and property values near spent fuel pool sites. This examination provides a perspective on how important changes to these site demographic variables are for this regulatory analysis. The base case and the three additional site population densities, distributions, and economic characteristics near spent fuel pool locations are discussed in Section 4.3.2.11. These population and economic characteristics were used as additional inputs into the MACCS2 calculations that otherwise still used the SFPS reference plant specific values. Although the results provided in Table 40 provides insight into the analysis sensitivity to site population demographics in the U.S., the results are not representative of any specific site because site specific meteorology for these additional sites is not used. These measures are also subject to large uncertainties, as it is difficult to model the impact of disruptions to many different aspects of local economies, the loss of infrastructure on the general U.S. economy, or the details of how long-term protective actions would be performed.

Table 40 Sensitivity of Offsite Property Cost Offset Results to Population Demographics within 50 Miles (Base Case using EPA Intermediate PAG Criterion)

SFP Group	Site Population	Offsite Property Cost Offsets (2012 million dollars)		
		2% NPV	3% NPV	7% NPV
1	Low	$0.27	$0.24	$0.16
	Median	$0.86	$0.77	$0.51
	Average (base case)	$1.57	$1.40	$0.94
	High	$2.58	$2.30	$1.54
2	Low	$2.04	$1.79	$1.14
	Median	$6.75	$5.93	$3.79
	Average (base case)	$11.50	$10.10	$6.46
	High	$13.43	$11.80	$7.55
3	Low	$2.09	$1.58	$0.66
	Median	$6.84	$5.18	$2.16
	Average (base case)	$12.07	$9.13	$3.81
	High	$17.08	$12.91	$5.39
4	Low	$2.60	$2.31	$1.53
	Median	$8.69	$7.72	$5.11
	Average (base case)	$14.35	$12.75	$8.44
	High	$16.14	$14.34	$9.48

4.5.4.2 Offsite Property Consequences Beyond 50 Miles Sensitivity

Because a spent fuel pool fire under certain scenarios and environmental conditions could result in impacts to offsite property located beyond 50 miles from the postulated accident site, this case evaluates the sensitivity of offsite property cost offsets for damages occurring beyond 50 miles from the site, using the base case assumptions and the intermediate EPA PAG criterion. Table 41 shows the sensitivity on offsite property cost offsets of extending the consequence analysis beyond 50 miles for the base case.

Table 41 Sensitivity of Offsite Property Cost Offset Results to Consequences beyond 50 Miles (Base Case using EPA Intermediate PAG Criterion)

SFP Group	Case	Offsite Property Cost Offsets (2012 million dollars)			
		2% NPV	3% NPV	7% NPV	% increase
1	Base case - within 50 miles	$1.84	$1.64	$1.10	
	Sensitivity - beyond 50 miles	$3.36	$3.00	$2.01	83%
2	Base case - within 50 miles	$9.03	$7.93	$5.08	
	Sensitivity - beyond 50 miles	$28.79	$25.29	$16.18	219%
3	Base case - within 50 miles	$11.45	$8.66	$3.61	
	Sensitivity - beyond 50 miles	$27.17	$20.55	$8.57	137%
4	Base case - within 50 miles	$9.81	$8.71	$5.76	
	Sensitivity - beyond 50 miles	$39.62	$35.20	$23.29	304%

4.5.4.3 Offsite Property Costs Sensitivity to Habitability Criteria

As discussed in Section 4.5.1.3, a long-term cleanup policy for recovery after a severe nuclear power plant accident does not currently exist. The actual decisions regarding how land would be recovered and populations relocated after an accident would be made by a number of local, State, and Federal jurisdictions and would most likely be based on a long-term cleanup strategy, which is currently being developed by the NRC, EPA, and other Federal agencies. Furthermore, a cleanup standard may not have an explicit dose level for cleanup. Instead, the cleanup strategy may give local jurisdictions the ability to develop localized cleanup goals after an accident, to allow for a number of factors that include sociopolitical, technical, and economic considerations. Given the uncertainties in which long-term habitability criterion would be used, Table 42 provides a low and high value for the long-term phase habitability criterion for use in a sensitivity analysis to analyze the effect on the costs for offsite property damage.

Table 42: Sensitivity of Offsite Property Damage Cost Offsets within 50 Miles to Different Habitability Criteria

SFP Group	Habitability Criteria	Offsite Property Cost Offsets (2012 million dollars)		
		2% NPV	3% NPV	7% NPV
1	Low Est. (500 mrem annually)	$2.63	$2.35	$1.57
	Base Case (4rem / 5years)	$1.57	$1.40	$0.94
	High Est. (2 rem annually)	$1.48	$1.32	$0.88
2	Low Est. (500 mrem annually)	$16.56	$14.54	$9.31
	Base Case (4rem / 5years)	$11.50	$10.10	$6.46
	High Est. (2 rem annually)	$11.10	$9.75	$6.24
3	Low Est. (500 mrem annually)	$18.71	$14.15	$5.90
	Base Case (4rem / 5years)	$12.07	$9.13	$3.81
	High Est. (2 rem annually)	$11.50	$8.70	$3.63
4	Low Est. (500 mrem annually)	$19.28	$17.13	$11.33
	Base Case (4rem / 5years)	$14.35	$12.75	$8.44
	High Est. (2 rem annually)	$14.02	$12.45	$8.24

This sensitivity analysis uses three protective action levels—the Pennsylvania PAG of 500 mrem annually for the low estimate, the EPA intermediate phase PAG level of 2 rem in the first year, and 500 mrem annually thereafter for the base case, and 2 rem annually for the high estimate—to evaluate post-accident collective dose and offsite property costs. As discussed in Section 4.3.2.11, offsite property costs are inversely proportional to changes in collective dose resulting from changes in habitability criteria (i.e., lower PAG guidelines result in lower collective dose value and higher offsite property costs). These results show the cost offsets increase by up to 67 percent (7 percent net present value) than those in the Group 1 base case result when the 500 mrem annual limit is used. Conversely, offsite property damage cost offsets decrease by up to 6 percent (7 percent net present value) than those in the Group 1 base case result when the 2 rem annual limit is used.

4.5.4.4 Offsite Property Cost Offset Sensitivity to Seismic Initiator Frequency Assumptions

Although the Spent Fuel Pool Study reference plant hazard exceedance frequencies curves discussed in 4.3.2.1 of this analysis fall close to the upper end of each spent fuel pool group in terms of hazard estimates, there are some CEUS sites that exceed those estimates. To analyze the seismic risk hazard for these CEUS sites, a high estimate using the bounding plant hazard exceedance frequency curve is used to produce the high estimate seismic bins and initiating event frequencies. These seismic frequencies are provided in Table 8. Several other bounding assumptions are also made to arrive at the bounding spent fuel pool release frequency provided in Table 13. These include the loss of all ac power for all spent fuel pool initiators, a conservative liner fragility value (see Table 10) even though a realistic analysis may be able to justify a value of factor of 2 or more lower, and assuming a bounding value of 1.0 for the conditional probability for failure to successfully mitigate the high-density storage spent fuel accident. These conservative (bounding) assumptions were used to calculate the offsite property cost offset estimate sensitivity to the seismic initiating frequency assumptions. Further discussion of this approach is provided in Section 4.3.2.3 of this analysis.

Table 43 Sensitivity of Offsite Property Cost Offset within 50 Miles to Changes in Seismic Initiator Frequency Assumptions

SFP Group	Seismic Initiator Case	Offsite Property Cost Offsets (2012 million dollars)		
		2% NPV	3% NPV	7% NPV
1	Base Case	0.17	0.15	0.10
	High Estimate	1.84	1.64	1.10
2	Base Case	0.27	0.24	0.15
	High Estimate	9.03	7.93	5.08
3	Base Case	0.26	0.20	0.08
	High Estimate	11.45	8.66	3.61
4	Base Case	0.27	0.24	0.16
	High Estimate	9.81	8.71	5.76

4.5.4.5 Offsite Property Cost Offset Sensitivity to a Uniform Fuel Pattern during an Outage

As discussed in Section 4.5.1.5, the alternative 2 base case assumes that the licensee has prearranged the spent fuel pool such that discharged assemblies can be placed directly into a 1x4 arrangement for the discharges of the last two outages. This approach is consistent with the requirements discussed in Section 9.3 of the Spent Fuel Pool Study (Ref. 2). However, those requirements do allow for the fuel to be stored in a less favorable configuration for some time following discharge if other considerations prevent prearrangement. To capture the effects of non-beneficial arrangement of discharged fuel, this regulatory analysis evaluates the situation in which the discharged spent fuel is uniformly arranged during the outage to evaluate the effect of this aspect on offsite property attribute.

For the offsite consequence analysis, the sequences with recently discharged fuel in a uniform configuration were binned in a similar manner to the low-density and high-density (1x4) loading scenarios. Because licensees are required to move their recently discharged fuel to a more favorable configuration after a certain amount of time, this sensitivity assumes that the high-density uniform case becomes identical to the high-density (1x4) case during OCP3. While the uniform case has different release categories, the situations that lead to release are largely the same as the low-density and high-density (1x4) base cases.

Table 44 provides a comparison of the effect on the offsite property cost offsets if a plant operator initially places discharged spent fuel in a uniform pattern and achieves the 1x4 pattern by the end of OCP 2 (i.e., within 25 days) versus placing the fuel directly into the 1x4 pattern.

Table 44 Sensitivity of Offsite Property Cost Offsets within 50 Miles to Initial Loading Pattern of Discharged Fuel

SFP Group	Initial Loading Pattern of Discharged Fuel	Offsite Property Cost Offsets (2012 million dollars)		
		2% NPV	3% NPV	7% NPV
1	Base Case - 1x4	1.84	1.64	1.10
	Uniform fuel pattern	2.03	1.81	1.21
2	Base Case - 1x4	9.03	7.93	5.08
	Uniform fuel pattern	14.82	13.02	8.33
3	Base Case - 1x4	11.45	8.66	3.61
	Uniform fuel pattern	15.56	11.77	4.91
4	Base Case - 1x4	9.81	8.71	5.76
	Uniform fuel pattern	18.50	16.44	10.87

4.5.5 Onsite Property

This attribute measures the expected monetary effects on onsite property, including replacement power costs, decontamination, and refurbishment costs, from the proposed action. There are two forms of onsite property costs that each alternative must disposition. The first type of onsite property costs are the cleanup and decontamination costs for the unit. The second type of onsite property costs is the cost to replace the energy from the damaged or shutdown unit(s). The cost offsets for low-density spent fuel pool storage are quantified relative to the regulatory baseline based on the probabilistic considerations provided in the Spent Fuel Pool Study (Ref. 2) and the onsite property estimates described in Section 4.3.2.6.

Because many nuclear power plants reactor units are co-located on a plant site, it is assumed for these sites that both units may not operate (e.g., because of significant site damage or contamination resulting in high occupational exposure to the undamaged unit) caused by the spent fuel pool accident. In modeling the replacement energy costs based on this scenario, it is assumed for the high estimate that replacement energy would be purchased for two units.

Based on these modeling assumptions, the onsite property results are provided in Table 45.

Table 45 Summary of Onsite Property Cost Offsets for Low-density Spent Fuel Pool Storage

Group	Case	Onsite Property Cost Offsets (2012 dollars)								
		Low Estimate			Base Case			High Estimate		
		2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
1	Onsite Property - Replacement Energy	$90	$80	$50	$1,980	$1,730	$1,080	$7,120	$6,250	$3,900
1	Onsite Property - Cleanup, Decontamination, Repair, & Refurbishment	$5,900	$5,200	$3,100	$11,900	$10,300	$6,200	$35,700	$30,900	$18,600
1	Group 1 Total	$5,990	$5,280	$3,150	$13,880	$12,030	$7,280	$42,820	$37,150	$22,500
2	Onsite Property - Replacement Energy	$50	$40	$30	$7,500	$6,480	$3,850	$27,010	$23,340	$13,880
2	Onsite Property - Cleanup, Decontamination, Repair, & Refurbishment	$3,200	$2,800	$1,600	$44,300	$37,800	$21,700	$132,800	$113,400	$65,200
2	Group 2 Total	$3,250	$2,840	$1,630	$51,800	$44,280	$25,550	$159,810	$136,740	$79,080
3	Onsite Property - Replacement Energy	$80	$60	$20	$11,510	$8,530	$3,250	$41,490	$30,740	$11,700
3	Onsite Property - Cleanup, Decontamination, Repair, & Refurbishment	$4,700	$3,500	$1,300	$64,400	$47,300	$17,700	$193,100	$142,000	$53,200
3	Group 3 Total	$4,780	$3,560	$1,320	$75,910	$55,830	$20,950	$234,590	$172,740	$64,900
4	Onsite Property - Replacement Energy	$50	$40	$20	$6,820	$5,960	$3,670	$23,710	$20,810	$12,990
4	Onsite Property - Cleanup, Decontamination, Repair, & Refurbishment	$3,000	$2,600	$1,500	$40,800	$35,200	$20,900	$122,300	$105,700	$62,800
4	Group 4 Total	$3,050	$2,640	$1,520	$47,620	$41,160	$24,570	$146,010	$126,510	$75,790

As Table 45 shows, based on these calculations, the delta cost offset for the frequency-weighted onsite property base case estimate ranges from $13,380 to $75,910 per pool (2 percent net present value) to $12,030 to $55,830 per pool (3 percent net present value), and to $7,280 to $25,550 per pool (7 percent net present value). Low and high estimates are also provided in Table 45.

4.5.6 Industry Implementation

Industry implementation accounts for the projected net economic effect on the affected licensees to implement the mandated changes. Costs evaluated for dry storage include upfront and incremental DSC capital and loading costs. Additional costs above the regulatory baseline are considered negative and cost savings are considered positive. The quantitative results for industry implementation are given in terms of expected costs if a policy decision is made to accelerate the transfer of spent fuel stored in spent fuel pools to dry storage. These expected costs are not frequency weighted. Assumptions used for developing the industry implementation cost model are discussed in Sections 4.3.1.7, 4.3.4.3, and 4.3.4.4.

Group 1 Spent Fuel Pool

As previously discussed in Section 4.3.4.3, during each refueling outage the representative Group 1 plant discharges 284 fuel assemblies to the spent fuel pool. For the regulatory baseline case, the plant is expected to load the required number of DSCs with a 68-assembly capacity each refueling outage to retain sufficient space in the spent fuel pool to discharge one full core of fuel (full core reserve). For the Alternative 2, low-density spent fuel pool storage case, the representative Group 1 plant spent fuel pool stores 852 assemblies, which is equivalent to the discharge from the last three refueling outages. For the alternative 2 case, the plant achieves this low-density storage condition within 5 years and then maintains this storage condition up through cessation of commercial operation. The cumulative DSC implementation costs for a single Group 1 spent fuel pool are shown in Figure 18.

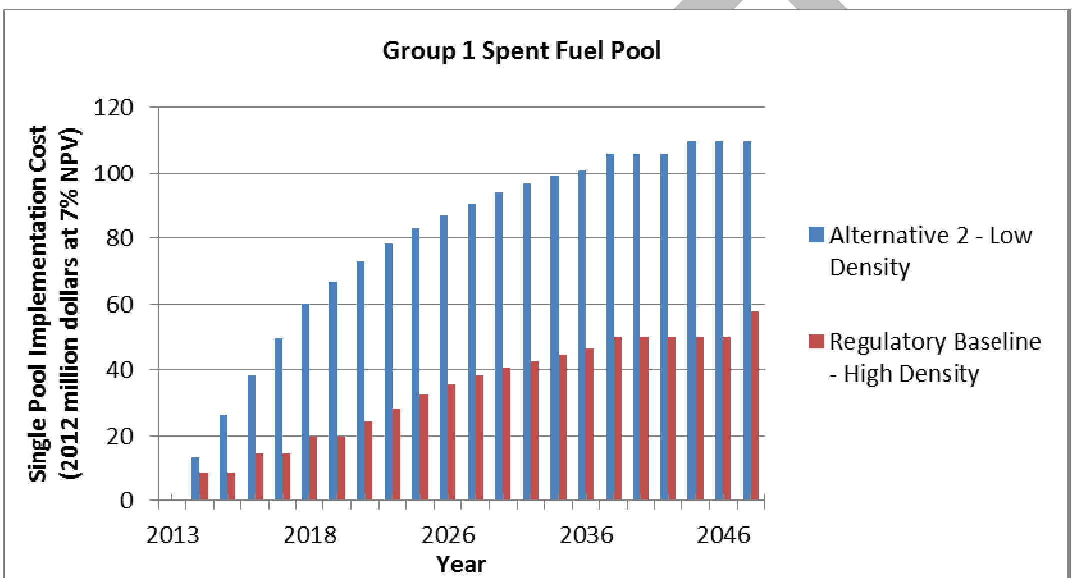


Figure 18 Cumulative dry cask storage implementation costs for a single Group 1 spent fuel pool

Group 2 Spent Fuel Pool

A similar calculation is performed for the Groups 2 spent fuel pools. As previously discussed in Section 4.3.4.3, every 18-months the representative PWR plant discharges 84 fuel assemblies to the spent fuel pool. For the regulatory baseline case, the plant is expected to load the required number of Holtec Hi-Storm FW DSCs with a 37-assembly capacity each refueling outage to retain sufficient space in the spent fuel pool to discharge one full core of fuel (full core reserve). For the Alternative 2, low-density spent fuel pool storage case, the representative plant spent fuel pool stores 312 fuel assemblies, the equivalent to the discharge from the last three refueling outages. The cumulative DSC implementation costs for Group 2 plants are shown in Figure 19.

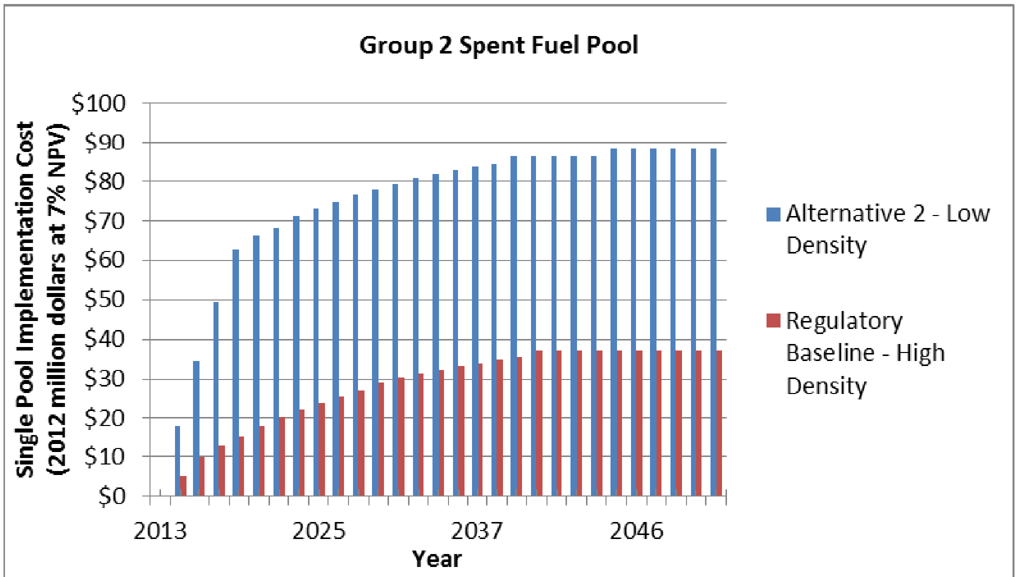


Figure 19 Cumulative dry cask storage implementation costs for a single Group 2 spent fuel pool

<u>Group 3 Spent Fuel Pool</u>

In 2018, the representative Group 3 plant is assumed to begin commercial operation. At this time, there are no spent fuel assemblies stored in the spent fuel pool. The unit is assumed to operate on an 18-month refueling cycle, discharging an estimated 69 assemblies per cycle as discussed in Section 4.3.4.3. For the regulatory baseline, the representative new nuclear plant is expected to begin dry storage in 2038 and will load a sufficient number of Holtec Hi-Storm FW casks to maintain its full core offload capability. The cumulative DSC implementation costs for Group 3 plants are shown in Figure 20.

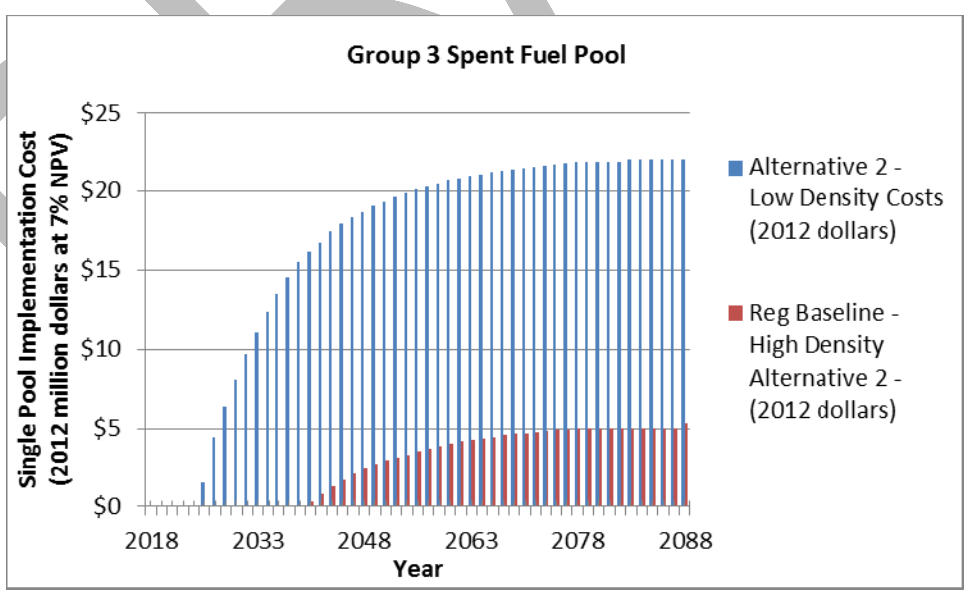


Figure 20 Cumulative dry cask storage implementation costs for a single Group 3 spent fuel pool

Group 4 Spent Fuel Pool

The representative Group 4 spent fuel pool is shared between two PWR units and is assumed to have 1,637 fuel assemblies stored in the spent fuel pool in a high-density 1x4 loading configuration. Each reactor unit operates on an 18-month refueling cycle and discharges 84 assemblies during the shoulder months from May through June and September into early November during the same calendar year. For the regulatory baseline, the Group 4 spent fuel pool is expected to load the required number of DSCs with a 37-assembly capacity each refueling outage to retain sufficient space in the spent fuel pool to discharge one full core of fuel (full core reserve). For the low-density case, the DSC has a 33-assembly capacity because of the higher heat load of the spent fuel. At the cessation of commercial operation, which occurs on average in 2038 for the Group 4 spent fuel pool reactors, the full core is offloaded into the spent fuel pool. The analysis further assumes that the entire spent fuel pool inventory will be placed into dry storage by 2048 for the regulatory baseline and by 2043 for the low-density storage case. The cumulative DSC implementation costs for Group 4 plants are shown in Figure 21.

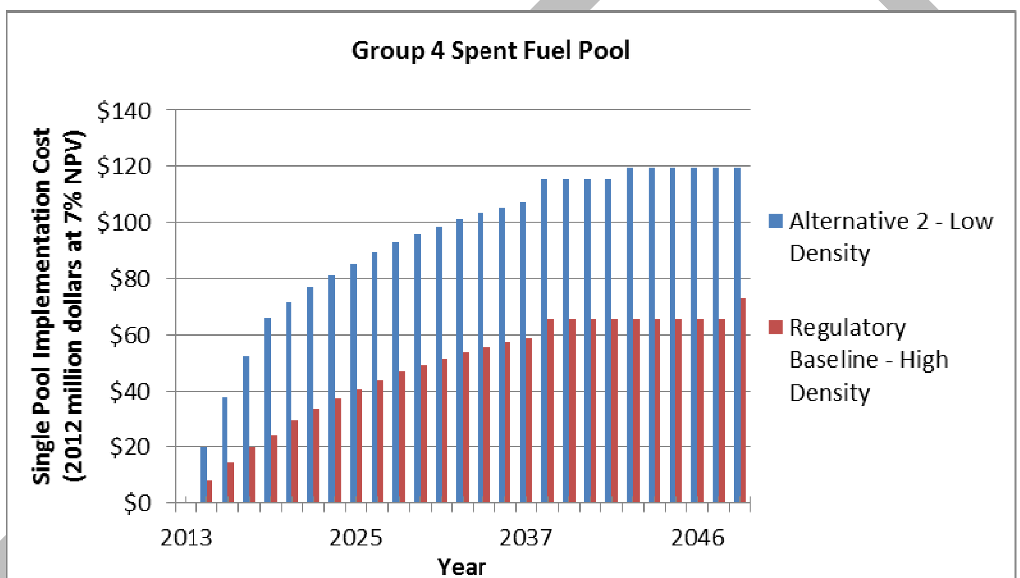


Figure 21 Cumulative dry cask storage implementation costs for a single Group 4 shared spent fuel pool

4.5.6.1 Industry Implementation Cost Summary

Table 46 provides a summary of the industry implementation costs for each spent fuel pool group and provides the number of additional DSCs that are needed to store the hotter spent fuel.

Table 46 Industry Implementation Costs for Low-Density Spent Fuel Pool Storage for a Single Spent Fuel Pool

SFP Group	No. of additional DSCs needed	Implementation Costs (2012 million dollars		
		2% NPV	3% NPV	7% NPV
1	12	$52.6	$55.2	$52.3
2	15	$51.4	$53.8	$51.3
3	10	$42.4	$35.8	$16.7
4	11	$48.8	$50.4	$46.4

Table 46 shows, the incremental costs associated with DSC upfront costs and the earlier purchasing and loading of DSCs on a periodic basis. The estimated industry implementation costs for low-density spent fuel storage relative to the regulatory baseline and calculated in accordance with the current regulatory framework, ranges from $42.4 to $52.6 million (2 percent net present value), $35.8 to $55.2 million (3 percent net present value), and $16.7 to $52.3 million (7 percent net present value).

4.5.6.2 Implementation Costs to Install Open Frame Low-Density Racks in an Existing Spent Fuel Pool

The re-racking of a spent fuel pool with open frame low-density racks is a preventive risk reduction alternative, which is intended to reduce radiological material available and promote air cooling to prevent the onset of self-sustaining clad oxidation in the event of loss of spent fuel pool water inventory. As stated in Alternative 2, older spent fuel assemblies are expeditiously moved from spent fuel pool storage to dry cask storage beginning in year 2014 to achieve low-density spent fuel storage and provide an opportunity to re-rack the spent fuel pool. Re-racking a spent fuel pool involves replacing the existing high-density storage rack modules with new open frame low-density racks and is estimated to take approximately 2½ years based on a hypothetical spent fuel pool re-racking schedule to install high-density racks provided in EPRI TR-1021048 (Ref. 8). The EPRI estimated schedule is provided in Figure 22.

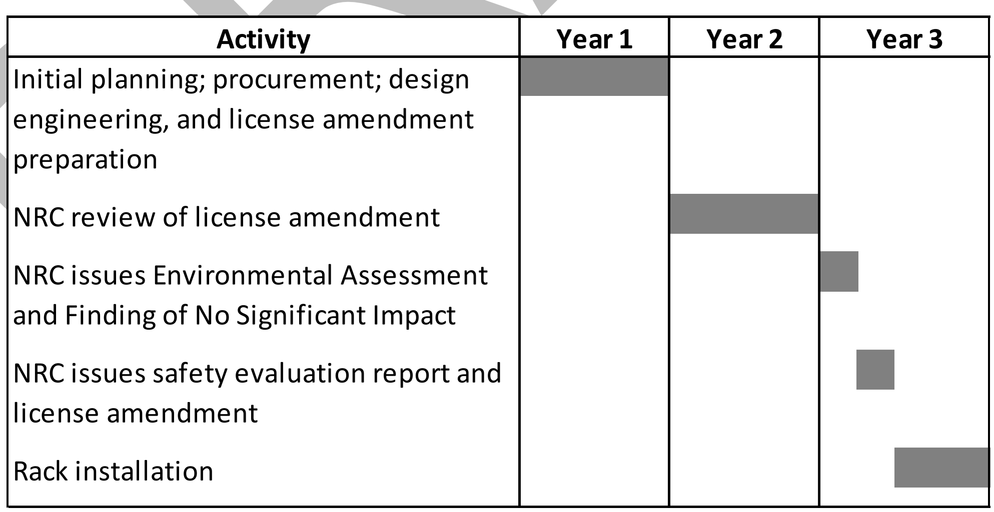


Figure 22 Estimated schedule for spent fuel pool re-racking project

The licensee would need to perform comprehensive safety analyses for the spent fuel pool re-rack project. These analyses will generally evaluate spent fuel pool criticality analysis;

mechanical and structural design; seismic design; radiation protection provisions during rack removal and installation; changes to plant technical specifications; heavy loads analyses for the spent fuel pool during rack removal and installation; and spent fuel pool thermal-hydraulic; decay heat analyses; and radiological consequences of beyond-design-basis events.
In addition to these design and engineering costs, other cost components include preparation of a license amendment and changes to the plant's technical specifications; specification and procurement of low-density replacement racks; rack manufacture, rack installation, and handling and disposal of the old high-density storage racks. One licensee estimated (Ref. 3) the cost for a single unit spent fuel pool re-rack project to be $7.5 million in 1979 which is equivalent to $23.7 million[20] in 2012 dollars.

This cost element was not included in this alternative because it would add substantial cost and is inefficient in terms of regulatory benefit given that much of the benefit is achieved by storing less fuel in the existing high-density racks for less cost.

4.5.7 Industry Operation

Industry operation accounts for the projected net economic effect caused by routine and recurring activities required by the proposed alternative. Annual operating costs for an ISFSI during reactor operation include the costs associated with NRC inspections; security; radiation monitoring; ISFSI operational monitoring; technical specification and regulatory compliance, including implementation of new certificate of compliance (CoC) amendments; personnel cost and code maintenance associated with fuel selection for dry storage; personnel costs for spent fuel management and fabrication surveillance activities; electric power usage for lighting and security systems; road maintenance to the ISFSI site; and miscellaneous expenses associated with ISFSI maintenance. NRC license fees for dry storage are included as part of the 10 CFR 50 operating license fees. As discussed in Section 4.3.4.4, incremental costs associated with annual ISFSI operating costs are insignificant for this analysis.

Industry operation also includes annual operating costs following reactor shutdown for decommissioning, which includes the costs associated with transporting spent fuel offsite. These costs were beyond the scope of the evaluation of expedited transfer of spent fuel to dry cask storage and are not included in this analysis.

The ability of a nuclear power plant operator to transfer spent fuel to dry storage during power operation is dependent upon what other activities are scheduled in the fuel handling area, plant-specific limitations on use of cask lifting crane or movement restrictions of heavy loads, or resource limitations if fuel handling equipment or personnel are shared between multiple reactor units. Furthermore, there could be operational impacts associated with large DSC loading campaigns as depicted in Figure 14 through Figure 17. These unintended consequences could include additional management support or attention to dry storage operations for longer periods, potential impacts on plant outage schedules or maintenance schedules because of increased staffing needs to support cask loading operations, and additional dry cask storage vendor oversight.

[20] This cost was converted from the licensee's cost estimate of $7.5 million in 1979 dollars using the CPI cost inflator. The licensee's cost estimate includes the following: design, materials, fabrication; removal and disposal of old racks; transportation and installation of new racks; project management, licensing, quality assurance; contingency allowance; and allowances for funds used during construction.

4.5.8 NRC Implementation

These costs, if calculated, would further reduce the calculated net benefit for this regulatory and backfit analysis.

4.5.9 NRC Operation

These costs, if calculated, would further reduce the calculated net benefit for this regulatory and backfit analysis.

4.5.10 Other Considerations

The other considerations are provided in relation to the regulatory baseline.

4.5.10.1 Seismic Hazard Model Uncertainties

There remain significant uncertainties in estimating the frequency of events for natural phenomena, which are postulated to challenge spent fuel pool cooling or integrity. This regulatory analysis uses the existing USGS 2008 model to evaluate seismic hazards at CEUS nuclear power plants. A new probabilistic seismic hazard model is currently being developed and will consist of two parts: (1) a seismic source zone characterization and (2) a ground motion prediction equation (GMPE) model. Although part (1) is now complete (Ref. 56), the GMPE update is still in progress. Furthermore, the NRC is currently developing an independent probabilistic seismic hazard assessment (PSHA) computer code to incorporate part (1) and part (2) when complete. While the USGS (2008) hazard model is not sufficiently detailed for regulatory decisions, it is used for this regulatory analysis because it is the most recent and readily available hazard model and was used in the Spent Fuel Pool Study.

4.5.10.2 Other Modeling Uncertainties

There are also significant uncertainties in the calculation of event consequences in terms of the dispersion and disposition of radioactive material into the site environs. This is due in part to significant uncertainties regarding the degree to which topographical features and other phenomena are modeled at distances away from the evaluated site. Estimating economic consequences also includes large uncertainties, as it is difficult to model the impact of disruptions to many different aspects of local economies and the loss of infrastructure on the general United States economy. An example of this is the supply chain disruptions that followed the 2011 Tohoku earthquake and subsequent tsunami on Japan or the 2004 Indian Ocean earthquake and tsunami on Thailand.

4.5.10.3 Cask Handling Risk

The NRC recognizes that there are costs and risks associated with the handling and movement of spent fuel casks. These cost and risk impacts, if included in this analysis, would further reduce the overall net benefit in relation to the regulatory baseline. These effects (e.g., the added risks of handling and moving casks) were conservatively ignored in order to calculate the maximum potential benefit by only comparing the safety of high-density fuel pool storage relative to low-density fuel pool storage and its implementation costs without consideration of cask movement risk.

4.5.10.4 Mitigating Strategies

The release of fission products to the environment from events that may cause the loss of spent fuel pool cooling or integrity, such as seismic events, missiles, heavy load drops, loss of cooling or make-up, inadvertent drainage or siphoning and pneumatic seal failures, are estimated to be range between 7.39×10^{-7} to 3.46×10^{-5} per year without successful mitigation. Operator diagnosis and recovery are important factors considered in the development of the event frequencies for these events and portions of this evaluation are premised on licensees having taken appropriate actions to understand the potential consequences of spent fuel pool accident events and develop appropriate procedures and mitigating strategies to respond and mitigate the consequences.

The Spent Fuel Pool Study (Ref. 2) evaluated the potential benefits of mitigation measures required under 10 CFR 50.54(hh)(2) (Ref. 33), which were implemented following the September 11, 2001 attacks. These mitigation measures are intended to maintain spent fuel pool cooling in the event of a loss of large areas of the plant caused by explosions or fire. Neither the Spent Fuel Pool Study nor previous spent fuel pool studies considers the post-Fukushima improvements required by NRC and being implemented by the plants. These improvements are intended to increase the likelihood of restoring or maintaining power and mitigation capability during severe accidents.

The new spent fuel pool level instrumentation required under Order EA-12-051 and the mitigation strategies now required under Order EA-12-049, significantly enhance the likelihood of successful mitigation beyond that considered in this regulatory analysis because of the following features:

- Portable equipment with redundant sets (e.g., N+1) that is sufficient to supply all functions, simultaneously for the entire site, including equipment for the spent fuel pool. This portable equipment provides reasonable protection from seismic events, which are a dominant contributor to spent fuel pool risk.

- The mission time for this equipment is indefinite, versus the 12-hour mission time for the 50.54(hh)(2) equipment.[21]

- The new EA-12-049 mitigating strategies (Ref. 73) are capable of being deployed in all modes, which means that the new strategies can address spent fuel pool cooling issues that could occur in any operating cycle phase.

- The new spent fuel pool level instrumentation required under Order EA-12-051 (Ref. 74), ensures a reliable indication of the water level in the spent fuel pool for identification of the following pool water level conditions:
    - A level that is adequate to support operation of the normal fuel pool cooling system,
    - A level that is adequate to provide substantial radiation shielding for a person standing on the spent fuel pool operating deck, and

[21] This section of the regulations deals with the development and implementation of guidance and strategies intended to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities under the circumstances associated with loss of large areas of the plant resulting from explosions or fire.

    - A level where fuel remains covered and actions to implement make-up water addition should no longer be deferred.

- The minimum spent fuel pool makeup flow rate under Order EA-12-049 is set to match the design basis heat load for the spent fuel pool, which is typically a full core offload in addition to the recently removed fuel from the last refueling outage. This results in a lower flow rate than that in NEI guidance for Part 50.54 (hh)(2) equipment and an earlier transition to spray, if necessary, because of leaks.

- The method of filling the spent fuel pool is via a connection to the normal spent fuel pool makeup system located away from the spent fuel pool floor, reducing the impacts on human performance because of potentially adverse environmental conditions (e.g., high temperature, humidity, and radiation) following an event.

This additional equipment, strategies, and features provided by Orders EA-12-049 and EA-12-051, provide additional accident mitigation capability and would further enhance the likelihood of successful mitigation, thereby further reducing the value for the conditional probability of release used in this regulatory analysis.

4.5.10.5 Cost Uncertainties

It is difficult to determine costs that could be incurred 50 to 100 years in the future. Changes in technology, regulation, or public policy could all have a profound effect on the actual cost. The purpose of including costs is to try to discern differences between the identified alternatives. Of course, this analysis is based on best estimates of current spent fuel strategies and cost. In reality, if the spent fuel facility is anticipated to be stored at a non-operating plant site for extended periods, the costs will be heavily discounted, and the discernible differences between storage alternatives will be negligible.

5. PRESENTATION OF RESULTS

This section presents the analytical results, including discussion of supplemental considerations, uncertainties in estimates, and results of sensitivity analyses on the overall benefits. The results are presented in two different ways, in order to address the differing decision criteria between regulatory analyses and backfit analyses (10 CFR 50.109).

5.1 <u>Regulatory Analysis</u>

5.1.1 Summary Table

The following summary table provides the quantified and qualified costs and benefits for low-density spent fuel pool storage for each spent fuel group. For the quantitative analysis, the low estimate, base case, and high estimate results within 50 miles are reported.

Table 47 Summary of Totals for Alternatives

Net Monetary Savings (or Costs) – Total Present Value	Non-Monetary Benefits/Costs
Alternative 1: Regulatory Baseline – Maintain the Existing Spent Fuel Storage Requirements $0	**Qualitative Benefits and Costs:** None.
Alternative 2 – Low-density Spent Fuel Pool Storage *Group 1 – BWR Mark I and Mark II with non-shared spent fuel pools* **Industry:** ($53 million) using a 2% discount rate ($55 million) using a 3% discount rate ($52 million) using a 7% discount rate **NRC:** Not calculated **Benefits:** $0.2 million – $122 million using a 2% discount rate $0.2 million – $109 million using a 3% discount rate $0.1 million – $73 million using a 7% discount rate	**Qualitative Costs:** None. **Qualitative Benefits:** Modeling Uncertainties. Cask Handling Risk Mitigating Strategies Cost Uncertainties
Group 2 – PWR and BWR Mark III with non-shared spent fuel pools **Industry:** ($51 million) using a 2% discount rate ($54 million) using a 3% discount rate ($51 million) using a 7% discount rate **NRC:** Not calculated **Benefits:** $0.3 million – $137 million using a 2% discount rate $0.3 million – $121 million using a 3% discount rate $0.2 million – $77 million using a 7% discount rate	**Qualitative Costs:** None. **Qualitative Benefits:** Modeling Uncertainties. Cask Handling Risk Mitigating Strategies Cost Uncertainties
Group 3 – New reactor spent fuel pools **Industry:** ($42 million) using a 2% discount rate ($36 million)) using a 3% discount rate ($17 million) using a 7% discount rate **NRC:** Not calculated **Benefits:** $0.3 million – $108 million using a 2% discount rate	**Qualitative Costs:** None. **Qualitative Benefits:** Modeling Uncertainties. Cask Handling Risk Mitigating Strategies Cost Uncertainties

Net Monetary Savings (or Costs) – Total Present Value	Non-Monetary Benefits/Costs
$0.3 million – $81 million using a 3% discount rate $0.1 million – $34 million using a 7% discount rate *Group 4 – Reactor units with shard spent fuel pools* **Industry:** ($49 million) using a 2% discount rate ($50 million) using a 3% discount rate ($46 million) using a 7% discount rate **NRC:** Not calculated **Benefits:** $0.3 million – $205 million using a 2% discount rate $0.3 million – $182 million using a 3% discount rate $0.2 million – $120 million using a 7% discount rate	**Qualitative Costs:** None. **Qualitative Benefits:** Modeling Uncertainties. Cask Handling Risk Mitigating Strategies Cost Uncertainties

As shown in Table 47, the calculated benefits for requiring low-density spent fuel pool storage (Alternative 2) for the low estimate and base case are less than industry costs to achieve a low-density spent fuel loading pattern for each spent fuel pool group. All of the spent fuel pool group high estimate cases achieve a positive net benefit using the current regulatory framework.

Similar to the seismic event analyzed for the Spent Fuel Pool Study, no offsite early fatalities are calculated to occur. This results from the following two reasons:

1. In comparison to reactors, spent fuel pools have a larger proportion of longer-lived radionuclides, which are less likely to cause the significant doses required for acute health effects.

2. Despite the large releases for certain predicted spent fuel pool accident progressions, the release from the most recently discharged fuel (which contains the shorter-lived radionuclides) is predicted to be insufficiently fast and insufficiently large to reach the acute thresholds associated with offsite early fatalities. When doses do exceed minimum levels for early fatalities, emergency response, as treated in the main report, effectively prevents any early fatality risk, at least in part because the modeled accident progression results in releases that are long compared with the time needed for relocation.

In addition, the predicted long-term exposure of the population, which could result in latent cancer fatality risk, is also low for the following reasons:

1. The individual latent individual latent cancer fatality risk within 0-10 miles for the studied scenarios is predicted to be on the order of 10^{-10} to 10^{-11} per year, based on the linear no threshold (LNT) dose response model.

2. The risk within 10 miles of the analyzed accident is dominated by low dose received at a low dose rate. According to alternate dose response models, excluding the uncertain effects of low radiation dose could reduce the quantified individual latent cancer fatality

risk within 10 miles to be approximately 10^{-14} per year, a reduction of approximately 3,000 times.

3. Average individual latent cancer fatality risk is low and decreases slowly as a function of distance from the plant. Additionally, the predicted individual risks of latent cancer fatalities are dominated by long-term exposures to very lightly contaminated areas for which doses are small enough to be considered habitable. Therefore, the use of alternate dose response models would significantly reduce the quantified latent cancer fatality risk by at least an order of magnitude.

5.1.2 Implementation and Operation Costs

5.1.2.1 Alternative 2 – Low-density Spent Fuel Pool Storage

5.1.2.1.1 Spent Fuel Pool Group 1 – BWR Mark I and Mark II reactors with non-shared spent fuel pool

Table 48 Summary of Total Implementation and Operation Costs for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 1

Attribute	Costs per spent fuel pool (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Occupational Health (Routine)	$0.03	$0.03	$0.03
Industry Implementation	$52.61	$55.17	$52.28
Industry Operation	nc	nc	nc
NRC Implementation	nc	nc	nc
NRC Operation	nc	nc	nc
Total per pool	$52.64	$55.20	$52.31
Total for 31 pools	$1,632	$1,711	$1,622

The low-density spent fuel pool storage alternative for BWR Mark I and Mark II reactors with a non-shared spent fuel pool total implementation and operation costs is the summation of those costs for the industry and the NRC. As shown in Table 48, the total estimated costs for a single Group 1 spent fuel pool to achieve and maintain a low-density spent fuel pool loading ranges from $52.64 million (2 percent net present value), to $55.20 million (3 percent net present value), and to $52.31 million (7 percent net present value). The total cost for all 31 spent fuel pools in this group is approximately $1.6 billion. These costs are dominated by the capital costs for the DSCs and the loading costs for the storage systems to achieve low-density storage in the spent fuel pool than that required for the regulatory baseline.

5.1.2.1.2 Spent Fuel Pool Group 2 – PWR and BWR Mark III reactors with non-shared spent fuel pool

Table 49 Summary of Total Implementation and Operation Costs for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 2

Attribute	Costs per spent fuel pool (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Occupational Health (Routine)	$0.03	$0.03	$0.03
Industry Implementation	$51.37	$53.80	$51.33
Industry Operation	nc	nc	nc
NRC Implementation	nc	nc	nc
NRC Operation	nc	nc	nc
Total per pool	$51.40	$53.83	$51.36
Total for 48 pools	$2,467	$2,584	$2,465

The low-density spent fuel pool storage alternative for PWR and BWR Mark III reactors with a non-shared spent fuel pool total implementation and operation costs is the summation of those costs for the industry and the NRC. As shown in Table 49, the total estimated costs for a single Group 2 spent fuel pool to achieve and maintain a low-density spent fuel pool loading ranges from $51.40 million (2 percent net present value), to $53.83 million (3 percent net present value), and to $51.36 million (7 percent net present value). The total cost for all 48 spent fuel pools in this group range is approximately $2.5 billion. These costs are dominated by the capital costs for the DSCs and the loading costs for the storage systems to achieve low-density storage in the spent fuel pool than that required for the regulatory baseline.

5.1.2.1.3 Spent Fuel Pool Group 3 – New power reactors with non-shared spent fuel pool

Table 50 Summary of Total Implementation and Operation Costs for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 3

Attribute	Costs per spent fuel pool (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Occupational Health (Routine)	$0.01	$0.01	$0.01
Industry Implementation	$42.41	$35.75	$16.74
Industry Operation	nc	nc	nc
NRC Implementation	nc	nc	nc
NRC Operation	nc	nc	nc
Total per pool	$42.42	$35.76	$16.75
Total for four pools	$169.7	$143.1	$67.0

The low-density spent fuel pool storage alternative for new reactors with a non-shared spent fuel pool total implementation and operation costs is the summation of those costs for the industry and the NRC. As shown in Table 50, the total estimated costs for a single Group 3 spent fuel pool to achieve and maintain a low-density spent fuel pool loading ranges from $42.42 million (2 percent net present value), to $35.76 million (3 percent net present value), and to $16.75 million (7 percent net present value). The total cost for all four spent fuel pools in this group range between $67 and $170 million. These costs are dominated by the capital costs for the DSCs, the loading costs for the storage systems to achieve low-density storage in the spent fuel pool, and the additional ISFSI annual operation and maintenance costs required for establishing and storing spent fuel at the ISFSI 15 years early than that required for the regulatory baseline.

5.1.2.1.4 Spent Fuel Pool Group 4—Reactor units with a shared spent fuel pool

Table 51 Summary of Total Implementation and Operation Costs for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 4

Attribute	Costs per spent fuel pool (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Occupational Health (Routine)	$0.02	$0.02	$0.03
Industry Implementation	$48.78	$50.41	$46.39
Industry Operation	nc	nc	nc
NRC Implementation	nc	nc	nc
NRC Operation	nc	nc	nc
Total per pool	$48.80	$50.43	$46.41
Total for 11 pools	$536.8	$554.8	$510.6

The low-density spent fuel pool storage alternative for reactors units with a shared spent fuel pool total implementation and operation costs is the summation of those costs for the industry and the NRC. As shown in Table 52, the total estimated costs for a single Group 4 shared spent fuel pool to achieve and maintain a low-density spent fuel pool loading ranges from $48.80 million (2 percent net present value), to $50.43 million (3 percent net present value), and to $46.41 million (7 percent net present value). The total cost for all 11 spent fuel pools in this group range between $511 and $555 million. These costs are dominated by the capital costs for the DSCs, and the loading costs for the storage systems to achieve low-density storage in the spent fuel pool than that required for the regulatory baseline.

5.1.3 Total Benefits and Cost Offsets

5.1.3.1 Alternative 2 – Low-density Spent Fuel Pool Storage

5.1.3.1.1 Spent Fuel Pool Group 1 – BWR Mark I and Mark II reactors with non-shared spent fuel pool

Table 52 Summary of Total Benefits and Cost Offsets for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 1

Attribute	Benefits and Cost Offsets (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$0.05 - $35.6	$0.04 – $31.7	$0.03 – $21.2
Occupational Health (Accident)	<$0.01 – $0.1	<$0.01 – $0.09	<$0.01 – $0.06
Offsite Property	$1.66 – $85.7	$1.48 – $76.4	$0.10 – $51.1
Onsite Property	<$0.01 – $1.1	<$0.01 – $0.99	<$0.01 – $0.60
Total per pool	$1.7 – $123	$1.54 – $109	$0.15 – $73.0
Total for 31 pools	$53 – $3,800	$48 – $3,380	$4.7 – $2,260

The Spent Fuel Pool Group 1 total benefits are shown in the Table 52. These benefits include the public health (accident) and occupational health (accident) benefits summed with the cost offsets. The cost offsets consists of the sum of the offsite property and onsite property attributes relative to the regulatory baseline. The offsite property cost offset is the largest contributor to the benefits, of which the majority of those costs occur during the long-term phase.

5.1.3.1.2 Spent Fuel Pool Group 2 – PWR and BWR Mark III reactors with non-shared spent fuel pool

Table 53 Summary of Total Benefits and Cost Offsets for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 2

Attribute	Benefits and Cost Offsets (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$0.06 – $38.7	$0.05 – $34.0	$0.03 – $21.8
Occupational Health (Accident)	<$0.01 – $0.11	<$0.01 – $0.96	<$0.01 – $0.06
Offsite Property	$0.27 – $97.5	$0.24 – $85.6	$0.15 – $54.8
Onsite Property	<$0.01 – $1.2	<$0.01 – $1.0	<$0.01 – $0.59
Total per pool	$0.35 – $138	$0.31 – $122	$0.20 – $77.3
Total for 48 pools	$17 – $6,600	$15 – $5,830	$10 – $3,710

The Spent Fuel Pool Group 2 total benefits are shown in the Table 53. These benefits include the public health (accident) and occupational health (accident) benefits summed with the cost offsets. The cost offsets consists of the sum of the offsite property and onsite property attributes relative to the regulatory baseline. The offsite property cost offset is the largest contributor to the benefits, of which the majority of those costs occur during the long-term phase.

5.1.3.1.3 Spent Fuel Pool Group 3 – New power reactors with non-shared spent fuel pool

Table 54 Summary of Total Benefits and Cost Offsets for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 3

Attribute	Benefits and Cost Offsets (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$0.06 – $31.9	$0.05 – $24.1	$0.02 – $10.1
Occupational Health (Accident)	<$0.01 – $0.97	<$0.01 – $0.07	<$0.01 – $0.03
Offsite Property	$0.26 – $74.5	$0.20 – $56.3	$0.08 – $23.5
Onsite Property	<$0.01 – $1.1	<$0.01 – $0.78	<$0.01 – $0.29
Total per pool	$0.34 – $108	$0.27 – $81.3	$0.12 – $33.9
Total for 4 pools	$1.4 – $430	$1.1– $330	$0.5 – $140

The Spent Fuel Pool Group 3 total benefits are shown in the Table 54. These benefits include the public health (accident) and occupational health (accident) benefits summed with the cost offsets. The cost offsets consists of the sum of the offsite property and onsite property attributes relative to the regulatory baseline. The offsite property cost offset is the largest contributor to the benefits, of which the majority of those costs occur during the long-term phase.

5.1.3.1.4 Spent Fuel Pool Group 4 – Reactor units with a shared spent fuel pool

Table 55 Summary of Total Benefits and Cost Offsets for Low-Density Spent Fuel Pool Storage—Spent Fuel Pool Group 4

Attribute	Benefits and Cost Offsets (2012 dollars in millions)		
	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$0.06 – $52.1	$0.05 – $46.3	$0.03 – $30.6
Occupational Health (Accident)	<$0.01 – $0.13	<$0.01 – $0.11	<$0.01 – $0.07
Offsite Property	$0.27 – $151.2	$0.24 – $134.3	$0.16 – $88.9
Onsite Property	<$0.01 – $1.3	<$0.01 – $1.2	<$0.01 – $0.70
Total per pool	$0.35 – $205	$0.31 – $182	$0.21 – $120
Total for 11 pools	$3.9 – $2,250	$3.4 – $2,000	$3.4 – $1,320

The Spent Fuel Pool Group 4 total benefits are shown in the Table 55. These benefits include the public health (accident) and occupational health (accident) benefits summed with the cost offsets. The cost offsets consists of the sum of the offsite property and onsite property attributes relative to the regulatory baseline. The offsite property cost offset is the largest contributor to the benefits, of which the majority of those costs occur during the long-term phase.

5.1.4 Sensitivity Analysis

This section summarizes the results of the sensitivity analyses that were performed as an additional consideration in performing safety goal screening for the evaluated alternatives. In this section, a low and high estimate is provided which combines the range of expected spent fuel pool attributes with conservative assumptions to model the range of pool accidents postulated. These high and low estimates are expected to over and under estimate the consequences from spent fuel pool fires for any individual spent fuel pools assigned to the group.

5.1.4.1 Dollar per Person-rem Conversion Factor

The NRC is currently revising the dollar per person-rem averted conversion factor based on recent information regarding the value of a statistical life. However, until the NRC completes the update and publishes the appropriate guidance documents, the NRC performs sensitivity analysis to estimate the impact on the calculated results when more current VSL and cancer risk factor are used. The NRC used the U.S. Environmental Protection Agency's (EPA) VSL as an interim value in the sensitivity analysis as described in Section 4.4.2. The effect of using the higher dollar per person-rem conversion factor on the calculated results is provided below. As previously discussed, the consequences calculated for the high and low estimate are expected to over- and underestimate respectively the consequences if compared to plant-specific spent fuel pool analyses within this spent fuel pool grouping.

5.1.4.1.1 Spent Fuel Pool Group 1—BWR Mark I and Mark II reactors with non-shared spent fuel pool

Table 56 Dollar Per Person-Rem Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage within 50 miles—Group 1 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$96,000	$85,600	$57,200	$5,433,200	$4,845,800	$3,243,000	$71,176,000	$63,482,400	$42,485,000
Occupational Health (Accident)	$1,884	$1,680	$1,124	$17,158	$15,304	$10,242	$210,074	$187,367	$125,394
Offsite Property	$165,692	$147,782	$98,902	$8,959,243	$7,990,830	$5,347,787	$85,673,027	$76,412,549	$51,138,370
Onsite Property	$5,990	$5,280	$3,150	$67,520	$58,650	$35,470	$1,139,040	$989,660	$598,900
Total Benefits	***$269,600***	***$240,300***	***$160,400***	***$14,477,100***	***$12,910,600***	***$8,636,500***	***$158,198,100***	***$141,072,000***	***$94,347,700***
Occupational Health (Routine)	-$50,800	-$55,600	-$56,400	-$50,800	-$55,600	-$56,400	-$50,800	-$55,600	-$56,400
Industry Implementation	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***
Net Benefit	**-$52,391,000**	**-$54,985,000**	**-$52,176,000**	**-$38,184,000**	**-$42,315,000**	**-$43,700,000**	**$105,537,000**	**$85,846,000**	**$42,011,000**

1. nc = not calculated

As shown in Table 56, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit for either the low estimate or base case when using a person-rem conversion factor twice as large as the conversion factor in NUREG-1530. When all the high estimates are combined, a positive net benefit is achieved. As Table 29 shows, the base case of the delta benefit for averted public health (accident) radiation exposure from a spent fuel pool accident resulting in spent fuel damage is approximately 360 person-rem for the Group 1 spent fuel pool. This dose represents the reduction of public health risk that results from a policy decision to transfer spent fuel from the spent fuel pool to dry storage in order to achieve low-density spent fuel loading in the pool. For a single BWR Mark I or Mark II reactor with a non-shared spent fuel pool (Group 1), the averted delta dose exposure is approximately 14.3 person-rem per year over a remaining licensed commercial operation of the reactor of 24 years (until year 2037). The value is based on a U.S. reactor site average population density of approximately 317 people per square mile within a 50-mile radius from the site. The calculated dose is the difference between an uncontrolled release of radionuclides from a full high-density spent fuel pool with no credit for successful mitigation to a full low-density spent fuel pool with credit for successful mitigation. The doses reflects the calculated health benefits that result if adherence to the EPA intermediate phase protective action guides that allow a dose of 2 rem in the first year and 500 mrem each year thereafter are used.

5.1.4.1.2 Spent Fuel Pool Group 2—PWR and BWR Mark III reactors with non-shared spent fuel pool

The effect of using the higher dollar per person-rem conversion factor on the calculated results is provided below. As previously discussed, the consequences calculated for the high and low estimate are expected to over- and underestimate respectively the consequences if compared to plant-specific spent fuel pool analyses within this spent fuel pool grouping.

Table 57 Dollar Per Person-Rem Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage within 50 miles—Group 2 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$118,000	$103,600	$66,400	$4,896,800	$4,301,400	$2,752,200	$77,482,600	$68,062,000	$43,549,200
Occupational Health (Accident)	$1,000	$800	$600	$13,200	$11,600	$7,400	$218,800	$192,200	$123,000
Offsite Property	$272,584	$239,442	$153,207	$9,031,983	$7,933,837	$5,076,442	$97,457,843	$85,608,518	$54,776,349
Onsite Property	$3,250	$2,840	$1,630	$51,800	$44,280	$25,550	$1,190,370	$1,018,500	$589,050
Total Benefits	***$394,800***	***$346,700***	***$221,800***	***$13,993,800***	***$12,291,100***	***$7,861,600***	***$176,349,600***	***$154,881,200***	***$99,037,600***
Occupational Health (Routine)	-$54,400	-$58,200	-$57,800	-$54,400	-$58,200	-$57,800	-$54,400	-$58,200	-$57,800
Industry Implementation	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***
Net Benefit	**-$51,030,000**	**-$53,512,000**	**-$51,166,000**	**-$37,431,000**	**-$41,567,000**	**-$43,526,000**	**$124,925,000**	**$101,023,000**	**$47,650,000**

1. nc = not calculated

As shown in

Table 57, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit when using a person-rem conversion factor twice as large as the conversion factor in NUREG-1530 for either the low estimate or base cases. When all the high estimates are combined, a positive net benefit is achieved.

5.1.4.1.3 Spent Fuel Pool Group 3—New power reactors with non-shared spent fuel pool

Table 58 Dollar Per Person-Rem Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage within 50 miles—Group 3 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$129,600	$98,000	$41,000	$6,279,200	$4,748,800	$1,981,600	$63,827,600	$48,271,400	$20,143,000
Occupational Health (Accident)	$1,400	$1,200	$400	$19,000	$14,400	$6,000	$193,400	$146,200	$61,000
Offsite Property	$264,273	$199,864	$83,400	$11,451,619	$8,660,606	$3,613,942	$74,506,474	$56,347,594	$23,513,013
Onsite Property	$4,780	$3,560	$1,320	$75,910	$55,830	$20,950	$1,062,030	$781,900	$293,960
Total Benefits	***$400,100***	***$302,600***	***$126,100***	***$17,825,700***	***$13,479,600***	***$5,622,500***	***$139,589,500***	***$105,547,100***	***$44,011,000***
Occupational Health (Routine)	-$29,000	-$25,800	-$12,800	-$29,000	-$25,800	-$12,800	-$29,000	-$25,800	-$12,800
Industry Implementation	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***
Net Benefit	**-$42,039,000**	**-$35,473,000**	**-$16,627,000**	**-$24,613,000**	**-$22,296,000**	**-$11,130,000**	**$97,151,000**	**$69,771,000**	**$27,258,000**

1. nc = not calculated

As shown in Table 58, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit when using a person-rem conversion factor twice as large as the conversion factor in NUREG-1530 for either the low estimate or base cases presented. The high estimates show a positive net benefit of between $27 and $97 million. This spent fuel pool group differs significantly from the other spent fuel pool groups analyzed in that these pools have not yet been constructed so that there is not a significant front ended DSC procurement cost difference between the two alternatives. However in comparison to the base case, the high estimate includes additional conservative assumptions regarding seismic fragilities, release fractions, spent fuel pool inventories, long-term habitability criteria, and site population densities that are overly conservative for the four units with combined licenses.

5.1.4.1.4 Spent Fuel Pool Group 4—Reactor units with a shared spent fuel pool

Table 59 Dollar Per Person-Rem Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage within 50 miles—Group 4 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$114,400	$101,600	$67,200	$5,246,400	$4,661,400	$3,083,600	$104,286,600	$92,655,000	$61,292,600
Occupational Health (Accident)	$1,000	$800	$600	$12,000	$10,800	$7,200	$250,000	$222,200	$147,000
Offsite Property	$271,158	$240,914	$159,368	$9,805,063	$8,711,458	$5,762,750	$151,185,571	$134,323,136	$88,856,614
Onsite Property	$3,050	$2,640	$1,520	$47,620	$41,160	$24,570	$1,349,250	$1,168,370	$700,210
Total Benefits	***$389,600***	***$346,000***	***$228,700***	***$15,111,100***	***$13,424,800***	***$8,878,100***	***$257,071,400***	***$228,368,700***	***$150,996,400***
Occupational Health (Routine)	$45,400	$49,400	$49,600	$45,400	$49,400	$49,600	$45,400	$49,400	$49,600
Industry Implementation	$48,780,000	$50,410,000	$46,390,000	$48,780,000	$50,410,000	$46,390,000	$48,780,000	$50,410,000	$46,390,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***$48,825,400***	***$50,459,400***	***$46,439,600***	***$48,825,400***	***$50,459,400***	***$46,439,600***	***$48,825,400***	***$50,459,400***	***$46,439,600***
Net Benefit	**-$48,436,000**	**-$50,113,000**	**-$46,211,000**	**-$33,714,000**	**-$37,035,000**	**-$37,562,000**	**$208,246,000**	**$177,909,000**	**$104,557,000**

As shown in Table 59, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit when using a person-rem conversion factor twice as large as the conversion factor in

NUREG-1530 for either the low estimate or base case presented. The high estimate shows a positive net benefit of between $105 and $208 million.

5.1.4.2 Consequences Extending Beyond 50 Miles

The RA Handbook states that in the case of nuclear power plants, changes in public health and safety from radiation exposure and offsite property impacts should be examined over a 50-mile distance from the plant site, although alternative distances from the plant may be used for sensitivity analyses. For this regulatory analysis, supplemental information (e.g., analyses and results) based on MACCS2 calculated results, is performed which extends the analysis beyond 50 miles for each spent fuel pool group.

5.1.4.2.1 Spent Fuel Pool Group 1 – BWR Mark I and Mark II reactors with non-shared spent fuel pool

Table 60 Consequences Extending Beyond 50 Miles Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage—Group 1 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$503,300	$448,900	$300,400	$22,835,700	$20,367,300	$13,630,700	$305,431,900	$272,417,500	$182,312,800
Occupational Health (Accident)	$942	$840	$562	$8,579	$7,652	$5,121	$105,037	$93,684	$62,697
Offsite Property	$573,290	$511,323	$342,198	$16,358,429	$14,590,231	$9,764,373	$323,691,221	$288,703,133	$193,211,821
Onsite Property	$5,990	$5,280	$3,150	$67,520	$58,650	$35,470	$1,139,040	$989,660	$598,900
Total Benefits	***$1,083,500***	***$966,300***	***$646,300***	***$39,270,200***	***$35,023,800***	***$23,435,700***	***$630,367,200***	***$562,204,000***	***$376,186,200***
Occupational Health (Routine)	-$25,400	-$27,800	-$28,200	-$25,400	-$27,800	-$28,200	-$25,400	-$27,800	-$28,200
Industry Implementation	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$52,635,400***	***-$55,197,800***	***-$52,308,200***	***-$52,635,400***	***-$55,197,800***	***-$52,308,200***	***-$52,635,400***	***-$55,197,800***	***-$52,308,200***
Net Benefit	**-$51,552,000**	**-$54,232,000**	**-$51,662,000**	**-$13,365,000**	**-$20,174,000**	**-$28,873,000**	**$577,732,000**	**$507,006,000**	**$323,878,000**

1. nc = not calculated

As shown in Table 60, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50 miles does not achieve a positive net benefit for either the low estimate or base cases presented. The high estimates show a positive net benefit of between $324 and $578 million. In comparison to the base case, the high estimate includes additional conservative assumptions regarding seismic fragilities, release fractions, spent fuel pool inventories, long-term habitability criteria, and site population densities that when taken together result in a net beneficial result.

5.1.4.2.2 Spent Fuel Pool Group 2—PWR and BWR Mark III reactors with nonshared spent fuel pool

Table 61 Consequences Extending Beyond 50 Miles Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage—Group 2 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$860,600	$755,900	$483,700	$20,609,300	$18,103,500	$11,583,500	$350,842,800	$308,185,900	$197,191,800
Occupational Health (Accident)	$500	$400	$300	$6,600	$5,800	$3,700	$109,400	$96,100	$61,500
Offsite Property	$1,860,702	$1,634,470	$1,045,811	$28,788,238	$25,288,046	$16,180,479	$402,559,059	$353,614,274	$226,259,013
Onsite Property	$3,250	$2,840	$1,630	$51,800	$44,280	$25,550	$201,170	$173,800	$103,350
Total Benefits	***$2,725,100***	***$2,393,600***	***$1,531,400***	***$49,455,900***	***$43,441,600***	***$27,793,200***	***$753,712,400***	***$662,070,100***	***$423,615,700***
Occupational Health (Routine)	-$27,200	-$29,100	-$28,900	-$27,200	-$29,100	-$28,900	-$27,200	-$29,100	-$28,900
Industry Implementation	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$51,397,200***	***-$53,829,100***	***-$51,358,900***	***-$51,397,200***	***-$53,829,100***	***-$51,358,900***	***-$51,397,200***	***-$53,829,100***	***-$51,358,900***
Net Benefit	**-$48,672,000**	**-$51,436,000**	**-$49,828,000**	**-$1,941,000**	**-$10,388,000**	**-$23,566,000**	**$702,315,000**	**$608,241,000**	**$372,257,000**

As shown in Table 61, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50-miles does not achieve a positive net benefit for either the low estimate or base cases presented. The high estimates show a positive net benefit of between $372 and $702 million. In comparison to the base case, the high estimate includes additional conservative assumptions regarding seismic fragilities, release fractions, spent fuel pool inventories, long-term habitability criteria, and site population densities that when taken together result in a net beneficial result.

5.1.4.2.3 Spent Fuel Pool Group 3 – New power reactors with non-shared spent fuel pool

Table 62 Consequences Extending Beyond 50 Miles Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage—Group 3 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$844,600	$638,700	$266,500	$23,666,800	$17,898,700	$7,468,900	$263,568,800	$199,331,200	$83,178,000
Occupational Health (Accident)	$700	$600	$200	$9,500	$7,200	$3,000	$96,700	$73,100	$30,500
Offsite Property	$1,546,992	$1,169,956	$488,205	$27,166,671	$20,545,551	$8,573,353	$262,776,843	$198,732,300	$82,928,034
Onsite Property	$4,780	$3,560	$1,320	$75,910	$55,830	$20,950	$1,062,030	$781,900	$293,960
Total Benefits	***$2,397,100***	***$1,812,800***	***$756,200***	***$50,918,900***	***$38,507,300***	***$16,066,200***	***$527,504,400***	***$398,918,500***	***$166,430,500***
Occupational Health (Routine)	-$14,500	-$12,900	-$6,400	-$14,500	-$12,900	-$6,400	-$14,500	-$12,900	-$6,400
Industry Implementation	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$42,424,500***	***-$35,762,900***	***-$16,746,400***	***-$42,424,500***	***-$35,762,900***	***-$16,746,400***	***-$42,424,500***	***-$35,762,900***	***-$16,746,400***
Net Benefit	**-$40,027,000**	**-$33,950,000**	**-$15,990,000**	**$8,494,000**	**$2,744,000**	**-$680,000**	**$485,080,000**	**$363,156,000**	**$149,684,000**

As shown in Table 62, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit when considering consequences beyond 50 miles for four of the nine cases presented. Two cases, the 2-percent and 3-percent discounted base cases and the high estimates show a positive net benefit range of between $2.7 and $485 million.

5.1.4.2.4 Spent Fuel Pool Group 4—Reactor units with a shared spent fuel pool

Table 63 Consequences Extending Beyond 50 Miles Sensitivity Analysis of Net Benefits for Low-Density Spent Fuel Pool Storage—Group 4 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$853,200	$758,100	$501,500	$24,572,200	$21,831,600	$14,441,900	$560,905,000	$498,344,700	$329,661,900
Occupational Health (Accident)	$500	$400	$300	$6,000	$5,400	$3,600	$125,000	$111,100	$73,500
Offsite Property	$1,898,771	$1,686,992	$1,115,969	$39,619,961	$35,200,961	$23,285,923	$779,796,081	$692,821,772	$458,311,191
Onsite Property	$3,050	$2,640	$1,520	$47,620	$41,160	$24,570	$1,349,250	$1,168,370	$700,210
Total Benefits	***$2,755,500***	***$2,448,100***	***$1,619,300***	***$64,245,800***	***$57,079,100***	***$37,756,000***	***$1,342,175,300***	***$1,192,445,900***	***$788,746,800***
Occupational Health (Routine)	-$22,700	-$24,700	-$24,800	-$22,700	-$24,700	-$24,800	-$22,700	-$24,700	-$24,800
Industry Implementation	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$48,802,700***	***-$50,434,700***	***-$46,414,800***	***-$48,802,700***	***-$50,434,700***	***-$46,414,800***	***-$48,802,700***	***-$50,434,700***	***-$46,414,800***
Net Benefit	**-$46,047,000**	**-$47,987,000**	**-$44,796,000**	**$15,443,000**	**$6,644,000**	**-$8,659,000**	**$1,293,373,000**	**$1,142,011,000**	**$742,332,000**

As shown in Table 63, the dollar per person-rem sensitivity analysis does not achieve a positive net benefit when considering consequences beyond 50-miles for four of the nine cases presented. Two cases, the 2-percent and 3-percent discounted base cases and the high estimates show a positive net benefit range of between $6.6 and $1,293 million.

5.1.4.3 Combined Effect of Consequences Extending Beyond 50 Miles and Dollar per Person-Rem Conversion Factor

This sensitivity analysis considers the combined effects of extending the analysis of consequences beyond 50 miles from the site and increasing the dollar per person-rem conversion value from $2,000 to $4,000 per person-rem averted. The combined effects of these two variables on the calculated net benefits are provided below.

5.1.4.3.1 Spent Fuel Pool Group 1 – BWR Mark I and Mark II reactors with non-shared spent fuel pool

Table 64 Combined Sensitivity Analysis that Analyzes Consequences beyond 50 Miles using a Revised Dollar per Person-Rem Conversion Factor on the Net Benefits for Low-Density Spent Fuel Pool Storage—Group 1 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$1,006,600	$897,800	$600,800	$45,671,400	$40,734,600	$27,261,400	$610,863,800	$544,835,000	$364,625,600
Occupational Health (Accident)	$1,884	$1,680	$1,124	$17,158	$15,304	$10,242	$210,074	$187,367	$125,394
Offsite Property	$573,290	$511,323	$342,198	$16,358,429	$14,590,231	$9,764,373	$323,691,221	$288,703,133	$193,211,821
Onsite Property	$5,990	$5,280	$3,150	$67,520	$58,650	$35,470	$1,139,040	$989,660	$598,900
Total Benefits	***$1,587,800***	***$1,416,100***	***$947,300***	***$62,114,500***	***$55,398,800***	***$37,071,500***	***$935,904,100***	***$834,715,200***	***$558,561,700***
Occupational Health (Routine)	-$50,800	-$55,600	-$56,400	-$50,800	-$55,600	-$56,400	-$50,800	-$55,600	-$56,400
Industry Implementation	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***	***-$52,660,800***	***-$55,225,600***	***-$52,336,400***
Net Benefit	**-$51,073,000**	**-$53,810,000**	**-$51,389,000**	**$9,454,000**	**$173,000**	**-$15,265,000**	**$883,243,000**	**$779,490,000**	**$506,225,000**

1. nc = not calculated

As shown in Table 64, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50-miles combined with a revised dollar per person-rem conversion factor does not achieve a positive net benefit for four of the nine cases presented. Two cases, the 2-percent and 3-percent discounted base cases and the high estimates show a positive net benefit range of between $173,000 and $883 million.

5.1.4.3.2 Spent Fuel Pool Group 2—PWR and BWR Mark III reactors with nonshared spent fuel pool

Table 65 Combined Sensitivity Analysis that Analyzes Consequences beyond 50 Miles using a Revised Dollar per Person-Rem Conversion Factor on the Net Benefits for Low-Density Spent Fuel Pool Storage—Group 2 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$1,721,200	$1,511,800	$967,400	$41,218,600	$36,207,000	$23,167,000	$701,685,600	$616,371,800	$394,383,600
Occupational Health (Accident)	$1,000	$800	$600	$13,200	$11,600	$7,400	$218,800	$192,200	$123,000
Offsite Property	$1,860,702	$1,634,470	$1,045,811	$28,788,238	$25,288,046	$16,180,479	$402,559,059	$353,614,274	$226,259,013
Onsite Property	$3,250	$2,840	$1,630	$51,800	$44,280	$25,550	$201,170	$173,800	$103,350
Total Benefits	***$3,586,200***	***$3,149,900***	***$2,015,400***	***$70,071,800***	***$61,550,900***	***$39,380,400***	***$1,104,664,600***	***$970,352,100***	***$620,869,000***
Occupational Health (Routine)	-$54,400	-$58,200	-$57,800	-$54,400	-$58,200	-$57,800	-$54,400	-$58,200	-$57,800
Industry Implementation	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***	***-$51,424,400***	***-$53,858,200***	***-$51,387,800***
Net Benefit	**-$47,838,000**	**-$50,708,000**	**-$49,372,000**	**$18,647,000**	**$7,693,000**	**-$12,007,000**	**$1,053,240,000**	**$916,494,000**	**$569,481,000**

1. nc = not calculated

As shown in Table 65, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50-miles combined with a revised dollar per person-rem conversion factor does not achieve a positive net benefit for four of the nine cases presented. Two cases, the 2-percent and 3-percent discounted base cases and the high estimates show a positive net benefit range of between $7.7 and $1,053 million.

5.1.4.3.3 Spent Fuel Pool Group 3 – New power reactors with non-shared spent fuel pool

Table 66 Combined Sensitivity Analysis that Analyzes Consequences beyond 50 Miles using a Revised Dollar per Person-Rem Conversion Factor on the Net Benefits for Low-Density Spent Fuel Pool Storage—Group 3 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$1,689,200	$1,277,400	$533,000	$47,333,600	$35,797,400	$14,937,800	$527,137,600	$398,662,400	$166,356,000
Occupational Health (Accident)	$1,400	$1,200	$400	$19,000	$14,400	$6,000	$193,400	$146,200	$61,000
Offsite Property	$1,546,992	$1,169,956	$488,205	$27,166,671	$20,545,551	$8,573,353	$262,776,843	$198,732,300	$82,928,034
Onsite Property	$4,780	$3,560	$1,320	$75,910	$55,830	$20,950	$1,062,030	$781,900	$293,960
Total Benefits	***$3,242,400***	***$2,452,100***	***$1,022,900***	***$74,595,200***	***$56,413,200***	***$23,538,100***	***$791,169,900***	***$598,322,800***	***$249,639,000***
Occupational Health (Routine)	-$29,000	-$25,800	-$12,800	-$29,000	-$25,800	-$12,800	-$29,000	-$25,800	-$12,800
Industry Implementation	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***	***-$42,439,000***	***-$35,775,800***	***-$16,752,800***
Net Benefit	**-$39,197,000**	**-$33,324,000**	**-$15,730,000**	**$32,156,000**	**$20,637,000**	**$6,785,000**	**$748,731,000**	**$562,547,000**	**$232,886,000**

1. nc = not calculated

As shown in Table 66, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50-miles combined with a revised dollar per person-rem conversion factor does not achieve a positive net benefit for the low estimate cases presented. The base cases and high estimates show a positive net benefit range of between $6.8 and $748 million.

5.1.4.3.4 Spent Fuel Pool Group 4 – Reactor units with a shared spent fuel pool

Table 67 Combined Sensitivity Analysis that Analyzes Consequences beyond 50 Miles using a Revised Dollar per Person-Rem Conversion Factor on the Net Benefits for Low-Density Spent Fuel Pool Storage—Group 4 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$1,706,400	$1,516,200	$1,003,000	$49,144,400	$43,663,200	$28,883,800	$1,121,810,000	$996,689,400	$659,323,800
Occupational Health (Accident)	$1,000	$800	$600	$12,000	$10,800	$7,200	$250,000	$222,200	$147,000
Offsite Property	$1,898,771	$1,686,992	$1,115,969	$39,619,961	$35,200,961	$23,285,923	$779,796,081	$692,821,772	$458,311,191
Onsite Property	$3,050	$2,640	$1,520	$47,620	$41,160	$24,570	$1,349,250	$1,168,370	$700,210
Total Benefits	***$3,609,200***	***$3,206,600***	***$2,121,100***	***$88,824,000***	***$78,916,100***	***$52,201,500***	***$1,903,205,300***	***$1,690,901,700***	***$1,118,482,200***
Occupational Health (Routine)	-$45,400	-$49,400	-$49,600	-$45,400	-$49,400	-$49,600	-$45,400	-$49,400	-$49,600
Industry Implementation	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$48,825,400***	***-$50,459,400***	***-$46,439,600***	***-$48,825,400***	***-$50,459,400***	***-$46,439,600***	***-$48,825,400***	***-$50,459,400***	***-$46,439,600***
Net Benefit	**-$45,216,000**	**-$47,253,000**	**-$44,319,000**	**$39,999,000**	**$28,457,000**	**$5,762,000**	**$1,854,380,000**	**$1,640,442,000**	**$1,072,043,000**

1. nc = not calculated

As shown in Table 67, calculated net benefits for requiring low-density spent fuel pool storage when considering consequences beyond 50-miles combined with a revised dollar per person-rem conversion factor does not achieve a positive net benefit for the low estimate cases presented. The base cases and high estimates show a positive net benefit range of between $5.8 and $1,854 million.

5.2 <u>Backfit Analysis</u>

This backfit analysis examines the impacts of a generic backfit requiring low-density spent fuel pool storage at any U.S. spent fuel pool relative to the baseline used in the regulatory analysis, which consists of existing requirements including the recently issued orders.

This backfit analysis differs from most NRC's backfit analyses in that the NRC is not imposing or proposing to impose any requirements on its licensees. Instead, the NRC is assessing the safety benefits and costs of hypothetical requirements that, if implemented, would result in the use of low-density spent fuel pool storage and a corresponding increase in onsite dry cask storage at U.S. spent fuel pools. An NRC rulemaking to impose requirements like the ones analyzed in this document would need to include a backfit analysis. This section provides a discussion of some of the elements that would be analyzed as part of a generic backfit of these requirements. Before imposing these requirements through a rulemaking the NRC would, at the very least, publish a regulatory bases for public comment. If it is determined that rulemaking is required, the NRC would then issue a proposed rule for public comment.

Low-density Spent Fuel Pool Storage Alternative Provisions that Constitutes a Backfit

- All spent fuel assemblies that have cooled for at least 5 years (older spent fuel assemblies) after discharge from the reactor core are expeditiously moved from spent fuel pool storage from spent fuel pool storage to dry cask storage.

- The completion of the initial movement of older spent fuel assemblies to dry cask storage is achieved within 5 years of the effective date of the requirement.

- Following each refueling outage, the older spent fuel assemblies stored in the pool shall be moved to dry cask storage in a timely manner.

In performing this analysis, the NRC considered the nine factors in 10 CFR 50.109, “Backfitting,” (Ref. 35), as described in the following subsections.

5.2.1 General Description of the Activity Required to Complete the Backfit

The alternative would require that each licensee incur upfront costs, including engineering, design, and licensing costs; equipment costs; construction costs; and start up and testing costs, as necessary for their independent spent fuel storage installation to accept the dry storage cask systems. The licensee would also need to purchase and load dry storage casks on a periodic basis in compliance with the regulatory requirement.

5.2.2 Potential Change in the Risk to the Public from the Accidental Offsite Release of Radioactive Material within 50-miles

Table 68 Public Health (Accident) Person-rem Averted

SFP Group	Dose (averted person-rem)			Benefits (2012 million dollars)								
				2% Discount			3% Discount			7% Discount		
	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.
1	30.7	1739.3	22,785	$0.05	$2.72	$35.59	$0.04	$2.42	$31.74	$0.03	$1.62	$21.24
2	39.2	1,625	31,899	$0.06	$2.45	$38.74	$0.05	$2.15	$34.03	$0.03	$1.38	$21.77
3	62.3	3,016	62,541	$0.06	$3.14	$31.91	$0.05	$2.37	$24.14	$0.02	$0.99	$10.07
4	36.9	1,695	33,689	$0.06	$2.62	$52.14	$0.05	$2.33	$46.33	$0.03	$1.54	$30.65

If the NRC were to generically implement the low-density storage alternative, the storage of spent fuel in dry storage casks would decrease the accidental offsite release of radioactive material from a postulated spent fuel pool accident. As Table 68 shows, dry cask storage would decrease the radiation exposure to the public by between 30.7 and 62,500 person-rem. The dose to the public mostly comes from the reoccupation of land after decontamination and the exposure to the workers who are decontaminating the public land. This analysis also assumes that 0.5 percent of the public will not evacuate during the accident. This resultant radiation dose is included within the public health exposure. The base case averted dose ranges between 1,630 and 3,020 person-rem, which corresponds to a monetized benefit between $1 million and $1.62 million (7 percent net present value).

5.2.3 Potential Impact on Radiological Exposure of Facility Employees

Table 69 Facility Employee Exposure

SFP Group	Parameter	Dose (averted person-rem)			Benefits (2012 million dollars)								
					2% Discount			3% Discount			7% Discount		
		Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.
1	accident short- & long-term	0.6	5.5	67.3	$0.001	$0.009	$0.105	$0.001	$0.008	$0.094	$0.001	$0.005	$0.063
	routine	-6.8	-6.8	-6.8	-$0.025	-$0.025	-$0.025	-$0.028	-$0.028	-$0.028	-$0.028	-$0.028	-$0.028
	Total	-6.2	-1.3	60.4	-$0.02	-$0.02	$0.08	-$0.03	-$0.02	$0.07	-$0.03	-$0.02	$0.03
2	accident short- & long-term	0.3	4.4	90.1	$0.001	$0.007	$0.109	$0.000	$0.006	$0.096	$0.000	$0.004	$0.062
	routine	-8.6	-8.6	-8.6	-$0.027	-$0.027	-$0.027	-$0.029	-$0.029	-$0.029	-$0.029	-$0.029	-$0.029
	Total	-8.2	-4.2	81.6	-$0.03	-$0.02	$0.08	-$0.03	-$0.02	$0.07	-$0.03	-$0.03	$0.03
3	accident short- & long-term	0.7	9.2	189.5	$0.001	$0.010	$0.097	$0.001	$0.007	$0.073	$0.000	$0.003	$0.031
	routine	5.7	5.7	5.7	-$0.015	-$0.015	-$0.015	-$0.013	-$0.013	-$0.013	-$0.006	-$0.006	-$0.006
	Total	6.4	14.9	195.2	-$0.01	-$0.01	$0.08	-$0.01	-$0.01	$0.06	-$0.01	$0.00	$0.02
4	accident short- & long-term	0.3	3.9	80.8	$0.001	$0.006	$0.125	$0.000	$0.005	$0.111	$0.000	$0.004	$0.074
	routine	6.3	6.3	6.3	-$0.023	-$0.023	-$0.023	-$0.025	-$0.025	-$0.025	-$0.025	-$0.025	-$0.025
	Total	6.6	10.2	87.1	-$0.02	-$0.02	$0.10	-$0.02	-$0.02	$0.09	-$0.02	-$0.02	$0.05

If imposed on licensees, these requirements would provide added assurance that nuclear industry workers are not subjected to unnecessary radiological or hazardous chemical exposures as the result of mitigative and clean-up activities associated with a spent fuel pool accident that results in a radioactive release. Storage of spent fuel in dry storage casks would decrease the post-accidental offsite radiation exposure to facility employees from a postulated spent fuel pool accident. The exposure of facility employees comes from a short-term dose, based on the exposure during the accident, and a long-term dose, based on the exposure from the onsite cleanup costs. Facility employees, however, receive additional radiation exposure during DSC loading and handling activities, ISFSI operations, and maintenance and surveillance activities, resulting in a net increase in radiation exposure as shown in Table 69 for the low estimate and base case. A more in-depth discussion of the person-rem exposure to facility employees can be found in Sections 4.3.2.8, 4.3.3.1, 4.5.2, and 4.5.3.

5.2.4 Installation and Continuing Costs Associated with the Backfit, including the Cost of Facility Downtime or the Cost of Construction Delay

Table 70 Installation and Continuing Costs Associated with the Backfit

SFP Group	Cost Parameter	Costs (2012 million dollars) 2% Discount	3% Discount	7% Discount
1	Implementation costs	$52.61	$55.17	$52.28
	Operation costs	nc	nc	nc
	Total	$52.61	$55.17	$52.28
2	Implementation costs	$51.37	$53.80	$51.33
	Operation costs	nc	nc	nc
	Total	$51.37	$53.80	$51.33
3	Implementation costs	$42.41	$35.75	$16.74
	Operation costs	nc	nc	nc
	Total	$42.41	$35.75	$16.74
4	Implementation costs	$48.78	$50.41	$46.39
	Operation costs	nc	nc	nc
	Total	$48.78	$50.41	$46.39

1. nc = not calculated

Implementation and continuing costs include the upfront costs, which include engineering, design, and licensing costs; equipment costs; construction costs; and startup and testing costs, as necessary, for each site's independent spent fuel storage installation to accept the dry storage cask systems. In addition, the licensee would need to purchase and load dry storage casks on a periodic basis in compliance with regulatory requirements. As these actions are assumed not to affect normal power operations, there are no assumed replacement energy costs or construction delays. A more detailed analysis of the industry implementation and operation costs is provided in Section 4.3.3.

5.2.5 Potential Safety Impact of Changes in Plant or Operational Complexity, including the Relationship to Proposed and Existing Regulatory Requirements

If imposed on licensees, these requirements are not expected to have a significant effect on facility complexity. The scheduling and performance of loading spent fuel assemblies from the spent fuel pool into casks and transporting them to the ISFSI would add additional complexity to plant operations, especially during the initial 5-year loading phase. The added plant operations complexity is not significant and will not substantially affect the reference plant operational practices or result in substantial indirect costs. However, should a cask drop accident occur during plant operation, even though its likelihood is remote, the event could challenge plant safety systems in mitigating the consequences.

5.2.6 Estimated Resource Burden on the NRC Associated with the Proposed Backfit and the Availability of Such Resources.

The establishment of the requirements needed to require operators of United States spent fuel pools to move expeditiously all spent fuel assemblies that have cooled for at least 5 years (older spent fuel assemblies) after discharge from the reactor core from spent fuel pool storage to dry cask storage would require rulemaking. The rulemaking would not result in a substantial increase in annual expenditures of agency resources.

5.2.7 Potential Impact of Differences in Facility Type, Design, or Age on the Relevancy and Practicality of the Proposed Action

There is no expected significant differentiation in how individual plants would implement the requirement to expeditiously move all spent fuel assemblies that have cooled for at least 5 years (older spent fuel assemblies) after discharge from the reactor core from spent fuel pool storage to dry cask storage. If imposed on licensees, these requirements do not directly relate to the facility type, design, or age.

5.2.8 Whether the Proposed Backfit is Interim or Final and, if Interim, the Justification for Imposing the Proposed Backfit on an Interim Basis

This consideration is not relevant to the analysis at this time because no requirements are being proposed.

5.2.9 Other Information Relevant and Material to the Proposed Backfit

Tables 71 through 74 summarize the described benefits and costs by spent fuel pool grouping if United States spent fuel pool operators were required to expeditiously move older spent fuel assemblies from spent fuel pool storage to dry cask storage.

Table 71 Summary of Backfitting Net Benefits for Low-density Spent Fuel Pool Storage within 50 miles—Group 1 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$48,000	$42,800	$28,600	$2,716,600	$2,422,900	$1,621,500	$35,588,000	$31,741,200	$21,242,500
Occupational Health (Accident)	$942	$840	$562	$8,579	$7,652	$5,121	$105,037	$93,684	$62,697
Occupational Health (Routine)	-$25,400	-$27,800	-$28,200	-$25,400	-$27,800	-$28,200	-$25,400	-$27,800	-$28,200
Total Benefits	***$23,500***	***$15,800***	***$1,000***	***$2,699,800***	***$2,402,800***	***$1,598,400***	***$35,667,600***	***$31,807,100***	***$21,277,000***
Industry Implementation	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000	-$52,610,000	-$55,170,000	-$52,280,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$52,610,000***	***-$55,170,000***	***-$52,280,000***	***-$52,610,000***	***-$55,170,000***	***-$52,280,000***	***-$52,610,000***	***-$55,170,000***	***-$52,280,000***
Net Benefit	**-$52,587,000**	**-$55,154,000**	**-$52,279,000**	**-$49,910,000**	**-$52,767,000**	**-$50,682,000**	**-$16,942,000**	**-$23,363,000**	**-$31,003,000**

Table 72 Summary of Backfitting Net Benefits for Low-density Spent Fuel Pool Storage within 50 miles—Group 2 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$59,000	$51,800	$33,200	$2,448,400	$2,150,700	$1,376,100	$38,741,300	$34,031,000	$21,774,600
Occupational Health (Accident)	$500	$400	$300	$6,600	$5,800	$3,700	$109,400	$96,100	$61,500
Occupational Health (Routine)	-$27,200	-$29,100	-$28,900	-$27,200	-$29,100	-$28,900	-$27,200	-$29,100	-$28,900
Total Benefits	***$32,300***	***$23,100***	***$4,600***	***$2,427,800***	***$2,127,400***	***$1,350,900***	***$38,823,500***	***$34,098,000***	***$21,807,200***
Industry Implementation	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000	-$51,370,000	-$53,800,000	-$51,330,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$51,370,000***	***-$53,800,000***	***-$51,330,000***	***-$51,370,000***	***-$53,800,000***	***-$51,330,000***	***-$51,370,000***	***-$53,800,000***	***-$51,330,000***
Net Benefit	**-$51,338,000**	**-$53,777,000**	**-$51,325,000**	**-$48,942,000**	**-$51,673,000**	**-$49,979,000**	**-$12,547,000**	**-$19,702,000**	**-$29,523,000**

Table 73 Summary of Backfitting Net Benefits for Low-density Spent Fuel Pool Storage within 50 miles—Group 3 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$64,800	$49,000	$20,500	$3,139,600	$2,374,400	$990,800	$31,913,800	$24,135,700	$10,071,500
Occupational Health (Accident)	$700	$600	$200	$9,500	$7,200	$3,000	$96,700	$73,100	$30,500
Occupational Health (Routine)	-$14,500	-$12,900	-$6,400	-$14,500	-$12,900	-$6,400	-$14,500	-$12,900	-$6,400
Total Benefits	***$51,000***	***$36,700***	***$14,300***	***$3,134,600***	***$2,368,700***	***$987,400***	***$31,996,000***	***$24,195,900***	***$10,095,600***
Industry Implementation	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000	-$42,410,000	-$35,750,000	-$16,740,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$42,410,000***	***-$35,750,000***	***-$16,740,000***	***-$42,410,000***	***-$35,750,000***	***-$16,740,000***	***-$42,410,000***	***-$35,750,000***	***-$16,740,000***
Net Benefit	**-$42,359,000**	**-$35,713,000**	**-$16,726,000**	**-$39,275,000**	**-$33,381,000**	**-$15,753,000**	**-$10,414,000**	**-$11,554,000**	**-$6,644,000**

Table 74 Summary of Backfitting Net Benefits for Low-density Spent Fuel Pool Storage within 50 miles—Group 4 Spent Fuel Pool

Attribute	Low Estimate (2012 dollars)			Base Case (2012 dollars)			High Estimate (2012 dollars)		
	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
Public Health (Accident)	$57,200	$50,800	$33,600	$2,623,200	$2,330,700	$1,541,800	$52,143,300	$46,327,500	$30,646,300
Occupational Health (Accident)	$500	$400	$300	$6,000	$5,400	$3,600	$125,000	$111,100	$73,500
Occupational Health (Routine)	-$22,700	-$24,700	-$24,800	-$22,700	-$24,700	-$24,800	-$22,700	-$24,700	-$24,800
Total Benefits	***$35,000***	***$26,500***	***$9,100***	***$2,606,500***	***$2,311,400***	***$1,520,600***	***$52,245,600***	***$46,413,900***	***$30,695,000***
Industry Implementation	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000	-$48,780,000	-$50,410,000	-$46,390,000
Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
Total Costs	***-$48,780,000***	***-$50,410,000***	***-$46,390,000***	***-$48,780,000***	***-$50,410,000***	***-$46,390,000***	***-$48,780,000***	***-$50,410,000***	***-$46,390,000***
Net Benefit	**-$48,745,000**	**-$50,383,500**	**-$46,380,900**	**-$46,173,500**	**-$48,098,600**	**-$44,869,400**	**$3,465,600**	**-$3,996,100**	**-$15,695,000**

The analyzed alternative would also incur onsite and offsite property cost offsets from an accident. These cost offsets are summarized in Table 75.

Table 75 Summary of Cost Offsets for Onsite and Offsite Property

SFP Group	Parameter	Total Cost Offsets (2012 million dollars)								
		2% Discount			3% Discount			7% Discount		
		Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.
1	Offsite Property	$0.17	$8.96	$85.67	$0.15	$7.99	$76.41	$0.10	$5.35	$51.14
	Onsite Property	$0.01	$0.07	$1.14	$0.01	$0.06	$0.99	$0.00	$0.04	$0.60
	Total	$0.17	$9.03	$86.81	$0.15	$8.05	$77.40	$0.10	$5.38	$51.74
2	Offsite Property	$0.27	$9.03	$97.46	$0.24	$7.93	$85.61	$0.15	$5.08	$54.78
	Onsite Property	$0.00	$0.05	$1.19	$0.00	$0.04	$1.02	$0.00	$0.03	$0.59
	Total	$0.28	$9.08	$98.65	$0.24	$7.98	$86.63	$0.15	$5.10	$55.37
3	Offsite Property	$0.26	$11.45	$74.51	$0.20	$8.66	$56.35	$0.08	$3.61	$23.51
	Onsite Property	$0.00	$0.08	$1.06	$0.00	$0.06	$0.78	$0.00	$0.02	$0.29
	Total	$0.27	$11.53	$75.57	$0.20	$8.72	$57.13	$0.08	$3.63	$23.81
4	Offsite Property	$0.27	$9.81	$151.19	$0.24	$8.71	$134.32	$0.16	$5.76	$88.86
	Onsite Property	$0.00	$0.05	$1.35	$0.00	$0.04	$1.17	$0.00	$0.02	$0.70
	Total	$0.27	$9.85	$152.53	$0.24	$8.75	$135.49	$0.16	$5.79	$89.56

Tables 76 through 79 summarize the results for each spent fuel pool grouping of the backfitting net benefit sensitivity analysis that extends analysis of consequences beyond 50 miles from the plant site and used a higher per person-rem conversion factor to monetize averted dose.

Table 76 Combined Sensitivity Analysis Considering the Consequences beyond 50 Miles and using a Revised Dollar per Person-Rem Conversion Factor on the Backfitting Net Benefits for Low-Density Spent Fuel Pool Storage—Group 1 Spent Fuel Pool

SFP Group	Attribute	Net Benefit (2012 million dollars)								
		Low Estimate			Base Case			High Estimate		
		2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
1	Public Health (Accident)	$1.01	$0.90	$0.60	$45.67	$40.73	$27.26	$610.86	$544.84	$364.63
	Occupational Health (Accident)	$0.00	$0.00	$0.00	$0.02	$0.02	$0.01	$0.21	$0.19	$0.13
	Occupational Health (Routine)	-$0.05	-$0.06	-$0.06	-$0.05	-$0.06	-$0.06	-$0.05	-$0.06	-$0.06
	Total Benefits	***$0.96***	***$0.84***	***$0.55***	***$45.64***	***$40.69***	***$27.22***	***$611.02***	***$544.97***	***$364.69***
	Industry Implementation	-$52.61	-$55.17	-$52.28	-$52.61	-$55.17	-$52.28	-$52.61	-$55.17	-$52.28
	Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	Total Costs	***-$52.61***	***-$55.17***	***-$52.28***	***-$52.61***	***-$55.17***	***-$52.28***	***-$52.61***	***-$55.17***	***-$52.28***
	Net Benefit	**-$51.65**	**-$54.33**	**-$51.73**	**-$6.97**	**-$14.48**	**-$25.06**	**$558.41**	**$489.80**	**$312.41**

1. nc = not calculated

Table 77 Combined Sensitivity Analysis Considering the Consequences beyond 50 Miles and using a Revised Dollar per Person-Rem Conversion Factor on the Backfitting Net Benefits for Low-Density Spent Fuel Pool Storage—Group 2 Spent Fuel Pool

SFP Group	Attribute	Net Benefit (2012 million dollars)								
		Low Estimate			Base Case			High Estimate		
		2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
2	Public Health (Accident)	$1.72	$1.51	$0.97	$41.22	$36.21	$23.17	$701.69	$616.37	$394.38
	Occupational Health (Accident)	$0.00	$0.00	$0.00	$0.01	$0.01	$0.01	$0.22	$0.19	$0.12
	Occupational Health (Routine)	-$0.05	-$0.06	-$0.06	-$0.05	-$0.06	-$0.06	-$0.05	-$0.06	-$0.06
	Total Benefits	***$1.67***	***$1.45***	***$0.91***	***$41.18***	***$36.16***	***$23.12***	***$701.85***	***$616.51***	***$394.45***
	Industry Implementation	-$51.37	-$53.80	-$51.33	-$51.37	-$53.80	-$51.33	-$51.37	-$53.80	-$51.33
	Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	Total Costs	***-$51.37***	***-$53.80***	***-$51.33***	***-$51.37***	***-$53.80***	***-$51.33***	***-$51.37***	***-$53.80***	***-$51.33***
	Net Benefit	**-$49.70**	**-$52.35**	**-$50.42**	**-$10.19**	**-$17.64**	**-$28.21**	**$650.48**	**$562.71**	**$343.12**

1. nc = not calculated

Table 78 Combined Sensitivity Analysis Considering the Consequences beyond 50 Miles and using a Revised Dollar per Person-Rem Conversion Factor on the Backfitting Net Benefits for Low-Density Spent Fuel Pool Storage—Group 3 Spent Fuel Pool

SFP Group	Attribute	Net Benefit (2012 million dollars)								
		Low Estimate			Base Case			High Estimate		
		2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
3	Public Health (Accident)	$1.69	$1.28	$0.53	$47.33	$35.80	$14.94	$527.14	$398.66	$166.36
	Occupational Health (Accident)	$0.00	$0.00	$0.00	$0.02	$0.01	$0.01	$0.19	$0.15	$0.06
	Occupational Health (Routine)	-$0.03	-$0.03	-$0.01	-$0.03	-$0.03	-$0.01	-$0.03	-$0.03	-$0.01
	Total Benefits	***$1.66***	***$1.25***	***$0.52***	***$47.32***	***$35.79***	***$14.93***	***$527.30***	***$398.78***	***$166.40***
	Industry Implementation	-$42.41	-$35.75	-$16.74	-$42.41	-$35.75	-$16.74	-$42.41	-$35.75	-$16.74
	Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	Total Costs	***-$42.41***	***-$35.75***	***-$16.74***	***-$42.41***	***-$35.75***	***-$16.74***	***-$42.41***	***-$35.75***	***-$16.74***
	Net Benefit	**-$40.75**	**-$34.50**	**-$16.22**	**$4.91**	**$0.04**	**-$1.81**	**$484.89**	**$363.03**	**$149.66**

Table 79 Combined Sensitivity Analysis Considering the Consequences beyond 50 Miles and using a Revised Dollar per Person-Rem Conversion Factor on the Backfitting Net Benefits for Low-Density Spent Fuel Pool Storage—Group 4 Spent Fuel Pool

SFP Group	Attribute	Net Benefit (2012 million dollars)								
		Low Estimate			Base Case			High Estimate		
		2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV	2% NPV	3% NPV	7% NPV
4	Public Health (Accident)	$1.71	$1.52	$1.00	$49.14	$43.66	$28.88	$1,121.81	$996.69	$659.32
	Occupational Health (Accident)	$0.00	$0.00	$0.00	$0.01	$0.01	$0.01	$0.25	$0.22	$0.15
	Occupational Health (Routine)	-$0.05	-$0.05	-$0.05	-$0.05	-$0.05	-$0.05	-$0.05	-$0.05	-$0.05
	Total Benefits	***$1.66***	***$1.47***	***$0.95***	***$49.11***	***$43.62***	***$28.84***	***$1,122***	***$996.86***	***$659.42***
	Industry Implementation	-$48.78	-$50.41	-$46.39	-$48.78	-$50.41	-$46.39	-$48.78	-$50.41	-$46.39
	Industry Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Implementation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	NRC Operation	nc	nc	nc	nc	nc	nc	nc	nc	nc
	Total Costs	***-$48.78***	***-$50.41***	***-$46.39***	***-$48.78***	***-$50.41***	***-$46.39***	***-$48.78***	***-$50.41***	***-$46.39***
	Net Benefit	**-$47.12**	**-$48.94**	**-$45.44**	**$0.33**	**-$6.79**	**-$17.55**	**$1,073**	**$946.45**	**$613.03**

As shown in Tables 76 through 79, including the sensitivity analysis that includes consequences beyond 50-miles and using the $4,000 per person-rem conversion to monetize averted dose result in the high estimate cases to be cost-beneficial and some of the base cases to be inconclusive as the net benefit value calculated is within plus or minus $5 million.

This combined sensitivity case would also incur onsite and offsite property cost offsets from a spent fuel pool accident. These cost offsets are summarized in Table 80.

Table 80 Summary of Combined Sensitivity Analysis Cost Offsets for Onsite and Offsite Property

SFP Group	Parameter	Total Cost Offsets (2012 million dollars)								
		2% Discount			3% Discount			7% Discount		
		Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.
1	Offsite Property	$0.57	$16.36	$323.69	$0.51	$14.59	$288.70	$0.34	$9.76	$193.21
	Onsite Property	$0.01	$0.07	$1.14	$0.01	$0.06	$0.99	$0.00	$0.04	$0.60
	Total	$0.58	$16.43	$324.83	$0.52	$14.65	$289.69	$0.35	$9.80	$193.81
2	Offsite Property	$1.86	$28.79	$402.56	$1.63	$25.29	$353.61	$402.56	$353.61	$226.26
	Onsite Property	$0.00	$0.05	$0.20	$0.00	$0.04	$0.17	$0.20	$0.17	$0.10
	Total	$1.86	$28.84	$402.76	$1.64	$25.33	$353.79	$402.76	$353.79	$226.36
3	Offsite Property	$1.55	$27.17	$262.78	$1.17	$20.55	$198.73	$0.49	$8.57	$82.93
	Onsite Property	$0.00	$0.08	$1.06	$0.00	$0.06	$0.78	$0.00	$0.02	$0.29
	Total	$1.55	$27.24	$263.84	$1.17	$20.60	$199.51	$0.49	$8.59	$83.22
4	Offsite Property	$1.90	$39.62	$779.80	$1.69	$35.20	$692.82	$1.12	$23.29	$458.31
	Onsite Property	$0.00	$0.05	$1.35	$0.00	$0.04	$1.17	$0.00	$0.02	$0.70
	Total	$1.90	$39.67	$781.15	$1.69	$35.24	$693.99	$1.12	$23.31	$459.01

5.3 Disaggregation

In order to comply with the guidance provided in Section 4.3.2, "Criteria for the Treatment of Individual Requirements" of the Regulatory Analysis Guidelines (Ref. 57), the NRC conducted a screening review to ensure that the aggregate analysis does not mask the inclusion of individual requirements that are not cost-beneficial when considered individually and not necessary to meet the stated objectives. Consistent with the Regulatory Guidelines, the NRC evaluated, on a disaggregated basis, each new regulatory provision expected to result in incremental costs. Based on this screening review, the NRC did not identify any requirements needing further consideration. The NRC believes that each of these provisions described in Section 5.2 is necessary in the aggregate for the expedited transfer of spent fuel to DSCs. However, the Commission has not found that accelerated transfer to DSCs to provide a substantial safety benefit, nor to be cost justified.

5.4 Safety Goal Evaluation

Safety goal evaluations are applicable only to regulatory initiatives considered to be generic safety enhancement backfits subject to the substantial additional protection standard in 10 CFR 50.109(a)(3).

Societal risk is based on the statistically expected number of early and latent cancer fatalities. The Safety Goals for the Operation of Nuclear Power Plants: Policy Statement (Ref. 45) defines the early fatality area calculation as that within 1.6 kilometers (1 mile) from the site boundary. As discussed above, the resultant release is not expected to result in any offsite early fatalities. A 16-kilometer (10-mile) radius is defined for calculating latent cancer fatalities. The second quantitative objective of the policy statement is for the risk to the population in the vicinity of a nuclear power plant from an accident at a nuclear power plant should not exceed 0.1 percent of the sum of cancer fatality risks resulting from all other causes. Based on recent data (http://www.cancer.org/research/cancerfactsfigures/index) the total fatality rate from cancer in the U.S. is 580,350 per 315,747,500 persons (http://www.census.gov/popclock/) or a risk of 1.84×10^{-3} per year, which results in a safety goal of 1.84×10^{-6} per year. Using the bounding frequency of damage to the spent fuel of 7.68×10^{-5} per year, which considers all initiators that could challenge spent fuel pool cooling or integrity, and the conditional individual latent cancer fatality risk within a ten-mile radius of 4.4×10^{-4} yields a bounding latent cancer fatality risk of 2.37×10^{-9} cancer fatalities per year. This calculated value of 2.37×10^{-9} latent cancer fatality risk per reactor-year associated with a spent fuel pool accident is less than represents a 1.9 percent fraction of the 1.84×10^{-6} per year societal risk goal value based on the calculation area specified in the Safety Goal Policy Statement.

The safety goal policy statement specified two qualitative safety goals and two quantitative health objectives (QHOs), which established expectations related to the frequency of severe accidents associated with nuclear reactors and the potential for release of radioactive materials from an operating reactor core. Previous NRC evaluations of SFPs, including NUREG-1353 and NUREG-1738, compared the estimated risks from SFP accidents to the QHOs as part of the rationale for determining appropriate regulatory actions. Some considerations in comparing SFP risks to the QHOs are that the potential consequences of a SFP accident can exceed those of reactor accidents in terms of the amount of long-lived radioactive material released, the land area affected, and the economic consequences. The safety goal relates to the risks to an individual from nuclear power in comparison to other risks that an individual faces. The staff uses the safety goal in regulatory decisionmaking processes as a measure of health consequences to determine if a potential action provides a substantial safety improvement. Although a SFP fire might affect larger areas and more people than a reactor accident, the risks to individuals remains bounded by the assessment of the population close to the facility. For this reason the use of the existing QHOs is appropriate for determining whether the substantial safety enhancement threshold is met.

The significant difference between the calculated consequences of a SFP fire and a reactor accident has led some stakeholders to propose alternate performance measures to help in the decision-making process. Such measures could include a revised consideration of economic consequences, collective dose to populations, or other estimates that reflect the large consequences and reduce the influence of the low event frequencies and implementation of protective actions in assessing the overall societal risks associated with SFP accidents. However, the Commission has previously directed that these performance measures should be consistent with the overall safety goals the Commission policy established and should not be so conservative that it creates a de facto new policy.[22]

The development of surrogate measures for SFPs could be useful if the conditional probability of a significant SFP fire is very high for particular event scenarios (a so-called cliff-edge effect). Although the staff has used various conservative assumptions in this assessment in order to estimate the potential benefits of reducing the density of spent fuel stored in pools, the expected ability of pools to retain their integrity and the availability of mitigation capabilities leads the staff to conclude that exceeding design basis values associated with spent fuel pools are unlikely to result in such a cliff-edge effect and that the frequency of damage to stored fuel is appropriately low to satisfy overall societal risk goals. Therefore, the staff has not identified this as an area for which it needs to develop new methodologies, guidance or criteria. In the Staff Requirements Memorandum (SRM) for SECY-12-0110, "Consideration of Economic Consequences Within the U.S. Nuclear Regulatory Commission's Regulatory Framework," the Commission directed the staff to proceed with improvements to the guidance for estimating offsite economic costs. The staff is continuing its efforts and planning related to the SRM and is scheduled to provide the Commission with a paper in December 2013. Factors considered likely to change as a result of the staff's activities (e.g., dollars per person-rem conversion factor) have been addressed in this evaluation through the presentation of additional cases and sensitivity studies.

From the staff's evaluation, the risk of a spent fuel pool accident appears to meet the Safety Goal Policy Statement public health objectives. Therefore, the Regulatory Baseline is justified for the alternative described in Section 2.2 as evaluated.

5.5 CRGR Results

This section addresses regulatory analysis information requirements for rulemaking actions or staff positions subject to review by the Committee to Review Generic Requirements (CRGR). All information called for by the CRGR is presented in this regulatory analysis.

6. DECISION RATIONALE

This section presents the decision rationale, including the basis for selection, any decision criteria used, the regulatory instrument to be used (if applicable), and the statutory basis for the selected regulatory action. The decision rationale is presented in two different ways to address the differing decision criteria between regulatory analyses and backfit analyses (10 CFR 50.109).

6.1 Regulatory Analysis

Table 47 shows that a requirement for low-density spent fuel storage alternative does not achieve a cost-beneficial increase in public health and safety for any of the spent fuel pool

[22] "Commission Guidance on Implementation of the NRC's Safety Goal Policy," memorandum from the Secretary of the Commission to the EDO, dated November 6, 1987.

groupings using the current regulatory framework when all event initiators, which may challenge spent fuel cooling or pool integrity, are considered.

Sensitivity studies provided in Section 5.1.4 show that there are cases using conservative assumptions in each sensitivity study in which the low-density spent fuel storage alternative was cost-justified.

The NRC staff identified other considerations discussed in Section 4.5.10 that would further reduce the quantified benefits and make the proposed alternative less justifiable.

The outcome of this regulatory analysis indicates that undertaking additional study of the low-density SFP storage alternative is not justified. Except in those cases where action is needed to ensure adequate protection of public health and safety, the process used by the NRC is to consider additional regulatory requirements is to assess the potential benefits from such regulations against the costs of implementing new requirements. The potential benefits of a requirement to expedite the removal of spent fuel from storage pools could be to reduce the risk to the public from possible accidents involving spent fuel pools. Assessments of risk and changes in risk from possible actions involve identifying what can go wrong, what are the consequences, and how likely is it to occur. In the case of hypothetical accidents involving spent fuel pools, the assessments have shown that impacts on public health and safety can be avoided but that the potential economic consequences can be very large. However, the assessments also show that the design and construction of spent fuel pools, the characteristics of the spent fuel assemblies, and the availability of mitigating systems result in the likelihood of a release of radioactive materials because of an accident affecting a spent fuel pool is very low. This evaluation of a low probability, high consequence event is similar to previous NRC risk assessments and related regulatory analyses for potential issues related to nuclear reactor and spent fuel pools.

Based on the NRC's assessment of the costs and benefits, the agency has concluded that the risk because of beyond-design-basis accidents in spent fuel pools, while not negligible, is sufficiently low that the added costs involved with expediting the movement of spent fuel from the pool to achieve the low-density fuel pool storage alternative evaluated for the reference plant is not warranted.

6.2 Backfit Analysis

The NRC conducted a backfit analysis relative to the backfit requirements in 10 CFR 50.109. The NRC determined that the low-density storage alternative does not meet the safety goal screening criteria when comparing the risk of a spent fuel pool accident with the Safety Goal Policy Statement quantitative health objectives. Therefore, the staff concluded that the low-density storage alternative does not result in a substantial safety enhancement.[23]

Although, the analysis could have stopped with this finding, the staff used insights from the Spent Fuel Pool Study to perform a regulatory analysis that estimates the risk reduction and quantifies the benefits and costs associated with expediting the removal of fuel from spent fuel pools. The analysis determined that the cost-justified criteria are not met when evaluating the averted accident consequences within 50-miles of the site consistent with the regulatory framework. Sensitivity studies that extend the analyses to consider even stronger earthquakes, higher likelihood of failures, consideration of accident consequences beyond 50-miles of the site on more populous region, among others did identify cases where the benefits outweighed the costs and the net benefit was positive. However, even for these high estimate cases a cost-beneficial conclusion, although necessary, is not sufficient to justify a backfit.

In light of the findings above, the NRC concludes that the expedited transfer of spent fuel to dry cask storage would neither provide a substantial increase in the overall protection of public health and safety nor sufficient safety benefit to warrant the expected implementation costs.

6.3 Conclusion

The regulatory screening analysis and the backfitting discussion indicate that a requirement for low-density spent fuel pool storage with an associated requirement for expedited transfer of spent fuel from the spent fuel pool to dry storage to meet the low-density spent fuel pool storage requirement, are not justified.

The risk because of beyond-design-basis accidents in the spent fuel pool evaluated in this analysis is sufficiently low that the added costs involved with expediting the movement of spent fuel from the pool to achieve the low-density fuel pool storage alternative are not warranted.

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[23] In addition to the primary question of whether or not to perform further assessments of expediting the transfer of spent fuel from storage pools to dry cask storage, the SFPS and staff's interactions with stakeholders identified other possible improvements to the storage of spent fuel. Examples include the possible investigation of alternate loading patterns (e.g., the 1x8 high-density loading pattern assessed in the SFPS, in addition to the standard 1x4 high-density loading pattern), capability of licensees to directly offload fuel into more coolable patterns, and the possible enhancement of mitigation strategies during identified periods when the heat load from recently discharged fuel assemblies is especially high. The staff has taken note of these possible improvements but determined that they do not provide a substantial safety enhancement such that generic regulatory action could be pursued. This finding reflects the low probability of the initiating events that would challenge the integrity of the spent fuel pools (same as event frequencies used to assess revisions to spent fuel pool loading densities) and the fact that these alternative actions would have similar or lesser safety benefit. So even though these alternatives would likely involve lower costs than the expedited transfer of spent fuel to dry cask storage, the staff finds that they do not satisfy the first criterion of 10 CFR 50.109 to provide a substantial safety enhancement.

6.4 Implementation

No further regulatory action is recommended for the resolution of this issue. The outcome of this regulatory analysis indicates that undertaking additional study of the low-density spent fuel pool storage alternative is not justified.

7. REFERENCES

1. GE Nuclear Energy, "BWR/6 General Description of a Boiling Water Reactor," [print graphic]. Retrieved from www4.ncsu.edu/~doster/NE405/Manuals/BWR6GeneralDescription.pdf, accessed July 15, 2013.

2. Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool at a Selected US Mark I Boiling Water Reactor (Spent Fuel Pool Study), Interim Report (Draft), dated June 2013 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12159A180).

3. Consolidated Edison Company of New York, Inc., "Preliminary Design Report for Reracking the Indian Point Unit No. 2 Spent Fuel Pool," Docket No. 50-249, dated September 1979 (ADAMS Accession No. ML100320085).

4. Devcan Version 6.6.1, National Cancer Institute. Retrieved from http://surveillance.cancer.gov/devcan/. Source: NCHS public use data file for the total U.S., April 2012.

5. Duderstadt, J.J., and L.J. Hamilton, "Nuclear Reactor Analysis," John Wiley & Sons, New York, 1976.

6. EPRI TR-1018058, "Occupational Risk Consequences of the Department of Energy's Approach to Repository Design, Performance Assessment, and Operation in the Yucca Mountain License Application," dated August 2008.

7. EPRI TR-1018722, "Cost Estimate for an Away-From-Reactor Generic Interim Storage Facility (GISF) for Spent Nuclear Fuel," dated May 2009.

8. EPRI TR-1021048, "Industry Spent Fuel Storage Handbook," dated July 2010.

9. EPRI TR-1021049, "Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage after Five Years of Cooling," dated 2010.

10. EPRI TR-1025206, "Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage after Five Years of Cooling, Revision 1, dated August 2012.

11. Gauld, I.C., et al., "Isotopic Depletion and Decay Methods and Analysis Capabilities in SCALE," *Nuclear Technology* **174**, 2, 169, 2011.

12. INPO 11-005, "Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station, Rev. 0, November 2011.

13. INPO 11-005 Addendum, "Lessons Learned from the Nuclear Accident at Fukushima Daiichi Nuclear Power Station, August 2012.

14. International Commission on Radiological Protection (ICRP), "1990 Recommendations of the International Commission on Radiological Protection," Publication 60, *Ann. ICRP* 21 (1-3), 1991.

15. _____. 2008. "The 2007 Recommendations of the International Commission on Radiological Protection," Publication 103. *Ann*. ICRP 37 (2-4), 2008.

16. Jones-Lee, M.W., "Valuing International Safety Externalities: Does the 'Golden Rule' Apply?" Journal of Risk and Uncertainty, 29.3:277-287, 2004.

17. Kiyoshi, Kurokawa, et al. Japan. The National Diet of Japan. "Fukushima Nuclear Accident Independent Investigation Commission," The National Diet of Japan, 2012.

18. Lamarsh, J.R. "Introduction to Nuclear Engineering," Addison-Wesley Publishing Company, Reading, MA, 1975.

19. Newell, R., and W. Pizer. "Discounting the distant future: how much do uncertain rates increase valuations?" Discussion Paper 00-45, May 14, 2001, Resources for the Future. Retrieved from http://weber.ucsd.edu/~carsonvs/papers/824.pdf, accessed 7/31/2013.

20. Nuclear Energy Institute, "B.5.b Phase 2 & 3 Submittal Guideline," NEI-06-12, Revision 2, December 2006 (ADAMS Accession No. ML070090060).

21. Nuclear Energy Institute, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," NEI Report NEI 12-06, Revision 0, dated August 21, 2012 (ADAMS Accession No. ML12242A378).

22. Nuclear Energy Institute, 2013. "Nuclear Waste Disposal," Retrieved from http://www.nei.org/resourcesandstats/documentlibrary/nuclearwastedisposal/factsheet/safelymanagingusednuclearfuel/, accessed 7/10/2013.

23. Nuclear Street: Nuclear Powered Portal, "AP1000.jpg," [print graphic]. Retrieved from http://nuclearstreet.com/images/img/ap1000.jpg, accessed 7/31/2013.

24. Office of Management of the Budget Circular A-4, "Regulatory Analysis," issued September 2003.

25. PRM-50-100, "Require Licensees to Improve Spent Nuclear Fuel Pool Safety," dated July 26, 2011.

26. PRM-51-10, "Proposed Amendment to 10 CFR Part 51," dated August 25, 2006.

27. PRM-51-12, "Proposed Amendment to 10 CFR Part 51 (Rescinding finding that environmental impacts of pool storage of spent nuclear fuel are insignificant), dated March 16, 2007.

28. Rearden, B. T., et al. , "Enhancements in SCALE 6.1," PHYSOR 2012 – Advances in Reactor Physics – Linking Research, Industry, and Education, Knoxville, Tennessee, USA, April 15-20, 2012, on CD-ROM, American Nuclear Society, LaGrange Park, IL, 2012.

29. SECY-11-0032, "Consideration of the Cumulative Effects of Regulation in the Rulemaking Process," dated March 2, 2011 (ADAMS Accession No. ML110190027).

30. SECY-12-0095, "Tier 3 Program Plans and 6-Month Status Update in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Subsequent Tsunami," dated July 13, 2012 (ADAMS Accession No. ML12165A089).

31. SRM-SECY-93-086, "Backfit Considerations," dated June 30, 1993 (ADAMS Accession No. ML003760758).

32. SRM-SECY-12-0025, "Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami," dated March 9, 2012 (ADAMS Accession No. ML120690347).

33. Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities," Section 50.54, "Conditions of licenses."

34. Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities," Section 50.82, "Termination of License."

35. Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities," Section 50.109, "Backfitting."

36. Title 10 of the *Code of Federal Regulations* (10 CFR), Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

37. Title 25 of the *Pennsylvania Code*, Part 219, "Standards for Protection against Radiation, Subchapter D, "Radiation Dose Limits for Individual Members of the Public," Retrieved from http://www.pacode.com/secure/data/025/025toc.html, accessed July 19, 2013.

38. U.S. Department of Labor, Bureau of Labor Statistics, "Databases, Tables & Calculators by Subject: CPI Inflation Calculator," Retrieved from http://www.bls.gov/data/inflation_calculator.htm, accessed on 7/19/2013.

39. U.S. Environmental Protection Agency, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA-400-R-92-001, Washington D.C., May 1992, Retrieved from http://www.epa.gov/radiation/docs/er/400-r-92-001.pdf, accessed July 19, 2013.

40. U.S. Environmental Protection Agency, National Center for Environmental Economics, "Valuing Mortality Risk Reductions for Environmental Policy: A White Paper", dated December 2010, Retrieved from http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0563-1.pdf/$file/EE-0563-1.pdf, accessed July 26, 2013.

41. U.S. Nuclear Regulatory Commission (NRC). "General Electric Company Notice of Issuance of an Environmental Assessment and Finding of No Significant Impact for License Renewal of the Morris Operation Independent Spent Fuel Storage Installation," 69 FR 71082, December 8, 2004.

42. General Electric Hitachi-NRC Temporary Instruction 2515/183. “NRC Inspection Report No. 072-000001/11-01 (DNMS),” dated May 13, 2011 (ADAMS Accession No. ML111330253).

43. _____. “Recommendations for Enhancing Reactor Safety in the 21st Century,” 2001.

44. _____. “Risk Assessment of Operational Events Handbook (RASP),” Volume 2, External Events Revision 1.01, dated January 31, 2008 (ADAMS Accession No. ML080300179).

45. _____. “Safety Goals for the Operation of Nuclear Power Plants,” 51 FR 28044, August 4, 1986 as corrected and republished at 51 FR 30028, August 21, 1986.

46. _____. NUREG-0800, “Standard Review Plan,” Section 9.1.2, Revision 4, “New and Spent Fuel Storage,” March 2007.

47. _____. NUREG-1150, “Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants,” 1990 (ADAMS Accession No. ML040140729).

48. _____. NUREG-1353, “Regulatory Analysis for the Resolution of Generic Issue 82, Beyond-Design-Basis Accidents in Spent Fuel Pools,” 1989.

49. _____. NUREG-1409, “Backfitting Guidelines,” 1990.

50. _____. NUREG-1437, “Generic Environmental Impact Statement for License Renewal of Nuclear Plants,” Draft Report for Comment.

51. _____. NUREG-1488, “Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains,” April 1994.

52. _____. NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants," February 1995.

53. _____. NUREG-1530, “Reassessment of NRC’s Dollar per Person-Rem Conversion Factor Policy,” 1995.

54. _____. NUREG-1738, “Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants,” 2001.

55. _____. NUREG-1935, "State-of-the-Art Reactor Consequence Analyses (SOARCA) Report," November 2012.

56. _____. NUREG-2115, “Central and Eastern United States Seismic Source Characterization for Nuclear Facilities,” U.S. Department of Energy (DOE) Report, DOE/NE-0140; Electric Power Research Institute Report, EPRI 1021097, 2012. Retrieved from http://www.ceus-ssc.com.

57. _____. NUREG/BR-0058, Revision 4, “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” 2004.

58. _____. NUREG/BR-0184, “Regulatory Analysis Technical Evaluation Handbook,” 1997.

59. _____. NUREG/CR–0649, "Spent Fuel Heat up Following Loss of Water during Storage," 1979.

60. _____. NUREG/CR-3568, "A Handbook .for Value-Impact Assessment," December 1983.

61. _____. NUREG/CR-4627, Rev. 2, "NRC Labor Rates in the Generic Cost Catalog," 1992.

62. _____. NUREG/CR-4982, "Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82," July 1987.

63. _____. NUREG/CR-5176, "Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants," January 1989.

64. _____. NUREG/CR-5281, "Value/Impact Analyses of Accident Preventive and Mitigative Options for Spent Fuel Pools," dated March 31,1989 (ADAMS Accession No. ML071690022)

65. _____. NUREG/CR-6349, "Cost-Benefit Considerations in Regulatory Analysis," Brookhaven National Laboratory, Upton, New York, 1995.

66. _____. NUREG/CR-6441, "Analysis of Spent Fuel Heatup following Loss of Water in a Spent Fuel Pool: A User's Manual for the Computer Code SHARP," March 2002 (ADAMS Accession No. ML021050336).

67. _____. NUREG/CR-6525, Rev. 1, "SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program," Sandia National Laboratories: Albuquerque, NM, 2003.

68. _____. NUREG/CR-6613, SAND97-0594: "Code Manual for MACCS2 User's Guide," Sandia National Laboratories: Albuquerque, NM, 1997.

69. _____. NUREG/CR-6864, "Identification and Analysis of Factors Affecting Emergency Evacuations," 2005.

70. _____. NUREG/CR-7009, "MACCS2 - Calculated Environmental Impact of Reactor Core Melt Accidents - Best Practices from State-of-the-Art Reactor Consequence Analyses Study," expected to be published in 2013.

71. _____. Regulatory Guide 3.54, Rev. 1, "Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation," 1999.

72. _____. 2013. "U.S. Independent Spent Fuel Storage Installations," Retrieved from http://www.nrc.gov/waste/spent-fuel-storage/locations.pdf, accessed July 5, 2013.

73. _____. "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," Order EA-12-049, March 12, 2012, (ADAMS Package Accession No. ML12054A736).

74. _____. “Order Modifying Licenses With Regard to Reliable Spent Fuel Pool Instrumentation,” Order EA-12-051, March 12, 2012, (ADAMS Accession No. ML12056A044).

75. _____. *Prioritization of Recommended Actions to be taken in Response to Fukushima Lessons Learned*, Commission Paper SECY-11-0137, October 3, 2011, (ADAMS Package Accession No. ML11272A111).

76. _____. Safety/Risk Assessment Results for Generic Issue [GI] 199. Implications of Updated Probabilistic Seismic hazard Estimates in Central and Eastern United States on Existing Plants,” (ADAMS Package Accession No. ML100270582).

77. _____. Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel,” dated May 7, 2013, (ADAMS Accession No. ML13105A122).

78. Wada, Koji, Toru Yoshikawa, Takeshi Hayashi, and Yoshiharu Aizawa, “Emergency Response Technical Work at Fukushima Dai-ichi Nuclear Power Plant: Occupational Health Challenges Posed by the Nuclear Disaster,” Occupational and Environmental Medicine 2012; 69:599-602, April 12, 2012.

79. Westinghouse Electric Company AP1000 Design Control Document, “Tier 2 Chapter 9 – Auxiliary Systems – Section 9.1 Fuel Storage and Handling,” Revision 19, (ADAMS Accession No. ML11171A491).

APPENDIX A: SPENT FUEL DATA AND TABLES

Table 81 Dry Spent Fuel Storage at U.S. Commercial Nuclear Power Plants

Plant Name	Company Name	Fuel Type	Location	License Type	Storage Technology	Year Loaded
Surry 1 & 2	Dominion Generation	PWR	Co-located	Site-specific	CASTOR V/21 MC-10, NAC I-28 CASTOR X/, TN-32	1986
				General	NUHOMS-32PTH	2007
H.B. Robinson	Progress Energy	PWR	Co-located	Site-specific	NUHOMS-07P	1989
				General	NUHOMS-24PTH	2004
Oconee 1, 2, 3	Duke Energy	PWR	Co-located	Site-specific	NUHOMS-24P	1990
				General	NUHOMS-24P NUHOMS-24PHB	2000
Fort St. Vrain (shutdown)	U.S. DOE (Previously owned by Public Service Colorado)	HTGR	–	Site-specific	Foster Wheeler MVDS	1991
Calvert Cliffs 1 & 2	Constellation Energy	PWR	Co-located	Site-specific	NUHOMS-24P NUHOMS-32P	1992
Palisades	Entergy Nuclear Operations	PWR	Co-located	General	VSC-24 NUHOMS-32PT NUHOMS-24PTH	1993
Prairie Island 1 & 2	Xcel Energy	PWR	Co-located	Site specific	TN-40	1993
Point Beach 1 & 2	FPL Energy Point Beach	PWR	Co-located	General	VSC-24 NUHOMS-32PT	1995
Davis Besse	FirstEnergy Nuclear Operating Co.	PWR	Co-located	General	NUHOMS-24P	1995
Arkansas Nuclear One 1 & 2	Entergy Nuclear Operations	PWR	Co-located	General	VSC-24 HI-STORM 24P HI-STORM 32P	1996
North Anna 1 & 2	Dominion Generation	PWR	Co-located	Site-specific	TN-32	1998
				General	NUHOMS-32PTH	2008
Susquehanna 1 & 2	PPL Susquehanna LLC	BWR	Co-located	General	NUHOMS-52B NUHOMS-61BT	1999
Peach Bottom 2 & 3	Exelon Generation	BWR	Co-located	General	TN-68	2000
Dresden 1, 2, 3 (Unit 1 – shutdown)	Exelon Generation	BWR	Co-located	General	HI-STAR 68B HI-STORM 68B	2000
Hatch 1 & 2	Southern Nuclear Operating Co.	BWR	Co-located	General	HI-STAR 68B HI-STORM 68B	2000
Rancho Seco (shutdown)	Sacramento Municipal Utility District	PWR	–	Site-specific	NUHOMS-24P	2001
McGuire 1 & 2	Duke Energy	PWR	Co-located	General	TN-32 NAC UMS	2001
Trojan (shutdown)	Portland General Electric	PWR	–	Site-specific	TranStor Overpack HI-STORM 24P MPC	2002
Oyster Creek	Exelon	BWR	Co-located	General	NUHOMS-61BT	2002

Plant Name	Company Name	Fuel Type	Location	License Type	Storage Technology	Year Loaded
	Generation					
Yankee Rowe (shutdown)	Yankee Atomic Electric Co.	PWR	Stand Alone	General	NAC MPC	2002
Columbia	Energy Northwest	BWR	–	General	HI-STORM 68B	2002
Big Rock Point (shutdown)	Entergy Nuclear Operations	BWR	Stand Alone	General	FuelSolutions W150	2002
FitzPatrick	Entergy Nuclear Operations	BWR	Co-located	General	HI-STORM 68B	2002
Maine Yankee (shutdown)	Maine Yankee Atomic Power	PWR	Stand Alone	General	NAC UMS	2002
Palo Verde 1, 2, 3	Arizona Public Service	PWR	–	General	NAC UMS	2003
San Onofre 1, 2, 3 (Unit 1 – shutdown)	Southern California Edison	PWR	–	General	NUHOMS-24PT	2003
Duane Arnold	FPL Energy.	BWR	Co-located	General	NUHOMS 61BT	2003
Haddam Neck (shutdown)	Connecticut Light & Power	PWR	–	General	NAC MPC	2004
Sequoyah 1 & 2	Tennessee Valley Authority	PWR	Co-located	General	HI-STORM 32P	2004
Millstone 1, 2, 3 (Unit 1 – shutdown)	Dominion Generation	Unit 1 – BWR Unit 2, 3 – PWR	Co-located	General	NUHOMS-32PT	2005
Farley 1 & 2	Southern Nuclear Operating Co.	PWR	Co-located	General	HI-STORM 32P	2005
Browns Ferry 1, 2, 3	Tennessee Valley Authority	BWR	Co-located	General	HI-STORM 68B	2005
Quad Cities 1 & 2	Exelon Generation	BWR	Co-located	General	HI-STORM 68B	2005
River Bend	Entergy Nuclear Operations	BWR	Co-located	General	HI-STORM 68B	2005
Fort Calhoun	Omaha Public Power District	PWR	Co-located	General	NUHOMS-32PT	2006
Hope Creek	PSEG Nuclear	BWR	Co-located	General	HI-STORM 68B	2006
Grand Gulf	Entergy Nuclear Operations	BWR	Co-located	General	HI-STORM 68B	2006
Catawba 1 & 2	Duke Energy	PWR	Co-located	General	NAC UMS	2007
Indian Point 1, 2, 3 (Unit 1 – shutdown)	Entergy Nuclear Operations	PWR	Co-located	General	HI-STORM 32P	2008
Vermont Yankee	Entergy Nuclear Operations	BWR	Co-located	General	HI-STORM 68B	2008
Limerick 1 & 2	Exelon Generation	BWR	Co-located	General	NUHOMS 61BT	2008
St. Lucie 1 & 2	FPL Energy	PWR	Co-located	General	NUHOMS 32PT	2008
Seabrook	FPL Energy	PWR	Co-located	General	NUHOMS 32PT	2008

Plant Name	Company Name	Fuel Type	Location	License Type	Storage Technology	Year Loaded
Monticello	Xcel Energy	BWR	Co-located	General	NUHOMS 61BT	2008
Humboldt Bay (shutdown)	Pacific Gas & Electric	BWR	Co-located	Site-specific	HI-STAR 100	2008
Kewaunee	Dominion Generation	PWR	Co-located	General	NUHOMS-32P	2009
Diablo Canyon 1 & 2	Pacific Gas & Electric	PWR	–	Site-specific	HI-STORM 32P	2009

Source: EPRI 1021048, pp. 2-10 to 2-12 (Ref. 8).

Table 82 Expected Dry Spent Fuel Storage Facility Development at U.S. Commercial Nuclear Power Plants

Plant Name	Company Name	Location	Fuel Type	Approximate Loading Year
Beaver Valley 1	FirstEnergy Nuclear Operating Co.	–	PWR	2013-2014
Brunswick 1 & 2	Progress Energy	Co-located	BWR	2010-2011
Braidwood 1 & 2	Exelon Generation	–	PWR	2011
Byron 1 & 2	Exelon Generation	Co-located	PWR	2010
Clinton	Exelon Generation	–	BWR	2016
Comanche Peak	TXU Generating Company	–	PWR	2014-2016
Cook 1 & 2	Indiana Michigan Power	–	PWR	2011
Cooper	Nebraska Public Power District	Co-located	BWR	2010
Crystal River	Progress Energy	–	PWR	2012
Fermi	Detroit Edison	Co-located	BWR	2010
Ginna	Constellation Energy	Co-located	PWR	2010
LaCrosse (shutdown)	Dairyland Power	–	BWR	2011
LaSalle 1 & 2	Exelon Generation	Co-located	BWR	2010
Nine Mile Point 1 & 2	Constellation Energy	–	BWR	2012
Perry	FirstEnergy	Co-located	BWR	2010
Pilgrim	Entergy Nuclear Operations	–	BWR	2014-2015
Salem 1 & 2	PSEG Nuclear	Co-located	PWR	2010
Summer	South Carolina Electric & Gas	–	PWR	2015-2017
Turkey Point 3 & 4	FPL Energy	–	PWR	2011
Vogtle 1 & 2	Southern Nuclear Operating Co.	–	PWR	2013-2014
Waterford 3	Entergy Nuclear Operations	–	PWR	2011-2012
Watts Bar 1 & 2	Tennessee Valley Authority	–	PWR	2020

Source: EPRI 1021048, p. 2-13 (Ref. 8).

Table 83 Spent Fuel Pool Capacities

Plant Name	Spent Fuel Pool			
	Group[1]	Assoc. Reactor Core Size (no. of assemblies)	Technical Specification Capacity (assemblies/core equivalents)	Estimated Cs-137 Inventory (MCi)
Arkansas Nuclear 1	2	177	968/ 5.5	41.7
Arkansas Nuclear 2	2	177	988/ 5.6	42.8
Beaver Valley 1	2	157	1627/ 10.4	77.6
Beaver Valley 2	2	157	1627/ 10.4	77.6
Braidwood 1	4	193	2984/ 7.7 per unit[2]	142.2
Braidwood 2	4	193		
Browns Ferry 1	1	764	3471/ 4.5[4]	52.3
Browns Ferry 2	1	764	3471/ 4.5[4]	52.3
Browns Ferry 3	1	764	3471/ 4.5	52.3
Brunswick 1	1	560	1803/ 3.2	24.0
Brunswick 2	1	560	1839/ 3.3	24.7
Byron 1	4	193	2984/ 7.7 per unit[2]	142.2
Byron 2	4	193		
Callaway	2	193	2363/ 12.2	114.5
Calvert Cliffs 1	4	217	1830/ 4.2 per unit[4]	79.4
Calvert Cliffs 2	4	217		
Catawba 1	2	193	1421/ 7.3	64.8
Catawba 2	2	193	1421/ 7.3	64.8
Clinton	2	624	3796/ 6.1	61.3
Columbia	1	764	2658/ 3.5	36.6
Comanche Peak 1	2	193	1684/ 8.7[4]	78.7
Comanche Peak 2	2	193	1689/ 8.7[4]	79.0
Cooper	1	548	2651/ 4.8	40.6
Crystal River 3	6	177	1474/ 8.3	68.5
Davis-Besse	2	177	1624/ 9.2	76.4
D.C. Cook 1	4	193	3613/ 9.3 per unit[2]	175.4
D.C. Cook 2	4	193		
Diablo Canyon 1	2	193	1324/ 6.9	59.7
Diablo Canyon 2	2	193	1324/ 6.9	59.7
Dresden 2	1	724	3537/ 4.9	54.3
Dresden 3	1	724	3537/ 4.9	54.3
Duane Arnold	1	368	2829/ 7.7	47.5
Farley 1	2	157	1407/ 9.0	66.0
Farley 2	2	157	1407/ 9.0	66.0
Fermi 2	1	764	4608/ 6.0	74.2
FitzPatrick	1	560	3239/ 5.8	51.7
Fort Calhoun	2	133	1083/ 8.14	50.1
Ginna	2	121	1321/ 10.9	63.3
Grand Gulf 1	2	800	4348/ 5.4	68.5
Hatch 1	1	560	3349/ 6.0[4]	53.9
Hatch 2	1	560	2933/ 5.2[4]	45.8
Hope Creek 1	1	764	4006/ 5.2	62.6
Indian Point 2	2	193	1374/ 7.1	62.3
Indian Point 3	2	193	1345/ 7.0	60.8
Kewaunee	6	121	1205/ 10.0	57.2
La Salle County 1	1	764	3986/ 5.2[4]	62.2

Plant Name	Spent Fuel Pool			
	Group[1]	Assoc. Reactor Core Size (no. of assemblies)	Technical Specification Capacity (assemblies/core equivalents)	Estimated Cs-137 Inventory (MCi)
La Salle County 2	1	764	4078/ 5.3[4]	64.0
Limerick 1	1	764	4117/ 5.4	64.8
Limerick 2	1	764	4117/ 5.4	64.8
McGuire 1	2	193	1463/ 7.6	67.0
McGuire 2	2	193	1463/ 7.6	67.0
Millstone 1	6	–	–	–
Millstone 2	2	217	1346/ 6.2	59.6
Millstone 3	2	193	1860/ 9.6	88.0
Monticello	1	484	2301/ 4.75	35.1
Nine Mile Point 1	1	532	4086/ 7.7	68.6
Nine Mile Point 2	1	764	4049/ 5.3	63.4
North Anna 1	4	157	1737/ 5.5 per unit[2]	79.2
North Anna 2	4	157		
Oconee 1	4	177	1312/ 3.7 per unit[2]	55.2
Oconee 2	4	177		
Oconee 3	2	177	825/ 4.7	34.2
Oyster Creek	1	560	3035/ 5.4	47.8
Palisades	2	204	892/ 4.4	36.3
Palo Verde 1	2	241	1329/ 5.5	57.4
Palo Verde 2	2	241	1329/ 5.5	57.4
Palo Verde 3	2	241	1329/ 5.5	57.4
Peach Bottom 2	1	764	3819/ 5.0	59.0
Peach Bottom 3	1	764	3819/ 5.0	59.0
Perry 1	2	748	4020/ 5.4	63.2
Pilgrim 1	1	580	3859/ 6.7	63.3
Point Beach 1	4	121	1502/ 6.2 per unit[2]	69.7
Point Beach 2	4	121		
Prairie Island 1	4	121	1386/ 5.7 per unit[2]	63.6
Prairie Island 2	4	121		
Quad Cities 1	1	724	3657/ 5.1[4]	56.6
Quad Cities 2	1	724	3897/ 5.4[4]	61.3
River Bend 1	2	624	3104/ 5.0	47.9
Robinson 2	2	157	544/ 3.5	20.4
St. Lucie 1	2	217	1706/ 7.9	78.6
St. Lucie 2	2	217	1491/ 6.9	67.2
Salem 1	2	193	1632/ 8.5	75.9
Salem 2	2	193	1632/ 8.5	75.9
San Onofre 2	6	217	1542/ 7.1	69.9
San Onofre 3	6	217	1542/ 7.1	69.9
Seabrook 1	2	193	1236/ 6.4	55.0
Sequoyah 1	4	193	2091/ 5.4 per unit[2]	95.1
Sequoyah 2	4	193		
Shearon Harris 1	4	157 (PWR)	PWR fuel: 3404 / 21.7 or	167.2
		560 (BWR)	BWR fuel: 4628 / 8.3	73.2
South Texas Project 1	2	193	1969/ 10.2	95.6
South Texas Project 2	2	193	1969/ 10.2	95.6

Plant Name	Spent Fuel Pool			
	Group[1]	Assoc. Reactor Core Size (no. of assemblies)	Technical Specification Capacity (assemblies/core equivalents)	Estimated Cs-137 Inventory (MCi)
Summer 1	2	157	1276/ 8.1	59.1
Summer 2	3	–	–	–
Summer 3	3	–	–	–
Surry 1	4	157	1044/ 3.3 per unit[2]	42.7
Surry 2	4	157		
Susquehanna 1	1	764	2840/3.7[4]	40.1
Susquehanna 2	1	764	2840/ 3.7[4]	40.1
Three Mile Island 1	2	177	1338/ 7.6	61.3
Turkey Point 3	2	157	1395/ 8.9	65.3
Turkey Point 4	2	157	1389/ 8.9	65.0
Vermont Yankee	1	368	3355/ 9.1	57.7
Vogtle 1	2	193	1476/ 7.6[4]	67.7
Vogtle 2	2	193	2098/ 10.9[4]	100.5
Vogtle 3	3	–	–	–
Vogtle 4	3	–	–	–
Waterford 3	2	217	2398/ 11.0	115.1
Watts Bar 1	2	193	1610/ 8.3	74.8
Wolf Creek 1	2	193	2363/ 12.2	114.5

Notes:
1. The Group column corresponds to the spent fuel pool groupings discussed in Section 3.1.1.
2. Common pool shared by two reactors. Shared spent fuel pools are required to maintain one full core reserve. However, with the practice that both reactors refuel during the shoulder months of the same year it was judged that shared pools attempt to maintain at least a 1.5 full core reserve in practice.
3. Shearon Harris spent fuel pool holds fuel from Robinson and Brunswick.
4. Spent fuel pools connected by transfer canal.

Table 84 Regulatory Analysis Inputs Summary

Parameter	Spent Fuel Pool Group 1			Spent Fuel Pool Group 2, 3, & 4		
	Low Est.	Base Case	High Est.	Low Est.	Base Case	High Est.
Seismic hazard initiating event frequency (USGS 2008 model) (per year)						
- Seismic bin 3	1.65E-05	1.65E-05	2.24E-05	1.65E-05	1.65E-05	see Table 8
- Seismic bin 4	4.90E-06	4.90E-06	7.09E-06	4.90E-06	4.90E-06	see Table 8
ac power fragility	100% (bounding value)					
Liner fragility						
- Seismic bin 3	10%	10%	100%	2%	5%	25%
- Seismic bin 4	50%	100%	100%	16%	50%	100%
- Cask drop	100% (bounding value)					
Percent of operating cycle natural circulation cooling is insufficient						
- Seismic bin 3	8%	8%	100%	8%	100% (bounding value)	
- Seismic bin 4	30%	100% (bounding value)		30%	100% (bounding value)	
- Cask drop	8%	100% (bounding value)		8%	100% (bounding value)	
- All other initiators	100% (bounding value)					
Cs-137 release fraction						
- Alternative 1	3%	40%	90%	10%	75%	90%
- Alternative 2	0.5%	3%	5%	0.5%	3%	5%
High-density loading spent fuel pool Cs-137 inventory (MCi)						
- SFP Group 1	40.6	52.7	63.3	-	-	-
- SFP Group 2	-	-	-	57.4	67.9	78.2
- SFP Group 3	-	-	-	33.7	44.4	54.2
- SFP Group 4	-	-	-	63.6	101.1	142.2
Low-density loading spent fuel pool Cs-137 inventory (MCi)						
- SFP Group 1	19.8	22	26.4	-	-	-
- SFP Group 2	-	-	-	15.7	17.4	20.9
- SFP Group 3	-	-	-	15.7	17.4	20.9
- SFP Group 4	-	-	-	31.4	34.8	41.8
Population density within 50 miles of site (people/square mile)	169	317	722	169	317	722
Long-term habitability criteria	500 mrem annually	2 rem first year and 500 mrem each year thereafter	2 rem annually	500 mrem annually	2 rem first year and 500 mrem each year thereafter	2 rem annually
Onsite Property: decontamination, repair, & refurbishment	$303 million	$606 million	$1.82 billion	$303 million	$606 million	$1.82 billion
Short-term occupational exposure (accident) (person-rem)	18,070	28,380	48,880	18,070	28,380	48,880
Long-term occupational exposure (accident (person-rem)	4,580	14,000	46,000	4,580	14,000	46,000
Economic data near site	Palisades	Surry	Peach Bottom	Palisades	Surry	Peach Bottom