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This report contains the results of these activities and includes three main outputs. The first is a discussion in Chapter 2 on how risk-informed decision making can be applied to decommissioning plants. The second is a summary in Chapter 3 of the risk assessment of SFPs at decommissioning plants. The third output or Chapter 4 provides the implications of SFP risks on regulatory requirements, and outlines where industry commitments in combination with additional staff assumptions may be useful in improving spent fuel pool safety at decommissioning plants. Chapter 5 is a summary of the findings of the report.

After a period of one year following permanent shutdown, the results of this report estimated the generic frequency of events leading to zirconium fires at decommissioning plants to be less X than ~~3~~$x10^{-6}$ per year for a plant that implements the design and operational characteristics assumed in the risk assessment performed by the staff. This frequency was estimated based on the assumptions that the characteristics of the ten industry decommissioning commitments (IDCs) proposed by NEI (See Appendix 6) and the four staff decommissioning assumptions (SDAs) identified in Chapters 3 and 4 of the report would be implemented. This estimate could be much higher for a plant that does not implement these characteristics. The most significant contributor to this risk is a seismic event which exceeds the design basis earthquake. However, the overall frequency of this event is within the staff recommended pool performance guideline (PPG) identified in this report for large radiological releases due to a zirconium fire of $1x10^{-5}$ per year. As discussed below, zirconium fires are estimated to be similar to large early release accidents postulated for operating reactors in some ways, but less severe in others.

The thermal-hydraulic analysis presented in Appendix 1 demonstrates that the decay heat necessary for a zirconium fire exists in typical spent fuel pools of decommissioning plants for a period of several years following shutdown. The analysis shows that the length of time over which the fuel is vulnerable depends on several factors, including fuel burn-up and fuel storage configuration in the SFP.. In some cases analyzed in Appendix 1, the required decay time to preclude a zirconium fire is 5 years[1]. However, the exact time will be plant specific; therefore, plant-specific analysis would be needed to demonstrate shorter zirconium fire vulnerabilities.

The consequence analysis presented in Appendix 4 demonstrates that the consequences of a zirconium fire in a decommissioning plant can be very large. The integrated dose to the public is generally comparable to a large early release from an operating plant during a potential severe core damage accident and early fatalities are very sensitive to the effectiveness of evacuation. For a decommissioning plant with about one year of decay time, the onset of radiological releases from a zirconium fire is significantly delayed compared to those from the most limiting operating reactor accident scenarios. This is due to the relatively long heat up time of the fuel. For many of the sequences leading to zirconium fires, there are very large delay times due to the long time required to boil off the large spent fuel pool water inventory. Thus, while the consequences of zirconium fires are in some ways comparable to large early releases from postulated reactor accidents, the time of release occurs much later following

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[1] In the area of dry storage, it is noted that currently certified casks may be loaded with spent fuel with a minimum of five years cooling. The risk of a zirconium fire in dry cask storage is largely eliminated by limiting the maximum fuel cladding temperature and minimizing the oxygen available. The temperature is explicitly modeled using bounding fuel characteristics. The maximum clad temperature occurs during vacuum drying when little oxygen is available and the fuel is in an inert environment for storage.

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Table 3.1 Spent Fuel Pool Cooling Risk Analysis Frequency of Fuel Uncovery (per year)

INITIATING EVENT	Frequency of Fuel Uncovery
Loss of Pool Cooling	$1.4X10^{-08}$
Loss of Coolant Inventory	$3.1X10^{-09}$
Loss of Off-site Power - Plant centered and grid related events	$3.0X10^{-08}$
Loss of Off-site Power - Events initiated by severe weather	$1.3X10^{-07}$
Internal Fire	$4.5X10^{-08}$
Cask Drop [7]	$2.0X10^{-07}$
Seismic Event [8]	4.5 <~~3~~.0X10^{-06}
Aircraft Impact	$2.9X10^{-09}$
Tornado Missile	$<1.0X10^{-09}$
Total	$<3.4X10^{-06}$

This table summarizes the fuel uncovery frequency for each accident initiator. The frequencies are point estimates, based on the use of point estimates for the input parameters. For the most part these input parameter values would be used as the mean values of the probability distributions that would be used in a calculation to propagate parameter uncertainty. Because the systems are very simple with little support needs, the point estimates therefore reasonably correlate to the mean values that would be obtained from a full propagation of parameter uncertainty. Due to the large margin between the loss of cooling and inventory sequence frequencies and the pool performance guideline, this propagation was judged to be unnecessary (See Section 5 of Appendix 2a for further discussion of uncertainties).

The above results show that the estimated frequency for a zirconium fire is less than 4.5 ~~3~~X10^{-6} per year, with the dominant contribution being from a severe seismic event. A more specific characterization of the seismic risk is discussed in Chapter 3.4.1.

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[7] For a single failure proof system without a load drop analysis. The staff assumed that facilities that chose the option in NUREG-0612 to have a non-single failure proof system performed and implemented their load drop analysis including taking mitigative actions to the extent that there would be high confidence that the risk of catastrophic failure was less than or equivalent to that of a single failure proof system.

[8] This contribution applies to SFPs that satisfy the seismic checklist and includes seismically induced catastrophic failure of the pool (which dominates the results) and a small contribution from seismically induced failure of pool support systems.

During stakeholder interactions with the staff, the staff proposed the use of a seismic checklist, and in a letter dated August 18, 1999 (See Appendix 5), NEI proposed a checklist that could be used to show robustness for a seismic ground motion with a peak ground acceleration (PGA) of approximately 0.5g. This checklist was reviewed and enhanced by the staff. The staff has concluded that plants that satisfy the revised seismic checklist can demonstrate with reasonable assurance a high-confidence low-probability of failure (HCLPF)[10] at a ground motion that has a very small likelihood of exceedence.

U.S. nuclear power plants, including their spent fuel pools, were designed such that they can be safely shutdown and maintained in a safe shutdown condition if subjected to ground motion from an earthquake of a specified amplitude. This design basis ground motion is referred to as the safe shutdown earthquake (SSE). The SSE was determined on a plant specific basis consistent with the seismicity of the plant's location. In general, plants located in the eastern and central parts of the US, had lower amplitude SSE ground motions established for their designs than the plants located in the western parts of the US, which had significantly higher SSEs established for them because of the higher seismicity for locations west of the Rocky Mountains. As part of this study, the staff with assistance from Dr. Kennedy (See Appendix 5), reviewed the potential for spent fuel pool failures to occur in various regions in the U.S. due to seismic events with ground motion amplitudes exceeding established SSE values.

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~~Thus, the seismic~~ component of risk can be limited to an acceptable level if it can be ~~demonstrated~~ that there ~~is a HCLPF for seismic ground motion greater than or equal to three times SSE at CEUS sites and two times SSE at West Coast sites. As discussed in Appendix 5b, for CEUS plants that can demonstrate HCLPF at three times their SSE value and West Coast plants that can demonstrate HCLPF at two times their SSE value,~~ the frequency of ~~fuel uncovery~~ is judged to be ~~less than~~ $3X10^{-6}$ per year.

The seismic checklist (Appendix 5d) was developed to provide a simplified method for demonstrating a high confidence of a low probability of failure and thus an acceptably low value of seismic risk. The checklist includes elements to assure there are no weaknesses in the design or construction nor any service induced degradation of the pools that would make them vulnerable to failure under earthquake ground motions that exceed their design basis ground motion. Spent fuel pools that satisfy the seismic checklist, as written, would have a high confidence in a low probability of failure for seismic ground motions up to 0.5 g peak ground acceleration (1.2g peak spectral acceleration). ~~Thus, sites in the central and eastern part of the U.S. that have three times~~ SSE values less than or equal to 0.5 g PGA and pass the seismic check ~~list would have an~~ acceptably low ~~level of~~ seismic risk. Similarly, West Coast sites ~~that have two times SSE values less than 0.5 g, and pass the seismic check list would have acceptably low values of seismic risk. From a practical point of view, a limited number of sites in the central and eastern part of the U.S. have three times SSE values greater than 0.5g; the two times SSE values exceed 0.5g for two West Coast plants.~~ In order to demonstrate acceptably low seismic risk, ~~these central and eastern sites for which the three times SSE values exceed 0.5g and the two West Coast sites~~ the Pilgrim and HB Robinson sites would have to perform additional plant specific analyses to demonstrate that the seismic risk is low for the ~~HCLPF for their spent fuel pools at three times SSE and two times SSE values of ground acceleration, respectively. The staff notes~~

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[10] The HCLPF value is defined as the peak seismic acceleration at which there is 95% confidence that less than 5% of the time the structure, system, or component will fail.

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Using a HCLPF value of 0.5 g PGA, Dr. Kennedy's study indicates (see Table 3) that the annual frequency of seismically induced failure of spent fuel pool structures varies from $1.3X10^{-6}$ to $13.6X10^{-6}$. We assume that the seismic induced failure of the spent fuel pool structure directly leads to the uncovering of the fuel and radioactive release. In the draft recommendation the staff proposed to use $3X10^{-6}$ as the annual frequency of seismic failure and equivalently the frequency of radioactive release. However, comments from the Advisory Committee on Reactor Safeguards and other stake holders indicated that the proposed approach of using HCLPF values of 3XSSE for Eastern and Central US and 2XSSE for the Western US is too conservative. Also, the proposed approach contained two tiers of assessments for the Eastern and the Western United States and was complicated by the fact that seismic fragility information for ground motion levels beyond 0.5 g is not readily available from a peer reviewed data base. Given that the original staff recommendation was based on several areas of conservatism and given large uncertainties in the estimates, we reexamined the results of Table 3. Our review indicates that only two operating eastern plants have frequencies significantly greater than $3X10^{-6}$. All other plants, which exceed $3X10^{-6}$, lie within the range of $3X10^{-6}$ to $4.5X10^{-6}$. The conservatism and uncertainties cited earlier blur the distinction between these values; therefore, it should not be used as a sole decision criterion. Therefore, the staff recommends that only those plants which significantly exceed $3X10^{-6}$ value should be required to conduct plant-specific analysis beyond the confirmation of the checklist. This process results in identification of four sites in the Eastern US, only ~~two~~ three of which are operating reactor sites - Pilgrim, ~~and~~ H. B. Robinson, and Vogtle sites. In the Western US the Diablo Canyon and San Onofre sites are also beyond the scope of a simple screening evaluation. Based on the NRC sponsored study, Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear power Plants, NUREG/CR 5176, January 1989, the seismic HCLPF capacity of the H. B. Robinson spent fuel pool has been estimated to be 0.65 g. For the Pilgrim, Diablo Canyon and San Onofre sites, it may be necessary to conduct a detailed site specific seismic risk evaluation, or to delay decommissioning until such time that a zirconium fire risk is minimal. To summarize the staff recommendation for seismic vulnerability of spent fuel pools, (1) all sites must conduct an assessment of the spent fuel pool structures using the revised seismic check list in order to identify any structural degradation, potential for seismic interaction from superstructures and over head cranes, and to verify that they have a seismic HCLPF value of 0.5 g, (2) those sites that cannot demonstrate that a seismic HCLPF value exists, may either under take some remedial action or conduct site specific seismic risk assessment and (3) Pilgrim, H. B. Robinson, Diablo Canyon and San Onofre sites must use the seismic check list to identify any structural degradation or other anomalies and then conduct a site specific seismic risk assessment.

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safeguards and insurance indemnification. The technical results of this report can be used either to justify plant-specific exemptions from these requirements, or to determine how these areas will be treated in risk-informed regulations for decommissioning sites. Since both the IDCs and SDAs are essential in achieving the levels of safety presented in this analysis, future regulatory activity would properly reflect such commitments and assumptions. Chapter 4.3 examines the implications of the technical results for those specific regulatory decisions.

4.1. Summary of the Technical Results

The thermal-hydraulic analysis presented in Appendix 1 demonstrates that the decay heat necessary for a zirconium fire exists in typical spent fuel pools of decommissioning plants for a period of several years following shutdown. The analysis shows that the length of time over which the fuel is vulnerable depends on several factors, including fuel burn up and fuel configuration. In some cases analyzed in Appendix 1, the required decay time to preclude a zirconium fire is 5 years. However, the exact time will be plant specific, and therefore plant-specific analysis is needed to justify the use of shorter decay periods. Guidelines for plant specific analyses can be found in Appendix 1.

The consequence analysis presented in Appendix 4 demonstrates that the consequences of a zirconium fire in a decommissioning plant can be very large. The integrated dose to the public is generally comparable to a large early release from an operating plant during a potential severe core damage accident. Early fatalities are very sensitive to the effectiveness of evacuation.

For a decommissioning plant with about one year of decay time, the onset of radiological releases from a zirconium fire is significantly delayed compared to those from the most limiting operating reactor accident scenarios. This is due to the relatively long heat up time of the fuel. In addition, for many of the sequences leading to zirconium fires, there are very large delay times due to the long time required to boil off the large spent fuel pool water inventory. Thus, while the consequences of zirconium fires are in some ways comparable to large early releases from postulated reactor accidents, the time of release is much longer from initiation of the accident.

The generic frequency of events leading to zirconium fires at decommissioning plants is estimated to be less than ~~3×10^{-6}~~ 4.5×10^{-6} per year for a plant that implements the design and operational characteristics discussed below. This estimate can be much higher for a plant that does not implement these characteristics. The most significant contributor to this risk is a seismic event which exceeds the design basis earthquake. The overall frequency of this event is within the recommended pool performance guideline (PPG) for large radionuclide releases due to zirconium fire of 1×10^{-5} per year. As noted above, zirconium fires are estimated to be similar to large early release accidents postulated for operating reactors in some ways, but less severe in others.

4.2 Risk Impact of Specific Design and Operational Characteristics

This section discusses the design and operational elements that are important in ensuring that the risk from a SFP is sufficiently low. The relationship of the elements to the quantitative risk findings is discussed as well as how the elements support additional safety principles of RG 1.174 as they apply to a SFP.

SDA #3 Each decommissioning plant will successfully complete the seismic checklist provided in Appendix 5 to this report. If the checklist cannot be successfully completed, the decommissioning plant will perform a plant specific seismic risk assessment of the SFP and demonstrate that SFP seismically induced structural failure and rapid loss of inventory is less than the generic bounding estimates provided in this study ($\leq\cancel{3}\times10^{-6}$ per year).

$<1.5\times10^{-6}$

The quantification of accident sequences in Chapter 3 associated with loss of cooling or loss of inventory resulted in low risk due to a number of elements that enhance the ability of the operators to respond successfully to the events with on-site and off-site resources. Without these elements, the probability of the operators detecting and responding to the loss of cooling or inventory would be higher and public risk from these categories of SFP accidents could be significantly increased. Some elements were also identified that reduce the likelihood of the loss of cooling or loss of inventory initiators, including both design and operational issues. The elements proposed by industry (IDCs) are identified below.

To reduce the likelihood of loss of inventory the following was committed to by industry:

IDC #6 Spent fuel pool seals that could cause leakage leading to fuel uncovery in the event of seal failure shall be self limiting to leakage or otherwise engineered so that drainage cannot occur.

IDC #7 Procedures or administrative control to reduce the likelihood of rapid drain down events will include (1) prohibitions on the use of pumps that lack adequate siphon protection or (2) control for pump; suction and discharge points. The functionality of anti-siphon devices will be periodically verified.

IDC #9 Procedures will be in place to control spent fuel pool operations that have the potential to rapidly decrease spent fuel pool inventory. These administrative controls may require additional operations or management review, management physical presence for designated operations or administrative limitations such as restrictions on heavy load movements.

The high probability of the operators recovering from a loss of cooling or inventory is dependent upon the following:

IDC #2 Procedures and training of personnel will be in place to ensure that on-site and off-site resources can be brought to bear during an event.

IDC #3 Procedures will be in place to establish communication between on-site and off-site organizations during severe weather and seismic events.

IDC #4 An off-site resource plan will be developed which will include access to portable pumps and emergency power to supplement on site resources. The plan would principally identify organizations or suppliers where off-site resources could be obtained in a timely manner.

IDC #5 Spent fuel pool instrumentation will include readouts and alarms in the control room (or where personnel are stationed) for spent fuel pool temperature, water level, and area radiation levels.