4.0 Implications of Spent Fuel Pool Risk For Regulatory Requirements

An important motivation for performing the risk analysis contained in this report is to provide insight into the regulatory requirements that would be needed to limit the risk at decommissioning plants. In order to do that, Section 4.1 presents a brief summary of the risk results that are most pertinent to that end.

The analysis in Section 3 explicitly examines the risk impact of specific design and operational characteristics, taking credit for industry commitments proposed by NEI in a letter to the NRC dated November 12, 1999 [See Ref. 1 or Appendix 6]. Additional assumptions (staff decommissioning assumptions-SDAs) came to light as a result of the staff's risk assessment. These additional assumptions in SFP design and operational characteristics were found to be necessary to achieve the low risk findings in this report. Two SDA's are identified in Section 3, while the remainder are developed from the safety principles of RG 1.174 and are summarized in Section 4.1. Section 4.2 examines the design and operational elements that are important in ensuring that the risk from a SFP is sufficiently low and how these elements support the safety principles of RG 1.174 as they apply to a SFP.

In addition, the industry and other stakeholders have proposed the use of risk-informed decision-making to assess regulatory requirements in three specific areas; emergency preparedness, 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. Section 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,

B/65

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} 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 the safety principles of RG 1.174 as they apply to a SFP.

4.2.1. Impact of Proposed Changes

> "When proposed changes result in an increase in core damage frequency and/or risk, the increases should be small and consistent with the intent of the Commission's Safety Goal Policy Statement."

The staff's risk assessment as discussed in Section 3 shows that the baseline risk (represented as the frequency of zirconium fire in a decommissioning spent fuel pool) is estimated to be less than 3×10^{-6} per year. As was discussed in Section 2, the staff has determined that such a fire results in a large radionuclide release and poses a highly undesirable end state for a spent fuel pool accident. Therefore the staff has judged that a pool performance guideline (PPG) of 1×10^{-5} per year derived from the RG 1.174 application of LERF, should be applied. The risk assessment shows that the SFP zirconium fire frequency is well under the recommended PPG. The assessments conducted for this study also show that the accident progresses much more slowly than at an operating reactor. For many scenarios, recovery and mitigation times of approximately 100 hours are available from onset of the loss of cooling initiators. Even for extremely unlikely events such as severe seismic events and heavy load drops failing the pool floor, ten hours or more time is available to initiate off-site protective actions if necessary prior to zirconium fire initiation. Therefore, the risk assessment shows that both low likelihoods and long response times are associated with SFP accidents at decommissioning plants. These conclusions are predicated on the industry commitments and staff assumptions discussed in this report being fulfilled.

The staff consequence analysis in Appendix 4 shows that the early health impacts from zirconium fire scenarios are significantly impacted by evacuation. As for operating plants, evacuation of the public is the preferred protective action to minimize exposure and early health impacts to the population surrounding the site in the event of a severe accident. Emergency planning requirements for operating plants specify that licensee's have the means for assessing the impact of an accident and have the capability of notifying off-site officials within 15 minutes of declaring an emergency. In addition, the licensee must demonstrate that there are means in place for promptly alerting and providing instructions to the public in case protective actions are needed. Furthermore, detailed off-site emergency plans are required to provide for prompt implementation of protective actions (including evacuation of the public). However, this analysis indicates that for the slowly evolving SFP accident sequences at decommissioning plants, there is a large amount of time to initiate and implement protective actions, including public evacuation, in comparison to operating reactor accident sequences.

In addition to SDA #1 and SDA #2, the low numerical risk results shown in Section 3 and Appendix 2 are derived from a number of design and operational elements of the SFP. As shown in those sections, the dominant risk contribution is from seismic events beyond the plant's original design basis. The baseline seismically initiated zirconium fire frequency from our risk assessment is predicated upon implementation of the seismic checklist shown in Appendix 5. The staff therefore assumed that such a checklist (SDA #3) would be successfully implemented at all decommissioning facilities.

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 ($<3x10^{-6}$ per year).

The quantification of accident sequences in Section 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.

IDC #8 An on-site restoration plan will be in place to provide repair of the spent fuel pool cooling systems or to provide access for make-up water to the spent fuel pool. The plan will provide for remote alignment of the make-up source to the spent fuel pool without requiring entry to the refuel floor.

The staff's risk evaluation also shows that the potential for pool failure due to heavy load drop to be significant if appropriate design and procedural controls are not in place.

IDC #1 Cask drop analyses will be performed or single failure proof cranes will be in use for handling of heavy loads (i.e. phase II of NUREG-0612) will be implemented).

4.2.2. Defense-in-Depth

"The Proposed Change Is Consistent with the Defense-in-Depth Philosophy."

The staff's risk assessment demonstrates that the risk from a decommissioning plant SFP accident is very small if industry commitments and additional staff assumptions are implemented as assumed in the risk study. Due to the very different nature of a SFP accident versus an accident in an operating reactor, with respect to system design capability needs and event timing, the defense-in-depth function of reactor containment is not necessary. However the staff has identified that defense-in-depth in the form of accident prevention and some form of emergency planning can be useful for as long as a zirconium fire is possible, as a means of achieving consequence mitigation. The degree to which it may be required as an additional barrier is a function of the uncertainty associated with the prediction of the frequency of the more catastrophic events, such as beyond design basis earthquakes. There can be a trade off between the formality with which the elements of emergency planning (procedures, training, performance of exercises) are treated and the increasing safety margin as the fuel ages and the time for response gets longer.

4.2.3 Safety Margins

"The Proposed Change Maintains Sufficient Safety Margins."

As discussed in Section 2, the safety margins associated with fuel in the spent fuel pool are much greater than those associated with an operating reactor due to the low heat removal requirements and long time frames available for recovery from off normal events. Due to these larger margins the staff judges that the skid mounted and other dedicated SFP cooling and inventory systems in place do provide adequate margins. Additionally, the surveillance programs that verify Boraflex condition provide assurance of margin with respect to shutdown reactivity.

4.2.4. Implementation and Monitoring Program

> "The Impact of the Proposed Change Should Be Monitored Using Performance Measurement Strategies."

RG 1.174 states that an implementation and monitoring plan should be developed to ensure that the engineering evaluation conducted to examine the impact of the proposed changes continues to reflect the actual reliability and availability of SSCs that have been evaluated. This will ensure that the conclusions that have been drawn will remain valid. Applying this guideline for the SFP risk evaluation results in identification of three primary areas for performance monitoring: 1) the performance and reliability of SFP cooling and associated power and inventory make-up systems, 2) the Boraflex condition for high density fuel racks, and 3) crane operation and load path control for cask movements.

Performance and reliability monitoring of the SFP systems, heat removal, AC power and inventory should be carried out similar to the provisions of the maintenance rule (10 CFR 50.65).

With respect to monitoring of the Boraflex absorber material, the current monitoring programs identified in licensee's responses to Generic Letter 96-04 [Ref. 2] were assumed to be maintained by decommissioning plants until all fuel is removed from the SFP. The staff assumption is stated in SDA #4.

SDA #4 Licensees will maintain a program to provide surveillance and monitoring of Boraflex in high density spent fuel racks until such time as spent fuel is no longer stored in these high-density racks.

With respect to monitoring and control of heavy load activities and load path control, licensee guidance in this area will be provided by IDC # 1.

4.3. Implications for Regulatory Requirements Related to Emergency Preparedness, Security and Insurance

The industry and other stakeholders have expressed interest in knowing the relevance of the results of this study to decisions regarding specific regulatory requirements. These decisions could be made in response to plant-specific exemption requests, or as part of the integrated rulemaking for decommissioning plants. Such decisions can be facilitated by a risk-informed examination of both the deterministic and probabilistic aspects of decommissioning. Three examples of such regulatory decisions are presented in this section.

4.3.1 Emergency Preparedness

The requirements for emergency preparedness are contained in 10CFR 50.47 [Ref. 3] and Appendix E to 10 CFR Part 50 [Ref. 4]. Further guidance on the basis for EP requirements is contained in NUREG-0396 [Ref. 5], and NUREG-0654/FEMA-REP-1 [Ref 6]. The overall objective of EP is to provide dose savings (and in some cases immediate life saving) from accidents.

In the past, the NRC staff has typically granted exemptions from off-site emergency planning requirements for decommissioning plants that could demonstrate that they were beyond the period in which a zirconium fire could occur. The rationale for those decisions was that, in the absence of a zirconium fire, a decommissioning plant had no appreciable scenarios for which the consequences justify the imposition of an off-site EP requirement. The results of this technical study confirm that position for both the scenarios resulting in a potential zirconium fire as well as credible pool criticality events.

In some cases, emergency preparedness exemptions have also been granted to plants which were still in the window of vulnerability for zirconium fire. In these cases, the justification was that enough time had elapsed since shutdown that the evolution of a zirconium fire accident would be slow enough that the staff had confidence that mitigative measures and, if necessary, off-site protective actions could be implemented without preplanning. The staff believes that the technical analysis discussed in Section 3 and the decision criteria laid out in Section 2 have direct bearing on how such exemption requests should be viewed in the future. In addition, this information has bearing on the need for, and the extent of, emergency preparedness requirements in the integrated rulemaking.

The consequence analysis presented in Appendix 4 demonstrates that the off-site consequences of a zirconium fire are comparable to those from operating reactor postulated severe accidents. Further, the analysis demonstrates that timely evacuation can significantly reduce the number of early fatalities due to a zirconium fire. The thermal-hydraulic analysis presented in Appendix 1 confirms our earlier conclusion that zirconium fire events evolve slowly, even for initiating events that result in a catastrophic loss of fuel pool coolant. The results in Section 3 also show that the frequency of zirconium fires is low when compared with the risk guidelines derived from RG 1.174. Thus the risk associated with early fatalities from these scenarios is low which provides some basis to support reductions in EP requirements for decommissioning plants. With respect to the potential for pool criticality, the staff's assessment discussed in Section 3 and Appendix 3 demonstrates that credible scenarios for criticality are highly unlikely and are further precluded by the assumptions of Boraflex monitoring programs. Additionally, even if some criticality event was to occur, it would not be expected to have off-site consequences. Therefore, the conclusions regarding possible reductions in EP program requirements are not affected.

One important safety principle of RG 1.174 is consistency with the defense-in-depth philosophy. Defense-in-depth is included in a plant design to account for uncertainties in the analysis or operational data. The spent fuel pools at operating reactors and decommissioning facilities do not exhibit the defense-in-depth accorded to the reactor. As discussed in Section 1, this difference is justified in light of the considerably greater margin of safety of the SFP compared with reactors. For SFPs at operating reactors, defense-in-depth consists mainly of the mitigating effect of emergency preparedness.

The risk assessments contained in this report indicate that the safety principles of RG 1.174 can be applied to assess whether changes to emergency preparedness requirements are appropriate. The risk of a release from a spent fuel accident is very low. Notwithstanding this low risk, the safety principles in RG 1.174 dictate that defense-in-depth be considered and, as discussed previously, emergency preparedness provides defense-in-depth. However, because of the considerable time available to initiate and implement protective actions, there does not appear to be a need for formal emergency plans for rapid initiation and implementation of protective actions. The principle aspects of emergency planning which is needed for SFP events is the means for identification of the event and for notification of State and local emergency response officials. It should be noted that there will continue to be a need for on-site emergency preparedness for response to the more likely accidents which only have on-site consequences. This study indicates that a one year period provides adequate decay time necessary to reduce the pool heat load to a level that would provide sufficient human response time for anticipated transients, and minimize any potential gap release. This is also the decay time that would result in a 10-12 hour delay from fuel uncovery to zirconium fire, even for very improbable severe seismic events or heavy load drop causing total loss of pool inventory.

Any future reduction of the one year decay time would be contingent on plant specific thermal hydraulic response, scenario timing, human reliability results and system mitigation and recovery capabilities. That is, any licensee wishing to gain relief from regulatory requirements prior to the one year post-shutdown, would need to demonstrate that plant specific vulnerability to a zirconium fire satisfies the risk informed decision process, risk insights and recommended criteria described in Sections 2 and 3.

4.3.2 Security

Currently licensees that have permanently shutdown reactor operations and have offloaded the spent fuel into the SFP are still required to meet all the security requirements for operating reactors in 10 CFR 73.55 [Ref 7]. This level of security would require a site with a permanently shutdown reactor to provide security protection at the same level as that for an operating reactor site. The industry has asked the NRC to consider whether the risk of radiological release from decommissioning plants due to sabotage is low enough to justify modification of safeguards requirements for SFPs at decommissioning plants.

In the past, decommissioning licensees have requested exemptions from specific regulations in 10 CFR 73.55, justifying their requests on the basis of a reduction in the number of target sets susceptible to sabotage attacks, and the consequent reduced hazard to public health and safety. Limited exemptions based on these assertions have been granted. The risk analysis in this report does not take exception to the reduced target set argument; however, the analysis does not support the assertion of a lesser hazard to public health and safety, given the consequences that can occur from a sabotage induced uncovery of fuel in the SFP when a zirconium fire potential exists. Further, the risk analysis in this report did not evaluate the potential consequences of a sabotage event that could directly cause off-site fission product dispersion, for example from a vehicle bomb that was driven into or otherwise significantly damaged the SFP, even if a zirconium fire was no longer possible. However, this report would support a regulatory framework that relieves licensees from selected requirements in 10 CFR 73.55 on the basis of target set reduction when all fuel has been placed in the SFP.

The risk estimates contained in this report are based on accidents initiated by random equipment failures, human errors or external events. PRA practitioners have developed and used dependable methods for estimating the frequency of such random events. By contrast, this analysis, and PRA analyses in general, do not include events due to sabotage. No established method exists for estimating the likelihood of a sabotage event. Nor is there a method for analyzing the effect of security provisions on that likelihood. Security regulations are based on a zero tolerance for sabotage involving special nuclear material - which includes spent fuel. The regulations are designed and structured to remove sabotage from design basis threats at a commercial nuclear power plant, regardless of the probability or consequences.

The technical information contained in this report shows that the consequences of a zirconium fire would be high enough to justify provisions to prevent sabotage. Moreover, the risk analysis could be used effectively to assist in determining priorities for, and details of, the security capability at a plant. However, there is no information in the analysis that bears on the level of security necessary to limit the risk from sabotage events. Those decisions will continue to be made based on a deterministic assessment of the level of threat and the difficulty of protecting a specific facility.

10 CFR 72 [Ref. 8] allows facilities not associated with an operating power reactor to store spent fuel at an independent spent fuel storage installation (ISFSI). 10 CFR 73.51 did not consider the risk posed by vehicle-borne bombs at facilities where potential criticality and fuel heat-up were still issues. The staff also noted that the applicability of 10 CFR 26 [Ref 9] has not been thoroughly evaluated for decommissioning reactors once the fuel has been removed from the reactor vessel and placed in the SFP, and specifically does not apply to ISFSIs licensed under 10 CFR 72. Given the importance of a vehicle bomb threat to the integrity of SFP, and the significance of HRA to the conclusions reached in the SFP risk analysis, the staff recommends that for coherency in the regulations, both of these subjects be revisited during the overall integration of rules for decommissioning reactors.

4.3.3 Insurance

In accordance with 10 CFR 140 [Ref.10], each 10 CFR 50 licensee is required to maintain public liability coverage in the form of primary and secondary financial protection. This coverage is required to be in place from the time unirradiated fuel is brought onto the facility site until all of the radioactive material has been removed from the site, unless the Commission terminates the Part 50 license or otherwise modifies the financial protection requirements under Part 140. On March 17, 1999, the staff proposed to the Commission that insurance indemnity requirements for permanently shutdown reactors be developed in an integrated, risk-informed effort along with requirements for emergency preparedness and security. In the past, licensees have been granted exemptions from financial protection requirements on the basis of deterministic analyses that indicate that a zirconium fire could no longer occur. The analysis in this report supports continuation of this practice, and would support a revised regulatory framework for decommissioning plants that reduces the level of insurance protection when a generic or plant-specific thermal-hydraulic analysis demonstrates that a zirconium fire can no longer occur.

In the staff requirements memorandum (SRM) for SECY-93-127 [Ref. 11], the Commission suggested that withdrawal for secondary financial protection insurance coverage is allowed after the requisite minimum spent fuel cooling period has elapsed. Further, the Commission directed the staff to determine more precisely the appropriate spent fuel cooling period after plant shutdown, and to determine the need for primary financial protection for independent spent fuel storage installations (ISFSIs). Spent reactor fuel aged for one year can be stored in an ISFSI.

The NRC staff has considered whether the risk analysis in this report justifies relief from this requirement for a decommissioning plant during the period when it is vulnerable to zirconium fires. As part of this effort, the staff recognizes the structural similarities between a SFP at a decommissioning plant and a wet (as opposed to dry) ISFSI that could be considered under 10 CFR 72; ISFSIs are generally dry. Indemnification is not required for a separately-licensed ISFSI. The risk analysis in this report indicates high consequences of a zirconium fire, identifies a generic window of vulnerability up to a period of about 5 years after shutdown, and concludes that the predicted frequency of such an accident is within the acceptance guidelines of RG 1.174 after one year, provided that certain constraints are met.

Since the postulated consequences are high, the frequency of a zirconium fire occurring in a decommissioning plant SFP would have to be low to justify a reduction in indemnification protection. The zirconium fire frequencies presented in Section 3 for a decommissioning plant SFP are comparable to the large early releases frequencies (LERF) from some operating reactors, and are within the LERF guidelines of RG 1.174. A zirconium fire frequency criterion to justify reduction of the insurance requirement while a vulnerability to zirconium fires exists has not been established. The potential for a zirconium fire occurring at a decommissioning plant SFP has been described in this risk study to meet the LERF guidelines in RG 1.174 after a decay time of one year, provided that certain conditions are met. On a deterministic basis, the possibility exists that the 5-year window of vulnerability could be reduced with more refined thermal-hydraulic analysis or some other constraints on other parameters such as fuel configuration.