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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 study 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. Three 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 **(this needs to be added to 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 **(George H)**

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. Changes in Risk

RG 1.174 states that:

> "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 frequency of zirconium fire in a decommissioning spent fuel pool is estimated to be less than $3x10^{-6}$ per year.

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As was discussed in Section 2 and Appendix 4, such a fire can result 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 PPG is discussed in Appendix 4C.) 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 more than 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, 10 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 design commitments (IDCs) and staff decommissioning assumptions (SDAs) discussed in this report being fulfilled.

The staff has evaluated the risks associated with SFP accidents and the impacts of potential changes to regulatory requirements for decommissioning plants relative to applicable regulatory guidance. This includes guidance on acceptable levels of (total) risk to the public from a nuclear power plant contained in the Commission's Safety Goal Policy Statement, and guidance on the acceptable levels of risk increase from a change to a plant licensing basis contained in RG 1.174.

Risk Increases

The estimated risks associated with SFP accidents compare favorably with the quantitative health objectives (QHOs) derived from the Commission's Safety Goal Policy Statement. The comparisons, presented in Section 3.6.3, show that a typical site that conforms with the seismic checklist, IDCs, and SDAs, would meet the QHOs by about one to two orders of magnitude one year after shutdown, and greater margins at later times. The risk comparisons provided in Appendix 4C show that provided the facility is maintained at or below the recommended PPG of 1E-5 per year, the QHOs would continue to be met for even the most severe SFP source term.

The risk increases associated with relaxations in EP requirements also compare favorably with the guidance contained in RG 1.174. The estimated risk increases associated with the EP relaxation are summarized in Table 4 of the Appendix. The results indicate that relaxation of the requirements for radiological preplanning would result in an increase of about 1.5E-5 early fatalities and 2 person-rem per year, which is about a factor of 15 and five below the allowable increase inferred from the RG 1.174 LERF criteria. The increase in the risk measures related to the QHO are also substantially lower than the allowables from RG 1.174. Since the SFP fire frequency assumed in these comparisons (2.4E-6 per year) is about a factor of four lower than the PPG of 1E-5 per year, a plant operating nominally at the PPG would have a smaller margin to the allowable risk limits for the reference plant but would still be at or below the limits under the above assumptions.

The results of a sensitivity case indicates that even under the most optimistic assumptions regarding the value of EP in seismic events, the change in risk associated with relaxation of the requirements for radiological preplanning is still relatively small. The increases in early fatalities and individual early fatality risk remain below the maximum allowable for each risk measure. Population dose and individual latent cancer fatality risk are about a factor of two higher than the allowable value inferred from RG 1.174. This increase in individual latent cancer risk represents about nine percent of the QHO, thus, considerable margin to the QHO would still remain.

It must be kept in mind that the evacuation effectiveness assumed for "Full EP" in the sensitivity case is unrealistic for high g earthquakes, and that the risk increase associated with the EP relaxations would be closer to the baseline value. Also, the risk reduction estimates are based on the LLNL seismic hazard frequencies and the high ruthenium source term, and would be substantially lower if either the EPRI seismic hazard frequencies or the low ruthenium source term were used. Finally, the above comparisons are based on the risk levels one year after shutdown. Use of either the EPRI seismic hazard frequencies or the low ruthenium source term would reduce each of the risk measures by about a factor of 10, to values which are well below the RG 1.174 allowables and the QHOs. The risk impact will decrease even further in later years due to reduced consequences as fission products decay.

Measures to Assure Risk Increases Remain Small

The results of the risk assessment are predicated on the industry design commitments (IDCs) and staff decommissioning assumptions (SDAs) discussed in this report being fulfilled. 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 plánt'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

RG 1.174 states that:

"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 design commitments (IDCs) and additional staff decommissioning assumptions (SDAs) 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 as a means of achieving consequence mitigation can be useful for as long as a zirconium fire is possible.

Defense-in-depth for accident prevention is provided by licensee conformance with the IDCs and SDAs. Defense-in-depth for consequence mitigation is provided by the capability to implement emergency actions in decommissioning plants on an ad hoc basis, without the full compliment of regulatory requirements associated with operating reactors. This capability is afforded by the substantial delays in fission product release in SFP accidents relative to operating reactors, combined with the remaining EP requirements envisioned in the rulemaking plan. Specifically, as a result of the changes licensees would no longer be required to: have a formalized EPZ; coordinate with state and local organizations within those EPZs as to specific responsibilities and actions; have an offsite EOF, onsite TSC, and onsite OSC; promptly notify the public using such things as the siren system, tone alert radios, or National Weather radios; and conduct biennial full participation exercises. However, the decommissioning licensee would still be required to promptly notify offsite authorities, characterize the releases, and make protective action recommendations; have a means of promptly notifying offsite organizations and communicating with the public; and hold onsite biennial exercises and semiannual drills.

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

RG 1.174 states that:

"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.

The risk comparisons described in Section 4.2.1 also show that a typical site that conforms with the seismic checklist, IDCs, and SDAs, would meet the Commission's QHOs by about a factor of __ one year after shutdown, and greater margins at later times. The risk comparisons provided in Appendix X show that provided the facility is maintained at or below the recommended PPG of 1E-5 per year, the QHOs would continue to be met for even the most severe source term postulated in Appendix 4A.

The estimated risk increases associated with the EP relaxations are also well below the allowable increases inferred from the RG 1.174 LERF criteria. As discussed in Section 4.2.1, the increases in risk from the EP relaxation would be about a factor of 10 below the maximum allowable from RG 1.174. Since the SFP fire frequency assumed in these comparisons (2.4E-6 per year) is about a factor of 4 lower than the PPG of 1E-5 per year, a plant operating nominally at the PPG would have a smaller margin to the allowable risk limits for the reference plant but would still be at or below the limits.

4.2.4. Implementation and Monitoring Program

RG 1.174 states that:

> "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.

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.

4.3. Implications for Regulatory Requirements Related to Emergency Preparedness, Security and Insurance **(Tim C)**.

Table 4.2-1 Allowable Level of Risk Increase In Accordance With RG 1.174 ΔLERF Criterion (Based on Surry)

Risk Measure	Consequences -- conditional upon source term that produces greatest early fatalities (per event)		Allowable frequency increase in accordance with RG 1.174 (events per year)	Allowable risk increase (per year)
	Internal Events	Seismic Events		
Early fatalities	15	250	1E-6	2.5E-4
Population dose (p-rem within 50 miles)	3.6E6	1.1E7	1E-6	11
Latent cancer fatalities	11300	22000 [1]	1E-6	0.022
Individual early fatality risk at 1 mile	2.9E-2	8.7E-2	1E-6	8.7E-8
Individual latent cancer fatality risk at 10 mile [1]	5.5E-3	6.9E-2	1E-6	6.9E-8

1 - Values shown include a factor of three adjustment to account for differences in the cancer risk model used for NUREG-1150 and SFP accident calculations

Table 4.2-2 Evacuation Modeling for Major Contributors to SFP Fires

Event Type	Major Contributor	Freq (per year)	Minimum Time to Release at One Year (h)	Timely Notification of Off-Site Authorities?	Intact Infrastructure for Emergency Response?	Evacuation Model	
						Full EP	Relaxed Preplanning for Radiological Accidents
Boildown	LOOP (severe weather)	1.8E-7	>200	No	Yes	Late	Late
Rapid Draindown	Cask Drop	2.0E-7	~10	Yes	Yes	Early	Late
	Seismic [1]	2.0E-6	~10	Yes	No	No evacuation Relocation at 24 h	No evacuation Relocation at 24 h
	Seismic Sensitivity [2]					1.5x normal delay 0.5x normal speed (Model as Early)	3x normal delay 0.5x normal speed (Model as Late)

1 - Evacuation model for full EP case is consistent with NUREG-1150 assumptions for high acceleration earthquakes
2 - Evacuation model for full EP case is consistent with NUREG-1150 assumptions for low acceleration earthquakes

Table 4.2-3 Estimated Risk Increase Associated With Relaxing EP Requirements

Event Type Major Contributor	Freq (per year)	Consequences Per Event with Full EP					Consequences Per Event with Relaxed Preplanning for Radiological Accidents					Δ Risk per year from EP reduction				
		EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF	EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF	EF	p-rem	LCF	Ind Risk of EF	Ind Risk of LCF
Boildown [1]	1.8E-7	See Note 1					See Note 1					0	0	0	0	0
Cask Drop	2.0E-7	0.05	6.3E6	~5860	~1.4E-3	~2.5E-3	55	1.0E7	9320	3.23E-2	4.98E-2	1E-5	0.7	~7E-4	~6E-9	~9E-9
Seismic [2]	2.0E-6	See Note 2					See Note 2					0	0	0	0	0
Total	2.4E-6											1E-5	0.7	7E-4	6E-9	9E-9
Seismic Sensitivity	2.0E-6	0.05	6.3E6	~5860	~1.4E-3	~2.5E-3	55	1.0E7	9320	3.23E-2	4.98E-2	1.1E-4	7.4	6.9E-3	6.2E-8	9.5E-8

1 - Risk results with and without EP would be comparable for boildown sequences since the failure paths in these sequences involve failures to notify offsite authorities and would not be impacted by EP

2 - Risk results with and without EP would be comparable for large seismic events since emergency response would have marginal benefit because of its impairment by offsite damage

Table 4.2-4 Comparison of Risk Increase with RG 1.174 Allowable (Based on Surry)

Risk Measure	Risk Increase due to EP Relaxation (per year)		RG 1.174 Allowable Risk Increase (per year)
	Baseline [1]	Seismic Sensitivity [2]	
Early Fatalities	1E-5	1.2E-4	2.5E-4
Population Dose	0.7	8.1	11
Latent Cancer Fatalities	7E-4	7.6E-3	0.022
Individual Early Fatality Risk	6E-9	6.8E-8	8.7E-8
Individual Latent Cancer Fatality Risk	9E-9	1.0E-7	6.9E-8

1 - Assumes no effective evacuation in seismic events, regardless of pre-planning
2 - Assumes maximum effectiveness of emergency planning (i.e., early evacuation) when EP requirements are maintained, and minimum effectiveness (i.e., late evacuation) when EP requirements are relaxed