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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

*Dixie's
Comments
from review
of report of
2/4/00
Rec'd 2/7/00*

MEMORANDUM TO: Chairman Meserve
Commissioner Dicus
Commissioner Diaz
Commissioner McGaffigan
Commissioner Merrifield

FROM: William D. Travers
Executive Director
for Operations

SUBJECT: DRAFT FINAL TECHNICAL STUDY ON SPENT FUEL POOL ACCIDENT
RISK AT DECOMMISSIONING NUCLEAR POWER PLANTS

In March 1999, the NRC staff met with the Commission to discuss an ongoing effort to improve decommissioning regulations. An area of particular interest to the Commission was the perception that the risks at decommissioning nuclear power plants are very low yet many of the regulations governing decommissioning plants remain the same as those required for operating reactors. The staff proposed to take a risk-informed look at power reactor decommissioning requirements and to use the risk insights derived from this review to guide the promulgation of new regulations. The staff subsequently initiated a technical study on spent fuel pool accident risks at decommissioning plants. A preliminary study was completed in June 1999 and concluded that the risks at decommissioning nuclear power plants with recently irradiated fuel in the spent fuel pool could not be dismissed as low when compared to operating reactors due to the frequency and consequences of postulated events leading to drainage of the spent fuel pool and a subsequent zirconium fire. The staff then performed a more comprehensive study to better quantify the risk from a decommissioning nuclear power plant spent fuel pool and provide recommendations, where appropriate, on the factors that have the biggest impact on the risk. The results of the study are intended to support rulemaking in regulatory areas such as emergency planning, safeguards, and insurance for decommissioning plants. The details of this effort are discussed in SECY-99-168, "Improving Decommissioning Regulations for Nuclear Power Plants," dated June 30, 1999.

The staff has now completed a review and requantification of its preliminary risk assessment including independent outside technical review of its analyses and assumptions. Substantial efforts to involve public and industry representatives throughout this effort have been expended. The NRC solicited feedback on its June study assumptions and methods and held numerous public meetings including a 2-day public workshop. Attached for your information is the draft final technical study on spent fuel pool accident risks at decommissioning nuclear power plants.

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Q1147

The Commissioners

After a period of one year following final shutdown

does this apply to today after shutdown?

The results of this report estimated the generic frequency of events leading to zirconium fires at decommissioning plants to be less than 3×10^{-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 assumption that the industry commitments plus additional staff assumptions would be implemented. This estimate could be much higher for a plant that does not implement these operational 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 developed spent fuel pool performance guideline for large radionuclide releases (related to a zirconium fire) of 1×10^{-5} per year.

Concurrent with providing the Commission a copy of this draft report, the staff will be issuing it for public comment via the Federal Register and an NRC web page. Following resolution of any Commission and public comments and review by the ACRS, the staff will publish the final report in May 2000. The staff will utilize the industry commitments and the conclusions in this report to support an integrated decommissioning rulemaking plan to be submitted in June 2000 and develop interim guidance for any future plants that elect to decommission prior to establishing revised regulations.

Attachment: Draft Final Study on Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants

- cc w/att: SECY
- OGC
- OCA
- OPA
- CFO
- CIO

After an appropriate coordination following this

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Attachment: Draft Final Study on Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants

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**Draft Final Technical Study of Spent Fuel Pool Accident Risk
at Decommissioning Nuclear Power Plants**

February 2000
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Technical Study of Spent Fuel Pool Accidents for Decommissioning Plants

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Executive Summary

This report documents an evaluation of spent fuel pool (SFP) accident risks at decommissioning plants. It was done to provide an interim, risk-informed technical basis for reviewing exemption requests, and to provide a regulatory framework for integrated rulemaking. The application of this report is intended to eliminate to the extent practical, unnecessary regulatory burden, while maintaining safety and improving efficiency and effectiveness of the regulatory process. By establishing a consistent, predictable process fully open to public observation and comment, the agency intends to enhance public confidence in the regulatory process for decommissioning reactors. The report was initiated by the Commission when they asked the staff to consider whether the risk from decommissioning plants was low enough to justify generic regulatory relief in the areas of emergency planning, insurance indemnification and safeguards.

The current body of NRC regulations pertaining to light-water reactors (10 CFR 50) [Ref. 1] is primarily directed towards the safety of operating units. It is generally understood that this body of regulations is conservative when a plant transitions from an operating to a decommissioning status. In the past, decommissioning plants have requested exemptions to certain regulations as a result of their permanently defueled condition. When evaluating the acceptability of exemption requests from regulations for permanently shutdown plants, the staff has assessed the susceptibility of the spent fuel to a zirconium fire accident. To date, exemptions have been granted on a plant-specific basis, resulting in different analyses and criteria being used for the basis of the exemptions. In some cases, heat up evaluations of the spent fuel cooled only by air were requested. This criterion was used because of national laboratory studies that had identified the potential concern for a significant off-site radiological release from a zirconium fire which could occur when all water is lost from the spent fuel pool. A clad temperature of 565°C, based on the onset of clad swelling, was used as a limit to ensure no radiological release.

In March 1999, the staff formed a technical working group to evaluate spent fuel pool accident risks at decommissioning plants. A two month effort was launched to review the available technical information and methods and identify areas in need of further work. A substantial effort was made to involve public and industry representatives throughout the entire effort. A series of public meetings was held with stakeholders during and following the generation of a preliminary draft study that was published in June at the request of the Nuclear Energy Institute (NEI). The partially completed DRAFT report was released to facilitate a stakeholder/NRC two day workshop that was held in July 1999. Information gained at the workshop and through other stakeholder interactions was constructive in completing this report.

Estimates of the risk from heavy load handling accidents were revised and criticality concerns were addressed in response to stakeholder feedback. A checklist was developed to establish seismic capability of SFPs, and industry commitments were documented to address the vulnerabilities that had been identified by the June 1999 draft report. Independent technical quality reviews of controversial aspects of the report were initiated to bring in outside expert opinion on the details of the report. These experts evaluated several areas of the report, including the human reliability analysis, seismic considerations, thermal-hydraulic calculations, and probabilistic risk assessment (PRA) assumptions and treatment. The PRA results were re-quantified to take into account the industry commitments to reduce risk vulnerabilities.

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 of 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 final shutdown

The results of this report estimated the generic frequency of events leading to zirconium fires at decommissioning plants to be less than 3×10^{-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 1×10^{-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. 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 initiation of the accident. Therefore, this analysis indicates that for the slowly evolving SFP accident scenarios 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 summary, the risk assessment shows low numerical risk results in combination with satisfaction of the safety principles as described in R.G. 1.174, such as defense-in-depth, maintaining safety margins, and performance monitoring. The staff concludes that under the

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assumptions of this study there is a low level of public risk from SFP accidents at decommissioning plants. In addition, the study shows that, after a period of one year following final shutdown, the low likelihood that a zirconium fire would occur, in combination with the long time frames available for taking off-site protective actions, provides a basis for relaxation of emergency planning requirements.

baseline

Make one spare

Chapter 4 also addresses the report's implications on security and insurance provisions at decommissioning plants. For security, the risk insights can be utilized to assess what target sets are important to protect against sabotage. However, any reduction in security provisions would be constrained by an effectiveness assessment of the safeguards provisions against a design basis threat. Therefore, the staff concludes that some level of security is required as long as the fuel in the SFP is exposed to a sabotage threat. For insurance, the reports points out that no definitive criteria exists that would allow relaxation on the basis of low event probability alone while the potential for a zirconium fire exists. Finally, inconsistencies were identified in current regulations regarding vehicle-borne bomb threats and insurance indemnification requirements for ISFSIs and decommissioning nuclear power plants. These inconsistencies should be revisited during the overall integration of rules for decommissioning plants.

In summary, the report provides a comprehensive treatment of SFP risks at decommissioning plants as it relates to emergency planning, insurance, and security requirements. The report systematically examines the differences between an operating reactor spent fuel pool configuration, and the typical SFP configuration in place at one year post-shutdown for a decommissioning plant. It provides the technical basis for determining the regulatory requirements for decommissioning plants using risk-informed decision making.

1.0 Introduction

The current body of Nuclear Regulatory Commission (NRC) regulations pertaining to light-water reactors (10 CFR 50) [Ref. 1] is primarily directed towards the safety of operating units. As some reactors have reached permanent shutdown condition and entered decommissioning status, the NRC has been faced with establishing the appropriate requirements and regulatory oversight necessary to provide adequate protection to the public. For decommissioning plants, the potential public risk is due primarily to the possibility of a zirconium fire associated with the spent fuel rod cladding. Due to the decay heat generated by the spent fuel, it must be continuously cooled and remain covered by water after removal from the reactor. A postulated event could occur if the systems which provide heat removal from the fuel pool fail, causing the cooling water to boil off from the pool until the fuel is uncovered. Alternatively, a leak in the pool could occur, that if not corrected, could also result in the spent reactor fuel becoming uncovered. For either scenario, the uncovered and uncooled spent fuel could heat up causing a fire of its zirconium cladding and releasing large quantities of radionuclides.

Decommissioning plants have requested exemptions to certain regulations as a result of their permanently defueled condition. While the current Part 50 regulatory requirements (developed for operating reactors) ensure safety at the decommissioning facility, some of these requirements may be excessive and not substantially contributing to public safety. Areas where regulatory relief has been requested in the past include exemptions from off-site emergency planning (EP), insurance, and safeguards requirements. Requests for consideration of changes in regulatory requirements are appropriate since the traditional accident sequences that dominate operating reactor risk are no longer applicable. For a defueled reactor in decommissioning status, public risk is predominantly from potential accidents involving spent fuel. Spent fuel can be stored in the spent fuel pool (SFP) for considerable periods of time, as remaining portions of the plant continue through decommissioning and disassembly. To date, exemptions have been requested and granted on a plant-specific basis. This has resulted in some lack of consistency and uniformity in the scope of evaluations conducted and acceptance criteria applied in processing the exemption requests.

To improve regulatory consistency and predictability, the NRC has undertaken this effort to improve the regulatory framework applicable to decommissioning plants. This framework will utilize risk-informed approaches to identify the design and operational features necessary to ensure that risks to the public from these shutdown facilities are sufficiently small. This framework will form the foundation upon which regulatory changes will be developed, as well as the basis for requesting and approving exemption requests in the interim, until the necessary rulemaking is completed.

In support of this objective, the NRC staff has completed a draft assessment of spent fuel pool risks. This assessment utilized probabilistic risk assessment (PRA) methods and was developed from analytical studies in the areas of thermal hydraulics, core physics, systems analysis, human reliability analysis, seismic and structural analysis, external hazards assessment, and off-site radiological consequences. The focus of the risk assessment was to identify potential severe accident scenarios at decommissioning plants, and to estimate the likelihood and consequences of these scenarios. Of primary concern are events that lead to loss of spent fuel pool water inventory or loss of cooling to the spent fuel assemblies, and events that result in fuel configurations that could lead to criticality conditions. For some period after reactor shutdown and after sustained loss of inventory or cooling, it is possible for the fuel

to heat up to the point where rapid oxidation and burning of the zirconium fuel cladding occurs leading to significant releases of radionuclides.

stef *inter-parallel completed draft*
A preliminary version of this draft report was issued for public comment and technical review in June 1999. Comments received from stakeholders and other technical reviewers have been considered in preparing this assessment. Quality assessment of the staff's preliminary analysis has been aided by a small panel of human reliability analysis (HRA) experts who evaluated the human performance analysis assumptions, methods and modeling, as well as a broad quality review carried out at the Idaho National Engineering & Environmental Laboratory (INEEL). *stef* *informs from* *excuse!* *Summer*

The conclusions and findings of the study provide guidance for the design and operation of spent fuel pool cooling and inventory make-up systems as well as practices and procedures necessary to ensure high levels of operator performance during off-normal conditions. This report concludes that, with the fulfillment of industry commitments and satisfaction of a number of additional staff assumptions, the risks from spent fuel pools will be sufficiently small to justify exemptions from selected current regulatory requirements and to form the basis for related rulemaking.

This report is divided into three main parts. 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 in Chapter 4 provides the implications of SFP risk on regulatory requirements, and outlines where industry commitments in combination with additional staff assumptions may be useful in improving spent fuel pool safety.

2.0 Risk-Informed Decision Making

The regulatory framework proposed in this report for decommissioning plants is based on a risk-informed process. In 1995, the NRC published its PRA Policy Statement [Ref 1], which stated that the use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art of the methods. Probabilistic risk assessment provides a structured analytical method to assess the various combinations of failures and events that result in undesirable consequences, such as core damage in an operating reactor. The end points of PRAs can be extended to include public health effects by modeling the timing and mode of containment failure and radioactive releases to the environment.

Subsequent to issuance of the PRA Policy Statement, the agency published Regulatory Guide (RG) 1.174 [Ref.2] which contained general guidance for application of PRA insights to the regulation of nuclear reactors. The guidelines in RG 1.174 pertain to the frequency of core damage accidents (CDF) and large early releases (LERF). For both CDF and LERF, RG 1.174 contains guidance on acceptable values for the changes that can be allowed due to regulatory decisions as a function of the baseline frequencies. For example, if the baseline CDF for a plant is below 1×10^{-4} per year, plant changes can be approved that increase CDF by up to 1×10^{-5} per year. If the baseline LERF is less than 1×10^{-5} per year, plant changes can be approved which increase LERF by 1×10^{-6} per year.

For decommissioning plants, the risk is primarily due to the possibility of a zirconium fire associated with the spent fuel rod cladding¹. The consequences of such an event do not equate exactly to either a core damage accident or a large early release². Zirconium fires in spent fuel pools potentially have more severe long term consequences than an operating reactor core damage accident, because there may be multiple cores involved, and because there is no containment surrounding the SFP to mitigate the consequences. On the other hand, they are different from a large early release, because the postulated accidents progress very slowly (allowing time for protective actions to be taken to significantly reduce early fatalities), and the absence of short lived isotopes in the release (e.g., iodine isotopes will have decayed away though early health effects are still possible from Cesium isotopes). As a result, the criteria of RG 1.174 cannot be applied directly to the risk of a decommissioning plant.

Even though the event progresses more slowly than an operating reactor large early release event and the isotopic make-up is somewhat different, the risk assessment consequence calculations performed by the staff³ (assuming multiple cores) show that large inventories of radioisotopes could be released that could have significant late health effects (latent cancers) for the population at some distance from the plant, as well as the potential for a small number of early fatalities. The staff has therefore decided that the end state and consequences of a spent fuel pool fire are sufficiently severe that the RG 1.174 LERF baseline guideline of 1×10^{-5} per year (the value of baseline risk above which the staff will only consider very small increases in risk) provides an appropriate frequency guideline for a decommissioning plant SFP risk, and a useful tool to be used in combination with other factors such as accident progression timing, to assess features, systems and operator performance needs of a spent fuel pool in a decommissioning plant. The staff therefore proposes 1×10^{-5} per year as the recommended pool performance guideline (PPG) for baseline zirconium fire frequency. In its letter of November 12, 1999 [Ref. 3], the Advisory Committee on Reactor Safeguards (ACRS) recommended that application of the LERF guideline as discussed above be utilized. The staff agrees with this recommendation.

2.1 Principles of Regulatory Guide 1.174

As discussed in RG 1.174, quantitative risk assessment is only one tool utilized in risk-informed decision making. RG 1.174 articulates the following safety principles which should be applied to the decommissioning case:

- “The proposed change meets the current regulations unless it is explicitly related to a requested exemption or rule change, i.e., a “specific exemption” under 10 CFR 50.12 or a “petition for rulemaking” under 10 CFR 2.802.
- The proposed change is consistent with the defense-in-depth philosophy.

¹See chapter 3 for more complete discussion of fuel pool risk scenarios

²RG 1.174 describes LERF as the frequency of unmitigated releases that have the potential for early health effects, in a time frame prior to effective evacuation of close-in population

³See Appendix 4 for consequence and health impact assessment

- The proposed change maintains sufficient safety margins.
- 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 impact of the proposed change should be monitored using performance measurement strategies."

While the focus of RG 1.174 was decision-making regarding changes to the licensing basis of an operating plant, the same risk-informed philosophy can be applied to rulemaking for decommissioning plants or to consider potential exemptions to current requirements. The intent and scope of these safety principles are discussed below. However, since the application of this study specifically relates to exemptions to a rule or a rule change for decommissioning plants, a discussion of the first principle regarding current regulations is not necessary nor is it provided. A discussion on how the rest of these principles are satisfied as demonstrated by the staff's safety assessment is provided in Chapter 4.

2.1.1 Defense-in-Depth

Defense-in-depth describes a multi-layered design and operational philosophy whose goal is to prevent the initiation of accidents or to prevent their progression to serious consequences. The defense-in-depth philosophy applies to the operation of the spent fuel pool, whether at an operating plant or in a decommissioning plant. In accordance with the Commission White Paper on Risk-Informed Regulation (March 11, 1999), "Defense-in-depth is an element of the NRC's Safety Philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility. The defense-in-depth philosophy ensures that safety will not be wholly dependent on any single element of the design, construction, maintenance, or operation of a nuclear facility. The net effect of incorporating defense-in-depth into design, construction, maintenance and operation is that the facility or system in question tends to be more tolerant of failures and external challenges."

Therefore, application of defense-in-depth could mean in part that there is more than one source of cooling water or that pump make-up can be provided by both electric as well as direct drive diesel pumps. Additionally, defense-in-depth can mean that even if a serious outcome (such as fuel damage) occurs, there is further protection such as containment to prevent radionuclide releases to the public. However, implementation of defense-in-depth for SFPs is different from that applied to nuclear reactors because of the different nature of the hazards. The robust structural design of a fuel pool, coupled with the simple nature of the pool support systems, goes far toward preventing accidents associated with loss of water inventory or pool heat removal. Additionally, because the essentially quiescent (low temperature, low pressure) initial state of the spent fuel pool and the long time available for taking corrective action associated with most release scenarios provide significant safety margin, a containment structure is not considered necessary as an additional barrier to provide an adequate level of protection to the public. Likewise, the slow evolution of most SFP accident scenarios allows for reasonable human recovery actions to respond to system failures. Chapter 4 summarizes the specific design and operational features of the SFP, industry commitments and the additional staff assumptions that ensure that SFP defense-in-depth is maintained. This level of defense is

achieved through preventative measures, appropriate mitigating systems, and an appropriate level of emergency planning.

2.1.2 Safety Margins

A safety margin can relate to the difference between the expected value of some physical parameter (e.g., temperature, pressure, stress, reactivity) and the point at which adequate performance is no longer assured. An example of this would be a containment pressure calculation which may show a peak accident pressure of 40 psig is reached for a structure which has a design capability of 60 psig and an actual ultimate capability of 110 psig. In this case there is margin from the accident calculation of 20 psig to the design limit as well as a large margin of 70 psig to the actual expected failure limit.

The safety margins associated with fuel in the spent fuel pool for many physical processes and parameters are much greater than those associated with an operating reactor. The spent fuel pool is in a quiescent state, at or near ambient temperature and pressure. The decay heat levels are much lower than those of the fuel in an operating reactor. This allows much greater time for heating and boil off of the coolant water, and for heat up of the fuel itself, once uncovered. The fuel is covered with approximately 23 feet of water at or near ambient temperature. The pool is designed with ample margin to criticality, using both passive (geometry) and active (poisons) means of reactivity control. Chapter 4 describes the provisions that ensure the SFP maintains adequate safety margins in a decommissioning plant.

2.1.3 Impact of Proposed Changes

The impact of the proposed change should be small. As discussed above, the staff is applying the pool performance guideline (PPG) of 1×10^{-5} per year frequency for a zirconium fire, which was developed from the treatment for LERF in RG 1.174 and a change guideline of 1×10^{-6} per year (assuming that the 1×10^{-5} per year PPG is already met). This PPG is used to assess the impact and acceptability of SFP risk in decommissioning plants. Chapters 3 and 4 discuss the design and operational characteristics of the SFP that are relied upon to produce the low baseline risk results. These are identified in the context of industry commitments as well as additional staff assumptions needed to produce the low SFP risk conclusions.

2.1.4 Implementation and Monitoring Program

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 structures, systems, and components (SSCs) that have been evaluated. This will ensure that the conclusions that have been drawn will remain valid.

Therefore, with respect to all the above safety principles, implementation and monitoring of important considerations could include such actions as: comparing a check list against the spent fuel pool seismic design and construction; control of heavy load movements; development and implementation of procedures and other provisions to ensure human reliability; monitoring the capability, reliability, and availability of important equipment; and

checking the effectiveness of on-site emergency response and plans for communication with off-site authorities. In many areas the implementation and monitoring may already be accomplished by utility programs such as those developed under the maintenance rule [Ref. 4].

3.0 Risk Assessment of Spent Fuel Pools at Decommissioning Plants

As discussed in Chapter 1 of this paper, the risks from a decommissioning plant are very different from an operating plant. Once fuel is permanently removed from the reactor vessel, the primary public risk in a decommissioning facility is associated with the spent fuel pool. The spent fuel assemblies are retained in the storage pool, and are submerged in water to provide cooling of the fuel's remaining decay heat as well as to provide shielding for the radioactive assemblies. The most severe accidents postulated for SFPs are associated with the loss of water (either through boil-off or draining) from the pool.

Depending on the time since reactor shutdown and fuel rack configurations, there may be sufficient heat to cause the clad to heat up over time, swell and burst in the event of loss of pool water. The breach in the clad would result in the release of radioactive gases present in the gap between the fuel and clad, called "a gap release" (See Appendix 1). If the fuel continues to heat up, the temperature of the zirconium clad will reach the point of rapid oxidation in air. This reaction of zirconium and air is exothermic. The energy released from the reaction combined with the fuel's decay energy can cause the reaction to become self-sustaining and lead to the ignition of the zirconium, or a "zirconium fire." The increase in heat from the oxidation reaction could also raise the temperature in adjacent fuel assemblies and cause the propagation of the oxidation reaction. This zirconium fire would result in a significant release of the fission products contained in the spent fuel, which would be dispersed from the reactor site due to the thermal plume from the zirconium fire. Consequence assessments (Appendix 4) have shown that such a zirconium fire could have significant latent health effects (cancers) as well as the possibility of a small number of early fatalities. Gap releases for fuel from a reactor that has been shut down more than a year release only moderately small quantities of radionuclides, in the absence of a zirconium fire, and would only be of concern for on-site effects.

Based upon the preceding insights, the staff conducted its risk evaluation to estimate the likelihood of credible accident scenarios that could result in loss of pool water and fuel heat up to the point of rapid oxidation. In addition to developing an order-of-magnitude assessment of the level of risk associated with SFPs at decommissioning plants, the objective of this risk assessment included the identification of potential vulnerabilities, and the design and operational characteristics that would minimize these vulnerabilities. Since the decay time at which air cooling alone is sufficient to prevent a zirconium fire is very plant specific, the cut off time (when a zirconium fire can no longer occur) for this risk assessment cannot be pre-determined. Rather, the insights should be considered as generally applicable to a decommissioning plant until the spent fuel decay heat level decreases to a point where rapid oxidation would not occur with complete loss of water. After a decay period that precludes fuel heat up to zirconium fire conditions, no significant risk remains from storage of the spent fuel. Preliminary calculations (see Appendix 1) show this time will vary depending on fuel burn up, SFP storage configuration and loading pattern of the assemblies, and could occur at a period as long as five years from plant shutdown.

In order to support the risk evaluation, the staff conducted a thermal hydraulic assessment of the SFP for various scenarios such as loss of pool cooling and loss of inventory. These

calculations provided information on heat up and boil off rates for the pool, as well as heat up rates for the uncovered fuel assemblies and timing to initiation of zirconium fire for a number of scenarios and sequences. The results of these calculations provided fundamental information on the timing of accident sequences and provided insights on the time available to recover from events and time available to initiate off-site measures, if necessary. This information was then utilized in the risk assessment to support the human reliability analysis used to assess the likelihood of recovering level or cooling before a zirconium fire occurs.

For these calculations, the end state assumed for the accident sequences was when the water level reached the top of the fuel assemblies, rather than calculating the temperature response of the fuel as the level gradually drops. This simplification was utilized because of the complex heat transfer mechanisms and chemical reactions occurring in the fuel assemblies that are slowly being uncovered. This analytical approach understates the time that is available for possible operator recovery of SFP events prior to initiation of a zirconium fire. However, since the recoverable events such as small loss of inventory or loss of power/pool cooling, are very slowly evolving events, many days are generally available for recovery whether the end point of the analysis is uncovering of the top of the fuel or complete fuel uncovering. The extra time available (estimated to be in the tens of hours) as the water level boils down the assemblies, would not impact the very high probabilities of operator recovery from these events given the industry commitments and additional staff assumptions. In its letter of November 12, 1999 [Ref. 1], the ACRS recommended that the end state of top of fuel uncovering be used for the SFP analysis along with application of the LERF criteria discussed in Chapter 2. The staff agrees with this recommendation. However, there are some exceptions noted in our response to the ACRS. The details of the staff thermal hydraulic assessment are provided in Appendix 1.

Prior to the staff's preliminary risk assessment, the most extensive work on spent fuel pool risk was in support of Generic Issue (GI) 82, "Beyond Design Basis Accidents for Spent Fuel Pools" [Ref. 2]. This report assessed the SFP risk for operating reactors and concluded that a seismic event was the dominant initiating event for the loss of inventory.

While the staff drew from the GI 82 work in its assessment, it was concluded that because of significant differences between operating and decommissioning plant spent fuel pool cooling systems, a complete assessment of SFP risk at decommissioning plants should be conducted, considering all potentially significant initiators, and reflecting the unique features found in a shutdown facility. The results of the staff assessments are discussed below. A summary of industry commitments, staff assumptions (relied upon in the risk assessment) and a discussion of how the decision criteria in Chapter 2 is satisfied are discussed in Chapter 4. Conclusions on how the SFP risk insights and decision criteria apply to potential changes in emergency planning, insurance, and safeguard are also discussed in Chapter 4.

3.1 Basis and Findings of SFP Risk Assessment

In order to follow the framework for the regulatory decision process described in Chapter 2, a comprehensive assessment of SFP risk was necessary. To gather information on SFP design and operational characteristics for the preliminary risk assessment done for the June 1999 draft report, the staff conducted site visits to four decommissioning plants to ascertain what would be an appropriate model for decommissioning spent fuel pools. The site visits confirmed that the as-operated spent fuel pool cooling systems were different than those in operation when the plants were in power operation. The operating plant pool cooling and make-up systems have

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attached

generally been removed and replaced with portable and skid-mounted pumps and heat exchangers. While in some cases there are redundant pumps, physical separation, barrier protection and emergency on-site power sources are no longer maintained. Modeling information for the PRA analysis was determined from system walk-downs as well as limited discussions with the decommissioning plant staff. Since limited information was collected for the preliminary assessment on procedural and recovery activities as well as what the minimum configuration a decommissioning plant might have, a number of assumptions and bounding conditions were assumed for the June 1999 preliminary study. These preliminary results have been refined in this draft assessment after obtaining more detailed information from industry on SFP design and operating characteristics for a decommissioning plant, as well as a number of industry commitments that contribute to achieving low risk findings from SFP incidents. These revised results also reflect improvements in the PRA model since publication of the June 1999 report.

slat
NA

The staff identified the following nine initiating event categories to investigate as part of the quantitative risk assessment on SFP risk:

- Loss of Off-site Power from plant centered and grid related events
- Loss of Off-site Power from events initiated by severe weather
- Internal Fire
- Loss of Pool Cooling
- Loss of Coolant Inventory
- Seismic Event
- Cask Drop
- Aircraft Impact
- Tornado Missile

In addition, a qualitative risk perspective was developed for inadvertent criticality in the SFP. The risk model, as developed by the staff and supplemented through a quality review from Idaho National Engineering & Environmental Laboratory (INEEL), is provided in Appendix 2. Appendix 2 also includes the modeling details for the heavy load drop, aircraft impacts, seismic and tornado missile assessments. Input and comments from stakeholders were also utilized in updating the June 1999 preliminary model to the present draft model.

3.2 Characteristics of SFP Design and Operations for a Decommissioning Plant

Based upon information gathered from the site visits and interactions with NEI and other stakeholders, the staff has modeled the spent fuel pool cooling system (SFPC) (see Figure 3.1) as being located in the SFP area and consisting of motor-driven pumps, a heat exchanger, an ultimate heat sink, a make-up tank, a filtration system and isolation valves.

Suction is taken from the spent fuel pool via one of the two pumps and is passed through the heat exchanger and returned back to the pool. One of the two pumps on the secondary side of the heat exchanger rejects the heat to the ultimate heat sink. A small amount of water from the suction line is diverted to the filtration process and is returned back into the discharge line. A manually operated make-up system (with a limited volumetric flow rate) supplements the small losses due to evaporation. In the case of prolonged loss of SFPC system or loss of inventory events, the inventory in the pool can be made up using the firewater system, if needed. There are two firewater pumps, one motor-driven (electric) and one diesel-driven, which provide

firewater in the SFP area. A firewater hose station is provided in the SFP area. The firewater pumps are located in a separate structure.

Based upon information obtained during the site visits and discussions with the decommissioning plant personnel during those visits, the staff also made the following assumptions that are believed to be representative of a typical decommissioning facility:

- The make-up capacity (with respect to volumetric flow) is assumed to be as follows:

Make-up pump: 20 - 30 gpm
Firewater pump: 100 - 200 gpm
Fire engine: 100 - 250 gpm [depending on hose size: 1-½" (100 gpm) or 2-½" (250 gpm)]

The staff also assumed that for the larger loss-of-coolant inventory accidents, water addition through the make-up pumps does not successfully mitigate the loss of inventory event unless the location of inventory loss is isolated.

- The SFP operators perform walk-downs of the SFP area once per shift (8 to 12hour shifts). A different crew member is assumed for the next shift. The staff also assumed that the SFP water is clear and pool level is observable via a measuring stick in the pool that can alert fuel handlers to level changes.
- Plants do not have drain paths in their spent fuel pools that could lower the pool level (by draining, suction, or pumping) more that 15 feet below the normal pool operating level.

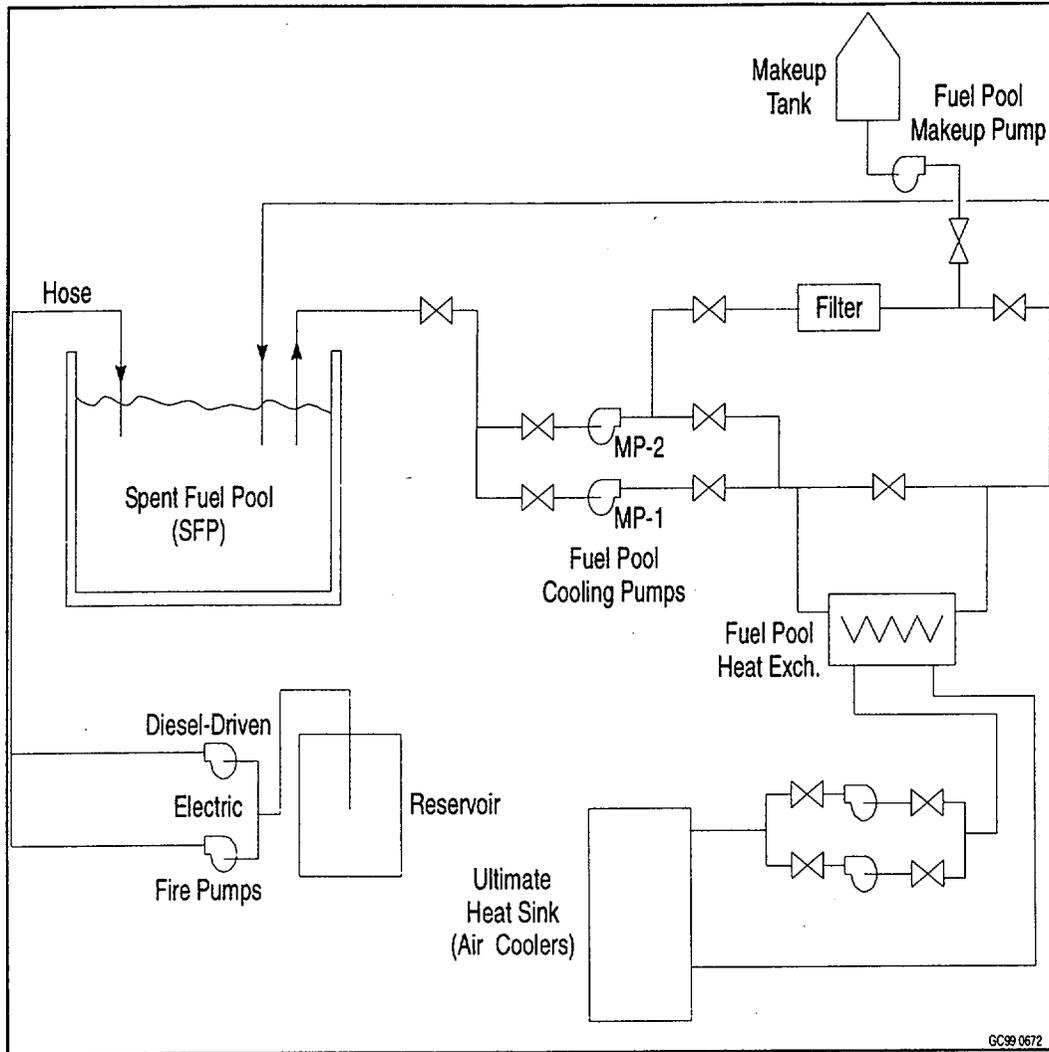
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Figure 3.1 Assumed Spent Fuel Pool Cooling System



Based upon the results of the June 1999 preliminary risk analysis and its associated sensitivity cases, it became clear that many of the risk sequences were quite sensitive to the performance of the SFP operating staff in identifying and responding to off-normal conditions. This is due to the fact that the remaining systems of the SFP are relatively simple with manual rather than automatic initiation of backups or realignments. Therefore, if scenarios such as loss of cooling or inventory loss to the pool occur, operator response to diagnose the failures and bring on-site and off-site resources to bear are instrumental for ensuring that the fuel assemblies remain cooled and a zirconium fire is prevented.

As part of its technical evaluations the staff assembled a small panel of experts⁴ which identified the attributes necessary to achieving very high levels of human reliability for responding to potential accident scenarios in a decommissioning plant SFP. (A discussion of these attributes and the HRA methodology used is provided in Section 3.2 of Appendix 2a.)

Upon consideration of the sensitivities identified in the staff's preliminary study and to reflect actual operating practices at many decommissioning facilities, the nuclear industry, through NEI, made important commitments (reproduced in Appendix 6) which were reflected in the staff's updated risk assessment. The revisions to the risk assessment generally reflect changes of assumptions in the areas shown below. The applicability of the specific industry decommissioning commitments (IDCs) with respect to the risk analysis results are discussed later in this chapter. How the commitments relate to specific risk conclusions and safety principles is also discussed in Chapter 4. Any future rulemaking or other regulatory activity would determine how these commitments are implemented.

Where additional operational and design considerations (beyond industry commitments) had to be assumed to ensure that the low risk estimates presented in this study are achieved, the staff identified additional staff decommissioning assumptions (SDAs) which are detailed in later sections of this report. As with the industry commitments, staff assumptions on SFP design and operational features, which were necessary to achieve the low SFP risk findings of this report, will be identified and implemented as appropriate in future regulatory activities.

Industry Decommissioning Commitments

- | | |
|--------|--|
| 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). |
| 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. |

⁴Panel composed of Gareth Parry, U.S. NRC; Harold Blackman, INEEL; and Dennis Bley, Buttonwood Consulting

- 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 #6 Spent fuel pool seals that could cause leakage leading to fuel uncover 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 controls 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) controls for pump suction and discharge points. The functionality of anti-siphon devices will be periodically verified.
- 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.
- 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.
- IDC #10 Routine testing of the alternative fuel pool make-up system components will be performed and administrative controls for equipment out of service will be implemented to provide added assurance that the components would be available, if needed.

Based upon the above design and operational features, industry commitments, technical comments from stakeholders and the input from the INEEL technical review, the staff's SFP risk model was updated. The results for the initiators which were assessed quantitatively are shown in Table 3.1.

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 ⁵	2.0X10 ⁻⁰⁷
Seismic Event ⁶	<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 3X10⁻⁶ 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.

⁵For 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.

⁶This 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.

Will this statement cause NEI to want to back out of some commitment since they may not be necessary to be below the PPE? Hopefully not. IT will change risk
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As discussed in more detail in Appendix 2, the results of the risk analysis depends on assumptions on the design and operational characteristics of the SFP facility. The inputs that have the potential to significantly influence the results are summarized below.

- The modeled system configuration is described in Chapter 3.2. The assumed availability of a diesel powered fire pump is an important element in the conclusion that fuel uncover frequency is low for the loss of off-site power initiating events and the internal fire initiating event. The assumption of the availability of a redundant fuel pool cooling pump is not as important since the modeling of the recovery of the failed system includes repair of the failed pump, not just the startup of the redundant pump. Finally, multiple sources of make-up water are assumed for the fire pumps. This lessens the concern for possible dependencies between initiating events (e.g., severe weather events, high wind events, or seismic events) and the availability of make-up water supply (e.g., fragility of the fire water supply tank).
- Credit is taken for industry/NEI commitments as described in Chapter 3.2. Without this credit, the risk is estimated to be more than an order of magnitude higher. Specifically,
 - IDC #1 is credited for lowering the risk from cask drop accidents.
 - IDCs # 2, 3, 4, and 8 are credited for the high probability of recovery of loss of cooling (including events initiated by loss of power or fire) and loss of inventory scenarios. In order to take full credit for these commitments, additional assumptions concerning how these commitments will be implemented have been made. These include: procedures and training are explicit in giving guidance on the capability of the fuel pool make-up system, and when it becomes essential to supplement with alternate higher volume sources; procedures and training are sufficiently clear in giving guidance on early preparation for using the alternate make-up sources; and walk-downs are performed on a regular (once per shift) basis and the operators document the observations in a log. The latter is important to compensate for potential failures to the instrumentation monitoring the status of the pool.
 - IDC # 5 is credited for the high probability of early identification and diagnosis (from the control room) of the loss of cooling or loss of inventory.
 - IDCs # 6, 7, and 9 are credited with lowering the initiating event frequency for the loss of inventory event from its historical levels. In addition, these commitments were used to justify the assumption that a large non-catastrophic leak rate is limited to approximately 60 gpm, and the assumption that the leak is self limiting after a drop in level of 15 feet. These assumptions may be non-conservative on a plant-specific basis depending on SFP configuration and specific commitments on configuration control.
 - IDC # 10 is credited for the equipment availabilities and reliabilities used in the analysis. In addition, if there are specific administrative procedures to control the out of service duration for the diesel fire pump, the relatively high unavailability for this pump (of 0.18) could be lowered.

- Initiating event frequencies for the loss of cooling, loss of inventory, and loss of off-site power are based on generic data. In addition, the probability of power recovery is also based on generic information. Site specific differences would proportionately affect the risk from these initiating events.

The various initiating event categories are discussed below. The staff's qualitative risk insights on the potential for SFP criticality are discussed at the end of this chapter.

3.3 Internal Event Scenarios Leading to Fuel Uncovery

The following summary is a description of the accident associated with each internal event initiator. Details of the assessment are provided in Appendix 2.

3.3.1 Loss of Cooling

The loss of cooling initiating event may be caused by the loss of coolant system flow from the failure of pumps or valves, from piping failures, from an ineffective heat sink (e.g., loss of heat exchangers), or from a local loss of power (e.g., electrical connections). While it may not be directly applicable due to design differences in a decommissioning plant, operational data from NUREG-1275, Volume 12 [Ref. 3] shows that the frequency of loss of spent fuel pool cooling events in which a temperature increase of more than 20°F occurred can be estimated to be on the order of two to three events per 1000 reactor years. The data also showed that, for the majority of events, the duration of the loss of cooling was less than one hour. Only three events exceeded 24 hours, with the maximum duration being 32 hours. There were four events where the temperature increase exceeded 20°F, with the maximum increase being 50°F.

The calculated fuel uncovery frequency for this initiating event is 1.4×10^{-8} per year. To have fuel uncovery, the plant operators would have to fail to recover the cooling system (either fails to notice the loss of cooling indications, or fails to repair or restore the cooling system). In addition, the operators would have to fail to provide make-up cooling using other on-site sources (e.g., fire pumps) or off-site sources (e.g., use of a fire brigade). For these recovery actions, there is a lot of time available. In the case of 1-year-old fuel (i.e., fuel that was in the reactor when it was shutdown one year previously), approximately 130 hours is available. Indications of a loss of pool cooling that are available to operators include: control room alarms and indicators, local temperature measurements, and eventually increasing area temperature and humidity and low pool water level from boil-off.

Based on the assumptions made, the frequency of fuel uncovery is estimated to be very low. A careful and thorough adherence to IDCs 2, 5, 8 and 10 is crucial to establishing the low frequency. In addition, however, the assumption that walk-downs are performed on a regular (once per shift) basis is important to compensate for potential failures of the instrumentation monitoring the status of the pool. The analysis has also assumed that the procedures and/or training are explicit in giving guidance on the capability of the fuel pool make-up system, and when it becomes essential to supplement with alternative higher volume sources. The analysis also assumed that the procedures and training are sufficiently clear in giving guidance on early preparation for using the alternative make-up sources.

It should be noted that there were two recent events involving a loss of cooling at SFPs. The first, occurring in December 1998 at Browns Ferry Unit 3, involved a temperature increase of

approximately 25°F over a two day period. This incident, caused by the short cycling of cooling water through a stuck-open check valve, was not detected by the control room indicators due to a design flaw in the indicators. In the second event, occurring in January 2000, the SFP temperature increased by approximately 40 to 50°F at the Duane Arnold Unit 1 plant. The incident, which was undetected for approximately two and a half days, was caused by operator failure to restore the SFP cooling system heat sink following maintenance activities. At this plant, there was no alarm for high fuel pool temperature, although temperature indicators are available in the control room. Since the conditional probability of fuel uncover is low given a loss of cooling initiating event, the addition of these two recent events to the database will not affect the conclusion that the risk from these events is low. However, the recent events further illustrate the importance of industry commitments, particularly IDC # 5 which requires temperature instrumentation and alarms in the control room. In addition, the staff assumption that walk-downs are performed on a regular (once per shift) basis, with the operator documenting the observations in a log, is also an important element to keep the risk low, since the walk-downs compensate for potential failures of the control room instrumentation.

Even with the above referenced industry commitments, the additional need of walk-downs being performed at least once per shift had to be assumed in order to arrive at the low accident frequency calculated for this scenario. This additional assumption is identified by the staff as a staff decommissioning assumption (SDA #1). In addition, this SDA includes the assumed presence of explicit procedures and operator training which provide guidance on the capability and availability of inventory make-up sources and the time available to initiate these sources.

SDA #1 Walk-downs of SFP systems will be performed at least once per shift by the operators. Procedures will be developed for and employed by the operators to provide guidance on the capability and availability of on-site and off-site inventory make-up sources and time available to initiate these sources for various loss of cooling or inventory events.

3.3.2 Loss of Coolant Inventory

This initiator includes loss of coolant inventory from events such as those resulting from configuration control errors, siphoning, piping failures, and gate and seal failures. Operational data provided in NUREG-1275, Volume 12 show that the frequency of loss of inventory events in which a level decrease of more than one foot occurred can be estimated to be less than one event per 100 reactor years. Most of these events are as a result of fuel handler error and are recoverable. Many of the events are not applicable in a decommissioning facility. NUREG-1275 shows that, except for one event that lasted for 72 hours, there were no events that lasted more than 24 hours. Eight events resulted in a level decrease of between one and five feet, and another two events resulted in an inventory loss of between five and ten feet.

Using the information from NUREG-1275, it can be estimated that 6% of the loss of inventory events will be large enough and/or occur for a duration that is long enough so that isolation of the loss is required if the only system available for make-up is the spent fuel pool make-up system. For the other 94% of the cases, operation of the make-up pump is sufficient to prevent fuel uncover.

The calculated fuel uncover frequency for loss of inventory events is 3.1×10^{-9} per year. Fuel uncover occurs if plant operators fail to initiate inventory make-up either by use of on-site sources such as the fire pumps or off-site sources such as the local fire department. In the

case of a large leak, isolation of the leak would also be necessary if the make-up pumps are utilized. The time available for operator action is considerable, and even in the case of a large leak, it is estimated that 40 hours will be available. Operators will be alerted to a loss of inventory condition by control room alarms and indicators, visibly decreasing water level in the pool, accumulation of water in unexpected locations and local alarms (radiation alarms, building sump high level alarms, etc.).

As in the case for the loss of pool cooling, the frequency of fuel uncover is calculated to be very low. Again a careful and thorough adherence to IDCs 2, 5, 8 and 10 is crucial to establishing the low frequency. In addition, the assumption that walk-downs (see SDA 1 above) are performed on a regular (once per shift) basis is important to compensate for potential failures of the instrumentation monitoring the status of the pool, the assumption that the procedures and/or training are explicit in giving guidance on the capability of the fuel pool make-up system, and when it becomes essential to supplement with alternative higher volume sources. The assumption that the procedures and training are sufficiently clear in giving guidance on early preparation for using the alternative make-up sources, are crucial to establishing the low frequency. In addition, IDCs 6, 7 and 9 have been credited with lowering the initiating event frequency.

3.3.3 Loss of Off-site Power from Plant-Centered and Grid Related Events

A loss of off-site power from plant-centered events typically involves hardware failures, design deficiencies, human errors (in maintenance and switching), localized weather-induced faults (e.g., lightning), or combinations of these. Grid-related events are those in which problems in the off-site power grid cause the loss of off-site power. With off-site power lost (and therefore on-site power is lost too, since we assume there is no diesel generator available to pick up the necessary electrical loads), there is no effective heat removal process for the spent fuel pool. If power were not restored quickly enough, the pool would heat up and boil off inventory until the fuel is uncovered. The diesel-driven fire pump would be available to provide inventory make-up. If the diesel-driven pump fails, and if off-site power were not recovered in a timely manner, recovery using off-site fire engines is a possibility. With 1-year-old fuel (i.e., the newest fuel in the fuel pool was shutdown in the reactor one year ago), approximately 130 hours is available for this recovery action.

Even given recovery of off-site power, the plant operators have to restart the fuel pool cooling pumps. Failure to do this or failure of the equipment to restart will necessitate other operator recovery actions. Again, considerable time is available.

The calculated fuel uncover frequency for this sequence of events is 3×10^{-8} per year. This frequency is very low, and similar to the cases for the loss of pool cooling and loss of inventory, is based on adherence to IDCs 2, 5, 8, and 10. In addition, the performance of regular plant walk-downs, and the availability of clear and explicit procedures and operator training is assumed as documented in SDA #1 above.

3.3.4 Loss of Off-site Power from Severe Weather Events

This event represents the loss of SFP cooling due to a loss of off-site power from severe weather-related events. This includes contributions from hurricanes, snow and wind, ice, wind and salt, wind, and one tornado event. Because of their potential for severe localized damage,

tornadoes and their direct impact to the site were analyzed separately in Appendix 2e and summarized in Chapter 3.4.3 of this report.

Until off-site power is recovered, the electrical pumps would be unavailable and the diesel-driven fire pump would be available to only provide make-up. When compared to the loss of off-site power events from grid-related and plant-centered causes, recovery of off-site power in this case is assumed to be less probable. In addition, given the conditions, it would be more difficult for off-site help to assist the fuel handlers at the site than for an ordinary loss of off-site power event.

The calculated fuel uncover frequency for this event is 1.3×10^{-7} per year. As in the previous cases, this estimate was based on IDCs 2, 5, 8, 10 and on assumptions documented in SDA #1. In addition, IDC 3, related to having procedures in place for communication between on-site and off-site organizations during severe weather, is also important in the analysis for increasing the likelihood of off-site resources being able to respond effectively.

3.3.5 Internal Fire

This event tree models the loss of SFP cooling caused by internal fires. The staff assumed that there is no automatic fire suppression system for the SFP cooling area. The fuel handler may initially attempt to manually suppress the fire given that they respond to the control room or local area alarms. If the fuel handler fails to respond to the alarm, or is unsuccessful in extinguishing the fire within the first 20 minutes, the staff assumed that the SFP cooling system will be significantly damaged and cannot be repaired within a few days. Once the inventory level drops below the SFP cooling system suction level, the fuel handlers have about 85 hours to provide some sort of alternative make-up, either using the site firewater system or by calling upon off-site resources. It was assumed that fire damages the plant power supply system such that the power to the electrical firewater pump is lost and would not be available.

The calculated fuel uncover frequency for this event is 4.5×10^{-8} per year. As in the previous cases, this estimate was based on IDCs 2, 5, 8 and 10 and on the staff assumptions in SDA #1. In addition, IDC 3, related to having procedures in place for communication between on-site and off-site organizations during severe weather, is also important in the analysis for increasing the likelihood of off-site resources being able to respond effectively to this fire event by increasing the likelihood for recovery using off-site resources.

3.3.6 Heavy Load Drops

The staff investigated the frequency of dropping a heavy load in or near the spent fuel pool, and investigated potential damage to the pool from such a drop. The previous assessment done for resolution of Generic Issue 82 (in NUREG/CR-4982 (Ref 4)) only considered the possibility of a heavy load drop falling on the pool wall. The assessment conducted for this study identified other failure modes, such as the pool floor, as also being credible for some sites. Details of the heavy load evaluation can be found in Appendix 2c. The analysis exclusively considered drops that were severe enough to catastrophically damage the spent fuel pool such that pool inventory would be lost rapidly and it would be impossible to refill the pool using on-site or off-site resources. In essence there is no possibility for mitigation in such circumstances, only prevention. A catastrophic heavy load drop (that caused a large leakage path in the pool) would lead directly to a zirconium fire approximately 10 hours after the drop, depending on fuel age, burn up, and configuration. The dose rates in the pool area prior to any zirconium fire

would be on the order of tens of thousands of rem per hour, making any potential recovery actions such as temporary large inventory addition systems very difficult. The staff concluded that non-catastrophic damage to the pool or its support systems from a load drop is captured and bound by other initiators.

Based on discussions with staff structural engineers, it was assumed that only spent fuel shipping casks had sufficient weight to catastrophically damage the pool if dropped. The staff assumed there is a very low likelihood that other heavy loads would be moved over the spent fuel pool, and in addition, if there were a drop of one of these lighter loads over the spent fuel pool, there would be a very low likelihood that it would cause catastrophic damage to the pool.

For a non-single failure proof load handling system, the likelihood of a heavy load drop (i.e., the drop frequency) was estimated, based on NUREG-0612 information, to have a mean value of 3.4×10^{-4} per year. The number of heavy load lifts was based on the NEI estimate of 100 spent fuel shipping cask lifts per year, which probably is an overestimate. For single failure proof load handling system or a plant conforming to the NUREG-0612 guidelines, the plant is estimated to have a drop frequency mean value of 9.6×10^{-6} per year, again for 100 heavy load lifts per year but using data from U.S. Navy crane experience. Once the load is dropped, the analysis must then consider whether the drop would do significant damage to the spent fuel pool.

When estimating the failure frequency of the pool floor and pool wall, the staff assumed that heavy loads physically travel near or over the pool approximately 13% of the total path lift length (the path lift length is the distance from the lift of the load to the placement of the load on the pool floor). The staff also assumed that the critical path length (the fraction of total path the load is lifted high enough above the pool that a drop could cause damage to the structure) is approximately 16% of the time the load is near or over the pool. The staff estimated the catastrophic failure rate from heavy load drops to have a mean value of 2.1×10^{-5} per year for a non-single failure proof system where reliance is placed on electrical interlocks, fuel handling system reliability, and safe load path procedures. The staff estimated the catastrophic failure rate from heavy load drops to have a mean value of 2×10^{-7} per year for a single failure proof system. The staff assumed that licensees which chose the non-single failure proof system option in NUREG-0612 performed appropriate analyses and mitigated actions to reduce the expected frequency of catastrophic damage to the same range as that of facilities with a single failure proof system.

NEI has made a commitment (IDC #1) for the nuclear industry that future decommissioning plants will comply with phases 1 and 2 to the NUREG-0612 guidelines. Consistent with this industry commitment, the additional assurance of a well performed and implemented load drop analysis, including mitigative actions, was assumed in order to arrive at a low accident frequency for non-single failure proof systems to be comparable to single failure proof systems.

SDA #2 Load Drop consequence analyses will be performed for facilities with non-single failure proof systems. The analyses and any mitigative actions necessary to preclude catastrophic damage to the spent fuel pool that would lead to a rapid pool draining would be sufficient to demonstrate that there is high confidence in the facilities ability to withstand a heavy load drop.

is there a wt. difference between shipping & transfer casks? are we making a distinction?

The estimated range of catastrophic damage to the PWR spent fuel pool, resulting in uncovering of the spent fuel, is 9.6×10^{-12} to 4.3×10^{-8} per year with a mean value estimated at 2.9×10^{-9} per year. The frequency of catastrophic BWR spent fuel pool damage resulting from a direct hit by a large aircraft is estimated to be the same as that for the PWR. Mark-I and Mark-II secondary containments generally do not appear to have any significant structures that might reduce the likelihood of aircraft penetration. Mark-III secondary containments may reduce the likelihood of penetration somewhat, as the spent fuel pool may be considered to be protected on one side by additional structures.

The mean value for an aircraft damaging a support system is in the 7×10^{-7} per year, or less, range. This is not the estimated frequency of fuel uncovering or a zirconium fire caused by damage to the support systems, since the frequency estimate does not include recovery, either from on-site or off-site sources. As an initiator to failure of a support system leading to fuel uncovering and a zirconium fire, an aircraft crash is bound by other more probable events. Recovery of the support systems will reduce the likelihood of spent fuel uncovering.

3.4.3 Tornadoes

A risk evaluation of tornado threats to spent fuel pools was performed (details are in Appendix 2e). The staff assumed that very severe tornadoes (F4 to F5 tornadoes on the Fujita scale) would be required to cause catastrophic damage to a PWR or BWR spent fuel pool. The staff then looked at the frequency of such tornadoes occurring and the conditional probability that if such a tornado hit the site, it would seriously damage the spent fuel pool or its support systems. To do this, the staff examined the frequency and intensity of tornadoes in each of the states within the continental U.S. using the methods described in NUREG/CR-2944 [Ref. 7]. The frequency of having an F4 to F5 tornado that directly impacts the site is estimated to be 5.6×10^{-7} per year for the central U.S., with a U.S. average value of 2.2×10^{-7} per year.

The staff then considered what level of damage an F4 or F5 tornado could do to a spent fuel pool or its support systems. Based on the buildings housing the spent fuel pools and the thickness of the spent fuel pools themselves, the estimated probability of catastrophic failure given a tornado missile is very low. Hence, the overall frequency of catastrophic pool failure caused by a tornado is extremely low (i.e., the calculated frequency of such an event is less than 1×10^{-9} per year)

The staff assumed that an F2 to F5 tornado would be required if significant damage were to occur to spent fuel pool support systems (e.g., power supply, cooling pumps, heat exchanger, or make-up water supply). These tornadoes have wind speeds that result in damage characterized as significant, severe or worse. The frequency of having an F2 to F5 tornado is estimated to be 1.5×10^{-5} per year for the central U.S., with a U.S. average value of 6.1×10^{-6} per year. This is not the estimated frequency of fuel uncovering or a zirconium fire caused by damage to the support systems, since the frequency estimate does not include credit for maintaining pool inventory from either on-site or off-site sources. The probability of failing to maintain inventory was estimated for the case of loss of off-site power from severe weather, where it was assumed that the principal impact of the severe weather was to hamper recovery of off-site power and also to increase the probability of failing to bring off-site sources to bear because of damage to the infrastructure. The situation with tornadoes is different, because the damage caused by a tornado is relatively localized. Therefore, while, a direct hit on the plant could also disable the diesel fire pump, it would be unlikely to also disable off-site resources to the same degree. Therefore, the probability of failing to bring in the off-site sources can be

argued to be the same as for the seismic case, i.e., 1×10^{-4} , (See Appendix 2b) under the assumption that NEI IDCs 3 and 4 are implemented. Therefore, the fuel uncover frequency from the loss of SFP support systems from tornado events is estimated to be less than 10^{-9} per year.

Missiles generated by high winds (for example, straightwinds or hurricanes) are not as powerful as those generated by tornadoes. Therefore, high winds are estimated to have a negligible impact on catastrophic failure of the SFP resulting in fuel uncover. With respect to impact on SFP inventory and cooling, the risk for pool uncover from high winds is assumed to be bounded by scenarios such as those where there is a loss of off-site power from severe weather, and where off-site power is not recovered.

3.4.4 Criticality in Spent Fuel Pool

In Appendix 3 the staff performed an evaluation of the potential scenarios that could lead to criticality and identified those that are credible.

In this section the staff provides its qualitative assessment of risk due to criticality in the SFP, and its conclusions that with the additional assumptions, the potential risk from SFP criticality is small.

The assessment referenced in Appendix 3 identified two scenarios as credible, which are listed below.

- (1) A compression or buckling of the stored assemblies due to being impacted by a dropped heavy load (such as fuel cask) could result in a more optimum geometry (closer spacing) and thus create the potential for criticality (see the NRC staff report "~~Assessment of the Potential for Criticality in Decommissioned Spent Fuel Pools,~~" in Appendix 3). Compression is not a problem for high-density PWR or BWR racks because they have sufficient fixed neutron absorber plates to mitigate any reactivity increase, nor is it a problem for low-density PWR racks if soluble boron is credited. But compression of a low-density BWR rack could lead to a criticality since BWR racks contain no soluble or solid neutron absorbing material. This is not a surprising result since low-density BWR fuel racks use geometry and fuel spacing as the primary means of maintaining subcriticality. High-density racks are those that rely on both fixed neutron absorbers and geometry to control reactivity. Low-density racks rely solely upon geometry for reactivity control. In addition, all PWR pools are borated, whereas BWR pools contain no soluble neutron absorbing material. If BWR pools were borated, criticality would not be achievable for a low-density rack compression event.
- (2) If the stored assemblies are separated by neutron absorber plates (e.g., Boral or Boraflex), loss of these plates could result in a potential for criticality for BWR pools. For PWR pools, the soluble boron in the fuel pool water would be sufficient to maintain sub-criticality. The absorber plates are generally enclosed by cover plates (stainless steel or aluminum alloy). The tolerances within a cover plate tend to prevent any appreciable fragmentation and movement of the enclosed absorber material. The total loss of the welded cover plate is not considered feasible.

Boraflex has been found to degrade in spent fuel pools due to gamma radiation and exposure to the wet pool environment. For this reason, the NRC issued Generic Letter 96-04 to all holders of operating licenses, on Boraflex degradation in spent fuel storage racks. Each addressee that uses Boraflex was requested to assess the capability of the Boraflex to maintain a 5% sub-criticality margin and to submit to the NRC proposed actions to monitor the margin or confirm that this 5% margin can be maintained for the lifetime of the storage racks. Many licensees subsequently replaced the Boraflex racks in their pools or re-analyzed the criticality aspects of their pools, assuming no reactivity credit for Boraflex.

Other potential criticality events, such as loose debris of pellets or the impact of water (adding neutron moderation) during personnel actions in response to accidents were discounted due to the basic physics and neutronic properties of the racks and fuel, which would preclude criticality conditions being reached with any credible likelihood. For example, without moderation fuel at current enrichment limits (no greater than 5 wt% U-235) cannot achieve criticality, no matter what the configuration. If it is assumed that the pool water is lost, a re-flooding of the storage racks with unborated water may occur due to personnel actions. However, both PWR and BWR storage racks are designed to remain subcritical if moderated by unborated water in the normal configuration. Thus, the only potential credible scenarios are those described above in 1 and 2 which involve crushing of fuel assemblies in low density racks or degradation of Boraflex over long periods in time. These conclusions were developed assuming present light water uranium oxide reactor fuel designs. Alternative fuel designs, such as mixed oxides (MOX) fuels would have to be reassessed to ensure that additional vulnerabilities for pool criticality did not exist.

To gain qualitative insights on the criticality events that are credible, the staff considered the sequences of events that must occur. For scenario 1 above, a heavy load drop into a low density racked BWR pool, compressing the assemblies would be required. From the work done on heavy load drop, the likelihood of a heavy load drop from a single failure proof crane has been determined to have a mean frequency of approximately $9.6E-6$ per year, assuming 100 cask movements per year at the decommissioning facility. From the load path analysis done in that appendix it was estimated that the load could be over or near the pool approximately 13% of the movement path length, dependent on plant specific layout. The additional frequency reduction in the appendix to account for the fraction of time that the heavy load is lifted high enough to damage the pool liner is not applicable here because the fuel assemblies could be crushed without the same impact velocity being required as for the pool liner. Therefore, the staff estimated a potential initiating frequency for crushing of approximately $1.2X10^{-6}$ per year (based upon 100 lifts per year). Criticality calculations conducted in Appendix 3 show that even if the low density BWR assemblies were crushed by a transfer cask, it is "highly unlikely" that a configuration would be reached that would result in a severe reactivity event, such as a steam explosion which could damage and drain the spent fuel pool. The staff judges the chances of such a criticality event to be well below 1 chance in 100 even given that the transfer cask drops directly onto the assemblies. This would put the significant criticality likelihood well below $1X10^{-8}$ per year, which justifies its exclusion from further consideration.

Deformation of the low density BWR racks by the dropped transfer cask was shown to most likely not result in any criticality events. However, if some mode of criticality was to be induced by the dropped transfer cask it would more likely be a small return to power for a very localized region, rather than the severe response discussed in the paragraph above. This type of event

would have essentially no off-site (or on-site) consequences since the reaction's heat would be removed by localized boiling in the pool, and water would provide shielding to the site operating staff. The reaction could be terminated with relative ease by the addition of boron to the pool. Therefore, the staff believes that qualitative (as well as some quantitative) assessment of scenario 1 demonstrates that it poses no significant risk to the public from SFP operation during the period that the fuel remains stored in the pool.

With respect to scenario #2 above, (the gradual degradation of the Boraflex absorber material in high density storage racks), there is currently insufficient data to quantify the likelihood of criticality occurring due to its loss. However, the current programs in place at operating plants to assess the condition of the Boraflex and take remedial action if necessary provide sufficient confidence that pool reactivity requirements will be satisfied. In order to meet the RG 1.174 safety principle of maintaining sufficient safety margins, the staff judges that continuation of such programs into the decommissioning phase would be required at all plants until all high density racks are removed from the SFP. Therefore, a staff assumption is identified in Section 4.2.4 requiring continuation of this activity, which should be reflected in future regulatory activity associated with SFP requirements.

comment
Next time

Based upon the above conclusions and staff assumption, we believe that qualitative risk insights demonstrate conclusively that SFP criticality poses no meaningful risk to the public.

SDA #4 was written in the RG-1.174 section that it applied to. SDA #1, 2, 3 were not applied to the section of RG-1.174. I suggest we put them in the RG-1.174 area that they apply to just like the IDC's

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, Chapter 4.1 presents a brief summary of the risk results that are most pertinent to that end.

The analysis in Chapter 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. One SDA is identified in Chapter 3, while the remainder are developed from the safety principles of RG 1.174 and are summarized in Chapter 4.1. Chapter 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. 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} 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.

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.”

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.

step

To reduce the likelihood of loss of inventory ^{commitments & assumptions} the following was committed to by industry:

- IDC #6 Spent fuel pool seals that could cause leakage leading to fuel uncover 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.

* Remains
RO
SFP
COP

SDA #1 SDA #1

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).

SDA#2

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 Chapter 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 Chapter 3 and the decision criteria laid out in Chapter 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 Chapter 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 Chapter 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 Chapter 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 uncover 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 Chapters 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 uncovering 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 Chapter 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.

5.0 Summary and Conclusions

The results of this report estimated the generic frequency of events leading to zirconium fires at decommissioning plants to be less than 3×10^{-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 10 IDCs proposed by NEI (See Appendix 6) and the four 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 1×10^{-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. 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 initiation of the accident. Therefore, this analysis indicates that for the slowly evolving SFP accident scenarios at decommissioning plants, there is a large amount of time to initiate and implement protective actions, including public evacuation, in comparison to an operating reactor accident sequences.

In summary, the risk assessment shows low numerical risk results in combination with satisfaction of the safety principles as described in R.G. 1.174, such as defense-in-depth, maintaining safety margins, and performance monitoring. The staff concludes that under the assumptions of this study there is a low level of public risk from SFP accidents at decommissioning plants. In addition, the study shows that after a period of one year following final shutdown, the low likelihood that a zirconium fire would occur, in combination with the long time frames available for taking off-site protective actions, provides a basis for relaxation of emergency planning requirements.

Chapters 4.3.2 and 4.3.3 addressed the report's implications on security and insurance provisions at decommissioning plants. For security, the risk insights can be utilized to assess what target sets are important to protect against sabotage. However, any reduction in security provisions would be constrained by an effectiveness assessment of the safeguards provisions against a design basis threat. Therefore, the staff concludes that some level of security is required as long as the fuel in the SFP is exposed to a sabotage threat. For insurance, the reports points out that no definitive criteria exists that would allow relaxation on the basis of low event probability alone while the potential for a zirconium fire exists. Finally, inconsistencies were identified in current regulations regarding vehicle-borne bomb threats and insurance indemnification requirements for ISFSIs and decommissioning nuclear power plants. These inconsistencies should be revisited during the overall integration of rules for decommissioning plants.

6.0 References

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