UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NEW REACTORS
OFFICE OF NUCLEAR REACTOR REGULATION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
WASHINGTON, DC 20555-0001

November 14, 2014

NRC INFORMATION NOTICE 2014-14: POTENTIAL SAFETY ENHANCEMENTS TO SPENT FUEL POOL STORAGE

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power reactor under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," including those that have permanently ceased operations and have spent fuel stored in spent fuel pools (SFPs).

All holders of and applicants for a power reactor early site permit, combined license, standard design approval, or manufacturing license under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." All applicants for a standard design certification, including such applicants after initial issuance of a design certification rule.

All holders of and applicants for an independent spent fuel storage installation license under 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform licensees of insights associated with the storage of spent fuel in SFPs gained through study of a reference boiling-water reactor SFP. The insights discussed in this IN may help optimize operating practices and event mitigation capabilities to further enhance the safety of spent fuel storage in pools. Addressees should review the information for applicability to their facilities and consider actions as appropriate. However, suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

BACKGROUND

On March 11, 2011, the Tōhoku earthquake and subsequent tsunami in Japan resulted in significant damage to the Fukushima Dai-ichi nuclear power station. The Fukushima Dai-ichi SFP-structures remained intact, and the spent fuel assemblies stored in the pools remained cool and water-covered throughout this event and subsequent recovery. Nevertheless, uncertainty regarding the status of the pools during the event raised questions about the safe storage of spent fuel and whether the NRC should require expedited transfer of spent fuel to dry cask storage at nuclear power plants in the U.S.

Subsequently, in the summer of 2011, the NRC staff initiated a research project, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," referred to as the SFP study or the SFPS. The results of the SFPS are published in NUREG-2161[1]. The SFPS examined the consequences of a hypothetical SFP accident initiated by an unlikely, beyond-design-basis seismic event. The SFPS concluded, consistent with earlier generic NRC studies, that the reference plant's SFP was a robust structure that is likely to withstand severe earthquakes without leaking. Nevertheless, the NRC staff analyzed the pool structure to determine the most likely location and size of leaks that could develop as a result of such an extreme earthquake. From that information, the NRC staff determined the conditions that would result in fuel overheating, considering both a low-density and high-density storage configuration, and the radiological consequences of any predicted release of radioactive material into the environment. In the unlikely event of a leak, and subsequent emptying of the SFP, this study showed that (for the scenarios and SFP studied) the spent fuel was only susceptible to overheating and a radiological release within a few months after it was moved from the reactor into the SFP. If a leak develops after those first few months from when the fuel was moved from the reactor into the SFP, then the study found that air cooling was sufficient to prevent overheating of the spent fuel (for the 72 hour time period analyzed in the SFPS). The SFPS demonstrated that the period in which fuel could overheat could be further reduced by dispersing the hottest assemblies among a larger number of colder assemblies and by the effective deployment of equipment and strategies implemented pursuant to the requirements of 10 CFR 50.54(hh)(2).

The SFPS analyzed cases with and without successful deployment of 10 CFR 50.54(hh)(2) equipment and strategies. For the included human reliability analysis, the SFPS assumed that there was sufficient staff to deploy the SFP mitigation systems and access was not impaired by damage to the reactor core and primary containment. If the earthquake had damaged multiple reactors and SFPs, some of these assumptions may be invalid.

In response to the Fukushima Dai-ichi accident, the NRC is currently implementing regulatory actions to further enhance nuclear reactor and SFP safety For example, on March 12, 2012, the staff issued Order EA-12-051[2], "Issuance of Order To Modify Licenses with Regard to Reliable Spent Fuel Pool Instrumentation," which required that licensees install reliable means of remotely monitoring wide-range SFP levels to support effective prioritization of event mitigation and recovery actions in the event of a beyond-design-basis external event. Also on March 12, 2012, the staff issued Order EA-12-049[3], "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events," which required licensees to develop, implement, and maintain guidance and strategies to maintain or restore core cooling, containment, and SFP cooling capabilities following a

---

1 Available in the Agencywide Documents Access and Management System (ADAMS) at Accession No. ML14255A365.

2 Available in ADAMS at Accession No. ML12054A679.

3 Available in ADAMS at Accession No. ML12054A735.

beyond-design-basis external event. These requirements ensure additional mitigation capability is in place (beyond that assumed in the SFPS) in the unlikely event in which degrading conditions occur in the SFPs.

The NRC used insights from the SFPS to perform a regulatory analysis[4] of the fuel storage practices at all U.S. operating nuclear reactors to help determine if expedited transfer of spent fuel to dry casks was warranted. A regulatory analysis is the standard method for evaluating the costs and benefits of a proposed Federal agency action. As part of its regulatory analysis, the staff first conducted a safety goal screening evaluation using the Commission's safety goal policy statement. The safety goal screening evaluation concluded that SFP accidents are a small contributor to the overall risks for public health and safety (less than one percent of the Commission's safety goal). Although the agency's guidance would normally allow the staff to stop the evaluation upon determining that the proposed action does not provide a sufficient safety enhancement to meet the threshold of the safety goal screening, the staff proceeded to perform a cost benefit analysis to provide the Commission additional information. The staff concluded that the expedited transfer of spent fuel to dry cask storage would provide only a minor or limited safety benefit (i.e., less than safety goal screening criteria), and that its expected implementation costs would not be warranted. Based on the regulatory analysis, including the NRC staff's review of operational experience, the NRC's oversight history, and other SFP studies, the NRC staff recommended to the Commission that further regulatory action not be pursued because the current regulatory framework is sufficient to ensure adequate protection of public health and safety. The Commission approved this conclusion in SRM-COMSECY-13-0030.[5]

DISCUSSION

The results of the SFPS and previous generic studies indicate that the current spent fuel storage provides adequate protection of the public health and safety. In addition, recent regulatory analyses have demonstrated that the safety benefits of further changes to SFP operating practices would be limited, largely as a result of the low frequency of challenges that could damage the SFP structure. However, the SFPS provided insights into operating practices and mitigation capabilities that could enhance defense-in-depth by further reducing the likelihood of fuel assemblies overheating in the event of substantial SFP damage.

Storing Spent Fuel in a More Favorable Loading Pattern

Spent fuel can be arranged in a dispersed pattern (e.g., 1 x 4 or a 1 x 8) that provides a more favorable response to a loss of cooling water. In a dispersed pattern, recently discharged (hot) assemblies are surrounded by older assemblies with less decay heat (cold). In some circumstances, other patterns which do not satisfy the definition of a dispersed pattern may be used for a limited period of time when other factors prevent directly discharging the assemblies into a dispersed pattern. See the illustration below for examples of the 1 x 4 and 1 x 8 arrangements.

---

4 Available in ADAMS at Accession No. ML13273A628.

5 Available in ADAMS at Accession No. ML14143A360.

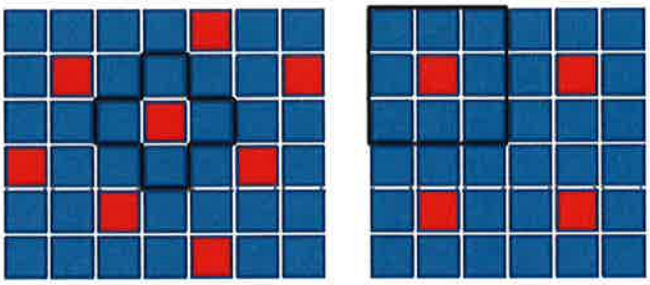

Illustration of SFP patterns
From left to right: 1 x 4; 1 x 8
Red = a recently discharged assembly (hot); Blue = an older, lower decay heat assembly (cold);
Black outline = repeating pattern

An air coolable fuel assembly is one where, in the unlikely event of a loss of cooling water from the SFP, natural circulation of air combined with radiative and conductive heat transfer between the fuel and the storage rack structures will prevent overheating of the fuel. From a risk perspective, a reduction in the time between when an assembly is added to the SFP and when it is air coolable is advantageous.

Although variability in the SFP loading configurations was not a focus of the SFPS, Section 9 of the SFPS, "Considerations of Uncertainty," cataloged sensitivity analyses, where the NRC staff compared the thermal response of spent fuel stored in contiguous and 1 x 8 patterns with the 1 x 4 pattern (baseline configuration used in the SFPS). In the unlikely event of a loss of cooling water in the SFP, natural circulation of air combined with radiative and conductive heat transfer between the fuel and the storage rack structures was found to reduce the likelihood of overheating of the fuel. In the 1 x 4 pattern, fuel was found to be air coolable for at least 72 hours for all but roughly the first 10 percent of the operating cycle. When the 1 x 8 fuel pattern was evaluated, air coolability for at least 72 hours was achieved earlier in the operating cycle. As such, to further enhance air cooling of spent fuel, licensees may choose to configure the SFP with a 1 x 8 loading pattern as an improvement over the standard 1 x 4 loading pattern. If licensees choose to configure the SFP in a 1 x 8 pattern, licensees may consider integrating the fuel movement necessary to achieve the chosen fuel configuration with necessary operational fuel movement and implementing over multiple operating cycles to minimize overall fuel transfers and the associated risk. See IN 2014-09 for recent examples of SFP misloading issues.

Directly Offloading Fuel from the Core into Dispersed Patterns in the SFP

The SFPS demonstrated that storing spent fuel in a dispersed pattern in SFPs promotes air coolability of the spent fuel in the unlikely event of a loss of water. In addition, the SFPS showed that minimizing the time that spent fuel is stored in a less favorable pattern could further reduce the likelihood of a release if the SFP were to completely drain. Licensees may choose to optimize spent fuel transfer into the SFP by direct placement in a dispersed pattern to further enhance the safety of SFPs.

Enhancing Mitigation Strategies

In addition to SFP loading patterns, the SFPS considered the benefit gained from the effective deployment of the strategies implemented under 10 CFR 50.54(hh)(2) in the event of complete SFP draining. While increasing the dispersal of the hottest fuel assemblies (from 1 x 4 to 1 x 8) significantly reduced the rate of temperature increase following a loss of coolant, the effective deployment of these strategies implemented under 10 CFR 50.54(hh)(2) was found to have the largest impact on the frequency of release of radioactive material. Effective implementation of these strategies reduced the frequency of release from the SFP.

The SFPS identified that these strategies can be challenged during periods of relatively higher SFP heat load. In some cases, the SFPS found that existing strategies required by 10 CFR 50.54(hh)(2) may not be effective, either because available equipment would not provide sufficient mitigation flow rate or radiation levels on the refueling floor would preclude access of responders to provide cooling water to the SFP. At the time of the SFPS, the actions being taken to comply with Order EA-12-049 were not fully developed and thus were not considered in the SFPS. In light of the SFPS, licensees may choose to provide additional mitigation capabilities through, for example, pre-deploying mitigation equipment during times of high SFP heat load, moving connection points and operating controls for spray nozzles to areas of lower dose, and providing additional water sources and connection points. Some or all of these additional mitigation capabilities may already be planned to comply with Order EA-12-049.

As discussed above, Order EA-12-049 requires, in part, actions associated with restoring and maintaining SFP cooling capability following a beyond-design-basis external event. For example, the NRC-endorsed industry guidance for compliance with this order, NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide" (ML12242A378), includes a provision for connection points for SFP makeup that do not require access to the refueling floor and additional provisions for the reasonable protection of the associated equipment from external events. These enhancements may provide additional capability for mitigating events that result in SFP draining, beyond those required by 10 CFR 50.54(hh)(2) and considered in the SFPS.

CONCLUSION

The NRC's studies continue to show that current SFPs are effectively designed to prevent accidents affecting the safe storage of fuel. The SFPS identified potential improvements that could help licensees further manage the risk of significant radiological releases associated with SFPs. This IN discusses insights from the SFPS regarding an unlikely, beyond-design-basis seismic event. Storing spent fuel in more favorable loading patterns, placing fuel in dispersed patterns immediately after core offload, and taking action to improve mitigation strategies when the SFP heat load is high may help licensees further reduce the risk associated with the SFP.

CONTACTS

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below.

Michael C. Cheok, Director
Division of Construction Inspection
and Operational Program
Office of New Reactors

Lawrence E. Kokajko, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Mark Lombard, Director
Division of Spent Fuel Management
Office of Nuclear Material Safety
and Safeguards

Technical Contact: Steve Jones, NRR
(301) 415-2712
e-mail: Steve.Jones@nrc.gov

Don Algama, RES
(301) 251-7940
e-mail: Don.Algama@nrc.gov

CONTACTS

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below.

/RA/

Michael C. Cheok, Director
Division of Construction Inspection
and Operational Program
Office of New Reactors

/RA/

Lawrence E. Kokajko, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA/

Mark Lombard, Director
Division of Spent Fuel Management
Office of Nuclear Material Safety
and Safeguards

Technical Contact: Steve Jones, NRR
(301) 415-2712
e-mail: Steve.Jones@nrc.gov

Don Algama, RES
(301) 251-7940
e-mail: Don.Algama@nrc.gov

ADAMS Accession No.: ML14218A493 **TAC No. MF4562**

OFFICE	NRR/JLD/PPSD	NRR/JLD/PPSD	QTE	RES/DSA/FSCB	NRR/DSS/SPBP	NRR/JLD/PPSD
NAME	RBernardo*	KWitt*	CHsu*	DAlgama*	SJones*	GBowman*
DATE	08/25/2014	08/25/2014	08/29/2014	09/17/2014	10/01/2014	10/02/2014
OFFICE	NRR/DSS/SPBP	RES/DSA/FSCB	NMSS/SFST/CSDAB	NRR/DE/ESGB	NRR/JLD	RES/DSA
NAME	GCasto*	RLee*	MRahimi*	GKulesa*	JDavis*	MCase*
DATE	10/02/2014	10/03/2014	10/01/2014	10/02/2014	10/08/2014	10/07/2014
OFFICE	NRR/DSS	OGC	NRR/DPR/PGCB	NRR/DPR/PGCB/LA	NRR/DPR/PGCB	NRO/DCIP
NAME	TMcGinty*	HBenowitz*	TKeene*	CHawes*	SStuchell	MCheok*
DATE	10/09/2014	11/03/2014	11/03/2014	11/03/2014	11/04/2014	11/05/2014
OFFICE	NMSS/MSTR/DD	NRR/DPR	NMSS/SFSM	NRR/DPR		
NAME	PHenderson	AMohseni	MLombard	LKokajko		
DATE	11/07/2014	11/12/2014	11/13/2014	11/14/2014		

OFFICIAL RECORD COPY