UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

December 18, 2013

The Honorable Allison M. Macfarlane
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: STAFF EVALUATION AND RECOMMENDATION FOR JAPAN LESSONS-LEARNED TIER 3 ISSUE ON EXPEDITED TRANSFER OF SPENT FUEL

Dear Chairman Macfarlane:

During the 608th meeting October 2-5, 2013, and the 610th meeting December 4-7, 2013, of the Advisory Committee on Reactor Safeguards we reviewed the NRC staff's regulatory analysis entitled, "Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," (henceforth referred to as the Tier 3 Generic Regulatory Analysis). Our Materials, Metallurgy, and Reactor Fuels Subcommittee reviewed this matter on July 9, September 19, and November 19, 2013. During these meetings we had the benefit of discussions with representatives of the NRC staff the Electric Power Research Institute and members of the public. We also had the benefit of the documents referenced.

CONCLUSIONS

1. The staff's safety goal screening analysis has adequately evaluated the safety benefits of expedited transfer from spent fuel pools (SFPs) to dry cask storage systems (DCSSs).

2. The safety goal screening evaluation has demonstrated that the NRC Safety Goal Policy and Quantitative Health Objectives (QHOs) are met with orders of magnitude margin for both current high-density SFP loadings and proposed low-density fuel loadings. Based on these results, the staff has concluded that there is insufficient safety benefit to justify the expedited transfer of spent fuel from U.S. pools to DCSSs. We agree with this conclusion.

3. The staff also performed supplementary regulatory analyses to evaluate the cost/benefit merits of expedited transfer of spent fuel to dry cask storage. In all of the base cases evaluated, the benefits of expedited transfer were found to be far less than the costs of implementation. The base case analyses are adequately conservative and support the staff's recommendation that more detailed evaluations of the benefits of expedited transfer of spent fuel need not be pursued.

4. The cumulative effects of conservatisms and assumptions used in the high estimates, and in sensitivity studies of the regulatory analyses, result in exaggerated frequencies of fuel damage and exaggerated benefits of expedited transfer.

BACKGROUND

In SECY-12-0095, the staff submitted a plan to evaluate whether regulatory action is warranted for the expedited transfer of fuel from spent fuel pools to DCSSs. In a memorandum entitled, "Updated Schedule and Plans for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," dated May 7, 2013, the staff updated plans to address Commission directions in staff requirements memoranda (SRMs) M120607C and M120807B to assist in the Tier 3 decision process.

There are three phases in the Tier 3 plan. Phase 1 uses the NRC's regulatory analysis process as a screening analysis to determine whether a substantial increase in public health and safety will result from expedited transfer of spent fuel from pools to dry casks. An affirmative outcome of Phase 1 would lead to more detailed and definitive analyses to be done in subsequent phases of the proposed effort.

The Tier 3 Generic Regulatory Analysis presents the staff's Phase 1 findings, conclusions, and recommendations for all U.S. spent fuel pools in the central and eastern United States (CEUS).

DISCUSSION

The staff performed their analysis in accordance with the NRC's normal decision making policies and guidance (NUREG/BR-0058) to ascertain whether there is a substantial increase in the overall protection of the public health and safety by reducing the inventory of spent fuel maintained in pools at nuclear power plants. The staff performed a generic screening analysis in which groups of plants with similar features were analyzed by using conservative inputs and assumptions to determine whether the NRC's safety goals are met with sufficient margin, and to evaluate the costs and benefits of safety enhancements.

Alternatives

The analysis evaluated two alternatives. Alternative 1 (Regulatory Baseline) would continue storage of fuel in high-density pool configurations in compliance with existing regulatory requirements, including a spent fuel configuration with preventive and mitigative capabilities specified under 10 CFR 50.54(hh)(2). The staff assumed, however, that mitigation capabilities required by these regulations would not be effective for this alternative.

Alternative 2 (Low-Density Spent Fuel Storage) would require the expedited transfer of fuel with more than five years decay time to DCSSs by CY 2019. Storage of high activity fuel would continue in low-density pool configurations. For this alternative the staff assumed that mitigation required per 10 CFR 50.54(hh)(2) would be effective and would substantially decrease the likelihood of accidental release of radionuclides.

The additional mitigation capabilities provided by compliance with NRC Orders EA-12-049 and EA-12-051 were not credited in the analysis of either alternative.

The staff noted, but did not evaluate other alternatives. These included arranging fuel assemblies with high decay heat rates within arrays of eight adjacent fuel assemblies with low decay heat rates, and enhanced mitigation strategies during operating cycle phases when the decay heat load in a spent fuel pool is high. The staff acknowledges that such enhancements could be less costly than Alternative 2 and could provide many of its benefits. The staff plans to inform licensees of these alternatives and will encourage them to assess and implement, as appropriate, such improvements on their own initiative to help manage the risks associated with plant-specific spent fuel pool designs, operating practices, and mitigation capabilities. In this, the staff is following current Commission direction to not perform regulatory analyses for these less costly approaches to managing risk from spent fuel pools because they are unlikely to provide a substantial safety enhancement warranting generic regulatory action.

Staff Considerations

The staff has considered a broad set of documents, facts, and sources in the Tier 3 Generic Regulatory Analysis including:

- previous NRC studies of spent fuel storage and spent fuel pool safety,
- domestic and international operating experience and practices,
- findings of structural and liner integrity at twenty Japanese spent fuel pools following the severe seismic events at Kashiwazaki in 2007 and at Fukushima in 2011,
- Order EA-12-051 requiring the installation of a reliable means for remotely monitoring SFP water levels following a beyond-design-basis external event,
- Order EA-12-049 requiring the development and implementation of strategies to maintain or restore SFP cooling capabilities, independent of alternating current power, following a beyond-design-basis external event,
- the plant-specific Spent Fuel Pool Study and regulatory analysis, and
- inputs received from stakeholders and the public.

The Spent Fuel Pool Study, particularly, served as an important basis throughout the staff's analysis.

Plant Groupings

Spent fuel pools were grouped by similarity in design and configuration:

- Group 1 included BWRs with Mark I and Mark II containments with non-shared spent fuel pools well above grade level
- Group 2 included PWRs and BWRs with Mark III containments with non-shared spent fuel pools at grade level
- Group 3 included AP1000 PWRs
- Group 4 included PWRs with shared spent fuel pools.

Onsite and offsite wet storage facilities that contain only spent fuel from decommissioned plants were not evaluated because of their very low decay heat rates. We find these groupings acceptable.

Safety Goal Screening Evaluation

The safety goal screening evaluation, as outlined in the regulatory analysis guidelines (NUREG/BR-0058), is designed to determine when a regulatory requirement should not be imposed generically on nuclear power plants because the residual risk is already acceptably low whether or not these requirements could be justified by backfit analysis. The safety goal evaluation is also used for determining whether the ‘substantial added protection’ standard of 10 CFR 50.109(a)(3) is met.

The NRC's Policy Statement on Safety Goals for the Operations of Nuclear Power Plants defines two Quantitative Health Objectives (QHOs), a prompt fatality QHO and a latent cancer QHO.

The prompt fatality QHO specifies that the expected number of fatalities resulting from an accident within a one-mile radius of a nuclear plant should not exceed 0.1% of the prompt fatality risks resulting from all other causes to which members of the U.S. population are generally exposed. In the Tier 3 Generic Regulatory Analysis the staff has determined that the release of radionuclides from a fire in a spent fuel pool with high-density fuel loading is not expected to result in any offsite early fatalities within one mile of the site boundary. This finding meets the prompt fatality QHO of $5x10^{-7}$ per year for an average individual within one mile of the site boundary.

The latent cancer QHO specifies that the risk of latent cancer fatalities to the population in the area near a nuclear power plant that might result from nuclear power plant operation should not exceed 0.1% of the sum of cancer fatality risks resulting from all other causes. Using recent data, the staff has determined that the cancer fatality risk from all causes in the U.S. is $1.84x10^{-3}$ per year. Applying the 0.1% criterion yields a QHO of $1.84x10^{-6}$ per year. The staff has determined that the individual latent cancer fatality risk resulting from a spent fuel pool accident in which large quantities of radionuclides are released is $1.52x10^{-8}$ per year.

Given the conservatisms incorporated in this Safety Goal Screening Evaluation, we agree that the staff’s analysis demonstrates that continued operation of spent fuel pools with high-density fuel loadings does not challenge the NRC safety goals and that the QHOs are met with orders of magnitude margin.

The staff undertook further supplementary analyses of the costs and benefits of adopting the low-density fuel loading alternative, again to ascertain if more detailed and definitive analyses were warranted. Some features of this cost/benefit analysis are discussed in the remainder of this report.

Design and Operational Variables

The influences of key variables affecting accident progression were evaluated for each plant group. These included seismic hazard exceedance frequency, liner fragility, operating cycle fraction with inadequate natural circulation cooling, cesium inventory, and release fraction. For each variable a base case, low estimate, and high estimate were selected for use in the analyses. For some variables (e.g., cesium inventory, seismic hazard exceedance frequency, population, and economic statistics), values were known or could be calculated with reasonable confidence. For other variables, conservative values were selected. Since the Phase 1 work was intended to be a screening analysis, this conservative approach was justified because it eliminated the need for detailed analysis of all sites and SFP designs. In some cases, however, this approach was inconsistently combined with other assumptions. For example, it was assumed that mitigation was ineffective for high-density SFP loadings, but mitigation worked effectively 95% of the times it was needed for low-density loadings. While such bounding approaches may be of interest for worst case evaluations, they can yield estimates that exaggerate benefits relative to costs.

Analysis Sequence

For each plant grouping, the Tier 3 Generic Regulatory Analysis sequence starts with the selection of the initiating event and follows with assessments of AC power fragility, liner fragility, adequacy of air cooling, fuel heat-up, effectiveness of mitigation, and radionuclide release. This analysis sequence is concluded by calculation of the radionuclide dispersion and an assessment of health and economic consequences of radionuclide release.

Seismic Hazards

The Tier 3 Generic Regulatory Analysis used the existing U.S. Geological Survey (USGS) 2008 model to evaluate seismic hazards at central and eastern United States nuclear power plants.

The staff developed seismic initiating event frequencies for two levels of peak ground acceleration (PGA) that could challenge the integrity of a spent fuel pool, 0.7g and 1.2g. The seismic hazard for the Spent Fuel Pool Study reference site was used for all plant groups in the base case analyses. For that hazard, the base case exceedance frequency for a 0.7g seismic event is on the order of 1.7×10^{-5} per year, and the frequency for a 1.2g seismic event is on the order of 4.9×10^{-6} per year.

In the high estimate sensitivity analyses, the seismic initiating event frequencies for each plant group were derived from the site which has the highest seismic hazard in that group. The high estimate frequency for a 0.7g seismic event varied from 2.2×10^{-5} per year for plant Group 1 to 5.6×10^{-5} per year for plant Group 4. The high estimate frequency for a 1.2g seismic event varied from 7.1×10^{-6} per year for plant Group 1 to 2.0×10^{-5} per year for plant Group 4.

We find the staff's approach and resulting exceedance frequencies to be reasonable.

Availability of AC Power

The staff assumed AC power was not available for all cases evaluated in the regulatory analysis. This assumption is conservative considering the many post-Fukushima regulatory actions taken or planned to assure availability of AC power following severe seismic and flooding events. This assumption was applied to both alternatives under consideration.

Liner Fragility

Following a severe seismic event, only liner failure can lead to a rapid loss of coolant sufficient to cause major fuel damage. Loss of coolant due to sloshing is limited, and boil-off due to loss of cooling is slow and readily mitigated. Although its concrete support structure can be damaged, an intact liner will retain the coolant and thus prevent fuel damage and release of radionuclides to the environment. This has been amply demonstrated at Fukushima and Kashiwazaki.

In the Spent Fuel Pool Study, a detailed nonlinear finite element analysis was performed to estimate the likelihood of pool liner failure for a 0.7g PGA earthquake (approximately 6 times greater than the safe shutdown earthquake design basis). The calculated maximum localized liner strain was approximately 3.7%, which is substantially lower than the failure strain (30-40%) of austenitic stainless steel liner material. Although the calculated strains were much lower than known failure strains, the staff accounted for various uncertainties in their analysis by estimating that the liner evaluated in the Spent Fuel Pool Study had a 5% probability of sufficient tearing to permit moderate SFP leakage following a 0.7g PGA earthquake.

In the Tier 3 Generic Regulatory Analysis of plants in Group 1, the staff used a base case liner fragility of 10% for a 0.7g PGA earthquake (i.e., twice the value used in the Spent Fuel Pool Study). A bounding value of 100% liner fragility was used in the base case analyses for a 1.2g PGA event and in the high estimate analyses for both seismic accelerations.

For plants in Groups 2, 3 and 4, the staff used the concrete structure fragilities taken from the H.B. Robinson spent fuel pool analysis reported in NUREG/CR-5176. The fragilities of the liners were conservatively assumed to be the same as the reinforced concrete structure. In the H.B. Robinson studies it was found that the spent fuel pool would have a 98% probability of surviving a 0.7g PGA earthquake with no pool leakage (2% fragility) and an 84% probability of surviving a 1.2g PGA earthquake with no leakage (16% fragility). In the Tier 3 Generic Regulatory Analysis for these plants subjected to the 0.7g PGA earthquake, the staff increased the liner fragility to 5% for the base case, and further increased the value to 25% for the high estimate. For the 1.2g PGA earthquake the staff selected a liner fragility of 50% for the base case and 100% for the high estimate.

After our review of the Spent Fuel Pool Study was completed, we found that the staff used the mechanical properties of plain carbon steels (NUREG/CR-6706) in their detailed analysis of liner strain. Plain carbon steels have much lower ductility than austenitic stainless steel and will deform more readily under the same loading conditions. Further, austenitic stainless steels have higher fracture toughness and two times greater resistance to unstable crack propagation. Given these additional conservatisms, we conclude that stainless steel liner fragilities are likely to be substantially lower than those used in the Tier 3 Generic Regulatory Analysis.

Mitigation

In order to maximize the benefits of low-density loading, the staff credited successful mitigation only in the analysis of Alternative 2. This assumption results in a factor of 19 reduction in release frequency compared to the high-density loading alternative. The operability of spent fuel pool mitigation equipment (pumps, connections, and instrumentation) following a beyond-design-basis event is not dependent on pool loading. The time available to implement mitigation options is also not affected strongly by the fuel pool loading alternatives. Therefore, we see no compelling reason to limit effective mitigation only to the low-density pool loading alternative, and conclude that it is unjustified.

Base Case Results

The staff has made conservative assumptions in the Tier 3 Generic Regulatory Analysis that were intended to maximize the benefits of low-density fuel pool loading. Although low estimates and high estimates are reported in the sensitivity studies, the staff considers the base case to be sufficiently conservative for use as the primary basis for their conclusions and recommendations. Given the conservatisms used throughout the analysis, we agree with the staff's position.

For plants in Group 1, the staff estimated that the base case release fractions for cesium were 40% for Alternative 1 and 3% for Alternative 2. For plants in Groups 2, 3 and 4, the base case release fractions for cesium were similar (75% for Alternative 1 and 3% for Alternative 2).

For each plant group, the health and economic consequences of releases were then evaluated based on the atmospheric and dispersion model from the Spent Fuel Pool Study, using appropriate adjustments for population densities, habitability criteria and economic factors. Notwithstanding the large differences in cesium release fractions, the staff found that the benefits of low-density spent fuel pool loading are not sufficient to meet the cost/benefit criteria for implementation or to justify further study of this alternative. We agree.

Overall, the staff has performed a great deal of work over a very short time to produce a thorough and systematic regulatory analysis. We agree with the staff's conclusions and recommendations developed in the safety goal screening evaluation and the base case regulatory analysis. However, for the high estimate sensitivity studies, we conclude that the staff's assumptions combined with the cumulative effects of many conservative inputs have led to exaggerated frequencies of fuel damage and exaggerated benefits of low-density fuel loading configurations.

Sincerely

/RA/

J. Sam Armijo
Chairman

Additional comments by ACRS Members Gordon R. Skillman, J. Sam Armijo, Ronald Ballinger, Stephen P. Schultz, and Peter Riccardella.

We agree with the Committee letter but wish to add the following comments. A decision to pursue expedited transfer of spent fuel to dry cask storage systems (Alternative 2) will require all U.S. plant owners and operators to undertake major operational activities at an intensity level far greater than current plant operations. These actions will be taken essentially in parallel over a very short time, and will not be risk free. In arriving at a final decision on the merits of Alternative 2 greater consideration should be given to Operational Focus, Industrial Risk, and Cost and Schedule Risk.

Operational Focus - Implementation of Alternative 2 will require focus at all U.S. plants on additional activities (expedited fuel handling) that are distinctly different from current nuclear power plant operating practice. Expedited fuel transfer requires a significantly different focus, and will require significant commitments of industry resources. This may lead to the diversion of experienced staff from current plant operation responsibilities.

Assumption of Industrial Risk – Implementation of Alternative 2 will require fuel handling actions at intensities not presently experienced. These actions include accelerated campaigns for fuel assembly hoisting, lowering, crane operations associated with heavy lifts for cask handling and cask movement, and assumption of associated radiological risks (exposure to workers). Clearly, station crews have performed this work safely for years. But the magnitude of the effort to accomplish expedited transfer required by Alternative 2 will be significantly in excess of current experience and qualified manpower. Further, schedule pressure, real or imagined, to accomplish fuel movement in a compressed schedule imposes risks associated with both on-site (for local storage) or off-site (for shipment to a central location or repository) requiring availability of transportation casks and roadway or railway logistics. It should not be assumed that the intensity of the efforts to accomplish early offload will not lead to unanticipated challenges to plant safety.

Cost and Schedule Risk – To maximize the benefits of Alternative 2, the staff's regulatory analysis assumed NRC costs would be zero, and industry costs would not escalate. These assumptions are not valid. Implementation of Alternative 2 will introduce both NRC and industry cost and schedule risks. Uncertainties in the many planning, licensing, pad construction, cask procurement, fabrication, loading, and transfer activities are likely to increase costs significantly and delay completion.

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3. ACRS Letter, Subject: Report on the Spent Fuel Pool Study, July 18, 2013 (ML13198A433)

4. ACRS Letter, Subject: Report on the Spent Fuel Pool Scoping Study, April 25, 2012 (ML12108A216)

5. NRC Staff Requirements M120607C - Meeting with the Advisory Committee on Reactor Safeguards, July 16, 2012 (ML121980043)

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