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

May 15, 2013

Mr. R.W. Borchardt
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: NEXT GENERATION NUCLEAR PLANT (NGNP) KEY LICENSING ISSUES

During the 604th meeting of the Advisory Committee on Reactor Safeguards (ACRS), May 9-10, 2013, we reviewed the staff's assessment of the U.S. Department of Energy (DOE)/Idaho National Laboratory (INL) NGNP key licensing issues. Our Subcommittee on Future Plant Designs reviewed INL key licensing issue white papers on January 17, 2013, and staff assessments of the INL white papers on April 9, 2013. During these meetings we had the benefit of discussions with representatives of the NRC staff, DOE, and INL. We also had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATIONS

1. The staff assessment of the NGNP white papers on key technical issues is appropriate, given the unavailability of many plant-specific design details, such as the selected fuel form (pebble or prismatic) and a complete plant design. The final assessments should be published after the issues raised in Recommendations 2, 3, and 4 are addressed.

2. The assessment documents should be revised to provide clear links to the numerous requests for additional information (RAIs) and responses that were developed during their assessment because the white papers have not been revised to incorporate those agreements.

3. The licensing basis event selection assessment should point out the need to clarify the definition of event sequences and event sequence families to ensure consistency in developing licensing basis events and design basis accidents (DBAs). Incoherent logic in the event trees should be addressed.

4. The staff's suggestion that the final selection of DBAs include postulated deterministic event sequences is inconsistent with a risk-informed framework proposed by the NGNP project and with other on-going NRC activities encouraged by the Commission. Although engineering judgment may be invoked to include postulated deterministic event sequences in the final selection of DBAs, if such sequences are not in the probabilistic risk assessment (PRA), the PRA is incomplete and should be revised to include them. They then can be fully evaluated and considered for inclusion as DBAs.

BACKGROUND

The Energy Policy Act of 2005 directed DOE to establish and manage the NGNP project. The project was to consist of research, development, design, construction, and operation of a prototype Generation IV-based nuclear reactor plant to generate electricity and/or hydrogen. The Act also designated INL as the lead laboratory for the project and directed INL to organize a consortium of industrial partners to carry out cost-shared research, development, design, and construction activities. The Act stipulated that the NRC has licensing and regulatory authority for any reactor developed by the project.

DOE selected a high-temperature gas-cooled reactor (HTGR) as the NGNP reactor technology. The mission of the NGNP project is to develop, license, build, and operate a prototype HTGR plant that generates high temperature process heat for use in hydrogen production and other energy intensive industries while also generating electric power. To fulfill this mission, DOE is considering a modular HTGR design with either a prismatic block or pebble bed core.

As required by the Act, DOE and the NRC have been engaged in interactions on technical and policy issues that could affect the design and licensing of the NGNP prototype. In 2008, DOE and NRC jointly submitted the NGNP Licensing Strategy Report to Congress, as required by the Act. The NGNP Licensing Strategy Report described four options that range from a deterministic approach similar to that used for current reactors to a new body of risk-informed, performance-based regulations that would require rulemaking. DOE and NRC endorsed Option 2, a risk-informed, performance-based approach that uses engineering judgment and analysis, complemented by NGNP design-specific PRA information to establish the licensing basis, including the selection of licensing basis events and technical requirements. Use of PRA would be commensurate with the quality and completeness of the PRA presented with the application. Option 2 is consistent with evolving staff and Commission positions as laid out in SECY-03-0047, "Policy Issues Related to Licensing Non-Light-Water Reactor Designs," and its staff requirements memorandum (SRM); NUREG-1860, "Feasibility Study for a Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing;" Recommendation 1 of *The Near-Term Task Force Review of Insights from the Fukushima Daiichi Accident* (NTTF Report); and NUREG-2150, "A Proposed Risk Management Regulatory Framework."

The 2008 NRC-DOE licensing strategy envisioned and described a process of building a prototype reactor, sited at INL. The NRC staff expectation is to license a prototype that will proceed through power ascension, testing, analysis, and power operation to provide more confidence to inform licensing a subsequent commercial full-scale demonstration facility or to provide confidence in the plant safety case. In contrast, the DOE position is that the development and licensing of a prototype reactor plant in accordance with 10 CFR 50.43(e)(2) would entail considerable regulatory uncertainty and related financial risk for the industry. DOE appears to be most interested in the establishment of a path for reactor designers to develop a modular reactor design that is directly representative of their planned commercial offering that incorporates required testing.

From 2009 to 2011, INL submitted a series of white papers to the NRC on key issues highlighted in the NGNP Licensing Strategy Report, including defense-in-depth; high temperature materials; fuel qualification; mechanistic source terms; structures, systems, and components (SSCs) safety classification; emergency planning; licensing basis event selection; and PRA. The staff reviewed the INL white papers and issued draft assessments on fuel qualification, mechanistic source terms, defense-in-depth, licensing basis event selection, and safety classification of SSCs.

The staff also issued a draft summary report regarding the following four NGNP licensing issues:

- Licensing basis event selection
- Source terms
- Containment functional performance
- Emergency preparedness

The staff emphasized that statements in their assessment and summary reports do not provide final regulatory decisions. Indeed, additional guidance from the Commission may be necessary as discussed below.

DISCUSSION

The staff found the INL proposed risk-informed, performance-based licensing approach generally reasonable, with several specific caveats. For example, the staff identified a number of issues, such as a lack of detailed design information, that challenge effective implementation of a risk-informed, performance-based licensing framework for the NGNP. The staff noted that such issues could be resolved during preapplication interactions with a prospective designer or applicant if additional design details and results from additional fuels and materials testing are available.

The lack of a detailed design resulted in numerous RAIs and responses being generated during the staff evaluations. The staff's final assessment reports need to address the issue of agreements reached during the review process, at least by providing an unambiguous link to the record of RAIs and responses.

Licensing Basis Event Selection

The white paper defined a process for licensing basis event selection that considers a combination of deterministic and probabilistic analyses. The process identifies event sequence families based on an identified set of initiating events and will establish the frequency of each of these event sequences.

For current operating reactors and new reactors, deterministic engineering judgment has been used to establish most events in the licensing basis, rather than event sequences selected from the plant PRA. In contrast, the licensing basis event white paper proposes to use PRA to establish the envelope of event sequences that the staff must consider for licensing the NGNP. This is a new application of a plant-specific PRA. For these reasons, the requirements and guidance for the technical adequacy of the plant-specific PRA are more demanding than those for a PRA that supports a design certification in accordance with 10 CFR Part 52.

The white paper proposed that the frequencies of licensing basis events be expressed in units of events per plant-year, where a plant is defined as a collection of reactor modules having certain shared systems. The proposed frequency ranges for the licensing basis event categories are as follows:

- Anticipated Events: event sequences with mean frequencies greater than $1x10^{-2}$ per plant-year
- Design Basis Events: event sequences with mean frequencies less than $1x10^{-2}$ per plant-year and greater than $1x10^{-4}$ per plant-year
- Beyond Design Basis Events: event sequences with mean frequencies less than $1x10^{-4}$ per plant-year and greater than $5x10^{-7}$ per plant-year

The staff agreed that the proposed categorization of licensing basis events into anticipated events, design basis events, DBAs, and beyond design basis events is a reasonable approach for the classification of licensing basis events. They also found that the proposed frequency-consequence curve and the associated dose calculation framework are generally reasonable. However, implementation of the approach will require more detailed design information to allow the staff to fully interpret or understand how an applicant has selected the events that lead to DBAs.

The staff observed that the proposed approach to defining licensing basis events may require future Commission direction on issues such as definition of dose acceptance criteria for the various event categories, frequency cutoffs for design basis events and beyond design basis events, and the “per-plant-year” method for addressing risk at multi-reactor module plant sites.

The staff also provided several additional recommendations on the selection of licensing basis events:

- Regulatory controls should be established to ensure that adequate fuel integrity is maintained throughout the normal operation envelope and for anticipated events.
- Bounding events that would fall within the beyond design basis event region should be evaluated to ensure adequate defense-in-depth for the containment of fission products in accordance with regulatory requirements.

The staff concluded that deterministic elements of the proposed approach should be strengthened to ensure conservative selection of bounding events, including events used to justify the siting source term and the proposed emergency response measures. However, the staff's suggestion that the final selection of DBAs include postulated deterministic event sequences is inconsistent with a risk-informed framework proposed by the NGNP project and with other on-going NRC activities encouraged by the Commission. Although engineering judgment may be invoked to include postulated deterministic event sequences in the final selection of DBAs, if such sequences are not in the PRA, the PRA is incomplete and should be revised to include them. They then can be fully evaluated and considered for inclusion as DBAs based on the proposed DBA criteria or through engineering judgment on grounds such as a high degree of uncertainty of the risk significance of the sequences.

Confusion seemed to exist in the white paper and in the staff assessments regarding the definition of event sequences and event sequence families. This should be clarified to ensure consistency in developing licensing basis events and DBAs. We also found that the illustrative event tree in the white paper suffered from incoherent logic. Altering the order of the top events in the tree could change the assignment of an event sequence from one event class to another. For example, permutations of the top events order (A-B-C, A-C-B, B-A-C, B-C-A, C-A-B, C-B-A) does not affect the frequency of the beyond design basis event sequence that involves failure of all three heat removal options. However, the order does affect the frequencies of intermediate sequences and their allocations to the anticipated event, design basis event, and other beyond design basis event categories. Therefore, careful consideration of the event sequence model logic structure is necessary during the application of this process.

Defense-in-Depth

The white paper defined defense-in-depth as a safety philosophy that is based on multiple lines of defense, safety margins, and compensatory measures that are applied to the design, construction, operation, maintenance, and regulation of nuclear plants to prevent and mitigate accidents and to ensure adequate protection of public health and safety. Defense-in-depth is closely linked to other potential technical/policy issues (e.g., mechanistic source term, containment functional performance, and emergency planning).

The staff anchored its discussion to an exposition of NRC's defense-in-depth policy in the NTTF Report. An element of defense-in-depth is the recognition that, in spite of other defense-in-depth precautions, serious fuel damage accidents may not be prevented and, therefore, may require containment structures and safety features to mitigate the release of radionuclides.

Demonstrating the adequacy and sufficiency of the defense-in-depth approach proposed by INL requires a thorough understanding, and proper implementation of, event selection, safety classification and treatment of SSCs, source term, emergency planning, and scope and applicability of PRA. Because detailed design information on these topics is not available for the NGNP, the staff cannot make a definitive determination on the adequacy and sufficiency of the proposed defense-in-depth approach.

Safety Classification of SSCs

Although the staff generally supported INL's use of a risk-informed approach for classifying SSCs, they noted that:

- It is not clear that the proposed classification categories clearly address all fission product release barriers, including the helium pressure boundary and the reactor building.
- SSCs will need to conform to ASME code requirements that have not yet been fully developed.

For SSC classification and treatment, the staff identified the following key issues:

- Key fission product barriers should be safety-related.
- The proposed approach should explicitly address the roles of non-safety-related with special treatment in relation to regulatory treatment of non-safety systems in providing defense-in-depth.

Fuel Qualification

The staff's assessment was that the current NGNP fuel qualification program is providing important information and insights, but is not sufficient as the basis for a comprehensive fuel qualification program and that additional elements are needed. These include:

- Establishment of fuel design service conditions and performance requirements for normal operations and accidents
- Irradiation and accident proof testing of NGNP fuel fabricated on the production lines of the NGNP fuel fabrication facility

The staff also identified fuel test irradiations in an HTGR neutron environment as a key issue that will need to be addressed. To date, the tristructural-isotropic (TRISO) fuel particle has only undergone irradiation testing in INL's Advanced Test Reactor, a water-cooled materials test reactor. The neutron energy spectrum of a helium-cooled HTGR differs from that of a water-cooled reactor, i.e., graphite neutron moderation versus water neutron moderation. The harder HTGR neutron energy spectrum promotes higher plutonium production and fission of plutonium. The staff viewed plutonium burnup as significant because plutonium fission is the main source of important fission products (e.g. palladium and silver) that are either known (palladium) or hypothesized (silver) to potentially degrade TRISO fuel particle performance under operating and accident conditions.

The staff noted the importance of considering HTGR fuel operating service conditions in terms of the apparent potential for large uncertainties and undetected anomalies involving such key incore parameters as maximum fuel operating temperature. It appears that such issues as HTGR core analysis and core monitoring can be addressed only in small part by analytical means and separate-effects validation testing. The staff concluded that adequate resolution of these issues will necessitate verification of initial and evolving NGNP fuel operating conditions and performance through special operational monitoring, testing, surveillance, and inspection programs for a NGNP prototype.

Mechanistic Source Terms

INL defined an event-specific mechanistic HTGR source term as one that is calculated for a specific licensing basis event. The staff indicated that INL's definition of event-specific mechanistic HTGR source term for modular HTGRs is generally consistent with the relevant Commission-approved staff recommendations in SECY-93-092, "Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and their Relationship to Current Regulatory Requirements," and SECY-03-047.

The staff noted that INL's proposed uncertainty evaluation methodology regarding the application of mechanistic source term models in best-estimate and conservative analyses of transients and accidents is generally reasonable subject to the following considerations. The Monte Carlo uncertainty analysis proposed by INL appears to address only parametric uncertainty. There should also be an assessment of model uncertainty if not rigorous quantification of this uncertainty. Of particular concern is the potential for either inaccurately predicted normal conditions or undetected anomalies to exceed those addressed in the licensing safety evaluation and the qualification, analysis, and validation that support it. Certain anomalous or off-normal operating conditions may have to be considered in establishing operating limits and factored into both the long-term and immediate pre-accident NGNP operating histories assumed in licensing safety analysis.

The staff has proposed that the event selection for siting source terms be supplemented by insights from "safety terrain" studies. These are based on exploratory studies of postulated extreme events. The selection and "physical plausibility" of such events should be explored through examination of the PRA sequences that lead to such events.

The staff noted that future Commission direction may be appropriate for the selection of siting source term events.

Containment Functional Performance

The high-temperature radionuclide retention capability of the TRISO-coated fuel particle is a key element in the design and licensing of modular HTGRs. The design concept is further defined by inherent and passive design features (e.g., low power density, negative temperature coefficient, slender core geometry, passively cooled reactor vessel) that keep the fuel within defined limits under both operating and accident conditions. This collection of design features, taken together, provides a functional containment.

The staff agreed with the INL description of a performance standard for a functional containment. This standard should:

- Ensure radionuclide retention within fuel during normal operation with relatively low release into the helium pressure boundary
- Limit radionuclide releases to the environment to meet the onsite and offsite radionuclide dose acceptance criteria (i.e., 10 CFR 50.34 and U.S. Environmental Protection Agency Protective Action Guides) at the exclusion area boundary with margin for a wide spectrum of off-normal events

The Commission has found the concept of functional containment generally acceptable, as indicated in the SRMs to SECY-93-092 and SECY-03-0047. However, approval of INL's proposed approach to functional containment for the modular HTGR concept would necessitate that the required fuel particle performance capabilities be demonstrated with a high degree of certainty.

Emergency Preparedness

In SECY-11-0152, "Development of an Emergency Planning and Preparedness Framework for Small Modular Reactors," the staff indicated a willingness to consider alternative emergency preparedness requirements for small modular reactor facilities. SECY-11-0152 describes an approach that could be used for determining emergency planning zones on a case-by-case basis for modular HTGRs. The staff recognized that design-specific policy issues may be associated with the approach suggested by INL for proposing a combined low population zone and exclusion area boundary (or a scaled or reduced emergency planning zone) partly based on event-specific release source terms calculated mechanistically for a spectrum of licensing basis events.

INL expects to collocate the NGNP with industrial facilities. Emergency preparedness issues related to licensing nuclear plants that are collocated with industrial facilities could be similar to those currently evaluated for the light-water reactors that are near industrial facilities. The staff finds that a policy issue requiring the Commission's consideration would be necessary if the intended usage differs significantly from existing practices.

Dr. Joy Rempe did not participate in the Committee's discussions regarding this matter.

Sincerely,

/RA/

J. Sam Armijo
Chairman

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