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

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Washington, DC 20555-0001

SUBJECT: REVIEW OF COMPUTER CODE DEVELOPMENT AND VALIDATION FOR NON-LIGHT-WATER REACTORS

Dear Mr. Furstenau:

During the 715th meeting of the Advisory Committee on Reactor Safeguards, April 30 through May 2, 2024, we completed our review of the status of computer code and model development for non-light water reactors (non-LWRs). This review supports the Committee's triennial review and evaluation of the NRC Safety Research program. During our April 3, 2024, meeting, we had the benefit of discussions with representatives of the NRC's Office of Regulatory Research (RES) staff. We also had the benefit of the documents referenced.

CONCLUSIONS AND RECOMMENDATIONS

The Committee recognizes the significant effort by the staff to develop, verify, and validate non-LWR code analysis capability. This will substantially improve the Agency's technical and regulatory readiness for reviewing non-LWR licensing applications.

1. The staff has optimally leveraged internal resources and the Department of Energy's (DOE) Nuclear Energy Advanced Modeling and Simulation (NEAMS) program. This relationship provides mutual benefit: DOE NEAMs gains from having end-user feedback and NRC gains best-in-class capability. This should be continued to provide effective and efficient safety reviews of non-LWR designs.

2. Staff training on the new reactor designs and associated phenomena during code development, application, and validation supports the agency's knowledge management objectives and should be continued.

3. While end user needs for the deterministic application of BlueCRAB computer codes have been largely met, applying these computer codes in probabilistic risk assessments may impose additional requirements. These include capability to incorporate uncertainties, and to couple deterministic and probabilistic codes. The explicit characterization of uncertainties facilitates modern evaluation models that are frequently used in risk-informed analyses.

4. The Agency should pursue a structured and deliberate process for the preservation and maintenance of datasets used to demonstrate the quality of non-LWR computer codes.

BACKGROUND

In 2016, the NRC staff published "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness" and subsequent near-, mid- and long-term implementation plans. These documents describe the objectives, strategies, and contributing activities necessary to achieve technical and regulatory readiness to ensure staff preparedness and capability to perform efficient reviews. The acquisition and development of computer codes and models for non-LWRs is among several strategies, specifically Strategy 2, being employed to achieve this goal.

Since 2016, as part of our periodic review of NRC Safety Research programs, we have provided letters reporting on our assessment of their progress, emphasizing capability and limitations specific to identifying and resolving safety issues associated with non-LWRs. In our March 1, 2021, letter we noted that the staff had completed their near-term action plan of identifying and assessing the available computer codes and databases. This involved the preparation of several documents assessing the need for and availability of analytical tools to support the licensing and regulation of non-LWR technologies. Accordingly, the mid-term strategy is focused on code development and validation as informed by completion of the near-term implementation strategy.

The subjects of our current review are two documents prepared by the staff: "Status Update on Computer Code and Model Development for Non-Light-Water Reactors," and "Verification and Validation (V&V) of the Comprehensive Reactor Analysis Bundle (BlueCRAB)." The BlueCRAB suite of NRC and DOE computer codes gives the NRC staff the capability to independently analyze a broad range of advanced non-LWRs and assess performance of their safety systems. The code suite features single- and multi-physics capability for the following analytical domains:

1) plant systems analysis;
2) fuel performance analysis;
3) severe accident progression and source term analysis;
4) consequence analysis;
5) licensing and siting dose analysis; and
6) nuclear fuel cycle analysis.

The code suite includes well-established NRC safety codes such as TRACE, SCALE and MACCS and several state-of-the-art specialty codes sponsored through DOE's NEAMS program.

Towards technical readiness, the staff has pursued an objective and traceable evaluation model approach for code development; specifically, one mirroring Regulatory Guide (RG) 1.203, "Transient and Accident Analysis Methods." As emphasized in RG 1.203, design-specific Phenomena Identification and Ranking Tables (PIRTs) have been used to establish computer code and modeling requirements. With the benefit of these PIRTs, computer codes have been selected for their applicability to one or more non-LWR designs or for their mutability to support

revision addressing the unique phenomenological and process characteristics of these designs. This approach has facilitated code development prioritization on specific capabilities required for non-LWR designs either currently in the review queue or anticipated.

DISCUSSION

Pursuant with the 2016 non-LWR "Vision and Strategy" report, the staff is currently engaged in mid-term strategic activities related to non-LWR computer code development and validation. With the benefit of seven years of progress, the technical scope is considerable across the six analytical domains highlighted above for the targeted set of non-LWR designs:

1) high temperature gas reactors (HTGRs, both pebble and prismatic);
2) liquid metal cooled fast reactors (LMFRs);
3) molten salt-cooled reactors (MSRs); and
4) heat-pipe-cooled microreactors.

These activities implement plans documented in several volumes dedicated to the highlighted analytical domains that have been the subject of our prior letters on this topic As there are several outstanding technical objectives, the documentation from the staff provides an interim status report of their progress.

VOLUME 1 – Plant Systems Analysis

Volume 1 considered codes for non-LWR systems analysis, specifically the analysis of design basis events. As with LWRs, these plant systems codes provide integral multi-physics capability and commonly contribute to the bulk of any safety analysis. Their use demands a high standard from a quality and completeness perspective. The staff's evaluation model approach addresses this requirement. Drawing on insights from PIRTs and candidate scenarios, software validation of the applicable BlueCRAB computer codes (i.e., SAM for plant systems, PRONGHORN for subchannels, SOCKEYE for heat pipes, and GRIFFIN for core neutronics) is ongoing by staff at both NRC and DOE.

The ongoing software V&V is a large-scale effort and the subject of the separate document provided by the staff. The report provides strong evidence that the staff is progressing as planned and that the codes show reasonable agreement with benchmarks. The principal challenge with this effort relates to the completeness of the datasets. Data incompleteness exacerbates uncertainties in code results. Both NRC and industry struggle to obtain data important in safety reviews for the more novel designs.

As insight is gained on dataset gaps for non-LWRs, experimental programs may be necessary. To the extent practical, partnerships with DOE and international organizations for such programs are encouraged to both be cost-effective and expedite code development and understanding. In the interim, the staff should be sensitive to the importance of quantifying uncertainties in their V&V activities. Future code development should also consider features to accommodate the explicit characterization of uncertainties to allow for best-estimate plus uncertainty evaluation models that are frequently used in risk-informed analyses.

Lastly, the preservation of datasets should be considered an integral part of the knowledge management program at the NRC. As described by the staff, currently the maintenance of

datasets is informal, and the data is not considered an official document. The NRC has a responsibility to make the basis for its computer codes as scrutable as it requires of the industry. As such, a more structured and deliberate process is necessary (such as that used by other government agencies via the U.S. General Services Administration Data.Gov website).

VOLUME 2 – Fuel Performance Analysis

Volume 2 considers fuel performance codes for non-LWRs by performing a comparison of current fuel performance codes, NRC's FAST and DOE's BISON. FAST leverages semi-empirical modeling techniques, which facilitates rapid solutions. In contrast, BISON employs mechanistic modeling to the extent practical. The staff noted that preserving this distinction between FAST and BISON recognizes that code selection depends on the application, i.e., design applications typically require more detailed solutions, whereas confirmatory applications tolerate greater model uncertainty. This is consistent with a previous committee recommendation to focus on simplicity, considering the anticipated use of FAST in confirmatory analyses.

To support non-LWRs, new modeling for material properties, fission gas release and fuel swelling have been added to FAST, specifically for the analysis of metallic (U-xPu-10Zr) and TRISO fuels. Validation of FAST against applicable datasets (i.e., EBR-II, FFTF and AGR) has begun, providing insights on model completeness and accuracy. While modeling gaps are evident, the staff states that FAST is ready for confirmatory analysis (i.e., involving the fuel forms noted). In parallel, the NRC staff is engaged with DOE's BISON code development staff to keep informed about their own code development and validation efforts for advanced reactor fuels.

VOLUME 3 – Severe Accident Progression, Source Term and Consequence Analysis

Volume 3 considers non-LWR code development for severe accident progression, source term and consequence analysis. This capability involves calculation of fission product inventory, its transport, the resulting source term, atmospheric dispersion, and dose consequences. The primary computer codes for this purpose are SCALE (fission product inventory), MELCOR (transport and source term), and MACCS (dispersion and dose). Some new modeling has been necessary for these codes. For example, smaller site boundary distances and releases elevate the importance of near-field atmospheric transport and the particular set of radionuclides considered relative to applications to large LWRs. Beyond these considerations, staff priority has been with the development and application of full-plant models of several representative non-LWR designs.

The staff has prepared these full-plant models with direct stakeholder engagement via public presentations and workshops. These meetings have been invaluable for the feedback from the end-user perspective, including the identification of practical challenges to the preparation of analyses. In particular, the experience with the full-plant model development and hands-on workshops provided an excellent learning opportunity to the staff. The value of this was recently demonstrated with the review of the Kairos HERMES design. Leveraging the experience gained through building full plant models, the staff was able to complete the HERMES model and analyses within six months.

VOLUME 4 – Licensing and Siting Dose Analysis

Volume 4 describes the staff's approach to identifying and assessing computer codes and data used for licensing and siting dose assessment, including transportation and decommissioning applications. Dose assessment codes have three major components: (1) source term input, in-plant transport, and release to the environment; (2) atmospheric transport and diffusion models and environmental pathways models; and (3) a dose consequence model. The NRC employs over 10 dose assessment codes for LWR applications that remain at least partially applicable to non-LWRs. For non-LWR applications, a significant part of the code development is a consolidation of these computer codes into the Software Integration for Environmental Radiological Release Assessments (SIERRA) code. This modernization of the analytical capability provides several benefits that will improve staff performance in technical reviews. These include ease of use, improved utilization of results with other computer codes, and code maintainability.

Progress on new capability related to atmospheric dispersal and transport has advanced to the V&V phase. Development in the areas of source term input and dose consequences is on pace for completion in 2026.

VOLUME 5 – Nuclear Fuel Cycle Analysis

Volume 5 describes the staff's plan to assess changes to the existing fuel cycle analyses for non-LWR designs, including radionuclide characterization, criticality, shielding, and transport for the nuclear fuel cycle and includes plans for modeling accidents and scenarios for the various non-LWR designs. It focuses on the staff's ability to: (1) perform independent fuel cycle safety analyses and consequence assessments; (2) identify gaps in knowledge and in computer code capability; and (3) assess technical and regulatory readiness.

Fuel cycle activities mirror those described for severe accident progression, including the use of the SCALE and MELCOR codes. Specific attention has been given to the preparation of a representative nuclear fuel cycle for each specific non-LWR design. For each stage of the fuel cycle, potential accident scenarios and hazards are identified. A set of credible accidents associated with different non-LWR technologies was selected for detailed analysis. Notably, the experience with the full-plant model development and hands-on workshops provided an excellent learning opportunity for the staff. The staff has engaged stakeholders via workshops and its website. A comprehensive report is scheduled for release later this year.

SUMMARY

The NRC staff has made significant progress implementing its non-LWR code and model development plans. In doing so, they have acted on our prior recommendations to preserve simplicity in the capability and to focus development efforts based on the expected hazard. In our assessment, codes in the analysis suite are complete with respect to the more important phenomena and processes identified in several design-specific non-LWR PIRTs. It is our opinion that the NRC is in a good position to support technical reviews of advanced reactor design applications anticipated in the near future.

These computer codes are valued knowledge repositories, the consequence of substantial domestic and international investments in experiments and model development. As such, continued investments in their development and maintenance are necessary to ensure staff competency and effectiveness in technical reviews.

We look forward to continued interactions with the staff on this topic; although, we are not requesting a formal response to this letter report.

Sincerely,

Walter L. Kirchner Signed by Kirchner, Walter on 05/24/24

Walter L. Kirchner
Chair

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