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

December 13, 2021

The Honorable Christopher T. Hanson
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: BIENNIAL REVIEW AND EVALUATION OF NRC SAFETY RESEARCH PROGRAM

Dear Chairman Hanson:

During the 690th meeting of the Advisory Committee on Reactor Safeguards, November 2-5, 2021, we completed our biennial review and evaluation of the NRC safety research program, which is primarily conducted by the NRC Office of Nuclear Regulatory Research (RES). We were briefed by RES staff on April 8, 2021. Our Research Program Subcommittee was also briefed during its June 25, July 23, and September 20, 2021 meetings. In addition, we were informed by briefings on topics of special interest and the referenced documents.

EXECUTIVE SUMMARY

The depth, breadth, and scope of the on-going safety research program continues to meet the Agency's current needs for regulatory decisions. This program enables staff to maintain core competencies and prepare for reviews of anticipated submittals. Although not part of the formal charter of our review, we note that RES is evolving from what was a static reactive organization to a more dynamic forward-looking one. RES continues to implement a systematic approach to prioritize research emphasizing "enterprise risk" in project selection, evaluation, and termination. The use of the future focused research (FFR) program, the establishment and implementation of non-light water reactor (non-LWR) integrated action plans (IAPs), and the recent RES leadership of agency-wide initiatives are enabling the Agency to become agile and more proactive in preparing for emerging technologies associated with future licensing submittals. The result is an organization that is having greater impact on agency priorities. The FFR program is an asset and should become a sustained agency activity. These activities are all signs of a healthy research organization and should support the Agency's broader efforts to transform itself into a modern risk-informed regulator.

In light of these findings regarding the health of the agency's research portfolio and the rate at which research results are obtained, we recommend that the interval between our formal letter reports be increased from two years to three years. We will continue to have more frequent briefings on research topics of special interest and provide reports as necessary.

BACKGROUND

NRC research activities include conducting confirmatory analyses, developing technical bases to support safety decisions, preparing the Agency for evaluation of the safety aspects associated with new technologies, building staff competencies, and facilitating agency transformation.

Our research reviews consider 1997 Commission guidance to examine the need, scope, and balance of the safety research program, as well as how RES anticipates research needs and positions the Agency for the changing environment. In this letter report, we focused our efforts on understanding the ability of the RES program to meet current and future agency needs, the prioritization and identification of new research projects, long-term planning, and RES response to our prior recommendations.

DISCUSSION

This report highlights selected findings from our review. Our detailed findings, conclusions, and recommendations are provided in Appendices A through C for each RES division: the Division of Risk Analysis (DRA), the Division of Safety Analysis (DSA), and the Division of Engineering (DE).

RES Programs Meet Agency's Near-term Needs

The portfolio of RES activities, which includes the user-need process and the FFR projects, are meeting agency needs and preparing the Agency to address anticipated near-term needs including non-LWR submittals. The balancing of current needs and future needs in the current ever-evolving reactor technology environment is admirable. The non-LWR IAPs and reference plant evaluations using DSA tools identify data gaps, prioritize data needs, and establish the adequacy of computational tools as well as provide staff experience in understanding non-LWR plant response. Important insights may also be gained from using DRA tools. We encourage staff to use reference plant evaluations with DRA tools to develop risk metrics for advanced reactors.

An important RES mission is to develop and maintain the required staff expertise to enable regulatory readiness through research excellence. Each RES division is tracking current and pending gaps in core competencies and taking steps to address these gaps, including gaps in emerging fields such as artificial intelligence, additive manufacturing, and machine learning. Not only are traditional methods, such as hiring prioritization, cross training, and mentoring being pursued, but the NRC university programs and grants are focused on mission-related areas to develop capabilities needed by the Agency. Several divisions use innovative methods, such as increased use of knowledge management seminars on virtual platforms and virtual assignments to external organizations, to develop staff competencies during the pandemic.

In addition, several divisions have reorganized to better support Agency missions. For example, DRA has reorganized to include a new branch to support Office of Nuclear Material Safety and Safeguards (NMSS) environmental projects. The new branch covers environmental hazard analysis, including subsurface monitoring, radon barriers and evapotranspiration. This branch will provide support to NMSS in the areas of dry cask storage licensing, spent fuel storage, and transportation, and decommissioning of the low-level waste business lines. We expect that this support will be extended to transportation of a “fueled” reactor, as anticipated for some advanced microreactor designs.

Furthermore, RES has implemented strategic partnerships, with international and domestic organizations, to develop competencies in emerging fields. International partnerships are also being leveraged by RES to provide some of the data previously obtained from the Halden facility. These collaborations increase staff capabilities, bring together international experts, and allow NRC to be part of international developments. Planned future briefings will allow us to monitor these on-going RES efforts.

Because of the limited experimental databases associated with advanced reactors and new Accident Tolerant Fuels (ATFs), we also continue to be concerned about the loss of the Halden reactor as a generator of in-pile fuel performance data. We share the concern, which was documented in the ATF Phenomena Identification and Ranking Table (PIRT), about the need for data to evaluate accident progression and the potential for criticality during reflood in reactor cores containing ATF. It is important for RES to communicate these data needs to designers or vendors proposing new reactor and fuel concepts.

Prioritization and Process Improvements

With input from other offices, RES applies a systematic approach that emphasizes ‘enterprise risk’ for research project selection, evaluation, and termination. Some RES efforts, such as code maintenance, require continual support. Other projects, such as concentrated efforts to obtain data to support regulatory decisions, may be discontinued or redirected, if subjected to more rigorous evaluations. We recommend that user-needs for these projects have a fixed end-date; new user-need requests should be required to reflect redirection after original objectives are achieved.

Recent Department of Energy Office of Nuclear Energy (DOE-NE) awards have assisted RES in prioritization of non-LWR activities. Furthermore, increased interactions with industry stakeholder organizations have enabled RES to prioritize activities related to regulatory guidance development and revisions as well as activities related to standards review and endorsements.

We support RES efforts to explore new ways to apply existing capabilities and make use of information gained from their programs. For example, Level 3 Probabilistic Risk Assessment (PRA) results will be considered in advanced reactor licensing reviews, Integrated Human Event Analysis System (IDHEAS) models are being applied to develop Title 10 of the *Code of Federal Regulations* (10 CFR) Part 53 Human Factors Engineering review guidance and operator reactor licensing requirements, and human factors expertise is being used in the Agency’s broader innovation initiative. In addition, DE is exploring what opportunities exist to learn from harvested components in the field and how best to obtain valuable information from this material. We encourage DE to also consider another new way to utilize knowledge gained from harvested material information. Namely, we recommend that staff consider whether it is possible to use harvested material information to add a predictive modeling capability to ageing management strategies along with the current approach of establishing limits of life.

Agency-Wide Initiatives

Of particular interest in our review were several new RES initiatives, such as DSA’s development of agency-wide strategies for an integrated code development and investment plan, an agency-wide data science and artificial intelligence strategy and preparing the Agency for regulating new fleet modernization technologies. These initiatives take a holistic longer-term (5-7 years) approach to agency needs. Implementation of new agency-wide strategies may require additional resources.

Of special interest are the FFR initiatives, which DE oversees. The effort on “digital twinning” is a good example of how FFR projects prepare the Agency for anticipated submittals. A digital twin is a representation of a physical asset such as a building, a machine, or even a nuclear reactor. The research is scoped to develop a proper infrastructure for addressing regulatory challenges, and to identify gaps associated with using digital twins. Staff is preparing an assessment of standards for use of artificial intelligence, machine learning, and multi-physics reactor models in digital twins.

We support the RES goal that FFRs become a sustained program. Many FFRs enable the Agency to be ready to regulate new technologies that enable fleet modernization. Annual reports summarizing FFR accomplishments could help facilitate this RES goal. In light of the potential impact on agency research from both a scope and resource allocation perspective, we recommend that a lessons-learned review be performed by RES to identify any improvements needed to maximize beneficial aspects of this initiative, particularly as the number of FFR topics grow.

DRA also has a new and important role in the Agency's transformation effort. They are utilizing organizational factors expertise to drive innovation and culture change, including building infrastructure, the procedures, and processes for maintaining and sustaining innovation. We support this substantial effort and are interested to learn more on how it is being coordinated, what has been accomplished and what is in development.

Future Interactions

In light of these findings regarding the health of the agency’s research portfolio and the rate at which research results are obtained, we recommend that the interval between our formal letter reports be increased from two years to three years.

We will continue our on-going reviews on significant research activities, such as the IDHEAS, Level 3 probabilistic risk assessment (PRA), and non-LWR readiness activities. As noted in Appendices A through C, our review also identified several important RES activities for which future briefings are planned. For example, we are scheduling briefings on several of the new agency-wide initiatives and FFR projects to assess their progress and the process used to select new projects. We plan to review topics of special interest, such as the University Nuclear Leadership Program and activities to address the loss of the Halden facility. These briefings provide a good avenue for keeping us informed of RES progress and enable us to give staff earlier feedback regarding the scope and benefit of research activities.

SUMMARY

The depth, breadth, and scope of the on-going safety research program continues to meet the Agency’s current needs for regulatory decisions. The safety research program is keeping pace with anticipated and current Agency needs, balancing these needs well and maintaining an achievable scope. This conclusion is based, among other inputs, on the development of the FFR program, establishment and implementation of non-LWR IAPs, and the recent agency wide initiatives.

RES programs position the Agency well for the changing environment, as illustrated by improving on-going processes, prioritizing projects, finding new ways to develop and maintain core competencies, and exploring ways to apply existing capabilities. These activities are all signs of a healthy research organization and should support the agency's broader efforts to transform itself into a modern risk-informed regulator.

In light of our findings regarding the health of the agency's research portfolio and the rate at which research results are obtained, we recommend that the interval between our formal letter reports be increased from two to three years. We will continue to have more frequent briefings on research topics of special interest and provide reports as necessary.

Sincerely,

Signed by Sunseri, Matthew on 12/13/21

Matthew W. Sunseri, Chairman

REFERENCES

1. Staff Requirements Memorandum (SRM), "SECY-97-149-NUCLEAR Safety Research Review Committee (NSRRC)," U.S. Nuclear Regulatory Commission, September 9, 1997.

2. Advisory Committee on Reactor Safeguards, Letter from Matthew W. Sunseri, Chairman of ACRS, to Kristine L. Svinicki, Chairman, U.S. Nuclear Regulatory Commission, Subject: Biennial Review and Evaluation of the NRC Safety Research Program, April 13, 2020 (ML20100F066).

3. "NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 1 – Computer Code Suite for Non-LWR Design Basis Event Analysis," Rev. 1, January 31, 2020 (ML20030A176).

4. "NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 2 – Fuel Performance Analysis for Non-LWRs," Revision 1, January 31, 2020, (ML20030A177).

5. "NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 3 – Computer Code Development Plans for Severe Accident Progression, Source Term, and Consequence Analysis," Revision 1, January 31, 2020 (ML20030A178).

6. Draft NRC Document, "NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 4 – Licensing and Siting Dose Assessment Codes," August 2020 (ML20028F255).

7. Draft NRC Document, "NRC Non-Light Water Reactor (Non-LWR) Vision and Strategy, Volume 5 – Radionuclide Characterization, Criticality, Shielding, and Transport in the Nuclear Fuel Cycle," November 3, 2020 (ML20308A744).

8. U.S. NRC, "Office of Nuclear Regulatory Research FY2021-23 Planned Research Activities," July 2021 (ML21175A13).

9. U.S. NRC, "Phenomena Identification Ranking Tables for Accident Tolerant Fuel Designs Applicable to Severe Accident Conditions," NUREG/CR-7283, ERI/NRC 21-204, July 2021.

10. Electric Power Research Institute, "Program on Technology Innovation: Early Integration of Safety Assessment into Advanced Reactor Design—Project Capstone Report," Final Report, October 2019.

APPENDIX A - Division of Risk Analysis

The Division of Risk Analysis (DRA) maintains, enhances, and develops tools and methods to perform risk evaluations. DRA facilitates transformation by enhancing the agency's Risk-Informed Decision Making (RIDM) capabilities, preparing it for future technologies, and overseeing the innovation activities. It serves as a new home for the agency innovation program.

DRA is organized in four branches: Fire and External Hazards; Human Factors and Reliability; Performance and Reliability; and Probabilistic Risk Assessment.

The Fire and External Hazards Analysis Branch is responsible for fire and external hazards research (except seismic risk, see *Appendix C - Division of Engineering*). Its current work is organized around four major projects: (1) Improving Fire Probabilistic Risk Assessment (PRA) Realism, which includes working with the Electric Power Research Institute (EPRI) to support additional improvements in fire PRA; (2) High Energy Arcing Faults (HEAF), which was removed from the pre-generic safety issue program, has continued as a research collaboration with EPRI and the Organization of Economic Co-operation and Development (OECD) to further advance our understanding of a risk posed by HEAF; (3) probabilistic flood hazard assessment, which includes developing the tools and guidance for reviewing a site’s flood hazards and potential consequences, is expected to be completed in 2023; and (4) subsurface characterization and waste covers, which is a new area in the branch developed to support Office of Nuclear Material Safety and Safeguards (NMSS) environmental projects; its environmental hazard analysis includes subsurface monitoring, radon barriers and evapotranspiration covers. Three of the four projects in this branch are either being sunset or performed as collaborative efforts; there is one new project in development. Hence, the need for the resources in the fire hazard area is expected to be reduced, presenting an opportunity to cross train staff and broaden their skills.

The Human Factors and Reliability Branch is responsible for developing and maintaining state-of-the-art human and organizational factors, including human reliability analysis guidance and methods. Its current work is organized around three major projects: (1) Human Reliability Analysis Methods and Data, which include research to improve realism by enhancing methods, reducing uncertainty, and utilizing human performance data; (2) Advanced Human Factors, Human Factors Licensing Review Guidance Updates, which includes developing human and organizational factors guidance for advanced technologies and supporting 10 CFR Part 53 by developing scalable Human Factors Engineering (HFE) review guidance and operator reactor licensing requirements; and (3) Organizational Factors, Agency Innovation and Culture Change, which includes utilizing organizational factors expertise to drive NRC innovation and culture change.

The Performance and Reliability Branch is responsible for research programs to assess reliability information, perform event assessments, and support the RIDM framework. Its current work is organized around three major projects: (1) Data Collection and Analytics, which includes reviews and evaluations of operating experience for the purpose of updating RIDM models; (2) Accident Sequence Precursor (ASP) Program, which includes evaluating U.S. nuclear power plant operating experience to identify, document, and rank operational events; and (3) RIDM and PRA Guidance and Standards, which includes developing guidance to determine the acceptability of PRAs and their results in decision making. Under the third project, this branch has plans to develop databases of methods used in PRAs and PRA standards, guidance on uses of non-PRA techniques, and an updated glossary of risk-related terms.

The Probabilistic Risk Assessment Branch is responsible for managing programs related to the PRA models and methods and supporting agency efforts to use risk information in all aspects of regulatory decision making. Its current work is organized around three major projects: (1) SAPHIRE and SPAR Models, which includes maintaining, expanding and enhancing their models, and development of the cloud-based SAPHIRE; (2) Level 3 PRA, which includes developing full-scope, site Level 3 PRA to support risk-informed decision making, and putting insights from the State-of-the-Art Reactor Consequence Analysis (SOARCA) in the proper risk context; and (3) Dynamic PRA, a FFR project designed to prepare NRC staff on the use of Dynamic PRA (DPRA) tools for anticipated submittals developed using DPRA methods.

Key findings and conclusions from our review of DRA activities are summarized below.

- Work in DRA is essential for risk-informed regulation; the division represents a prominent agency resource on all risk-related activities. One of the objectives of the division is to build and enhance staff core competencies, which has been accomplished by hiring and training staff, rotational assignments, and staff developmental assignments. Staffing limitations are known to have affected the completion schedule for projects, such as the Level 3 PRA and IDHEAS efforts. Cross training staff across branches is expected to provide greater flexibility in handling staff losses.

- DRA continues to leverage resources and skills through collaboration with other organizations. The Agency benefits from current international and domestic collaborations. However, we continue to encourage the staff to ensure agency expectations are emphasized in these collaborations.

- DRA is “sunsetting” some projects but finding new roles for existing capabilities. For example, Level 3 PRA results will support advanced reactor licensing reviews and IDHEAS models will be applied to develop 10 CFR Part 53 HFE review guidance and operator reactor licensing requirements, as well as to support the Agency’s broader innovation initiative. We strongly endorse these new applications of developed methods.

- DRA has initiated an effort to develop guidance to address PRA uncertainties. We strongly support this effort, because there is a clear need for more comprehensive guidance on how to treat uncertainty results in risk-informed regulatory decisions. This is an especially important issue for advanced reactors, with new design features for which operating data are not available and modeling experience is limited.

- DRA is currently looking to expand their support to NMSS in the areas of dry cask storage licensing, spent fuel storage, and transportation, and decommissioning of the low-level waste business lines. We expect that this support will be extended to transportation of “loaded” modules, as anticipated for some advanced microreactor designs. Developing risk tools for these applications will be an important step in “risk-informing” 10 CFR Parts 71 and 72. We plan to follow the progress of this effort.

- DRA work on the advanced reactor program is expected to increase over the next couple of years. Research is needed to address important issues, such as the graded use of PRA and development of risk metrics for non–LWRs related to the new 10 CFR Part 53 rulemaking; this research should be supported by pilot studies. The current effort led by EPRI and Vanderbilt University on this subject is concentrating on a Safety-in-Design approach, as an alternative to PRA. We plan to follow this topic and staff efforts to address important issues related to the use of PRA for non-LWRs.

- DRA has a new and important role in the agency's transformation effort, utilizing organizational factors expertise to drive innovation and culture change at the NRC. That includes building infrastructure, procedures, and processes for maintaining and sustaining innovation. We support this substantial effort. At this time, however, we do not have enough information to evaluate how it is being coordinated and what has been accomplished.

APPENDIX B - Division of Systems Analysis

The Division of Systems Analysis (DSA) is home to the safety-related computer codes that calculate the response of a nuclear reactor to off-normal events from accident initiation to associated worker and public radiation doses. Core competencies include neutronics and reactor physics, thermal hydraulics, fuel performance, severe accidents, source term and radiation health effects. The division relies on staff expertise, augmented by capabilities at national laboratories and other organizations, as necessary. Finding qualified staff in this area remains a challenge, one that is shared by the national laboratories, legacy reactor vendors, and new startup companies. Cross training of staff is encouraged, when possible; but the required technical capabilities in many cases are quite narrow and deep.

There are four branches in DSA: Accident Analysis; Code and Reactor Analysis; Fuel and Source Term Code Development; and Radiation Protection. Numerous international collaborations are used by all DSA branches to leverage experimental capabilities around the world. The experimental data are used to validate key parts of DSA's analytic tools. The international experiment capabilities would cost the NRC hundreds of millions of dollars to replicate in the U.S. In addition, DSA codes have a large international set of users, a testament to the quality and value of division products to the international reactor safety community.

The Accident Analysis Branch develops, maintains, and applies codes, such as TRACE and PARCS, to perform audit or confirmatory system-level transient analyses for LWRs and some non-LWRs. For other non-LWRs, the geometric configuration or the specific phenomena associated with the technology that cannot be simulated with their existing tools has led the group to use the newly developed Comprehensive Reactor Analysis Bundle (CRAB) suite of codes. The branch also reviews applicants' topical reports on their system level tools to confirm the adequacy of the calculational methodology, analytic modeling approach, and verification and validation results.

The importance of the Agency having tools to independently assess licensing applications continues to reap positive benefits. Independent assessment with agency tools, such as TRACE and FAST, allowed the Agency to move forward with licensee submittals in cases where validated industry tools were deemed insufficient. KATHY tests, which provided data for validating TRACE models, were essential in the Maximum Extended Load Line Limit Analysis Plus (MELLLA+) evaluations. Likewise, Halden BWR data were key in validating FRAPCON (now FAST) models. We encourage staff to expedite the release of KATHY data, and we continue to emphasize the need to obtain data to characterize the performance of new fuel designs.

The Fuel, Neutronics, Severe Accidents and Source Term Branch has used the FAST code for LWR fuel performance assessments and recently expanded the code to model both metallic fuel for fast reactors and TRISO particle fuel for high temperature reactors. Beyond advanced reactor fuel forms, priorities include both ATF and high burnup fuels for the existing fleet. Physics parameters necessary for safety analysis are calculated using SCALE and PARCs. Research is underway to evaluate reactivity worths of actinides and fission products and to better understand isotopic effects of high burnup and mixed oxide fuels. The group is also becoming familiar with similar DOE-NE tools. Although models require additional validation, these codes can simulate complicated non-LWR phenomena not currently incorporated into NRC codes. MELCOR is the branch's severe accident tool and is being applied to several small modular LWRs including the NuScale nuclear power module (50 MWe), BWRX-300, and Holtec-SMR-160. The code has also been extended for non-LWR systems, and updates for

ATF concepts are planned. Because of the smaller experimental databases associated with advanced reactors and new LWR fuels compared to the current fleet [as noted in the recent ATF PIRT] and the loss of the Halden reactor as a generator of in-pile fuel performance data, sensitivity analysis is being used to understand the influence of uncertainties on accident progression, consequences, and ultimately risk. As observed in several of our letters, we continue to be concerned about the need for data to validate models to characterize the response of (a) designs proposed or anticipated as near-term submittals, (b) high burnup fuel and new materials incorporated into some ATF concepts, and (c) accident progression and the potential for criticality during reflood in reactor cores containing ATF.

The Consequence Analysis Branch uses the MACCS code to calculate doses to workers and the public. It has an extensive user base with 600 users in over 25 countries, representing 125 different international organizations. A key focus for the branch is to improve and upgrade the code, which has not been updated since the 1990s. The branch is also improving near field dispersion models for SMRs and microreactors. They also support the National Aeronautics and Space Administration (NASA) in their space nuclear work.

The Radiation Protection Branch interfaces with several government agencies and international entities (e.g., ICRP, IRPA) because of the numerous codes in the RAMP code suite dedicated to licensing, emergency response, environmental assessment, and decommissioning. In response to one of our prior biennial review recommendations, DSA has initiated a major code consolidation activity to combine and integrate many of these codes together. Demonstration of the final consolidated product is anticipated at the end of FY-23 and follow-on documentation is to be provided by mid-FY-24. A new area of research for this group is using drones and virtual reality for radiation surveys. We suggest that this research also consider new technologies, such as gamma cameras and plastic scintillation fibers, which are being successfully deployed in Fukushima-related activities.

Three major areas of interest are DSA's readiness for advanced reactor licensing activities, DSA's agency-wide initiatives to develop a Code Investment Plan and a strategy related to data science and artificial intelligence.

The division's readiness for advanced reactors continues to increase. As observed in our letters, RES has issued six reports, Integrated Action Plans (IAPs), identifying modeling needs in key analytic tools that must be filled in order to properly analyze advanced reactors. Identification of experimental data gaps is also underway. An annual short summary report describing how results from this work compare to the IAPs, noting any necessary adjustments going forward, is recommended.

DSA applied their analytic tools to non-LWR reference plants and provided knowledge management seminars to inform staff and interested stakeholders. Reactor reference plant models, based on publicly available designs, have been developed for each of the major advanced reactor technologies for the staff to learn about the technologies and to establish functional working level models for these systems. Reference models serve as a starting point for actual designs anticipated under future licensing applications; as necessary, these models will be upgraded using plant specific information. Even though these models are not based on designs expected to be submitted, they have been very useful for the DSA and Office of Nuclear Reactor Regulation (NRR) staff in pre-application meetings, audits, and generation of focused Requests for Additional Information (RAIs). The recent DOE-NE advanced reactor awards are also being used by staff to prioritize future work in this area.

In response to an SRM, DSA initiated an effort to develop an agency Code Investment Plan focused on providing a holistic approach to the maintenance, state of the practice development, modernization, and consolidation of the 34 active computer codes used by the staff. The process is focused on examining needs in the next 5 to 7 years to provide input to the NRC budget formulation process. The approach is currently being socialized with relevant program offices. This effort is notable because it broadens the scope of prior activities; it goes beyond any single code and covers a longer period of time. This effort will ultimately be important to the success of portfolio management of the agency's suite of computation capabilities.

The data science and artificial intelligence initiative is new to the Division. Similar to the Code Investment Plan, the ultimate goal is to develop a strategy for the entire Agency. Currently, staff is in an information gathering phase, establishing technology "use cases", including resource prediction tools; business analytics and other internal process automation; autonomous control technologies/algorithms and digital reactor twins (see *Appendix C - Division of Engineering*); and big data applied to consequence analysis. The staff anticipates future workshops and stakeholder interactions will inform the ultimate strategy being developed. Given the breadth and depth of the topic, good definitions are necessary as are government standards. Key outputs from the strategy should be guidance for how to regulate artificial intelligence and what sort of credit it will receive in the licensing process. In the longer term, it would be beneficial to establish impactful domestic and international partnerships as this technology is applied to nuclear regulation.

Our review of DSA activities led to several findings:

- The breadth and depth of the capabilities in DSA are critical to providing the technical basis for reasonable assurance findings of the safety of reactor designs as part of the overall licensing process.

- The division successfully uses numerous international collaborations to leverage experimental capabilities around the world. These capabilities would cost the NRC hundreds of millions of dollars to replicate in the U.S. DSA codes have a large international set of users, a testament to their quality and value.

- The balancing of current needs and future needs (ATF, high burnup fuel, and advanced reactor applications) in the current ever-evolving reactor technology environment is admirable. Preparation for advanced reactor applications is coming along well across a range of anticipated reactor technologies. More results are expected next year. The reference plant evaluations are helping to identify data gaps, prioritize data needs, and establish the adequacy of computer tools. Recent DOE-NE funding awards have helped NRC prioritize its research activities. This balancing is critical to performing "the right research at the right time".

- The new efforts to develop an agency-wide code investment strategy is sound. The process is a holistic assessment focused on key needs over longer time periods (5-7 years) to have the greatest impact to the Agency.

- The new agency-wide data science and artificial intelligence initiative is a worthwhile endeavor. Good definitions, standards and use cases are critical to its value to NRC. The impact on reactor safety (e.g., autonomous control, vulnerability assessments) needs to be established. Getting started on this work early is laudable.

APPENDIX C - Division of Engineering

The Division of Engineering (DE) plans, develops, and directs safety research technology and engineering programs and standards development to enable the Agency to become a modern, risk informed regulator. To better support their current programs, the division has reorganized into five branches: Regulatory Guide and Programs Management; Reactor Engineering; Materials Engineering; Instrumentation, Controls, and Electrical Engineering; and Structural, Geotechnical, and Seismic Engineering. In support of these activities, DE maintains and develops a broad range of core competencies, including metallurgy, non-destructive examination methods, physical chemistry, and materials science; system and component design and performance (including high temperature applications), instrumentation and controls, electrical engineering; and structural, geotechnical, and seismic engineering.

During the agency's response to the national health crises in 2020 and 2021, there were challenges in personnel vacancies and in maintaining staff competencies. One example of an innovative approach by DE to continue competency development was in the area of non-destructive evaluation for advanced manufacturing technologies (AMT). An engineer from the branch was scheduled to go on rotation to Oak Ridge National Laboratory to gain experience but the pandemic prevented travel. Instead, a virtual rotation assignment was created to obtain some of the experience sharing until such time that travel is allowed to complete the rotation.

DE has made progress addressing recommendations from our last report. DE has followed through on external engagement, including with non-nuclear expertise, to prepare for emerging technologies, such as AMT. DE also made progress to address the Halden Gap. We note, however, that long lead times are required to obtain data with limited facilities. DE will need to publicize identified data needs well in advance to gain access to available facilities. Additionally, DE continues to evaluate research projects and discontinue work when research objectives have been met as observed with the embedded digital device project.

We identified several highlights and recommendations during our review.

- Industry is moving ahead with using AMT for the development of components for use in nuclear facilities. DE is identifying plans for research and working with external stakeholders to prepare the Agency for regulating the use of components fabricated using AMT. We recommend that DE include research to support development of appropriate requirements and guidance for quality assurance and inspection of AMT components intended for safety related and important to safety applications. We plan to follow DE progress in this area as part of our planned FFR project reviews.

- The current regulatory framework for seismic design is based on the concept of a safe shutdown earthquake (SSE). Within this confine, all structures, systems, and components (SSCs) important to safety are designed to be fully capable of satisfying their safety function at the ground motion levels of the SSE. The current research is exploring alternatives to this approach that accounts for the function and risk significance of each individual SSC. In this approach, safety margins of individual SSCs could be designed according to their contribution to system and plant level risk. This approach has the potential to reduce unnecessary conservatism built into the current approach. The benefits are potentially safer designs and better safety focus on the key SSCs during the operation and maintenance cycle of the plant. We agree that there is potential benefit to seismic safety of facilities designed and built under this proposed risk-informed performance-based seismic design approach. We plan to follow up as more details are available on the progress of the research.

- DE staff discussed twelve FFR initiatives, which the division oversees, and agency gains from this relatively new RES process. In light of the potential impact on agency research from both a scope and resource allocation perspective, we recommend that a lessons-learned review be performed by RES to identify any improvements needed to maximize beneficial aspects of this initiative, particularly as the number of FFR topics grows. As an example of how FFR projects prepare the Agency for anticipated submittals is the effort on "digital twinning." A digital twin is a representation of a physical asset such as a building, a machine, or even a nuclear reactor. The research is scoped to develop a proper infrastructure to address regulatory challenges, and gaps for using digital twins. Staff is preparing an assessment of standards for use of artificial intelligence, machine learning, and multi-physics reactor models in digital twins.

- One of the more important issues with digital twins is communication and knowledge management. Staff is proactively communicating and engaging with stakeholders; staff has also developed training programs to build their capabilities and capacities. Staff expects to engage with the DOE-NE, EPRI, and international stakeholders to enable information sharing and knowledge building. In this light, staff recently sponsored a well-attended digital twin workshop that was the first to address nuclear applications of this technology. Contact with experienced developers, nuclear and non-nuclear, is beneficial to this research. We will continue to follow this research as it progresses to use in the agency's regulatory decision-making capacity.

- DE discussed research activities associated with materials harvesting. Based on past experiences with harvesting, staff is exploring what opportunities exist to learn from components in the field and how best to obtain valuable information from this material. We encourage research staff to consider another new way to utilize knowledge gained from harvested material information. Is it possible that harvested material information could be used to add a predictive modeling capability to ageing management strategies along with the current approach of establishing limits of life? We recommend that staff consider this question in the scope of this research project. We will continue to follow DE progress on this topic.

- The new, Regulatory Guide and Programs Management Branch, serves as project manager for the agency's regulatory guide program. This program includes managing regulatory guide development, managing the internal review process, issuing regulatory guide comments including the original topic comments and the final verification process. There are approximately 350 regulatory guides being maintained by the branch with an additional 35 currently in the process of being issued. Over the last year, the branch has worked with internal and external stakeholders on guidance prioritization and review process improvements. The implemented changes have shortened the review period to 6-11 months. As part of the continuous improvement process, research staff requests to increase coordination with us. We look forward to working with DE to improve the review of regulatory guides. In addition, we reiterate our suggestion that staff move expeditiously to implement the EmBark Studios recommendations regarding code case approvals.

December 13, 2021

SUBJECT: BIENNIAL REVIEW AND EVALUATION OF NRC SAFETY RESEARCH PROGRAM

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