COMPLETING A RULEMAKING TO ESTABLISH A TECHNOLOGY-INCLUSIVE REGULATORY FRAMEWORK FOR OPTIONAL USE BY COMMERCIAL ADVANCED NUCLEAR REACTOR TECHNOLOGIES IN NEW REACTOR LICENSE APPLICATIONS AND TO ENHANCE COMMISSION EXPERTISE RELATING TO ADVANCED NUCLEAR REACTOR TECHNOLOGIES

A Report for
U.S. Senate Committee on Environment and Public Works
U.S. House of Representatives Committee on Energy and Commerce

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Enclosure

INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) developed this report as required by Section 103(e) of the Nuclear Energy Innovation and Modernization Act (NEIMA or the Act), which requires the NRC to submit to the appropriate congressional committees a report for (1) completing a rulemaking to establish a technology-inclusive regulatory framework for optional use by applicants in licensing commercial advanced nuclear reactor technologies in new reactor license applications and (2) ensuring that the NRC has adequate expertise, modeling, and simulation capabilities, or access to those capabilities, to support the evaluation of commercial advanced reactor license applications, including the qualification of advanced nuclear reactor fuel. The Act includes requirements for the development of this report, including coordinating and seeking stakeholder input in its development, providing cost and schedule estimates, and evaluating various policy and technical issues associated with advanced nuclear reactor technologies. The Act defines "advanced nuclear reactor" as a nuclear fission or fusion reactor, including a prototype plant, with significant improvements compared to commercial nuclear reactors under construction as of the date of enactment of the Act.

The NRC is an independent regulatory agency whose mission is to license and regulate the Nation's civilian use of radioactive materials to protect public health and safety, promote the common defense and security, and protect the environment. The NRC and the U.S. Department of Energy (DOE) have distinct roles, but have worked jointly through several memoranda of understanding (MOUs) (as described in SECY-21-0010, "Advanced Reactor Program Status," dated February 1, 2021 (Ref. 1)). The NRC and the DOE's Office of Fusion Energy Sciences have initiated routine interactions to develop longer term strategies for the possible deployment of safe fusion energy systems.

This report addresses each of the requirements of NEIMA Section 103(e), "Report To Complete a Rulemaking To Establish a Technology-Inclusive Regulatory Framework for Optional Use by Commercial Advanced Nuclear Reactor Technologies in New Reactor License Applications and To Enhance Commission Expertise Relating to Advanced Nuclear Reactor Technologies." In July 2019, as required by NEIMA Section 103(b) and Section 103(c), the NRC sent two reports to Congress: (1) "Approaches for Expediting and Establishing Stages in the Licensing Process for Commercial Advanced Nuclear Reactors" and (2) "Increasing the Use of Risk-Informed and Performance-Based Evaluation Techniques and Regulatory Guidance in Licensing Commercial Advanced Nuclear Reactors" (Ref. 2). These reports provide additional details on specific aspects related to the NRC's preparation for licensing advanced nuclear reactors.

BACKGROUND

The NRC's Policy Statement on the Regulation of Advanced Nuclear Power Plants, issued on July 8, 1986, in Volume 51 of the *Federal Register* (FR), page 24643 (51 FR 24643) (Ref. 3), and reissued as the Policy Statement on the Regulation of Advanced Reactors on October 14, 2008, in Volume 73 of the FR, page 60612 (73 FR 60612) (Ref 4), provides all interested parties, including the public, the Commission's views concerning the characteristics of advanced reactor designs. The policy statement identifies attributes that the Commission anticipated would be considered in advanced nuclear reactor designs, including highly reliable and less complex heat removal systems, longer time constants before reaching safety system challenges, reduced potential for severe accidents and their consequences, and use of the defense-in-depth philosophy of maintaining multiple barriers against radiation release. In the policy statement, the Commission also encouraged the earliest possible interaction of applicants, vendors, other government agencies, and the NRC to provide for the early identification of regulatory requirements for advanced reactors. Such interaction provides all interested parties, including the public, with a timely, independent assessment of the safety and security characteristics of advanced reactor designs. These interactions also contribute towards minimizing complexity and adding stability and predictability in the licensing and regulation of advanced reactors.

Following the issuance of the advanced reactor policy statement in 1986, the NRC interacted with the DOE and reactor developers on the potential for reviewing and licensing advanced reactor designs based in part on design information provided in the form of a preliminary safety information document. These activities resulted in the publication of assessments of preliminary designs such as NUREG-1368, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor," issued February 1994 (Ref. 5), and NUREG-1338, "Draft Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor [MHTGR]," issued March 1989 (Ref. 6). The NRC staff identified several potential policy issues during its assessments of advanced reactor designs and proposed approaches to resolve some of these issues in SECY-93-092, "Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS [Process Inherent Ultimate Safety]) and CANDU 3 [Canadian Deuterium Uranium] Designs and Their Relationship to Current Regulatory Requirements," dated April 8, 1993 (Ref. 7). The Commission approved the NRC staff's proposed approaches in a staff requirements memorandum (SRM) dated July 30, 1993 (Ref. 8).

During the 1990s, the NRC continued to develop review and licensing approaches for advanced reactors. These activities were done in parallel, and sometimes interwoven, with the NRC's efforts to improve risk-informed and performance-based approaches within the agency (e.g., the Commission's policy statement, "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities," published on August 16, 1995 (60 FR 42622) (Ref. 9)). The Commission provided further clarification in the white paper, "Risk-Informed and Performance-Based Regulation," dated March 1, 1999 (Ref. 10). In the early 2000s, the NRC continued to identify and resolve policy and technical issues during pre-application activities on advanced reactor designs, including the gas turbine modular helium reactor and the pebble bed modular reactor. In August 2008, the NRC and the DOE jointly issued, "Next Generation Nuclear Plant Licensing Strategy, A Report to Congress" (Ref. 11). The NRC staff continued activities related to advanced reactors following the specific work related to the Next Generation Nuclear Plant. In August 2012, the NRC published its strategy for and approach to preparing for the licensing of advanced reactors in its "Report to Congress: Advanced Reactor Licensing" (Ref. 12).

In 2016, the NRC issued its "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light-Water Mission Readiness" (Advanced Reactor Vision and Strategy Document) (Ref. 13), in response to increasing interest in advanced reactor designs, including possible legislation. The NRC considered the DOE's advanced reactor deployment goals developed in the 2016 timeframe when setting priorities for its readiness activities and continues to reassess its activities to support the DOE's deployment goals.

To achieve the goals and objectives stated in the NRC's Advanced Reactor Vision and Strategy Document, the NRC developed implementation action plans (IAPs). The IAPs identified the specific activities the NRC would conduct in the near-term (within 5 years), mid-term (5 to 10 years), and long-term (beyond 10 years). The NRC released its draft IAPs to obtain stakeholder feedback during a series of public meetings held between October 2016 and March 2017. The NRC staff also briefed the Advisory Committee on Reactor Safeguards (ACRS) on March 8 and 9, 2017. The NRC staff considered the ACRS comments and stakeholder feedback in the final near-term IAPs (Ref. 14) and mid-term and long-term IAPs (Ref. 15), dated July 2017.

The near-term IAPs address six individual strategies:

(1) Acquire/develop sufficient knowledge, technical skills, and capacity to perform non-light water reactor (non-LWR) regulatory reviews.

(2) Acquire/develop sufficient computer codes and tools to perform non-LWR regulatory reviews.

(3) Develop guidance for a flexible non-LWR regulatory review process within the bounds of existing regulations, including the use of conceptual design reviews and staged-review processes.

(4) Facilitate endorsing, as appropriate, industry codes and standards needed to support the non-LWR life cycle (including fuels and materials).

(5) Identify and resolve technology-inclusive policy issues (not specific to a particular non-LWR design or category) that impact regulatory reviews, siting, permitting, and/or licensing of non-LWR nuclear power plants.

(6) Develop and implement a structured, integrated strategy to communicate with internal and external stakeholders having interests in non-LWR technologies.

Based on input received from stakeholders on the draft near-term IAPs and ACRS recommendations, the NRC assigned highest priority to its execution of Strategies 3 and 5; however, activities are ongoing in support of all six strategies. The NRC staff issued SECY-21-0010, "Advanced Reactor Program Status," on February 1, 2021 (Ref. 1). This is the fourth annual paper that provides the status of the NRC staff's activities related to advanced reactors, including the progress and path forward on each of the IAP strategies. It also provides an overview of the various external factors informing the NRC staff's activities to prepare for the review and potential licensing of advanced reactors.

In the 2016 Advanced Reactor Vision and Strategy Document and mid-term and long-term IAPs, the NRC identified the potential need to initiate and develop a new risk-informed, performance-based, and technology-inclusive regulatory framework that focuses NRC staff review efforts commensurate with the risks posed by the advanced nuclear reactor design under consideration. In NEIMA, Congress directed the NRC to establish this new regulatory framework; the NRC plans to develop in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 53, "Licensing and regulation of advanced nuclear reactors," by October 2024.

COORDINATION AND STAKEHOLDER INPUT (NEIMA Section 103(e)(2))

The NRC staff coordinated with the DOE and other stakeholders in developing this report. Specifically, the NRC discussed plans for the preparation of this report with DOE representatives on October 23, 2020, and received DOE input on the draft report in May 2021. The NRC also discussed plans for the preparation of this report during public meetings on November 5, 2020, and on April 15, 2021, to seek input from licensees, trade associations, a diverse set of technology developers, vendors, members of the public, and other stakeholders.

The NRC staff initiated extensive stakeholder interactions in a series of public meetings, as well as regular engagement with the ACRS, and these discussions have informed the development of this report. As part of these interactions, the NRC staff is implementing a novel rulemaking approach of periodically releasing preliminary proposed rule language to facilitate public discussion. This allows for early public input as the rule language is refined. The NRC successfully managed the challenges presented by the COVID-19 public health emergency without any significant impact to the development of Part 53 by quickly adapting to a virtual working environment and conducting virtual public meetings and workshops to fully engage and encourage stakeholder participation. Stakeholders have provided diverse and significant input on the preliminary proposed rule language during public meetings, with some commenters expressing their desire to see additional changes in response to their comments. The NRC staff is evaluating the comments and will consider the varying stakeholder perspectives as it continues development of Part 53.

The NRC will continue to interact with the DOE and other stakeholders to gather information to inform the development of Part 53 as well as other NRC advanced reactor readiness activities. The NRC staff updates its public Web site and the associated docket on Regulations.gov (Docket ID NRC-2019-0062) as new information becomes available and compiles all released preliminary proposed rule language in one location (Ref. 16). The NRC will continue to engage with stakeholders as appropriate throughout the rulemaking process.

Since July 2016, the NRC has conducted about 50 public stakeholder meetings, approximately one every 6 weeks, to discuss advanced reactor topics of interest, including Part 53, advanced reactor content of application efforts, staged licensing, advanced reactor fuel qualification, and consensus codes and standards. The NRC has also conducted advanced reactor sessions at its annual Regulatory Information Conference and conducted several briefings to the various ACRS subcommittees and the ACRS full committee, which were open to the public. The NRC staff will continue to conduct public meetings with stakeholders approximately every 6 weeks in addition to the separate public meetings dedicated to the development of Part 53. The NRC staff also has routine public meetings with developers of specific advanced reactors related to design, review, and licensing issues. The NRC and the DOE's Office of Fusion Energy Sciences have also initiated routine interactions to inform the NRC staff and develop longer term strategies for the review and possible licensing of fusion energy systems, and these interactions have been accelerated to support the development of Part 53.

THE ABILITY OF THE COMMISSION TO COMPLETE A RULEMAKING TO ESTABLISH A TECHNOLOGY-INCLUSIVE REGULATORY FRAMEWORK FOR LICENSING COMMERCIAL ADVANCED NUCLEAR REACTOR TECHNLOGIES BY DECEMBER 31, 2027 (NEIMA Section 103(e)(4)(A))

Consistent with NEIMA Section 103, the NRC staff will establish by December 31, 2027, a risk-informed, technology-inclusive regulatory framework for advanced reactors for optional use by applicants for new commercial advanced nuclear reactor licenses. The NRC staff presented its proposed plan for this rulemaking to the Commission for approval in SECY-20-0032, "Rulemaking Plan on 'Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors (RIN-3150-AK31, NRC-2019-0062)," dated April 13, 2020 (Ref. 17). On October 2, 2020, the Commission approved the staff's proposed approach in SRM-SECY-20-0032 (Ref. 18) and directed the staff to accelerate its timeline and provide the Commission a schedule with milestones and resource requirements to achieve publication of the final rule by October 2024. The SRM also directed the NRC staff to inform the Commission of key uncertainties impacting publication of the final rule by October 2024. On November 2, 2020, the staff provided a response to SRM-SECY-20-0032 (Ref. 19) outlining a schedule for preparing a rulemaking package that conforms to the Commission's direction to achieve publication of the final rule by October 2024.

As described in the rulemaking plan, Part 53 will define technology-inclusive, performance-based requirements for advanced nuclear reactors. The NRC staff plans to focus the rulemaking on risk-informed functional requirements by building on concepts and language found in existing NRC requirements, Commission policy statements, and recent activities undertaken to implement the NRC's Advanced Reactor Vision and Strategy. The performance-based requirements will support a risk-informed approach that will acknowledge design features that prevent adverse consequences. The new rule will (1) continue to provide reasonable assurance of adequate protection of public health and safety and promote the common defense and security; (2) promote regulatory stability, predictability, and clarity; (3) reduce the need for exemptions from the current requirements in 10 CFR Part 50, "Domestic licensing of production and utilization facilities" (Ref. 20), and 10 CFR Part 52, "Licenses, certifications, and approvals for nuclear power plants" (Ref. 21); (4) establish new requirements to address non-LWR technologies; (5) recognize technological advancements in reactor design, where appropriate; and (6) credit the response of advanced nuclear reactors to postulated accidents, where appropriate, including slower transient response times and relatively small and slow release of fission products.

Consistent with Commission direction in SRM-SECY-20-0032, the NRC staff is considering appropriate treatment of fusion energy systems in the regulatory structure. The NRC staff's assessments of the potential risks posed by various fusion technologies and possible regulatory approaches for fusion energy systems will be done in parallel with development of the draft proposed rulemaking package for Part 53, and staff will develop an options paper for Commission consideration. The draft proposed Part 53 rule will be developed with the aim of accommodating fusion technologies as much as possible to maintain flexibility for future Commission direction. The NRC staff is considering a separate rulemaking to address fusion energy systems that would extend beyond 2024 but would be completed before 2027, which will allow additional time to assess fusion technologies to better incorporate them into a technology-inclusive regulatory framework.

THE EXTENT TO WHICH ADDITIONAL LEGISLATION, OR COMMISSION ACTION OR MODIFICATION OF POLICY, IS NEEDED TO IMPLEMENT ANY PART OF THE NEW REGULATORY FRAMEWORK (NEIMA Section 103(e)(4)(B))

The requirements of 10 CFR Part 53 will be consistent with the framework of the Atomic Energy Act of 1954, as amended (AEA), including promoting the common defense and security and adequately protecting public health and safety. The NRC staff evaluated the AEA and determined that it provides an appropriate safety and legal construct to support the use of risk-informed and performance-based evaluation techniques. The NRC staff is committed to developing a framework that achieves the goals of the Commission's advanced reactor policy statement (Ref. 4) and the NRC's principles of good regulation (independence, openness, efficiency, clarity, and reliability). Therefore, at this time, for nuclear fission reactors, the NRC staff has not identified additional legislation, Commission action, or modification of policy needed to implement a new regulatory framework.

THE NEED FOR ADDITIONAL COMMISSION EXPERTISE, MODELING, AND SIMULATION CAPABILITIES, OR ACCESS TO THOSE CAPABILITIES, TO SUPPORT THE EVALUATION OF LICENSING APPLICATIONS FOR COMMERCIAL ADVANCED NUCLEAR REACTORS AND RESEARCH AND TEST REACTORS, INCLUDING APPLICATIONS THAT USE ALTERNATIVE COOLANTS OR ALTERNATIVE FUELS, OPERATE AT OR NEAR ATMOSPHERIC PRESSURE, AND USE PASSIVE SAFETY STRATEGIES (NEIMA Section 103(e)(4)(C))

For the purpose of this section of the report, the NRC has focused on the following technologies: light-water small modular reactors; non-LWRs, including high-temperature gas-cooled reactors (HTGRs), liquid metal fast reactors (e.g., sodium-cooled fast reactors (SFRs)), and molten salt reactors (MSRs); and microreactors. As part of a holistic effort to ensure the NRC has access to adequate expertise, modeling, and simulation capabilities to support the NRC staff's evaluation of commercial advanced reactor license applications and research and test reactors (RTRs), the NRC has taken steps to augment existing capabilities in the following areas:

- NRC staff training and knowledge management
- acquiring and developing analytical tools

Given available resources and the potentially long lead times for adding capability to existing computer codes, the NRC's planning is based on a current understanding of industry plans. Changes in the advanced reactor landscape or developers' accelerated efforts could result in a need to revise the priorities assigned to augmenting analytical tools. In particular, the NRC has very limited expertise on fusion energy. At present, the NRC staff is working with the DOE Office of Fusion Energy Sciences staff and interacting with stakeholders to develop knowledge and capabilities.

NRC Staff Training and Knowledge Management

The NRC has adequate staffing and expertise to address its current advanced reactor activities and does not expect staffing to be a challenge for reviewing anticipated future advanced reactor licensing applications. IAP Strategy 1 focuses on staff development and knowledge management and supports the objective of enhancing advanced reactor technical readiness. As described below, the NRC has taken substantial actions to increase NRC staff knowledge of advanced reactors and the use of risk-informed and performance-based licensing approaches. The NRC also has assessed the staff's technical readiness and identified and filled critical skills necessary to review advanced reactor applications. The NRC staff has also increased its capability and capacity to accelerate development of regulations and guidance. These efforts will continue as part of the normal management of agency programs.

The NRC has contracted with experts from national laboratories to develop and provide training on various technology types, including an MSR training course developed and provided by Oak Ridge National Laboratory (ORNL), SFR training developed and provided by Argonne National Laboratory (ANL), and HTGR training developed and provided by ANL. The training materials for these courses have been made publicly available, and the training was video recorded to facilitate training additional staff as needed. Further, several staff members have received more specialized training in the use of the DOE's Multiphysics Object Oriented Simulation Environment (MOOSE) code, GRIFFIN neutron physics, Grizzly structural analysis code, and BISON fuel performance code. The DOE Nuclear Energy Advanced Modeling and Simulation (NEAMS) project actively develops these codes.

The NRC staff has also collaborated on a series of internal seminars on advanced reactor technical and regulatory topics such as probabilistic risk assessment, microreactors, and accident source terms. The NRC staff has begun leveraging NRC internal tools to record this information and provide it to a wider NRC staff audience.

The NRC staff will continue to assess and fulfill training needs to facilitate reviews of anticipated technologies using a variety of licensing processes. In addition to the training available on various advanced reactor technologies, online and instructor-led course material is available on RTR technology, oversight, and licensing. In coordination with its Technical Training Center, the NRC also offers staff hands-on training on RTR operation at the University of Texas at Austin Training, Research, Isotopes, General Atomics (TRIGA) reactor. Additional training material is under development to familiarize staff with RTR technology and regulation in the event that advanced reactor developers choose to pursue RTRs as part of their regulatory engagement plans (or licensing project plans).

Significant information is available on technical, policy, and regulatory issues associated with reviewing and licensing advanced reactor designs. The NRC staff has taken steps to organize and consolidate a large number of existing documents and training materials to make them more easily accessible and searchable and to develop additional knowledge management resources as needed to support staff development. In March 2019, the staff completed a report, "Advanced Non-Light-Water Reactors Materials and Operational Experience" (Ref. 22), summarizing the available domestic and international operational experience for both advanced power and research reactors with regard to materials and structural performance. The report focuses on SFRs and HTGRs and presents valuable knowledge to support NRC staff development and readiness activities in this area.

Additionally, the NRC staff contracted with Brookhaven National Laboratory to develop a report, "NRC Regulatory History of Non-Light Water Reactors (1950–2019)" (Ref. 23), that comprehensively describes the NRC's history with advanced reactor technology. This report has and will continue to assist the NRC staff in understanding the history of advanced reactor technologies and will facilitate future reviews of these technologies. In addition, the NRC has contracts in place with many of the national laboratories to supplement staff knowledge, support development of regulatory infrastructure, and support future application reviews.

The NRC entered into two MOUs with the DOE on the proposed Versatile Test Reactor at Idaho National Laboratory and on the Nuclear Energy Innovation and Capabilities Act to share technical expertise and knowledge and to ensure that the NRC has sufficient technical expertise to review advanced reactor licensing applications. The NRC plans to observe and participate in the DOE's Versatile Test Reactor safety review team to continue to expand staff knowledge and capacity to conduct regulatory reviews of future advanced reactor licensing applications. The NRC and the DOE are also collaborating with the U.S. Department of Defense (DOD) on microreactor research, development, and demonstration to guide interagency cooperation on DOD-sponsored fixed-site and mobile microreactor activities.

Currently, the NRC staff has limited expertise related to fusion energy. The NRC expects that many of the regulatory enhancements underway for non-LWRs will inform strategies for the licensing of fusion energy systems and NRC has formed a working group to enhance its expertise in this area. The NRC and the DOE's Office of Fusion Energy Sciences have initiated routine interactions to develop longer term strategies for the review of possible fusion energy systems, and the DOE is providing expertise and advice. In addition to the DOE, the NRC is interacting with fusion developers, the industry-led Fusion Industry Association, and the States through the Conference of Radiation Control Program Directors. The NRC has held public meetings to exchange information on its development of a regulatory framework for the review and possible licensing of fusion energy systems. The NRC will need to expand expertise in terms of both staff and simulation capabilities to support this regulatory framework.

Acquiring and Developing Analytical Tools

Near-term IAP Strategy 2 is devoted to acquiring and developing adequate computer codes and tools to perform non-LWR regulatory reviews. Modeling and simulation of many non-LWR designs involve certain physical processes and phenomena that either do not occur in LWRs or occur in regimes outside those well understood for existing designs. Therefore, the NRC staff has completed efforts to (1) identify and evaluate the existing computer codes, tools, and supporting information; (2) identify gaps in both analytical capabilities and supporting information and data; and (3) interact with domestic and international organizations working on non-LWR technologies to identify opportunities to collaborate and cooperate in closing the gaps while avoiding conflicts of interest. The staff has also made significant progress in filling these gaps.

The NRC staff has documented its continuing approach for developing computer codes in a series of recently published reports. The introductory document (Ref. 24) gives an overview of and the rationale for the NRC's approach to code development in support of advanced reactor reviews. Volume 1 (Ref. 25) focuses on in-reactor and plant systems analyses; Volume 2 (Ref. 26) focuses on fuel performance analyses; Volume 3 (Ref. 27) focuses on analyses of severe accidents that may lead to release of radioactive materials and offsite consequences; Volume 4 (Ref. 28) focuses on licensing and siting dose assessments; and Volume 5 (Ref. 29) focuses on criticality and shielding analyses for the front and back ends of the nuclear fuel cycle.

NRC staff efforts related to safety analysis codes have concentrated on ensuring the NRC has adequate capabilities to evaluate the broad spectrum of accident scenarios for designs expected to be submitted for review, including gas-cooled, liquid metal, molten salt, and heat pipe-cooled reactor designs. Due to the complexities involved in how different designs formulate their safety strategy, there is a varying emphasis on interaction between safety analyses for plant systems, fuel performance, and consequence analysis. Further, the technological maturity of these designs differs, and the projected timelines for application submittals to the NRC continue to evolve. The NRC staff has allocated resources for modeling and simulation capabilities based on these factors.

As part of the effort involved in identifying and selecting these computer codes, the NRC staff also evaluated where existing capabilities and validation are needed for non-LWR applications. The NRC has an MOU with the DOE that provides NRC access to DOE codes for regulatory purposes (Ref. 30). The DOE has primary responsibility for generically applicable code development, verification, and validation activities for the NEAMS codes. The NRC has thus focused its efforts on developing models using DOE codes to test their efficacy for different designs and to identify where additional efforts on the codes may be required, as well as augmenting NRC codes where they are appropriate for the task at hand. Continued efforts to close technical gaps between the existing and desired code capabilities include areas such as augmenting material property databases, adding additional modeling options to reflect design safety solutions that non-LWR applicants are expected to choose, and validating the codes using test data.

The proposed code suite for non-LWR safety analysis of in-reactor and plant systems makes use of existing NRC codes where practical and integrates them with several codes developed through the DOE's NEAMS program into the Comprehensive Reactor Analysis Bundle (CRAB). Use of the NEAMS codes helps fill modelling and analysis gaps in the NRC's codes which have been developed over the decades to largely support operating reactor fleet safety analyses. This "BlueCRAB" code suite consists of a selection of NRC codes (e.g., SCALE reactor physics, criticality safety, radiation shielding code, PARCS reactor core simulator code, TRACE thermal hydraulics in-reactor and plant system code, and FAST fuel performance code), updated and used within their demonstrated ranges of applicability, coupled with a set of DOE codes (e.g., MAMMOTH reactor physics code, Pronghorn thermal hydraulics code, BISON, SAM reactor transient analysis code, and Nek5000 computational fluid dynamics code). These codes are interconnected by MOOSE, which provides a high-level interface and coupling for computational analysis. BlueCRAB is further augmented by an internationally developed cross-section and burnup code (SERPENT) and a commercial computational fluid dynamics code (FLUENT). The BlueCRAB suite of codes was selected to perform analyses on a wide range of non-LWR designs, including SFR, HTGR, MSR, and microreactor designs. Through the establishment of a MOU between the NRC and the DOE's National Reactor Innovation Center (NRIC), the NRC anticipates being able to utilize computer code models developed through NRIC to augment the analytical capabilities of the NRC's BlueCRAB suite of codes. This MOU results in cost savings to the NRC.

For fuel performance analyses, which focus on specific phenomena that may differ for each fuel concept, the NRC staff has continued to develop its own FAST code. FAST already includes many of the physics models and material properties needed to analyze non-LWR fuel forms. The NRC staff has identified and undertaken efforts to close gaps between the code capability and the needed capability for reviewing non-LWR designs, focusing on tristructural isotropic (TRISO)-fuel and metallic fuel to accommodate near-term interest in SFRs, HTGRs, and heat pipe-cooled reactors. Additionally, the NRC staff, working closely with the NEAMS BISON fuel performance code development team, have become proficient in using BISON, and several BISON models have been incorporated into the FAST code. This collaboration and the NRC staff's ability to use the BISON code have resulted in additional fuel performance analysis capability that will support the NRC's safety analyses for all advanced fuel types and reactors.

In evaluating severe accidents and offsite consequences, the NRC staff has identified areas to expand the NRC's modeling and simulation capabilities for accident progression, source term, and consequence analysis for non-LWR technologies. These efforts involve three NRC computer codes. The first is MELCOR, the NRC code developed by Sandia National Laboratories and used for accident progression and source term analyses. MELCOR is also used internationally and throughout the nuclear industry for calculating source terms and is well validated for LWR designs. The NRC staff has developed a list of specific data and model needs to update the code for use across a variety of non-LWR designs. The staff has prioritized making updates to the code based on the degree of changes required within MELCOR coupled with the technological maturity of the non-LWR reactor designs. The second code is SCALE, a reactor physics, criticality safety, radiation shielding code developed by ORNL. MELCOR relies on the SCALE code to provide fission product and radionuclide inventories as well as reactor thermal and kinetics parameters. The NRC staff has identified additional data and validation tasks needed and is updating SCALE for use across a spectrum of non-LWR technology types. The third code is the MELCOR Accident Consequence Code System (MACCS). MACCS is used to model atmospheric releases of radioactive materials into the environment and the consequences of such releases. It has a long, active development history and a broad user base, including the NRC, the DOE, the nuclear industry, academia, and domestic and international research organizations. While MACCS is largely technology neutral in application, the NRC has previously validated its use for large releases from large LWRs. The NRC staff has identified and is in the process of performing evaluations of MACCS' ability to account for smaller sites and the potential different chemical and radionuclide makeup of non-LWR designs.

For the licensing and dose assessment codes, the NRC staff has identified several codes to support dose assessments for initial licensing reviews, National Environmental Policy Act reviews, siting reviews, emergency response, and other health physics calculations unique to non-LWR technologies. The NRC staff has developed a strategy for updating, consolidating, and applying the suite of NRC licensing and siting dose assessment codes in order to better evaluate non-LWR designs. The strategy is generally oriented toward generic activities that benefit all non-LWRs designs; however, the NRC staff has identified known issues for specific technologies and is addressing them. Specific tasks the NRC is currently undertaking include (1) code consolidation and modernization; (2) source term determination accounting for normal (routine) reactor coolant source terms, accident source terms, and transportation source terms; (3) atmospheric transport and dispersion modeling to include near-field atmospheric transport and dispersion modeling updates; (4) selection of dose coefficients; and (5) aquatic pathway, environmental accumulation, and human and non-human biota consequence modeling, including tritium and carbon-14 modeling.

The NRC staff has developed a plan to evaluate the nuclear fuel cycle (e.g., transportation of materials used to manufacture fuel, fuel fabrication operations, and spent fuel storage and transportation) for non-LWR applications. The goal is to understand, control, and predict the behavior of systems that contain radioactive material. This is accomplished using neutronics and radionuclide characterization computer codes that are fast, portable, well assessed, understood, and easy-to-use. The plan leverages existing NRC computer codes (i.e., SCALE and MELCOR) and consequence tools such as MACCS to establish NRC non-LWR fuel cycle safety analysis capabilities.

As previously discussed, the NRC staff continues to interact with the DOE, the Electric Power Research Institute (EPRI), national laboratories, reactor developers, utilities, and the international community related to computer codes, analytical tools, and advanced reactor fuel qualification. As mentioned, the NRC has an MOU with the DOE, and the NRC and DOE staff collaborate extensively on the development and usage of the NEAMS and BlueCRAB codes.

In May 2019, EPRI submitted a topical report to the NRC intended to provide a foundational basis for establishing the fuel performance of TRISO particles. This report is unique in that it provides a justification for fuel performance independent of the final fuel form or reactor design. The report represents the first stage in qualifying fuel for a TRISO-based reactor design and lays the groundwork for multiple advanced reactor vendors to support qualification of their respective fuel designs. The NRC staff issued its final safety evaluation (Ref. 31) approving the topical report in August 2020. Topical Report EPRI-AR-1(NP)-A, "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance," issued November 2020 (Ref. 32), is now approved for use in future licensing actions.

Also, in May 2019, ANL submitted a topical report to the NRC describing the quality assurance program plan for SFR metallic fuel data qualification. The topical report describes the quality assurance process(es) by which attributes of historical, analytical, and other data associated with SFR metallic fuel will be evaluated. The NRC staff issued its final safety evaluation (Ref. 33) approving the topical report in April 2020. Topical Report, "Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification ANL/NE-16/17-NP-A," issued October 2020 (Ref. 34), is now approved for use in future licensing actions.

As part of a related effort under NEIMA, the NRC staff is in the process of developing guidance related to the qualification of advanced nuclear reactor fuel. NRC staff efforts have been informed by interactions among an extensive group of external stakeholders, including the Working Group on the Safety of Advanced Reactors through the Nuclear Energy Agency, ORNL, ANL, and the industry-led Accelerated Fuel Qualification Working Group, among others. Fuel qualification is important in demonstrating that fuel behaves as established in the applicable licensing basis, and the NRC staff will continue to engage external stakeholders to ensure it has adequate expertise to support the evaluation of commercial advanced reactor fuel.

THE BUDGETS AND TIMEFRAMES FOR AQUIRING OR ACCESSING THE NECESSARY EXPERTISE TO SUPPORT THE EVALUATION OF LICENSE APPLICATIONS FOR COMMERCIAL ADVANCED NUCLEAR REACTORS AND RESEARCH AND TEST REACTORS (NEIMA Section 103(e)(4)(D))

As discussed in the Advanced Reactor Vision and Strategy Document and IAPs, the NRC plans to achieve its overarching advanced reactor readiness strategic goals and objectives by no later than 2025, including assuring readiness to effectively and efficiently review and regulate advanced reactors to ensure safety. As previously mentioned, currently the NRC staff has limited expertise related to fusion energy, and the NRC has initiated routine interactions with DOE, the fusion industry, Agreement States, and other stakeholders to expand its expertise with fusion technologies. The NRC staff has implemented strategies for enhancing commercial advanced reactor and RTR technical readiness to fulfill the near-term objectives of identifying work requirements, critical skills, and staff capacity requirements; assessing the NRC staff's current advanced reactor technical readiness; and closing gaps in technical readiness. The NRC staff has accelerated readiness activities to prepare to review potential advanced reactor applications and will continue to assess technical readiness and identify critical skills to expand its capability and capacity, as needed.

NRC efforts are focused on technology-inclusive capabilities for NRC codes, and on enhancing understanding and regulatory readiness related to technologies and materials anticipated to be proposed for use in advanced reactors. The NRC expects that its reviews will become more effective and efficient as its codes and expertise evolve and mature. If additional funds are needed for code development for emergent designs, such funding would be sought through the budget process.

COST-ESTIMATES, BUDGETS, AND TIMEFRAMES FOR DEVELOPING AND IMPLEMENTING A TECHNOLOGY-INCLUSIVE REGULATORY FRAMEWORK, INCLUDING COMPLETION OF A RULEMAKING (NEIMA Section 103(e)(3))

The NRC staff will develop a technology-inclusive regulatory framework and will provide a draft Final Rule to the Commission in March of 2024, to allow for publication of the final rule by October 2024. The staff's timeline for the completion of the rule, including specific milestones, is outlined in the staff response to SRM-SECY-20-0032 (Ref. 19). The NRC expects a consistent level of off-fee based funding. Those funds will be used to continue efforts related to the development of risk-informed and performance-based evaluation techniques and guidance for licensing commercial advanced nuclear reactors. If additional funds are needed to ensure publication of the Part 53 final rule by October 2024, such funding would be sought through the budget process. To prepare for the review of potential near-term applications, the NRC staff prioritized activities to increase the use of technology-inclusive, risk-informed, and performance-based licensing approaches within the existing regulatory framework, and these activities continue to inform Part 53 development.

CONCLUSION

The Advanced Reactor Vision and Strategy Document has guided the development of IAPs that support the achievement of the agency's overarching strategic goals and objectives, including ensuring readiness to review and regulate advanced reactors effectively and efficiently to ensure safety. The Advanced Reactor Vision and Strategy Document, related IAPs, and subsequent status papers (e.g. SECY-21-0010) describe the objectives, strategies, and contributing activities necessary to achieve advanced reactor mission readiness.

The enactment of NEIMA and subsequent direction from the Commission have accelerated the NRC staff's efforts to develop the new regulatory framework for optional use by applicants in licensing commercial advanced nuclear reactor technologies (10 CFR Part 53). The NRC staff initiated extensive stakeholder interactions through the iterative release of preliminary proposed rule language and a series of dedicated public meetings on Part 53 as well as regular engagement with the ACRS. These interactions have informed the development of Part 53. The NRC will continue to interact with the DOE and other stakeholders to gather information to inform the development of Part 53 as well as other NRC advanced reactor readiness activities.

The NRC has implemented activities to train staff, is enhancing safety analysis codes, and continues to interact with external experts to best facilitate access to adequate expertise, modeling, and simulation capabilities to support the NRC staff's review of license applications for commercial advanced nuclear reactor designs. As there are a wide variety of non-LWR designs, the NRC staff has prioritized its efforts based on the advanced reactor landscape considering anticipated licensing submittals on the near- and long-term horizons. As this landscape evolves, the NRC staff will continue to assess its technical readiness and access to expertise, modeling, and simulation capabilities to best position the agency to review commercial advanced reactor license applications of non-LWR designs.

ACRONYMS

ACRS	Advisory Committee on Reactor Safeguards
AEA	Atomic Energy Act of 1954, as amended
ANL	Argonne National Laboratory
CANDU	Canadian Deuterium Uranium
CFR	*Code of Federal Regulations*
CRAB	Comprehensive Reactor Analysis Bundle
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
FAST	Fuel Analysis under Steady-state and Transients
FR	*Federal Register*
HTGR	high-temperature gas-cooled reactor
IAP	implementation action plan
LWR	light water reactor
MACCS	MELCOR Accident Consequence Code System
MHTGR	modular high-temperature gas-cooled reactor
MOOSE	Multiphysics Object Oriented Simulation Environment
MOU	memorandum of understanding
MSR	molten salt reactor
NEAMS	Nuclear Engineering Advanced Modeling and Simulation
NEIMA	Nuclear Energy Innovation and Modernization Act
Non-LWR	non-light water reactor
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PARCS	Purdue Advanced Reactor Core Simulator
PIUS	Process Inherent Ultimate Safety
PRISM	Power Reactor Innovative Small Module
RTR	research and test reactor
SAM	System Analysis Module
SCALE	Standardized Computer Analyses for Licensing Evaluation
SFR	sodium-cooled fast reactor
SRM	staff requirements memorandum
TRACE	TRAC/RELAP Advanced Computational Engine
TRIGA	Training, Research, Isotopes, General Atomics
TRISO	tristructural isotropic

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