PREPARATIONS FOR EFFICIENT AND EFFECTIVE LICENSING OF ACCIDENT TOLERANT FUEL DESIGNS

A Report for the House and Senate Committees on Appropriations

By the U.S. Nuclear Regulatory Commission

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Enclosure

I. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) developed this report as directed by the Joint Explanatory Statement accompanying the Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Appropriations Act, 2019 (Public Law 115-244). The Joint Explanatory Statement directed the NRC to submit a plan describing the Commission's activities on accident tolerant fuels (ATF) with respect to the testing of materials, the development of consensus standards, and the validation of computer codes and how these activities will be integrated with the work of external organizations. This report also describes how the U.S. Department of Energy's (DOE's) Advanced Test Reactor (ATR), DOE's Transient Reactor Test Facility (TREAT), and the Halden Reactor Project (Halden) would support these efforts.

II. NRC PREPARATIONS FOR THE EFFICIENT AND EFFECTIVE LICENSING OF ACCIDENT TOLERANT FUEL DESIGNS

The U.S. nuclear industry, with DOE assistance, is planning to deploy some ATF designs in batch reloads[1] in the operating fleet by the mid-2020s. The NRC has established a strategy to enable timely regulatory decisions regarding ATF concepts, while ensuring safety. This strategy is outlined in the NRC's ATF Project Plan, which was issued in September 2018.

The ATF Project Plan covers the entire fuel cycle for both near-term (i.e., doped fuel pellets, coated zirconium fuel cladding, and iron-chromium-aluminum fuel cladding) and longer term (e.g., uranium silicide fuel pellets, silicon carbide fuel cladding, extruded metallic fuel) ATF concepts. The plan will ensure that the NRC is ready to review ATF topical reports in the late 2019 to early 2020 timeframe and plant-specific licensing actions in 2022 to support batch loading of ATF concepts by 2023. In fact, lead test assemblies (LTAs) containing some fuel rods constructed of ATF concepts are now being irradiated in U.S. commercial power reactors. Additionally, the NRC reviewed and approved transportation packages for the shipment of LTAs to these reactor sites. The NRC has also engaged with stakeholders on the appropriate regulatory requirements associated with the use of LTAs and has developed generic clarifying guidance expected to be issued mid-2019.

The NRC has been implementing the ATF Project Plan. This includes engagement with stakeholders to understand industry progress in ATF concept development and vendor licensing strategies for near-term concepts, and to communicate NRC actions and needs related to ATF licensing. In collaboration with nuclear fuel experts at the Pacific Northwest National Laboratory, the NRC has developed a preliminary report on the degradation and failure phenomena related to the ATF concept of chromium-coated fuel rod cladding. The report found that the processing technique for applying the coating can have a significant impact on the cladding performance and identified a limited set of new performance concerns. The report also noted where data gaps existed in the current testing database that would likely need to be supplemented through further experiments.

The NRC has also initiated a phenomena identification and ranking table (PIRT) exercise on the use of chromium-coated fuel rod cladding to identify mechanisms important to the safe application of the concept in reactors. A panel discussion with external experts will be held in April 2019 to supplement the preliminary report, assist the staff's efforts to identify any new

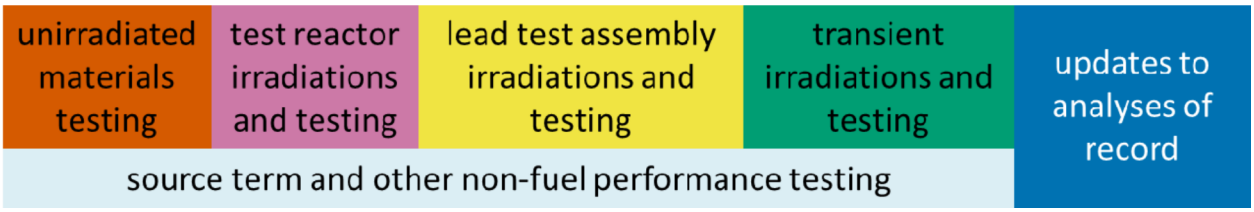
[1] A batch reload is the replacement of approximately one-third to one-half of the fuel assemblies in a commercial power reactor core with fresh, unirradiated fuel during routine maintenance and refueling outages on an 18- to 24-month basis.

phenomena, and rank the phenomena based on safety significance for operation at commercial power reactors. The final PIRT report for chromium-coated ATF concepts will be issued in July 2019.

Following issuance of the final PIRT report, the NRC will publish a draft interim staff guidance (ISG) document for the safety review of the chromium coated fuel rod cladding ATF concept. The NRC expects to make the draft ISG publicly available by the end of July 2019, and hold a public meeting to discuss its contents with stakeholders. The NRC will incorporate the feedback received at this public meeting, and through interactions with the NRC's Advisory Committee on Reactor Safeguards, to revise the draft ISG and formally publish the draft guidance in the *Federal Register* to request public comments. After addressing comments received in response to the *Federal Register* notice, the NRC plans to finalize the guidance by the end of December 2019. Issuance of this ISG, along with the enhanced stakeholder engagement on the document, will ensure nuclear fuel vendors are aware of NRC expectations for developing and justifying the safety case required to obtain approval for batch loading of the chromium coated fuel rod cladding ATF concept.

A. TESTING OF MATERIALS—PROGRAMS

The development of the technical basis necessary to qualify a new fuel design is an extensive process, in terms of both resources and time. The figure below depicts the basic steps that applicants take toward obtaining the appropriate data and experience needed to license any new fuel design for batch loading at U.S. commercial power reactors.



These steps include the following activities:

- **Unirradiated materials testing:** Characterize the material, mechanical, chemical, and thermal properties of an ATF design
- **Test reactor irradiations and testing:** Characterize the evolution of those properties obtained during unirradiated materials testing with irradiation and exposure to the reactor environment
- **LTA irradiations and testing:** Perform integral testing in a commercial power reactor to fully characterize the fuel in prototypical operating conditions and donor material in preparation for the next step
- **Transient irradiations and testing:** Use fuel segments harvested from LTAs or other irradiation programs to perform tests that mimic transient and accident conditions
- **Source term and other nonfuel performance testing:** Characterize fission product release and other severe accident behavior

- **Updates to analyses of record:** Develop, calibrate, verify, and validate analytical models to simulate the performance of the new fuel design under normal and accident conditions

The NRC does not plan to conduct independent material testing for specific ATF designs to confirm the applicant's data or to supplement the information submitted to the NRC for review. Instead, the NRC will rely on the applicant (i.e., nuclear fuel vendor), along with its domestic and international partners, to provide the complete technical basis to support the NRC's regulatory decision. Additionally, the NRC has conveyed the expectation to stakeholders that applicants will provide reactor and test generated fuel behavior data to the NRC in real time such that we can develop the appropriate expertise necessary for efficient licensing reviews and assess and prepare the NRC's analytical capabilities (see further details in Section C below).

The NRC has also communicated to its stakeholders and applicants that the completion of the technical basis will proceed consistent with the ATF Project Plan milestones provided there are no major disruptions or identification of substantive new phenomena important to safety. To ensure early identification of any challenges to the milestones, the NRC has increased its focus on stakeholder engagement. The staff has also increased engagement with the NRC's international partners through the International Atomic Energy Agency; the Organisation for Economic Co-operation and Development's Nuclear Energy Agency; and the TopFuel meeting organized by the American, European, Japanese, Chinese, and Korean nuclear societies to monitor state-of-the-art research and development progress on ATF concepts.

The NRC is similarly engaged with vendors of transportation packages and dry storage systems for ATF designs to understand (1) certification approaches and any associated testing programs to support their licensing strategies and (2) the testing and data requirements that support safe transportation and storage.

B. TESTING OF MATERIALS—FACILITIES

The industry will rely on many facilities, both domestic and international, to conduct testing and obtain data throughout the research and development process for ATF concepts. The knowledge and information gained through these activities will subsequently support licensing applications.

Halden Reactor Project

Over the past several decades, U.S. nuclear fuel vendors have relied on the unique capabilities of the Halden research reactor in Norway to fully develop the technical basis for the licensing of new or modified nuclear fuel designs. In June 2018, Halden's operator announced that it would permanently cease operation and begin decommissioning the reactor.

At the time of shutdown, Halden was conducting several experiments on ATF concepts that are under development by U.S. nuclear fuel vendors. The NRC expects that, although these experiments ended prematurely, they may still provide valuable information to further the technical basis for these concepts. The NRC is also aware of previous experiments and testing conducted at Halden that could prove beneficial to support licensing. The industry, in close

coordination with DOE, has developed mitigation plans such that delays are not expected for near-term ATF deployment because of the shutdown of the Halden facility.

As part of these mitigation plans, and even before announcement of the Halden decision, the industry has been exploring and planning to use the capabilities of DOE's ATR and TREAT. Additionally, the industry has looked at the capabilities of other facilities such as the High Flux Isotope Reactor and several other research and test reactors, including the Massachusetts Institute of Technology Reactor, the Belgian Reactor 2, and other facilities around the world. The NRC has remained closely engaged with nuclear fuel vendors and DOE on fuel qualification and testing plans to provide initial feedback on these proposals in an effort to avoid delays in licensing reviews.

DOE - Advanced Test Reactor

The ATR is a DOE test reactor located at Idaho National Laboratory (INL) in Idaho Falls, ID. The ATR is the only U.S. research reactor capable of providing large-volume, high-flux neutron irradiation in a prototypic pressurized-water reactor (PWR) environment. The NRC has developed an understanding of the capabilities of the reactor through our coordination with DOE on ATF over the past several years. NRC participated in a workshop at INL in May 2018, during which DOE provided a broad overview of current and planned ATF activities, and coordinated on DOE research and development activities that may support licensing and qualification of ATF. INL currently has two ATF test series underway, ATF-1 and ATF-2, that directly support the technical-basis development for several ATF concepts being pursued by U.S. nuclear fuel vendors. ATF-1 is a capsule experiment where a small-scale fuel pin (i.e. rodlet) of an ATF concept is encapsulated in an outer capsule such that the fuel pin is exposed to typical irradiation conditions but has no interaction with the coolant. ATF-2 is a loop experiment where ATF concept rodlets are exposed to both typical irradiation conditions and PWR coolant conditions including water chemistry and temperatures.

INL has proposed several enhancements to the ATR that could significantly mitigate the loss of Halden. These include increased capacity through the development of additional testing loops for ATF; enhanced testing design, fabrication, and instrumentation; and the potential for the addition of a boiling-water reactor loop to address the loss of testing capability caused by Halden's shutdown.

DOE - Transient Reactor Test Facility

TREAT is a DOE test reactor located at INL that was shut down in 1994. In late 2017, DOE restarted TREAT to aid in the development of advanced nuclear technologies, including ATF. TREAT is an air-cooled, thermal spectrum test facility designed to evaluate reactor fuels and structural materials. The reactor was designed to induce intense fission heating in the nuclear fuel being tested, test nuclear fuels under severe reactor accident conditions, and provide nondestructive test data though neutron imaging of fuel samples. The reactor can perform ramp, loss-of-coolant accident, and reactivity insertion accident tests, which are critical experiments in developing the technical basis of an ATF concept.

In summer 2019, the NRC plans to visit TREAT to discuss some of the elements that go into a TREAT test, such as design preparations, assembly, testing, and postirradiation examination of an ATF experiment. This interaction will better prepare the NRC to understand data that are

likely to be a part of future ATF licensing submittals, as the NRC expects that applicants will use the capabilities at TREAT in developing the safety case for their ATF concepts.

C. DEVELOPMENT OF CONSENSUS STANDARDS

The NRC staff is engaged with organizations that develop and maintain consensus standards that are used by the U.S. nuclear industry. These include, but are not limited to, the American Nuclear Society (ANS), American Society of Mechanical Engineers (ASME), American National Standards Institute (ANSI), and American Society for Testing and Materials (ASTM). The industry uses several consensus standards that are directly related to nuclear fuel rods and fuel assemblies.

For near-term ATF concepts, the NRC does not anticipate the need for modifications of current standards or the development of new standards. This is based on a number of factors, including (1) the variety of the approaches and techniques different vendors are pursuing within similar concepts (e.g., physical vapor deposition versus cold spray application of chrome coating), and (2) the implementation of the strategy laid out in the ATF Project Plan for the NRC to develop specific licensing roadmaps for each ATF concept in lieu of or in conjunction with the development of consensus standards on specific aspects of the design.

In the longer term, the NRC will determine whether the development or modification of consensus standards for new materials, such as silicon carbide, would better enable the licensing and deployment of ATF concepts.

D. VALIDATION OF COMPUTER CODES

The development and validation of computational analysis tools is an integral part of the completion of the technical basis used to demonstrate the safety of any new fuel design, including ATF concepts. Applicants seeking to license ATF concepts for use at U.S. commercial power reactors will need to develop these tools and validate them against experimental data in order to demonstrate adequate performance. The applicants must also assess the uncertainties within the analysis methodology and incorporate the appropriate adjustments to their methods to ensure conservative calculation of the figures of merit (i.e., specified acceptable fuel design limits).

The NRC maintains a suite of independent computational tools that allow the NRC to perform confirmatory analyses of applicant submittals.

For near-term concepts, the NRC has determined that it will modify the NRC's current suite of codes to incorporate ATF models and properties to be able to perform these analyses. To that end, the staff has begun incorporating both publicly available (published by fuel vendors, DOE laboratories, and international organizations) and proprietary materials property data and modifying the code architecture needed to support ATF modeling.

For longer term concepts, the NRC will determine if codes developed outside the agency can be used to perform confirmatory calculations. Through the NRC's engagement with DOE's Consortium for Advanced Simulation of Light Water Reactors (CASL) program, the staff is seeking to understand the capabilities of the CASL codes and to provide feedback to DOE on development activities that would benefit the NRC's review of ATF. Recently, staff attended a CASL workshop and training seminar to obtain hands-on experience with CASL codes and

methods that will better inform decisions on which computational tools may best serve the NRC as it moves toward the licensing of longer term ATF concepts.

III. SUMMARY

The NRC is prepared to conduct licensing reviews of ATF concepts in a manner consistent with industry schedules, which envision commercial deployment of near-term concepts in the mid-2020s. This preparation has included stakeholder interaction and engagement throughout the development of the NRC's ATF Project Plan. This stakeholder communication will continue with implementation of the strategy and activities described in the plan to ensure that applicants understand staff expectations for licensing (such as the need to provide high quality applications).