PREPAREDNESS FOR ACCIDENT TOLERANT FUEL LICENSING, INCLUDING HIGHER BURNUP AND ENRICHMENT

A Report for the
Senate Committee on Appropriations and the
House Committee on Appropriations

By the U.S. Nuclear Regulatory Commission

Enclosure

Introduction

The U.S. Nuclear Regulatory Commission (NRC) developed this report as directed by the explanatory statement accompanying the Consolidated Appropriations Act, 2021 (Public Law 116-260). The explanatory statement directed the NRC to report on the NRC's preparedness for licensing the use of accident tolerant fuel (ATF) with a focus on those steps that are being taken by the staff to ensure that the agency is prepared to review the expected licensing requests, including those for higher burnup limits, and increased enrichment levels.

Applicants are moving forward with plans to seek approval to batch load[1] fuel assemblies with two ATF technologies (coated cladding and doped pellets) that may have higher burnup limits and increased enrichment by the mid-2020s. The enrichment, fabrication, transportation, and use of the ATF fuel assemblies requires NRC licensing review and approval. The NRC has already received some licensing action requests for the use of ATF, including higher burnup limits and increased enrichment levels. The current list of these submittals and their approvals, if applicable, can be found on the NRC's ATF public Web page (Ref. 1).

The NRC staff assessed its regulatory framework and found the existing regulations and guidance are suitable for reviews of the ATF concepts (i.e., coated cladding and doped pellets) expected to be submitted in the near-term. The NRC also considers the existing regulatory framework to be generally acceptable for licensing fuel with increased enrichment (from 5 to approximately 10 percent uranium-235 by weight) and higher fuel burnup limits (from 62 to 75 gigawatt-days per metric ton of uranium (GWd/MTU), rod average) in the near-term. While the NRC's existing regulations and guidance support the review of ATF licensing actions, requests for enrichment limits higher than 5 percent uranium-235 by weight will require license amendments and exemptions. The NRC will continue to look for ways to enhance the regulatory framework through guidance and possible rulemaking activities.

The NRC completed or is performing the activities detailed in this report to support the NRC's efforts to complete the licensing of ATF, including higher burnup limits and increased enrichment, in parallel with the industry's research and development efforts while maintaining reasonable assurance of adequate protection of public health and safety, promoting the common defense and security, and protecting the environment.

Accident Tolerant Fuel Project Plan

While the NRC is ready to review and license ATF, higher burnup, and increased enrichment submittals under the current regulatory framework, the NRC is also taking steps to make agency processes more efficient and effective. The NRC has developed the ATF Project Plan (Ref. 2) to prepare for reviews of both near-term and longer-term ATF designs. The Project Plan, revised in October 2019, addresses the complete nuclear fuel cycle, including fuel fabrication, fresh fuel transport, in-reactor requirements, and spent fuel storage and transportation. The NRC staff engaged extensively with its stakeholders in the development of the plan, including licensees, nuclear fuel vendors, industry groups, nongovernmental organizations, and international counterparts, consistent with the NRC's Principles of Good Regulation and statutory requirements.

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[1] A batch load is the replacement of approximately one-third of the fuel assembles in the reactor core after each operating cycle.

The Project Plan outlines a new approach to fuel licensing in which the NRC engages with applicants earlier in their research and development phase, in part to identify and resolve potential safety issues promptly. The Project Plan also considers operational flexibilities that licensees may seek based upon ATF designs. Increased communication and engagement occur on many fronts, including routine vendor status meetings, attendance at industry conferences, and a significant increase in the number and frequency of presubmittal meetings. These meetings allow the NRC and stakeholders to exchange information and increase the efficiency of the review process. Additionally, the NRC holds meetings and issues communications to further support dialogue with stakeholders over specific technical or administrative issues. One valuable set of meetings is held monthly with the U.S. Department of Energy (DOE). In these meetings, DOE shares information on ATF status and research, which helps the NRC staff to anticipate what reviews may be needed.

In April 2021 (Ref. 3), the NRC issued a final report based upon information gathering activities including, phenomena identification and ranking tables (PIRT) and seven fuel performance literature reviews concerning near-term ATF concepts, including spent fuel transportation and storage, and reactor operating and accident conditions. NRC-issued ATF-related documents can be found on the NRC's ATF public Web page (Ref. 4).

The NRC is also developing or revising existing codes to be used for independent confirmatory calculations. These confirmatory calculations provide insight into fuel and reactor systems behavior as well as potential consequences of transient and accident scenarios and the identification of risk-significant factors. The NRC will update its codes as data and information are received.

Other General Preparatory Activities

The NRC is actively involved in two Electric Power Research Institute industry research frameworks/groups that are coordinating research on ATF, higher burnup, and increased enrichment limits. The first is the Collaborative Research on Advanced Fuel Technologies (CRAFT) for Light Water Reactors. The second is the Extended Storage Collaboration Program. Participation in both of these research frameworks/groups allows the NRC to be better prepared to review future licensing submittals due to its heightened awareness of vendor plans and research activities and provides the NRC the opportunity to offer feedback to stakeholders as appropriate.

The NRC frequently interacts with international counterparts and subject matter experts through Nuclear Energy Agency (NEA) working groups—most notably the Working Group on Fuel Safety—and through international cooperative research programs to expand our technical database and maintain awareness of relevant policy and technical issues with ATF. Some notable international activities include:

- The Organisation for Economic Co-operation and Development (OECD)/NEA-supported Studsvik Cladding Integrity Project led by Studsvik in Sweden has provided data on high burnup fuel and cladding performance during a simulated loss-of-coolant accident.
- The Japan Atomic Energy Agency has provided data on chromia doped fuel performance during a reactivity-initiated accident conducted in its Nuclear Safety Research Reactor.
- The NRC staff participates in the Cabri International Project, led by the Institute for Radiological Protection and Nuclear Safety in France, which studies the behavior of nuclear fuel and cladding during reactivity-initiated accidents.

- The NRC staff is participating in the OECD/NEA's QUENCH-ATF project through which it obtains data on coated cladding behavior in design-basis and beyond-design-basis loss-of-coolant-accident conditions. The NRC staff is participating in the OECD/NEA Framework for Irradiation Experiments that was launched to continue the spirit of international cooperation and highly-leveraged access to nuclear safety, fuels, and materials research that has been lost with the 2018 closure of the Halden reactor in Norway.

These international research programs enhance the NRC's understanding of safety significant fuel and thermal-hydraulic system behavior and provide valuable data to develop and validate independent models for the NRC's confirmatory analysis codes.

Coated cladding, doped pellets, higher burnup limits, and increased enrichments levels are expected to be the first set of technologies submitted to NRC for licensing review. The next sections describe the NRC's preparations for each of these technologies.

Coated Cladding

Nuclear fuel vendors are currently researching and testing fuel that uses a zirconium alloy cladding with a thin outer coating of either chromium or a proprietary material. This thin coating is intended to provide resistance to corrosion and wear and additional operational flexibility for power reactors. The NRC has not yet received any in-reactor topical reports or license amendment applications for batch loads of coated cladding but has actively engaged with stakeholders.

The NRC is prepared to review licensing submittals for coated fuel rod cladding. To get ready, the NRC contracted with nuclear fuels experts from DOE's Pacific Northwest National Laboratory (PNNL) to perform a literature review (Ref. 5) on degradation and failure phenomena related to the ATF concept of chromium-coated fuel rod cladding and to conduct a PIRT exercise on the topic. The NRC then published an interim staff guidance (ISG) on the subject (Ref. 6). This ISG is available for vendors to consult in preparing their topical report submittals, which should help to reduce the potential for schedule uncertainty and delays caused by submitting incomplete documents for review.

With regard to licensing the front-end (i.e., enrichment, fuel fabrication, and fresh fuel transportation) and the back-end fuel cycle(i.e., spent fuel transportation and storage) for coated cladding, the NRC staff has reviewed the applicable regulations and guidance and has issued two literature reviews (Refs. 7 and 8). From these reports, the NRC determined that no additions or modifications to the front-end and back-end regulatory framework are needed. Therefore, the NRC is prepared to review coated cladding front-end and back-end licensing actions consistent with the agency's safety-and-security mission and in parallel with the industry's efforts. The NRC has already reviewed and approved two submittals (Refs. 9 and 10) that allow fuel vendors to transport fresh fuel with coated cladding.

Doped Pellets

Fuel vendors are researching and testing fuel pellets that mix other materials, known as dopants, into the pellet during the manufacturing process. These dopants change the physical properties of the resulting fuel pellet with the goal of providing both operational and accident condition benefits for power reactors.

The NRC has already reviewed and approved two doped pellet topical reports for boiling water reactor fuels (Refs. 11 and 12) and a license amendment (Ref. 13), and the industry is currently researching doped pellets for pressurized water reactor fuels. Additionally, the staff has reviewed NRC regulations and guidance for the front-end and back-end licensing of doped pellets and determined that no additions or modifications are needed. Therefore, the NRC staff is prepared to review pressurized water reactor doped pellet submittals anticipated from vendors To date, the NRC has reviewed and approved a request (Ref. 9) that allows a fuel vendor to transport fresh fuel with doped pellets.

Higher Burnup

The current fuel burnup limits differ slightly among fuel vendors and fuel products, but fuel assemblies are generally limited to a maximum rod-average burnup of 62 GWd/MTU. There are potential applicants interested in raising this limit to around 75 GWd/MTU rod average. Burnup limits are not specified in any regulations, but instead are incorporated into power reactor licenses once approved in topical reports. Therefore, rulemaking is not needed in this area and the staff will only need to review topical reports and license amendment requests in order to approve increased burnup limits.

The phenomenon called fuel fragmentation, relocation, and dispersal (FFRD) and its possible resolutions are of significant interest to the NRC. FFRD is the fragmentation of fuel pellets due to expanding fission gas bubbles under accident conditions. The higher the burnup of the fuel during accidents, the smaller each fuel fragment becomes. These smaller pieces of fuel may axially relocate within the fuel rod if the rod balloons outward and may be ejected into the reactor coolant flow if the rod bursts. The fuel vendors and licensees may address FFRD in the licensing process to adopt higher burnup levels through modeling. Other possible methods for addressing FFRD are currently under development. To be aware of the progress in both technical and licensing areas of FFRD, the NRC staff is encouraging fuel vendors to have preapplication meetings on their licensing approaches to FFRD, which three vendors have done to date. The NRC staff expects additional preapplication meetings once vendors have further refined their approaches. Additionally, the NRC's participation in CRAFT will allow the agency to understand potential applicants' approaches to filling data gaps and the new approaches to licensing requests that are being developed for FFRD. Finally, the NRC staff is developing a research information letter that will summarize the NRC staff's understanding of available research information related to FFRD and how the information can be used to define conservative limits for the extent of fuel fragmentation during a reactor accident, the amount of fuel that could potentially be released from the rod, and the impact of fragmentation on the release of gaseous radionuclides. The NRC staff currently plans to issue the research information letter by late 2021 for use by stakeholders.

In addition to the Project Plan, the NRC has proactively reached out to potential applicants on higher burnup limits through two NRC-led public workshops. The first, which was held on July 30, 2020, included an overview of higher burnup limits and increased enrichment levels for the public and an exchange of information focusing on the components of a quality submittal. During the follow-up workshop on June 10, 2021, the NRC discussed the proposed research information letter, the environmental aspects of higher burnup limits, and higher burnup spent fuel storage and transportation issues. These two workshops provided a valuable exchange of information with a variety of stakeholders.

The NRC staff has reviewed the regulations and guidance for the back-end licensing of higher burnup fuel and determined that no additions or modifications are needed. Therefore, NRC is

prepared to review these expected submittals. The NRC did not need to review the regulations and guidance for the front-end licensing of higher burnup fuel because, from the front-end perspective, higher burnup fuel is no different from other fuel.

Increased Enrichment

As stated earlier in this report, the NRC considers the existing regulatory framework to be generally acceptable for licensing fuel with increased enrichment levels (from 5 to approximately 10 percent uranium-235 by weight) in the near-term using license amendments and exemptions. Amendments would be needed to change the enrichment limit in individual licenses, and exemptions would be needed by each licensee that wishes to exceed the enrichment limits in the regulations.

To efficiently support expected requests for increased enrichment levels, the NRC is exploring the regulatory options, including the possibility of initiating a rulemaking. Specifically, the NRC is preliminarily exploring whether a rulemaking to amend Title 10 of the *Code of Federal Regulations* 50.68, "Criticality accident requirements," which places an enrichment limit of 5 percent on fresh fuel or requires a criticality monitor to be in use, would be cost beneficial. The NRC is still in the early stages of this process and will continue to explore potential regulatory options focusing on enrichments up to 10 percent, which is the range of interest currently being expressed by potential applicants. Enrichments up to 20 percent may also be given some consideration as the staff looks at potential regulatory changes. Depending on the level of preapplication activities and other tangible interest expressed by potential applicants, a rulemaking could possibly be completed consistent with the industry's plans to seek approval to batch load fuel with increased enrichment in the mid-2020s, and licensees could request exemptions until the completion of the rulemaking. The NRC will continue to gauge interest in pursuing higher enrichment levels and adjust its efforts as warranted.

A key element for licensing increased fuel enrichment levels will be the front-end of the fuel cycle. The NRC staff reviewed the regulations and guidance for front-end licensing for increased enrichment and determined that no additions or modifications are needed. Therefore, the NRC is prepared to review front-end licensing actions for increased enrichment levels and has reviewed and approved several licensing actions that serve as preparatory steps to allow a fuel facility to achieve enrichments above 5 weight percent (Refs. 14 and 15). In addition, the NRC has issued one approval (Ref. 9) that allows a fuel vendor to transport fresh fuel rods with enrichments above 5 weight percent uranium-235.

To ensure that potential applicants understand the NRC's timelines for reviewing front-end licensing actions for increased enrichments, the NRC identified enrichment facility critical path items for approving batch loadings in 2023 and discussed them in a public letter to the Nuclear Energy Institute (Ref. 16).

Iron-Chromium-Aluminum (FeCrAl) Cladding and Longer-Term Accident Tolerant Fuel Concepts

The NRC monitors progress on the development of FeCrAl cladding and longer-term ATF concepts. The NRC staff frequently engages with DOE and fuel vendors to understand the current status and future direction of these concepts.

The NRC has not yet been provided with relevant detailed schedules, specific physical characteristics, or technical data from vendors for FeCrAl or other longer-term ATF concepts.

The NRC staff has, however, begun preliminary research to prepare for these reviews and to determine whether, and to what extent, changes to the existing regulatory framework may be needed to license these ATF technologies. With uncertain submittal timelines for these technologies, it would be premature for the NRC to undertake more intensive preparatory activities at this time.

Conclusion

The NRC continues to maximize its preparedness to license near-term ATF technologies (i.e., coated cladding and doped pellets), higher burnup limits, and increased enrichment levels, and is prepared to review requested licensing actions for batch loads. The NRC will continue to engage with potential applicants, licensees, and other external stakeholders to ensure that the appropriate steps are taken so that ATF, higher burnup, and increased enrichment licensing reviews are both timely and complete, consistent with maintaining reasonable assurance of adequate protection of public health and safety, promoting the common defense and security, and protecting the environment.

References

1 NRC ATF Public Web page, "ATF-related Licensing Actions," https://www.nrc.gov/reactors/atf/licensing-actions.html.

2. NRC ATF Project Plan, Version 1.1, "Project Plan to Prepare the U.S. Nuclear Regulatory Commission for Efficient and Effective Licensing of Accident Tolerant Fuels," October 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19301B166).

3. NUREG/CR-7283, ERI/NRC 21-204, "Phenomena Identification Ranking Tables for Accident Tolerant Fuel Designs Applicable to Severe Accident Conditions," prepared for the U.S. Nuclear Regulatory Commission by Energy Research Inc., April 2021 (ADAMS Accession No. ML21113A277).

4. NRC ATF Public Web page, "ATF-related Documents," https://www.nrc.gov/reactors/atf/related-docs.html.

5. PNNL-28437, "Degradation and Failure Phenomena of Accident Tolerant Fuel Concepts: Chromium Coated Zirconium Alloy Cladding," prepared for the U.S. Department of Energy by the Pacific Northwest National Laboratory, January 2019 (ADAMS Accession No. ML19036A716) and PNNL-28437, Revision 1, June 2019 (ADAMS Accession No. 19172A154).

6. ATF-ISG-2020-01, "Supplemental Guidance Regarding the Chromium-Coated Zirconium Alloy Fuel Cladding Accident Tolerant Fuel Concept," January 2020 (ADAMS Accession No. ML19343A121).

7. PNNL-29773, "Fresh Fuel Transportation of Accident Tolerant Fuel Concepts - Chromium Coated Zirconium Alloy Cladding," prepared for the U.S. Department of Energy by the Pacific Northwest National Laboratory, March 2020 (ADAMS Accession No. ML20134H981).

8. PNNL-30451, "Spent Fuel Storage and Transportation of Accident Tolerant Fuel Concepts - Cr-Coated Zirconium Alloy and FeCrAl Cladding," prepared for the U.S.

Department of Energy by the Pacific Northwest National Laboratory, March 2020 (ADAMS Accession No. ML20274A250).

9. Letter from John McKirgan, NRC, to Tanya Sloma, Westinghouse Electric Company, LLC, "Revision No. 12 of Certificate of Compliance No. 9297 for the Model Nos. Traveller STD, Traveller XL, and Traveller VVER Packages," September 15, 2020 (ADAMS Accession No. ML20255A297).

10. Letter from John McKirgan, NRC, to Timothy J. Tate, Framatome Inc., "Revision No. 11 of Certificate of Compliance No. 9319, for the Model Nos. MAP-12 and MAP-13 Transportation Packages," January 10, 2019 (ADAMS Package Accession No. ML19011A011).

11 Letter from Mirela Gavrilas, NRC, to Jerald Head, General Electric-Hitachi, "Final Safety Evaluation for General Electric Hitachi Nuclear Energy Americas, LLC Topical Report NEDC-33406P, Revision 2, 'Additive Fuel Pellets For GNF Fuel Designs' (TAC No. ME3082)" November 9, 2015 (ADAMS Package Accession No. ML15195A459).

12. ANP-10340P-A, Revision 0, Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods," Framatome Inc., May 2018 (ADAMS Accession No. ML18171A119).

13. Letter from Andrew Hon, NRC, to John A. Krakuszeski, Duke Energy Progress, LLC, "Brunswick Steam Electric Plant, Units 1 and 2 – Issuance of Amendment Nos. 299 and 327 to Revise Technical Specification 5.6.5b to Allow Application of Advanced Framatome Atrium 11 Fuel Methodologies (EPID L-2018-LLA-0273)," March 6, 2020 (ADAMS Accession No. ML20073F186).

14. Letter from Jacob Zimmerman, NRC to Wyatt Padgett, Louisiana Energy Services LLC, "U.S. Louisiana Energy Services – Amendment 85, Change to License Condition 6b and Enrichment Limit (Enterprise Project Identification Number L-2019-LLA-0264)," May 19, 2020 (ADAMS Package Accession No. ML20119A040).

15. Letter from Tyrone D. Naquin, NRC, to Scott P. Murray, Global Nuclear Fuels-America, "Global Nuclear Fuel – Americas LLC: Review of the Minimum Margin of Subcriticality for up to 8 Weight Percent Enrichment of Uranium-235 and Amendment 16 (Enterprise Project Identifier L-2020-LNS-0002)," August 13, 2020 (ADAMS Package Accession No. ML20219A463).

16. Letter from Kathryn M. Brock, NRC, to Janet R. Schlueter, Nuclear Energy Institute, "Preparing for Efficient and Effective Licensing of Accident Tolerant Fuel with Higher Enrichment," August 26, 2019 (ADAMS Package Accession No. ML19235A261).