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NUCLEAR REGULATORY COMMISSION STAFF FEEDBACK REGARDING GENERAL ATOMICS ELECTROMAGNETIC SYSTEMS WHITE PAPER: FUEL QUALIFICATION PLAN OF THE FAST MODULAR REACTOR (EPID L-2021-LRO-0034)

SPONSOR INFORMATION

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DOCUMENT INFORMATION

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Note: [[ ]] denotes proprietary information or export-controlled information.

Purpose of the White Paper: The purpose of this white paper (WP), entitled "Fuel Qualification Plan of the Fast Modular Reactor," is to describe an accelerated fuel qualification (AFQ) strategy for qualifying the uranium dioxide (UO_2) fuel pellet in silicon carbide (SiC) composite cladding design (SiC-SiC) that would be used in the General Atomics Electromagnetic Systems (GA-EMS) Fast Modular Reactor (FMR) design. The WP (1) identifies the regulations and Principal Design Criteria (PDC) that GA-EMS identified as applicable to fuel qualification; (2) describes the design bases for the FMR fuel system; (3) provides an overview of the FMR and FMR fuel design; (4) provides a preliminary assessment of the FMR fuel safety criteria; and (5) describes an approach to qualify the FMR fuel system that leverages information obtained from advanced modeling and simulation and modern testing techniques.

Action Requested: By letter dated February 23, 2023, (Reference 2) GA-EMS requested that the NRC staff prioritize the following questions when providing feedback on the WP:

1. Is the fuel performance envelope adequately described for this early phase of the FMR conceptual design?

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2. Are the fuel failure criteria of stress/strain adequate for this early phase of the FMR conceptual design? Should GA-EMS consider other fuel failure criteria and what other criteria would that be?
3. Are the material property data and physics models being implemented into BISON adequate for the FMR fuel performance analysis?
4. Comment on the NRC staff concerns regarding high burnup structure particularly if high burnup only occurs at temperatures below the threshold of 1273 [Kelvin (K)].
5. Noting that fast neutrons are created by the fission process in all reactors including [light-water reactor (LWRs)], comment on the plan to use the [Idaho National Laboratory (INL)] Advanced Test Reactor and legacy LWR fuel test data.
6. GA-EMS discussed three fuel test options to address technology gaps: use of thermal test reactors, use of thermal neutron filtering in thermal test reactors, and use of fast reactor neutrons. Which option should GA-EMS take to produce validation data for fuel qualification?

FEEDBACK AND OBSERVATIONS

1.1 Introduction

The feedback and observations on this white paper are preliminary and subject to change. The feedback and observations are not regulatory findings on any specific licensing matter and are not official agency positions. Additionally, the NRC staff did not address all priority areas in Reference 2 because selection of preliminary design and approach details is incumbent upon the applicant.

1.2 Regulatory Basis

GA-EMS provides a regulatory basis for fuel qualification in Section 2, “Regulatory Basis and Guidance.” The NRC staff compared the applicable regulations identified by GA-EMS with the regulatory basis specified in NUREG-2246, “Fuel Qualification for Advanced Reactors,” (Reference 3) and made the following observations:

- In general, the regulations and guidance outlined in the WP appear to reasonably reflect the appropriate subset of the potentially applicable regulations and guidance that are discussed in NUREG-2246.
- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(8) requires, in part, that applicants for a construction permit (CP) identify structures, systems, or components (SSCs) of a facility which require research and development to confirm the adequacy of their design. This regulation also requires CP applicants to identify and describe the program will be designed and conducted to resolve any safety questions associated with such SSCs. While WP Section 2.1, “Regulations Relevant to Fuel Qualification,” does not explicitly identify this regulation, testing described later in the WP could potentially be relied upon to address these requirements.
- WP Section 2.1 references NUREG-0800, “Standard Review Plan for the Review of

Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 4.2, "Fuel System Design," (Reference 4) as a general framework that can be used to help guide the regulatory compliance review for the FMR fuel design. The NRC staff notes that while NUREG-0800 Section 4.2 does provide a reasonable basis for ensuring that the regulatory requirements are met, it was developed specifically for LWR designs. The failure mechanisms for novel fuel designs and features, such as the SiC-SiC cladding discussed in the WP, may differ from the zirconium-based cladding failure mechanisms discussed in NUREG-0800 Section 4.2. The role of fuel in retaining radionuclides for a given design is also important for determining regulatory compliance. Therefore, in future licensing submittals, GA-EMS will need to ensure that the acceptance criteria used align with the role in which fuel is credited for the FMR design and that the appropriate physical failure mechanisms are considered.

- FMR PDC 2, "Design Bases for Protection Against Natural Phenomena," is listed separately in WP Section 2.2, "Principal Design Criteria Relevant to Fuel Qualification" as one of several PDC that "influence the definition of fuel performance requirements." The NRC staff notes that general design criteria (GDC) 2, "Design Bases for Protection Against Natural Phenomena," is integral to the guidance in NUREG-0800, Section 4.2, Appendix A, "Evaluation of Fuel Assembly Structural Response to Externally Applied Forces." The mechanical performance of fuel during externally applied loads is a significant element of fuel qualification; however, historically this is often analyzed separately. The NRC staff comment is only intended to convey that testing to obtain key structural response parameters is an important activity, not that it needs to be included in the parameters of this WP effort.
- The NRC staff notes that GA-EMS submitted the FMR PDCs as a topical report (TR) (Reference 5) on June 3, 2022. The FMR PDC TR was approved by the NRC staff (Reference 6) on July 6, 2023, and the -A (i.e., NRC staff approved) version of the PDC TR (Reference 7) was submitted by GA-EMS on August 3, 2023.

2 Technical Assessment

The NRC staff's feedback and observations below were developed by comparing the fuel qualification plan outlined in the WP against the fuel qualification assessment framework outlined in NUREG-2246. This comparison is provided below in Section, 2.1, "Comparison Against NUREG-2246," using the goals and subgoals that make up the fuel qualification assessment framework in NUREG-2246. Some FMR fuel design features described in the WP involve new or novel approaches that may require additional consideration during the review of a future licensing submittal. Feedback on the items specifically requested by GA-EMS is provided in Section 2.2, "GA-EMS Requested Feedback."

2.1 Comparison Against NUREG-2246

Sections 3, "Fuel Manufacturing Specifications," through Section 6, "Assessment of Experimental Data," of the WP present GA-EMS's evaluation of the FMR fuel design using NUREG-2246. Additionally, NUREG-2246 considers the use of AFQ techniques and lead test specimen programs that may shorten the timeline for qualifying fuel for use in a nuclear reactor at the desired parameters (e.g., burnup).

Since SiC-SiC cladding is a novel fuel design feature, the failure mechanisms and related key manufacturing parameters important to safety may not be well understood at this time. It is recognized that the testing plan described in the WP is intended, in part, to supply validation data to support fuel qualification. However, the NRC staff would expect to review further details supporting the determination of which parameters are considered important to safety analyses during future licensing submittal reviews (e.g., TR, design certification application).

The NRC staff notes that systematic approaches (e.g., a Phenomena Identification and Ranking Table or PIRT), when used to analyze potential fuel failure mechanisms and identify fuel design parameters that most significantly influence fuel integrity, provide assurance that the appropriate phenomena and design parameters have been identified and addressed. Even if this information is not included as part of a future licensing submittal or otherwise docketed, this information should be made available for NRC staff review through audits to confirm conclusions reached in a licensing submittal.

Sections 2.1.1 through 2.1.4 present the NRC staff's comparison of the information in the WP against NUREG-2246.

2.1.1 G1 – Fuel Manufacturing Specification

Section 3 of the WP provides summary information describing pellet and cladding dimensions for the FMR fuel system and fabrication processes. The NRC staff observed that key dimensions were presented along with tolerances for most of the parameters, where applicable. Under a future TR, the NRC staff will review the dimensions to ensure that limiting conditions are considered in the safety analyses. For example, pellet dimensional tolerances can affect parameters such as active fuel height and plenum volume, which may impact nuclear design calculations. The basis for the NRC staff review is described in NUREG-2246 which states:

> Staff recognizes that manufacturing processes for a nuclear fuel product may evolve over the product life cycle; therefore, a complete manufacturing specification is not expected as part of the licensing documentation. However, the licensing documentation should include sufficient information to ensure the control of key parameters affecting fuel performance during the manufacturing process.

In evaluating a future licensing submittal, the NRC staff would consider whether additional fuel specifications are important to fuel performance. For example, Section 3.2, "Fuel Constituents," of the WP mentions a **[[ ]]**. It is not clear to the NRC staff whether the **[[ ]]** is important to fuel performance and therefore should be included as a key parameter affecting fuel performance.

Table 4, "Impurity Elements and Maximum Concentration Limits," of the WP lists maximum allowable concentration limits for various impurity elements in the cladding. Additional information may be needed, likely through an audit, to support assertions in a future licensing submittal that fuel manufactured up to the specified limits for impurities would demonstrate adequate performance characteristics.

Section 3.3.3, “Quality Control Specifications,” of the WP lists attributes of the fuel system that are considered by GA-EMS to have an impact on the quality of the final product and would be “tightly controlled.” The NRC staff observed that this list does not include attributes of the fuel structural components **[[** **]]** or of the final fuel assembly. Attributes of these aspects of the fuel system may substantially influence fuel structural behavior.

2.1.2 G2 – Safety Criteria

2.1.2.1 G2.1 – Design limits during normal operation and anticipated operational occurrences

<u>G2.1.1 – Definition of fuel performance envelope</u>. Section 4.1.2, “Definition of Fuel Performance Envelope,” of the WP presents the fuel performance envelope used to define the conditions under which the FMR fuel system will be required to perform. The information contained generally aligns with the NRC staff’s understanding of the types of conditions that the fuel is expected to encounter for the FMR. The NRC staff notes that the performance envelope was developed using various computational methods which have not been reviewed or approved by the NRC staff. Accordingly, there is a potential that the envelope may change if errors are discovered during review of those methods, resulting in required modification(s) or approval limitation(s) or condition(s).

<u>G2.1.2 – Evaluation model</u>. Section 4.1.3, “Evaluation Model,” of the WP presents the evaluation methods used to assess fuel behavior for normal operation, anticipated operational occurrences (AOOs), and postulated accidents. The NRC staff will evaluate these methods as part of future licensing submittal reviews to ensure the methods are capable of assessing fuel behavior over the FMR fuel performance envelope. The NRC staff notes that evaluation methods are also useful for this early development stage from a design perspective, and that a key component is to ensure that the methods can model the appropriate failure mechanisms of the fuel. As previously mentioned, the NRC staff would expect that a comprehensive and systematic approach would be used to identify possible failure mechanisms and to justify establishment of appropriate fuel performance criteria and specifications.

2.1.2.2 G2.2 – Radionuclide release limits

Section 4.2, “Radionuclide Release Limits,” of the WP discusses the development of criteria for allowable core releases under normal operation, AOOs, and postulated accidents. It appears that GA-EMS will apply NUREG-0800 limits to the FMR fuel design. This approach appears reasonable based on the preliminary reactor design, but the entirety of the release path from a reactor design is considered when developing radionuclide release limits. As the design matures, GA-EMS will need to confirm the continued applicability of the FMR approach.

The NRC staff further notes that source term data will likely be developed concurrently as fuel testing progresses. An important consideration of the testing plan is to ensure that source term and fuel failure mechanisms are sufficiently understood such that they can be used to support accurate fuel performance modeling over the fuel performance envelope. As indicated in

Section 4.2.2, "Criteria for Barrier Degradation," of the WP, the existing database for fission gas release (FGR) and fission product transport does not comprehensively cover the operating envelope for the FMR. The necessary data and uncertainties should be developed to support future licensing reviews of the FMR design. The NRC staff notes that the applicability of legacy data based on traditional fuel designs may be validated (or invalidated) by the results of the planned tests using SiC-SiC composite cladding.

Multiple methods regarding FGR modeling are discussed in Section 4.2.3.1, "Conservative Transport Model," of the WP. The NRC staff notes that the methods mentioned have not been reviewed or approved for modelling fuel like the FMR fuel. **[[**

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2.1.2.3 G2.3 – Safe shutdown

NUREG-2246 identifies the components of achieving a safe shutdown as maintaining coolable geometry and ensuring that reactivity control elements can be inserted. These items are addressed in the subsections below.

<u>G2.3.1 Maintaining coolable geometry</u>. Section 4.3.1, "Maintaining Coolable Geometry," of the WP identifies phenomena which could impede fuel coolability and discusses evaluation models which could be used to predict behavior.

The list of phenomena relevant to the loss of coolable geometry appears to be based on **[[** **]]**, which seems like a reasonable starting point. During a future detailed licensing review, the NRC staff would likely verify the appropriate identification of the phenomena that could contribute to a loss of coolable geometry and that evaluation models are available to assess margin to a loss of coolable geometry. It is not clear to the NRC staff, without further information, whether additional phenomena specific to SiC-SiC cladding may exist that would require specific evaluation using models. For example, could differential expansion rates, or other mechanical interaction(s), **[[** **]]** contribute to cladding failure or a loss of coolable geometry? Are there unique features of the grids that could result in difficulties maintaining a coolable geometry? A thorough analysis of potential phenomena (e.g., PIRT) experienced by the SiC-SiC cladding within the fuel performance envelope would be beneficial to support the NRC staff's review of future licensing action requests.

Similar to comments in previous sections, the evaluation models presented have not been reviewed and approved by the NRC staff. While their approval is not required for the design phase, it will likely be required to support future licensing reviews.

<u>G2.3.2 Negative reactivity insertion</u>. The NRC staff did not identify information in WP that could currently address goal G2.3.2, "Negative reactivity insertion can be demonstrated," from NUREG-2246. However, the NRC staff notes that Section 4.3.2, "Control Element Insertion," of the WP recognizes the necessity of addressing this technical area, and states that this is an area of future development.

2.1.3 Evaluation Models

2.1.3.1 FRAPCON-4.0GA, FRAPTRAN-2.0GA, and BISON

Sections 5, “Fuel Performance Evaluation Models,” and 5.1, “Evaluation Model Capability,” of the WP, state that **[[** **]]**. It is stated that these methods are being used in the early design and testing phase of the FMR fuel assembly development and that a **[[** **]]**. The capabilities and assessment of these codes are addressed in Sections, “EM G1 – Evaluation model capabilities,” and “EM G2 – Evaluation model assessment,” below.

<u>EM G1 - Evaluation model capabilities</u>

EM G1.1 – Geomet<u>ry modeling</u>. The geometric modeling schemes in **[[** **]]** appear capable of roughly modeling the geometry of a fuel rod used in the FMR fuel system (which uses SiC-SiC cladding design). This assessment is based on the code descriptions provided in Pacific Northwest National Laboratory (PNNL)-19418, “FRAPCON-4.0: Integral Assessment,” (Reference 8) and PNNL-19400, “FRAPTRAN-2.0: Integral Assessment,” (Reference 9), for the intended design purpose as stated in Section 5.1, “Evaluation Model Capability,” of the WP. Current limitations of these codes, without further validation and development, prevent them from being useful for evaluating **[[** **]]** in licensing submittals.

BISON was chosen to model the FMR fuel design due, in part, to better geometry modeling capabilities. BISON has a long history and has been validated for LWR fuel. However, BISON has not been submitted to the NRC staff for review and approval, so its use to support licensing actions would involve additional evaluation efforts. Future reviews of FMR licensing submittals would likely focus on the ability to accurately model the composite SiC-SiC cladding design and quantify uncertainties associated with the cladding system. Additionally, the NRC staff would focus on BISON’s ability to model **[[** **]]**.

<u>EM G1.2 – Material modeling</u>. Based on the information in Section 5.1.2, “Material Modeling,” of the WP, BISON seems to have some capability for modelling fuel rod materials in the FMR, including for the UO_2 fuel pellet. As described in the WP, **[[** **]]** behavior of existing LWR fuel designs in temperature and burnup ranges typically seen during LWR operation. However, less data is available for higher burnup pellets. Some information is provided in Section 5.2.1, “Legacy Experimental Data to **[[** **]]** of the WP, but the NRC staff notes that the data is very limited and some of the experiments are comprised of code-to-code comparisons rather than actual experimental data. **[[** **]]**

The behavior of the cladding and interactions between the cladding and fuel pellet are currently less studied; however, the testing discussed in Section 6, "Assessment of Experimental Data," of the WP should help provide experimental data to validate the models discussed in Section 5.1.2. The WP implies that development of BISON models for SiC-SiC cladding is continuing. To support the review of licensing submittals in areas where surrogates are used to develop the BISON models **[[**

]] the NRC staff would likely require justifications for the use of surrogates and discussion regarding the resultant impacts on uncertainty analyses.

The NRC staff also notes that the use of a PIRT approach could be useful to focus development and validation of BISON models.

While the technical review of a licensing submittal would likely focus on the integrated code assessment (as opposed to individual material property models), justification for the specific material property models used would still be expected. This justification should include a discussion of the applicability of these models to the FMR fuel system and the conditions in which it is expected to operate; particular emphasis should be placed on areas where the underlying data used to develop the model differs significantly from the FMR conditions **[[**

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<u>EM G1.3 – Physics modeling</u>. Section 5.1.3, "Physics Modeling," of the WP, discusses the important physical models used for the analysis of fuel. The WP discusses two different methods of **[[**

]] but it does not describe a methodology for determining when to use each model or provide justification for this approach. BISON, in its entirety, is an analysis methodology. By substituting parts of other methodologies into the process, the overall analysis methodology is changed and, therefore, such substitutions should be appropriately justified.

Section 5.1.3.4, "Oxygen/Actinides Migration," of the WP indicates that GA-EMS does not expect fuel constituent migration for the FMR fuel because, compared to sodium-cooled fast reactor oxide fuel where the phenomenon has been observed, the FMR is operated at lower temperatures and does not contain plutonium. While these conditions may be true at the beginning of life for the FMR fuel, the fast spectrum, long operating life, and high burnup of the fuel may result in significant transmutation of the uranium in the fuel to plutonium and degradation of the fuel thermal conductivity such that steeper thermal gradients are produced. Further discussion of this phenomenon, its applicability to FMR fuel, and any anticipated effects on fuel system performance if it is found to be applicable, would be expected in a future licensing submittal.

Section 5.1.3.5, "Fuel Failure Criteria," in the WP discusses the use of American Society of Mechanical Engineers Boiler & Pressure Vessel Code Section III Division 5 stress limits for the cladding. During a licensing submittal review, the NRC staff would evaluate the capabilities of ANSYS (or other analysis methods and tools) to perform the necessary analyses for the FMR fuel assembly and the chosen service level limits for each component, with consideration for the safety significance of each component. For example, guide tubes necessary for ensuring reactivity control during accident conditions should not be allowed to buckle, which could prevent control rod insertion. Some discussion regarding this guidance is provided in NUREG-0800 Section 4.2, Appendix B, "Interim Acceptance Criteria and Guidance for the Reactivity Initiated Accidents."

Additionally, the NRC staff would evaluate the method for calculating allowable stresses, including any underlying assumptions, to confirm that it is appropriate for the burnup and temperature ranges of the FMR fuel qualification envelope.

Section 5.1.3 of the WP discusses physics modeling capabilities, but the NRC staff's review of a licensing action would include a systematic approach to determine all credible failure mechanisms to ensure the chosen acceptance criteria appropriately address safety. For example, it is unclear whether failures of the end plug weld are considered at this time. It is recognized that the testing provided in Section 6, "Assessment of Experimental Data," of the WP will help to provide this information. Although not directly tied to fuel performance, the physical responses of fuel materials have a direct impact on reactivity. Fast reactors often rely on negative reactivity feedback due to thermal expansion of fuel and core materials, so understanding the physical response of the FMR cladding and fuel (and other core materials) will be important to support neutronics modelling.

<u>EM G2 - Evaluation model assessment</u>

The NRC staff notes that the WP does not present information that shows that BISON has been adequately assessed against experimental data and addresses NUREG-2246 EM G2, "Evaluation Model Assessment.". However, testing is planned to obtain additional data (as discussed in Section 6 of the WP) that could support this determination. Specifically, to support the review of a licensing submittal, information should be provided that could support determinations that: (1) experimental data is available to assess BISON's applicability to the FMR fuel system; and (2) BISON has demonstrated the ability to predict fuel failure and degradation over a test envelope applicable to the FMR design.

Although other evaluation models are mentioned, only BISON received significant discussion in the WP. For example, ANSYS is mentioned as being used for the structural analysis, but it is not clear whether modifications were made to ANSYS to support modeling the FMR fuel design. The NRC staff's evaluation of future licensing submittals would include all evaluation models used to demonstrate compliance with the relevant regulations.

2.1.4 Experimental Data

The NRC staff considerations for a test envelope are described in NUREG-2246 Section 3.4.2, "ED G2-Test Envelope," which states:

> Data should be collected over a test envelope that spans the performance envelope (see section 3.2.1.1). The performance envelope should address normal operation, AOOs, and postulated accident conditions. The development of the test envelope should consider (1) steady-state integral testing of the fuel system in a prototypical environment, (2) high-power and undercooling tests to address AOO conditions and to assess design margins, (3) power ramp testing

to assess fuel performance during anticipated power changes, and (4) design-basis accident tests to establish margin to fuel breach and contribution to the source term under accident conditions. Typical design-basis accident scenarios of interest include overpower events (e.g., reactivity-initiated accidents) and undercooling events (e.g., loss-of-coolant accidents).

Section 6 of the WP discusses the use of integral fuel testing to qualify fuel. The incorporation of test data into the fuel qualification strategy described in the WP is consistent with considerations for experimental data highlighted in NUREG-2246 Section 2.3, "Accelerated Fuel Qualification.". During a detailed technical review, the NRC staff would review whether the integral test data (1) are independent of the data used to develop/train evaluation models, (2) was collected over a test envelope that covers the fuel performance envelope, (3) was accurately measured, and (4) was obtained from tests that are representative of prototypical conditions.

Section 6.1, "Independence of Validation Data," of the WP discusses tests that are prototypical of LWR versus FMR fuel designs. Therefore, these tests are used to validate the BISON models specifically for **[[ ]]** and are not integral tests of the FMR fuel assembly design by nature. The NRC staff notes that not all the tests described in Section 6.1 of the WP are actual experimental tests and that some of them are code-to-code comparisons. Additionally, the planned FMR burnups exceed those associated with the data provided in Section 6.1 of the WP. It was also not clear to the NRC staff whether the data set provided in Section 6.1 was independent of the data used to build the BISON models based on the FGR model discussion in Section 5.2.1 of the WP. The NRC staff would evaluate the detailed justification for the use of this data in any future licensing submittals.

The planned irradiation tests described in Section 6.2.2, "FMR Rodlet Tests," of the WP are designed to provide integral test data for the FMR fuel design. Due to the unique nature of the SiC-SiC cladding and the FMR design, it is difficult to achieve representative testing conditions for the performance envelope in existing test reactors. The WP presents various techniques that are planned to simulate the FMR fuel conditions as closely as possible with existing test reactors to achieve data necessary to qualify the FMR fuel design.

As described in Section 6.2.2.1, "FMR Rodlet Irradiation Test in [Advanced Test Reactor]," of the WP, GA-EMS plans to **[[ ]]**. The NRC staff is not aware of prior use of the **[[ ]]**. Therefore, as part of an associated licensing submittal, the NRC staff would need to consider whether application of **[[ ]]** is appropriate. The NRC staff notes that the planned testing includes **[[ ]]**. It is unclear if some of the **[[ ]]**. Such a comparison supporting the applicability of **[[ ]]** could be useful during the NRC staff's review of a future licensing submittal.

Regarding the use of **[[ ]]**, the NRC staff notes that certain phenomena, such as diffusion, are time at temperature dependent. While the temperature of the planned tests will likely bound the FMR cladding temperatures, the timeframe is much shorter. This means that fission gas which has escaped the pellets will have less time to diffuse through the cladding, if possible. This lower source term in the plenum and gap will mean increased uncertainty which must be accounted for in the cladding diffusivity models. Other phenomena, such as fuel fragmentation, are burnup dependent. While the behavior of the UO_2 pellets is generally better understood even up to relatively high burnups, potential interactions between fuel fragments and the SiC-SiC cladding are less understood. Depending upon the gap size and behavior throughout fuel pin irradiation, the fuel fragmentation and relocation characteristics might differ from those seen in LWR fuel designs. For example, if relocation occurs with larger pieces and a fuel chip relocates, it may cause a stress point and challenge cladding integrity. It is unclear from the information provided if the currently planned test matrix would investigate and characterize relocation.

The NRC staff notes that the WP did not discuss experiments to obtain FMR fuel assembly structural response data to support the aforementioned ANSYS structural analysis. Typically, pluck tests are performed for both unirradiated and irradiated (or simulated irradiated) conditions to determine harmonic frequencies and damping characteristics which are used as input to ANSYS (or other analysis methods or tools) in support of demonstrating compliance with GDC 2. The material properties of the grids, as a function of burnup, can have a significant impact on the overall structural response of the fuel assembly. It is assumed, based on the focus of this WP, that this topic would be addressed separately but it is brought-up here for awareness.

2.2 GA-EMS Requested Feedback

In its February 23, 2023, letter, GA-EMS requested that NRC staff prioritize several areas in the feedback provided on the WP. The NRC staff is not addressing all areas since the selection of preliminary design and approach details is incumbent upon the applicant and regulatory findings are reserved for formal licensing submittals (e.g., TR, design certifications). A summary of the NRC staff's feedback in response to specific GA-EMS requests is below.

1. Is the fuel performance envelope adequately described for this early phase of the FMR conceptual design?

   The NRC staff does not regulate the design phase of fuel qualification efforts. However, it appears that GA-EMS provided an envelope which bounds the expected ranges for the FMR. As noted in the NRC staff feedback above, this envelope is based on calculations from methods not previously reviewed and approved by the NRC staff. Therefore, the specific values may change based on a detailed review of future licensing submittals.

2. Are the fuel failure criteria of stress/strain adequate for this early phase of the FMR conceptual design? Should GA-EMS consider other fuel failure criteria and what other criteria would that be?

   It is incumbent upon an applicant to identify specific fuel failure criteria applicable to a conceptual design. However, consistent with the feedback above, the NRC staff will consider the systematic approach that GA-EMS uses to identify and disposition any possible failure mechanisms (e.g., PIRT) in its review of any future licensing submittal.

3. Are the material property data and physics models being implemented into BISON adequate for the FMR fuel performance analysis?

   The NRC staff cannot make an adequacy determination in WP feedback. The NRC staff notes that BISON has not previously been reviewed and approved. Specific comments on the models are provided in the technical feedback found in Section 2.1, above.

4. Comment on the NRC staff concerns regarding high burnup structure particularly if high burnup only occurs at temperatures below the threshold of 1273 K.

   The NRC staff, and the LWR industry as a whole, are concerned about UO_2 fuel behavior with increased burnup. It is widely known that UO_2 fuel begins to fragment at burnups above 55 gigawatt-days per metric ton of uranium (GWd/MTU) and that relocation can occur if gaps exist between the fuel and cladding. Additionally, fragmented fuel could disperse if there is a failure of the cladding. This has become an-area of significant research interest, as the industry desires increased enrichment levels and higher burnup limits. Based on the Commission's approval of SECY-21-0109, "Rulemaking Plan on use of Increased Enrichment of Conventional and Accident Tolerant Fuel Designs for Light Water Reactors," the NRC staff has initiated a rulemaking effort related to increased enrichment which includes addressing fuel fragmentation, relocation, and dispersal issues (Reference 10). GA-EMS is encouraged to follow the issue and participate in future public meetings, as it could potentially relate to FMR fuel behavior at high burnups.

5. Noting that fast neutrons are created by the fission process in all reactors including LWRs, comment on the plan to use the INL ATR and legacy LWR fuel test data.

   The NRC staff cannot make determinations regarding the acceptability of specific data sets in WP feedback. The NRC staff recognizes the difficulties with qualifying an advanced fuel design that cannot be developed as a lead test assembly in an operating reactor. Based on the licensing approach discussion in the WP, it appears that GA-EMS plans to first license, construct, and operate a research or test reactor before pursuing a commercial FMR. The regulation of research and test reactors differs from power reactors. It is possible to license a test or research reactor using the guidance presented in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," (Reference 11) and then use data obtained from operation of the demonstration unit to support licensing the full power FMR. The NRC staff has previously provided guidance regarding the use of test and research reactors and prototype reactors to inform the development of commercial power reactors in the enclosure to "A Regulatory Review Roadmap For Non-Light Water Reactors" (Reference 12).

6. GA-EMS discussed three fuel test options to address technology gaps: use of thermal test reactors, use of thermal neutron filtering in thermal test reactors, and use of fast reactor neutrons. Which option should GA-EMS take to produce validation data for fuel qualification?

Each method has strengths and weaknesses, and those could change depending on whether a research, test, or commercial FMR is under consideration. It is incumbent upon the applicant to choose the technique(s) for a methodology that will be submitted for review and approval.

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3. U.S Nuclear Regulatory Commission (NRC). NUREG-2246, "Fuel Qualification for Advanced Reactors," March 31, 2022, ML22063A131

4. U.S. NRC. NUREG-0800, "Standard Review Plan: Section 4.2, Fuel System Design," March 2007, ML070740002

5. GA-EMS. "Transmittal of GA-EMS Fast Modular Reactor Principal Design Criteria Topical Report," June 3, 2022, ML22154A555

6. U.S. NRC. "Safety Evaluation GA-EMS Fast Modular Reactor Principal Design Criteria Topical Report," July 6, 2023, ML23174A176

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