UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 19, 2020

Mr. Pete C. Gaillard, PE
Director, Regulatory Affairs
TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

SUBJECT: NRC FEEDBACK REGARDING TERRAPOWER WHITE PAPER "ADVANCED FUEL QUALIFICATION METHODOLOGY REPORT-REGULATORY GUIDANCE DEVELOPMENT REPORT" (EPID NO.: L-2020-LRO-0045)

Dear Mr. Gaillard:

By letter dated July 16, 2020 (Agencywide Documents Access and Management System Accession No. ML20209A155), TerraPower, LLC (TerraPower) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review the white paper titled "Advanced Fuel Qualification Methodology Report-Regulatory Guidance Development Report."

The white paper identifies and describes the regulatory guidance for metallic fuel for sodium fast reactors (SFRs.). The white paper describes how to develop and implement steps to identify regulatory requirements, acceptance criteria, and compliance approaches for SFR metallic fuel that may need to be addressed in a license application. TerraPower requested that the NRC staff review the white paper and provide written comments on areas where the white paper does not provide sufficient detail on the regulatory acceptance criteria for advanced reactor metallic fuel. The NRC staff has completed its assessment of the white paper and staff observations are in the enclosure to this letter.

If you have questions regarding this matter, please contact Mallecia Sutton at 301-415-0673 or by e-mail at Mallecia.Sutton@nrc.gov.

Sincerely,

/RA/

Benjamin G. Beasley, Chief
Advanced Reactor Licensing Branch
Division of Advanced Reactors and Non-Power
Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No. 99902087

Enclosure:
As stated

SUBJECT: NRC FEEDBACK REGARDING TERRAPOWER WHITE PAPER – ADVANCED FUEL QUALIFICATION METHODOLOGY REPORT"
(EPID NO.: L-2020-LRO-0045) DATED: NOVEMBER 19, 2020

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U.S Nuclear Regulatory Commission Staff Observations on TerraPower's Regulatory

Guidance Development Report White Paper

White Paper Assessment

1) General

a) The staff recognizes that the regulatory guidance development report uses the NUREG 0800 standard review plan (SRP) to develop the methodology framework and to inform the metallic fuel applicable regulations, regulatory design criteria, acceptance criteria, and compliance plans. The staff notes that the SRP assumes consistency with light water reactor (LWR) designs and fuel. The SRP was developed from many years of NRC experience in establishing safety requirements and staff experience in applying those requirements in evaluating the safety of LWRs. The staff notes that there is less experience with sodium fast reactors (SFRs) and metallic fuel. The regulatory guidance development report acknowledges that some SRP acceptance criteria may not be applicable or sufficient to address advanced reactor technologies that utilize different fuel forms or where the role of the fuel in the safety case and licensing basis is different. Additionally, the regulatory guidance development report states that acceptance criteria for metallic fuel will differ from the SRP acceptance criteria due to inherent differences between advanced reactor fuel and LWR technology or new acceptance criteria may be added. The white paper should state that justification and referenceable background information that provides the basis for modified or added acceptance criteria and compliance considerations will need to be provided by an applicant for their respective fuel design.

b) The NRC staff released a white paper titled "Fuel Qualification for Advanced Reactors (Draft)," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML20191A259), which was discussed at the October 1, 2020 Advanced Reactor Stakeholder Meeting. While the NRC staff's white paper is not the official agency position, it provides the staffs current thinking on a fuel qualification assessment framework that would satisfy regulatory requirements.

2) Methodology and Steps

a) Based on the methodology steps and Figure 1 of the report, it is unclear how the regulatory acceptance criteria (RAC) and regulatory compliance plan (RCP) fit into the process. The RAC and RCP appear to be the outcome of the process based on other sections. Please clarify how the RAC and RCP interface with each other and the overall process.

b) There are a few terms that do not appear to be consistent throughout the document. The use of "acceptance criteria" in multiple places with different meanings may cause some confusion. It is not initially clear that design criteria are regulatory design criteria (i. e., general design criteria (GDC), principle design criteria (PDC), and

advanced reactor design criteria (ARDC)). Clarification for the terms should be provided by using more description in the process step titles and unique or more descriptive identifiers for terminology such as acceptance criteria.

c) The methodology steps in the report appear to include the identification of regulatory requirements from Title 10 of the *Code of Federal Regulations* (10 CFR) and regulatory design criteria (GDC, PDC, ARDC) applicable to metallic fuel qualification from the SRP 4.2 Acceptance Criteria section. The RAC are then developed from the SRP acceptance criteria section with modifications specific for metallic fuel. The RAC appears to include applicable regulatory requirements from 10 CFR and design criteria (i.e., GDC, PDC, ARDC), applicable SRP acceptance criteria basis, metallic fuel specific acceptance criteria, compliance description, compliance specific consideration, and additional information. The established applicable regulatory requirements (10 CFR) and design criteria (GDC, PDC, ARDC) may then be used with identified RAC to develop an RCP. The process steps and flow chart do not seem to reflect all of the steps described in the report. The flowchart should be updated to accurately reflect all the necessary steps.

d) Figure 1 provides a flow chart for the steps in the methodology report process. The title of the figure states that it is “Fuel Qualification Methodology”. However, the figure appears to be the methodology steps for regulatory guidance development for use in fuel qualification. For clarification, the steps identified the Figure 1 and described in this section should align with the section that provides the detailed process description titles.

3) Process Description

a) The process description provides the detailed description of the process steps for the methodology. The process steps described in this section are not aligned with the steps shown in the Methodology and Steps section. Please use the same process steps, process step names, and place the descriptions in the same sequential order for the Methodology and Steps section to provide clarity for the methodology.

b) The scope of the report is limited to Section 4.2 of the SRP. The NRC staff does not see any reason why the methodology described in this report may not be applied to other sections of the SRP (including and beyond Sections 4.3 and 4.4 of the SRP) to develop regulatory requirements and compliance approaches. While the general approach is reasonable, there may be some specific items that may need to be modified when applying the approach to other sections.

c) The third bullet in the Define the Scope of the Fuel System states that fuel coolability is ensured to be maintained during postulated accidents. However, the SRP states that fuel coolability is always ensured to be maintained. This clarification includes both

during and after accidents. Either modify the bullet or provide additional guidance for post-accident conditions.

d) The NRC staff suggests that the description for RAC may be more appropriate toward the end of this section before the Generic RCP. The other items listed in this section appear in the RAC.

e) The description for Applicable Regulatory Requirements and Design Criteria states that the specific SFR regulatory requirement generally does not need to repeat the entire 10 CFR requirement. In general, this is a reasonable approach. However, the description should be as close as practical to the 10 CFR requirement to ensure that the applicable concerns are adequately addressed. Similarly, the description used for regulatory design criteria (PDC) should be as close as practical to the GDC, SFR-DC, or SRP requirements to ensure that the applicable concern of the criteria is adequately captured. Differences may need to be noted in the methodology if it is not clear that meaning has not changed (e.g., the Table 1 description for 10 CFR 100 does not include "scenario" from the SRP).

f) Table 1 includes 10 CFR Section 50.62 as a regulatory requirement for SFR metallic fuel qualification. Although Anticipated Transients Without Scram (ATWS) consideration should be made for SFRs from a design perspective, the staff does not consider the ATWS rule to be applicable from a fuel qualification perspective. Clarify why the regulatory requirement was added from a fuel qualification perspective.

g) The compliance descriptions and compliance specific considerations should consider the following:
1) sufficient information to ensure that key parameters affecting fuel performance are controlled during the manufacturing process through a manufacturing specification,
2) the evaluation model used to evaluate design limits should contain appropriate modeling capabilities and be adequately assessed against experimental data,
3) experimental data used for assessments is appropriate for the use.

4) Attachment 1 - Generic Regulatory Compliance Plan

a) The staff does not consider the ATWS rule (10 CFR 50.62) to be applicable from a fuel qualification perspective (see comment 3(f)).

b) Regulatory Acceptance Criteria (RACs)

i) 4.2-1

(1) The metallic fuel qualification methodology should include a systematic approach to determine all of the damage mechanisms and phenomena involved. The safety analysis evaluation model should have the appropriate physics to determine if the fuel system damage criteria are met.

(2) Available references for failure mechanisms and associated phenomena should be added, where applicable, in the lower level RACs.

(3) It is unclear how the following sentence relates to the fuel qualification methodology and what actions are to be taken: "Design-basis limits and associated specified acceptable fuel design limits should be assessed to

determine whether they remain applicable for new fuel designs (including the introduction of new materials) or for changes in the planned operating conditions (temperature, burnup, and power)." Please clarify the relationship to fuel qualification and what actions should be taken.

ii) 4.2-1.1

(1) The metallic fuel qualification methodology should include the development of a comprehensive list of the fuel system components for each specific design.

(2) The cladding irradiation effects of concern that are listed should not be limited to creep and swelling. All effects on the cladding from the expected environment should be addressed. Growth is not the only irradiation effect on the cladding that is of concern for LWRs (e.g. cladding embrittlement, etc.).

iii) 4.2-1.2

(1) The safety factors listed for establishing an acceptable limit based on appropriate data may not be appropriate for metallic fuel. It should be noted that the safety factors may need to be updated based on the strain fatigue response of the specific fuel design and the available margin and uncertainties.

iv) 4.2-1.3

(1) Fretting wear tests and analyses should not be limited to the contact points listed. It should be noted that all contacts points for specified fuel should be identified and addressed.

v) 4.2-1.5

(1) A reference should be added that provides information for the impacts of fuel-cladding chemical interaction and how the amount of wastage is determined.

vi) 4.2-1.6

(1) The operational tolerances in the acceptance criteria should be established such that the fuel or fuel components are not damaged. Growth is not the only irradiation effect on the cladding that is of concern for LWRs.

vii) 4.2-1.7

(1) The operational tolerances in the acceptance criteria should be established to prevent fuel or fuel component damage.

viii) 4.2-1.8

(1) The methodology should include a comprehensive determination of impacts from fuel component internal pressures for a specific fuel design.

ix) 4.2-1.9

(1) The acceptance criterion should include the worst-case hydraulic loads from accidents in addition to normal operation and anticipated operational occurrences (AOOs).

x) 4.2-1.10

(1) The acceptance criterion should include the worst-case hydraulic loads from accidents in addition to normal operation and AOOs.

xi) 4.2-2

(1) The metallic fuel qualification methodology should include a systematic approach to determine all of the damage mechanisms and phenomena involved. The safety analysis evaluation model should include the appropriate physics to determine if the fuel pin failure criteria is met.

(2) Available references for failure mechanisms and associated phenomena should be added where applicable in the lower level RACs.

xii) 4.2-2.1

(1) The fuel qualification methodology should include a systematic determination of the fuel pin failure mechanisms from overheating of the cladding. A similar thermal margin criterion should be established for metallic fuel similar to departure from nucleate boiling for Pressurized Water Reactors and Critical Power Ratio for Boiling Water Reactors (BWRs). The criteria should be developed such that it will ensure no fuel pin damage during normal operations and AOOs and minimal damage during accidents for the limiting conditions. Any damage during an accident should be accounted for in the radiological analysis.

For example, the cladding temperature could be limited to the sodium boiling temperature if it would remain above the eutectic liquefaction threshold at limiting conditions or if it would be conservative relative to another potential limiting cladding failure mechanism limit.

xiii) 4.2-2.3

(1) This RAC states that fuel clad mechanical interaction is not a major concern for metallic fuel with a softer matrix that is prone to creep. It should be noted that this statement should be justified for the specific fuel design as part of the fuel qualification methodology.

(2) The fuel qualification methodology should include a systematic determination of the mechanical loads that can cause deformation of the cladding. The design limits on maximum allowed cladding stress and strain should be established for all applicable mechanical loads as necessary.

xiv) 4.2-2.4

(1) The SRP assumption that cladding integrity is maintained if the applied stress is less than 90 percent of the irradiated yield stress at the appropriate temperature is used for LWR fuel designs. The identified limiting yield stress should be based on data which encompasses the expected conditions for normal operations and accident conditions while considering burnup effects. The assumptions used to identify the limiting yield stress for LWRs may not be applicable to metallic fuel. It should be noted that the assumptions for identifying the limiting yield stress should be justified.

(2) Appendix A does not contain discussion of methods for assessing structural deformation due to external forces. This discussion is contained in Appendix B. Update the reference appropriately.

xv) 4.2-2.5

(1) The metallic fuel qualification methodology should include a systematic approach to determine all of the mechanisms and phenomena that contribute to wastage. The safety analysis evaluation model should have the appropriate physics to evaluate wastage.

(2) Available references for mechanisms and associated phenomena for wastage should be added. The statement that incremental wastage during AOOs and postulated accidents is negligible and design limits established for normal operation remain applicable for AOOs and postulated accidents should be justified for a specific fuel design. The statement “[e]utectic penetration of the cladding during postulated accidents is limited by design limits on the maximum-allowed cladding temperature during postulated accidents should be justified for a specific fuel type.

xvi) 4.2-3

(1) The metallic fuel qualification methodology should include a systematic approach to determine all of the damage mechanisms and phenomena involved with respect to maintaining fuel coolability. The safety analysis evaluation model should have the appropriate physics to determine if the fuel coolability criteria is met.

(2) Available references for failure mechanisms and associated phenomena should be added where applicable in the lower level RACs.

(3) The following sentence should be clarified: “During postulated accidents, fuel failure (loss of cladding integrity) may occur as long as long as a coolable geometry is maintained for the fuel assembly.”

(4) The RAC states that control rod insertion criteria and core coolability criteria are not as strongly coupled as for LWRs due to the use of separate fuel assemblies and control assemblies for SFRs. However, BWRs use separate fuel assemblies and control rods. Clarify the intent of this statement.

xvii) 4.2-3.1

(1) The fuel qualification methodology should include a systematic determination of the cladding stress and strain loading which may result in significant cladding damage that might prevent adequate core cooling. The design limits should be established for all applicable stress and strain loading that may result in significant cladding damage which might prevent adequate core cooling as necessary.

xviii) 4.2-3.4

(1) The RAC states that in severe accidents, the large and rapid deposition of energy in the fuel or insufficient cooling could result in fuel melting and relocation of molten fuel within the pin. The terminology “severe accidents” should be avoided. The SRP is referring to a reactivity insertion accident which still falls under the category of accidents, not “severe accidents”.

xix) 4.2-3.5

(1) Appendix A does not contain discussion of methods for assessing structural deformation due to external forces. This discussion is contained in Appendix B. Update the reference appropriately.

xx) 4.2-4

(1) The RAC states that control rod insertion criteria and core coolability criteria are not as strongly coupled as for LWRs due to the use of separate fuel assemblies and control assemblies for SFRs. However, BWRs use separate fuel assemblies and control rods. Clarify the intent of this statement.

xxi) 4.2-5

xxii) 4.2-6

(1)The metallic fuel qualification methodology should include the development of a comprehensive list for the fuel system description and design drawings for each specific design.

(1) Appendix A does not contain discussion of methods for assessing structural deformation due to external forces. This discussion is contained in Appendix B. Update the reference appropriately.

(2) Clarification is needed for the discussion on the use of American Nuclear Society 5.4 for metallic fuel.

5) APPENDIX A - SRP REGULATORY REQUIREMENTS OR ACCEPTANCE CRITERIA NOT APPLICABLE FOR SFR

a) The NRC staff is not commenting on what portion or portions of regulations are applicable with respect to SFR fuel qualification for the Appendix.