framatome

Response to Request for Additional Information – ANP-10340, Revision 0, Supplement 1, Revision 0

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Topical Report

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FRAMATOME TRADEMARKS

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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

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Introduction

A Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) related to the “Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods” Topical Report was provided in Reference 1. Responses to the questions in Reference 1 are provided herein.

1.0 RAI 1

1.1 *Question*

Section 4.1, "Material Properties – Thermal Conductivity," of the subject TR reiterates a conclusion from the base TR that states [

] While there is a limit on the chromia concentration, there is no limit on the concentration of gadolinia. NRC staff requests Framatome provide confirmation that when present, the concentration of gadolinia will always be [

]

1.2 *Response*

The low leakage fuel management requires the power of the fresh fuel assemblies be depressed, which is achieved by the usage of gadolinia fuel in Framatome's fuel cycle designs. Gadolinia as a burnable absorber is also used to reduce core excess reactivity (boron concentration) and the power mismatch between the assemblies of successive reloads, which becomes more important when the goal is to increase fuel burnup and cycle length. Due to these requirements and basic function of gadolinia fuel, only an upper limit for the concentration of gadolinia is specified in the NRC approved topical reports since very low gadolinia concentration essentially is not effective for power distribution control. For example, fuel performance GALILEO topical report (Reference 3) and neutronics core design ARCADIA topical report (Reference 4) are approved for gadolinia concentrations [ ].

In addition to the limitation of gadolinia functionality, there is restriction on gadolinia concentration of the fuel manufacturing facility. The Framatome Richland manufacturing facility is qualified to fabricate gadolinia pellet with gadolinia concentration ranging from [ ]. In about 30 years of history of PWR neutronics cycle design using gadolinia in Framatome US, the minimum gadolinia concentration used has been [ ].

The gadolinia concentration is orders of magnitude higher than the chromia concentration in the chromia-doped fuel. In both the base topical report and this supplement, the nominal chromia content is [ ]. Therefore, the minimum gadolinia content is [ ] higher than the nominal chromia content.

2.0 RAI 2

2.1 *Question*

Section 4.2, "Behavioral Assessment – Fuel Melting," of the subject TR states that the fuel melting temperature of chromia (Cr_2O_3)-doped uranium dioxide (UO_2) is [ ] in comparison to standard UO_2 fuel. The NRC staff requests Framatome provide the basis for using a [ ] over all burnup values.

2.2 *Response*

The standard UO_2 fuel melting temperature is given by (Section 9.3.4 of Reference 5)

[ ]

3.0 RAI 3

3.1 *Question*

As discussed in Framatome document FS1-0049110, "GALILEO Fission Gas Release of Cr-doped Fuel Calibration and Validation," Revision 1.0, July 27, 2020, there is no fission gas release data for chromia-doped Urania-Gadolinia (UO_2-Gd_2O_3) fuel. Section 3.1, "Modeling Approach," states [

] NRC staff requests Framatome provide justification for using the chromia-doped fission gas release model with chromia-doped gadolinia fuel where there is no experimental data to validate the results. The discussion should include specific changes that have been made to the base UO_2 fission gas release model for the following fuel types: (1) Cr-doped UO_2, (2) UO_2-Gd_2O_3, and (3) Cr-doped UO_2-Gd_2O_3.

3.2 *Response*

In principle, the phenomena controlling the release of fission gas in chromia-doped UO_2 and chromia-doped UO_2-Gd_2O_3 fuel are the same as the standard UO_2 fuel. In the base topical report (Reference 6), the fission gas release (FGR) model for the standard UO_2-Gd_2O_3 fuel is extended to chromia-doped UO_2-Gd_2O_3 fuel.

Since the phenomena controlling the fission gas release in UO_2-Gd_2O_3 fuel are the same as UO_2 fuel in the NRC approved GALILEO topical report (Reference 3),

[

].

[

]

In the base approved topical report, [

].

In addition, [

].

Therefore, the current usage of the FGR model for chromia-doped UO_2-Gd_2O_3 fuel is conservative. In summary, the following is the relationship of the FGR models among the four fuel types.

[

]

[ ], comparative evaluations were made to further validate the chromia-doped UO_2-Gd_2O_3 FGR model. In Table 8-1 of Reference 2, an example of the maximum rod internal pressure analysis is shown. The example shows that the maximum pressure for a chromia-doped rod design is [ ] and the pressure licensing criterion is [ ]; thus, the available margin is [ ]. In addition to the maximum rod internal pressure and FGR determined by the [ ], Table 3-1 below also includes the maximum pressure and FGR from the [ ]. It is noted that the pressure and FGR are [ ]. This is usually the case, namely that the maximum rod internal pressure is [ ]. In UO_2-Gd_2O_3 rods the poison suppresses power early in life while the enrichment reduction limits power late in life. The primary effects are [ ]. Consequently, it is [ ].

Table 3-1
Pressure and FGR Comparison Using GALILEO Statistical Method

[ ]

To further demonstrate the chromia-doped UO_2-Gd_2O_3 FGR model, a comparative analysis was performed against standard (non-doped) UO_2-Gd_2O_3 fuel. The analysis is based on a [ ]. This is a plausible scenario where a [ ]. Since the purpose is to compare FGR and rod internal pressure between chromia-doped UO_2-Gd_2O_3 fuel and standard (non-doped) UO_2-Gd_2O_3 fuel, the only difference between standard (non-doped) and chromia-doped case is the [ ]. The pressure and FGR results for UO_2-Gd_2O_3 rods are summarized in Table 3-2. It shows that the chromia-doped UO_2-Gd_2O_3 rod pressure is [ ].

The comparison demonstrates that GALILEO predicts [ ].

Table 3-2
Pressure and FGR Comparison between Standard UO_2-Gd_2O_3 and Chromia-Doped UO_2-Gd_2O_3 Fuel

[ ]

4.0 RAI 4

4.1 *Question*

Section 5.3, "GALILEO Intragranular Gaseous Swelling Model for Chromia-doped Fuel," of the subject TR states "Furthermore, Figure 5-8, "Clad Diameter Change Predicted vs. Measured for Chromia-doped Database," confirms that the addition of the intragranular gaseous swelling model conservatively predicts the diameter change during power ramps and outward creep for chromia-doped fuel. Therefore, the transient cladding strain prediction will be conservative." Figure 5-8 does not appear conservative as there are data points both above and below the measured equals predicted line. NRC staff requests Framatome provide additional justification as to why the transient cladding strain prediction will be conservative. As part of the justification, NRC staff requests a discussion on the uncertainties used and a Figure similar to Figure 5-8 that shows predicted -vs- measured for the upper bound calculations where data points for M5 in PWRs are highlighted.

4.2 *Response*

Figure 5-8 of the subject topical report shows the direct comparison between code prediction and measurements. Presented in this figure is a "best-estimate" comparison, and it shows [ ]. In the reload analysis, [ ]. Based on the prediction in Figure 5-8, it is expected that the transient cladding strain (TCS) analysis in reload "will be conservative". Figure 5-8 shows that the prediction is conservative especially [ ].

Section 3.7.4 of Safety Evaluation in Reference 3 (GALILEO topical report) states that

[

].

Direct comparison between Figure 5-8 in the subject topical report and Figures 4-25 to 4-30 in Reference 3 (GALILEO topical report) shows that the scattering band for the chromia-doped fuel is similar to that for the standard fuels. Therefore, the best-estimate model prediction is appropriate. Figure 4-1 compares the measured to predicted chrome-doped fuel cladding diameter increase to that of the standard fuel cladding diameter increase. Note that two figures have the same scales, but with different origins.

Figure 4-1
Comparison of Best-Estimate TCS Prediction between Chromia-doped Fuel and Standard Fuel

Figure 5-8 of the subject topical report shows [

].

Figure 4-2 shows the 95/95 uncertainty assessment for predicted/measured rod diameter increase on the available database. [

].

[ ]

Figure 4-2
Clad Diameter Change Predicted vs. Measured – Upper Bound With Rod Q09_03

Figure 4-3
Clad Diameter Change Predicted vs. Measured – Upper Bound

5.0 RAI 5

5.1 *Question*

Section 7.0, "Qualification of Rod Growth to Chromia-Doped Fuel," of the subject TR states "an updated upper bound fuel rod axial growth model was defined from over

[

]. The NRC staff requests Framatome:

a) Provide a figure similar to Figure 11-1, "Predicted Fuel Rod Axial Growth by the Upper Bound Model as a Function of Experimental Axial Growth from AFA, GAIA, and HTP Fuel Assemblies, "of Reference 15 that highlights the chromia-doped data points, broken out by fuel type (i.e., AFA, GAIA, HTP) and whether or not gadolinia was present.

b) Provide additional clarification/confirmation that the fuel rod growth model

[ ]

c) Provide clarification if [ ] will always be used with chromia-doped fuel and if the model is appropriate for different cladding materials.

5.2 *Response*

a) The database of $M5_{Framatome}$ fuel rod axial growth contains [ ] from fuel rods with chromia-doped fuel. The measurements come from three different fuel designs:

[ ]

[ ]

There are no measurements with chromia-doped gadolinia fuel rods; however, gadolinia rods are non-limiting with respect to fuel rod axial growth due to their reduced power during operation and lower discharge burnup. Figure 5-1 shows the chromia-doped fuel rod axial growth measurements relative to the upper bound and best estimate fuel rod axial growth models. The best estimate model provides accurate predictions of the nominal axial growth and the upper bound model over predicts a significant percentage of the chromia-doped measurements.

The upper bound model overpredicts:

[ ]

Figure 5-1
Axial Growth of Chromia-Doped Fuel Rods

[ ]

b) The upper bound $M5_{Framatome}$ fuel rod axial growth model overpredicts [ ] of all fuel rod axial growth data, including standard UO_2, gadolinia, and chromia-doped fuel rods. Specifically, it overpredicts [ ] of the measurements from GAIA and HTP chromia-doped fuel designs. Including the measurements from the AFA-3G design, which is not used in the United States, the upper bound model overpredicts [ ] of the measurements from chromia-doped fuel.

c) [

].

6.0 RAI 6

6.1 *Question*

As described in Reference 5 of the subject TR, ANP-10338P-A, Revision 0, "AREA™ - ARCADIA® Rod Ejection Accident," December 2017, the AREA methodology is used for the evaluation of a control rod ejection accident in a PWR. Reference 5 states that the S-RELAP5 code is used to model the reactor coolant system response for Westinghouse and Combustion Engineering plants and the RELAP5/MOD2-B&W code is used for Babcock & Wilcox plants. The TR discusses use of S-RELAP5, but makes no mention of RELAP5/MOD2-B&W. NRC staff requests Framatome clarify if RELAP5/MOD2-B&W is to be used with Cr-doped fuel, and if so, provide additional details on any code modifications and qualification/validation performed to demonstrate its acceptability.

6.2 *Response*

[ ]

7.0 RAI 7

7.1 *Question*

Section 5.1.2, "Validation of GALILEO Thermal Conductivity Model to Irradiated Chromia-doped Fuel," used the REMORA2 test as a benchmark, however, little information was provided on the test itself. NRC staff requests Framatome provide additional information on the REMORA2 test, including the purpose of the test and general information about the test sample. In addition, provide a discussion of why this test is an appropriate comparison and how measurement of a single temperature validates thermal conductivity

7.2 *Response*

The main purpose of REMORA2 test is:

- to provide experimental results for the global validation of thermal behavior models for chromia-doped fuel with a high burnup through online measurement of the fuel pellet central temperature. This allows the comparison between the calculated centerline temperature from the fuel performance code and the measured temperature.
- to study the fission gas release (FGR) during the power transient for chromia-doped fuel at high burnup by the FGR measurement.

In addition, the post-irradiation examinations also record gas components, fuel density, and microstructure from ceramography examinations.

This PWR program was started in [

].

[ ]

It is agreed that temperature difference (centerline and surface temperatures) is needed to derive the thermal conductivity with known heat flux since the basic heat conduction equation is defined as $Q=KF(\Delta T/\Delta X)$; nevertheless, the pellet surface temperature is usually not measured during all fuel temperature measurement tests.

The centerline temperature benchmark is the integral test mainly to validate the thermal models, including fuel thermal conductivity model and others. Figure 5-3 of the subject topical report demonstrates good agreement over the whole range of test power and Figure 5-4 shows that GALILEO for chromia-doped fuel generates conservative upper bound values of fuel temperature when the fuel thermal conductivity uncertainty is applied.

8.0 REFERENCES

1. “Request for Additional Information Regarding Framatome Topical Report, ANP-10340P, Revision 0, Supplement 1, Revision 0,” ADAMS Accession No., ML21349A903, December 2021.

2. ANP-10340P-A, Revision 0, Supplement 1, Revision 0, “Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods,” June 2021.

3. ANP-10323P-A, Revision 1, “GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” November 2020.

4. ANP-10297P-A, Revision 0, “The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” February 2013.

5. FS1-0004682, Revision 7, “GALILEO Fuel Rod Performance Code Theory Manual,” July 2020.

6. ANP-10340P-A, Revision 0, “Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods,” May 2018.

7. BAW-10231P-A, Revision 1, “COPERNIC Fuel Rod Design Computer Code,” January 2004.