January 11, 2024
NRC:24:001

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

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

Ref. 1: Letter, Gerond A. George (NRC) to Ms. Gayle Elliott (Framatome), “Final Safety Evaluation for Framatome Topical Report ANP-10340P-A, Revision 0, Supplement 1, Revision 0, ‘Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods’, (EPID L-2021-TOP-0015),” October 16, 2023.

In Reference 1 the NRC approved topical report ANP-10340P-A, Revision 0, Supplement 1, Revision 0, “Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods” for referencing in license applications. The NRC requested that Framatome Inc. (Framatome) publish approved versions of the report. Proprietary and non-proprietary versions of the report are enclosed.

Please note that three Framatome topical reports referenced in the enclosed topical report, (References 4, 13 and 15) were not approved when it was submitted for review and have now been approved. This change in approval status is reflected in Section 9.0 (References) of the enclosed topical report.

Framatome considers some of the material contained in Enclosure 1 to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support withholding of information from public disclosure.

There are no commitments contained within this letter or its enclosures.

If you have any questions related to this information, please contact Mr. Morris Byram, Licensing Manager. He may be reached by telephone at (434) 221-1082 or by e-mail at Morris.Byram@framatome.com.

Sincerely,

ELLIOTT Gayle
Digitally signed by ELLIOTT Gayle
Date: 2024.01.11 13:49:14 -05'00'

Gayle Elliott, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: N. Otto
Project 728

Enclosures:

1. ANP-10340, Revision 0, Supplement 1P-A, Revision 0, “Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods ”
2. ANP-10340, Revision 0, Supplement 1NP-A, Revision 0, “Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods ”
3. Affidavit

Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods

ANP-10340
Revision 0
Supplement 1NP-A
Revision 0

Topical Report

October 2023

Framatome Inc.

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

October 16, 2023

Ms. Gayle Elliott, Director
Licensing and Regulatory Affairs
Framatome, Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME TOPICAL REPORT ANP-10340P, REVISION 0, SUPPLEMENT 1, REVISION 0, "INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS" (EPID L-2021-TOP-0015)

Dear Ms. Elliott:

By letter dated June 28, 2021 (Agencywide Documents Access and Management System Package Accession No. ML21187A198), as supplemented by letter dated April 11, 2022 (ADAMS Accession No. ML22105A047), Framatome, Inc. (Framatome) submitted Topical Report (TR) ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR [Pressurized Water Reactor] Methods," for U.S. Nuclear Regulatory Commission (NRC) staff review. By e-mail dated July 29, 2021 (ADAMS Accession No. ML21210A270), the NRC staff accepted the TR for review.

By letter dated April 21, 2023 (ADAMS Package Accession No. ML22130A115), an NRC draft safety evaluation (SE) regarding approval of ANP-10340P-A, Revision 0, Supplement 1, Revision 0 was provided to Framatome for proprietary review. By letter dated May 23, 2023 (ADAMS Package Accession No. ML23143A394), Framatome provided comments on the draft SE. The NRC staff's disposition of the Framatome comments on the draft SE are discussed in the attachment of the final SE which is enclosed with this letter.

The NRC staff has found that ANP-10340P-A, Revision 0, Supplement 1, Revision 0 is acceptable for referencing in licensing applications for nuclear power plants to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for NRC acceptance of the TR.

The NRC acceptance applies only to material provided in the subject TR. The NRC does not intend to repeat its review of the acceptable material described in the TR. When the TR appears as a reference in licensing applications, the NRC review will ensure that the material presented

NOTICE: Enclosure 1 to this letter contains Proprietary Information. When this letter is separated from Enclosure 1, this letter is decontrolled.

applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant specific review in accordance with applicable NRC review standards.

In accordance with the guidance provided on the NRC website, we request that Framatome publish approved proprietary and non-proprietary versions of TR ANP-10340P-A, Revision 0, Supplement 1, Revision 0 within three months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. For non-proprietary versions, Framatome shall strike the proprietary information markings in this letter and make the appropriate redactions and adjustments to document security classifications to the enclosed SE. Also, they must contain historical review information, including the NRC request for additional information (RAI) questions and Framatome's responses. The approved versions shall include a "-A" (designating approved) following the TR identification symbol.

As an alternative to including the RAI questions and RAI responses behind the title page, if changes to the TR were provided to the NRC staff to support the resolution of RAI responses, and the NRC staff reviewed and approved those changes as described in the RAI responses, there are two ways that the accepted version can capture the RAI questions:

1. The RAI questions and RAI responses can be included as an Appendix to the accepted version.

2. The RAI questions and RAI responses can be captured in the form of a table (inserted after the final SE) which summarizes the changes as shown in the approved version of the TR. The table should reference the specific RAI questions and RAI responses which resulted in any changes as shown in the accepted version of the TR.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Framatome will be expected to revise the TR appropriately or justify its continued applicability for subsequent referencing. Licensees referencing this TR would be expected to justify its continued applicability or evaluate their plant using the revised TR.

Sincerely,

/RA/

Gerond A. George, Chief
Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 99902041
Project No. 728

Enclosures:
1. Final SE (Proprietary)
2. Final SE (Nonproprietary)

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME TOPICAL REPORT ANP-10340P, REVISION 0, SUPPLEMENT 1, REVISION 0, "INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS" (EPID L-2021-TOP-0015) DATED OCTOBER 16, 2023

DISTRIBUTION:
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ADAMS Accession Nos.:
ML23180A165 (Package)
ML23180A143 (Letter)
ML23180A144 (Enclosure 1, Final SE)
ML23275A043 (Enclosure 2, Nonproprietary SE) ***concurrence via e-mail**

OFFICE	NRR/DORL/LLPB/PM*	NRR/DORL/LLPB/LA*	NRR/DSS/SFNB/BC*
NAME	NOtto	DHarrison	SKrepel
DATE	06/28/2023	07/06/2023	07/06/2023
OFFICE	OGC – NLO	NRR/DORL/LLPB/BC*	NRR/DORL/LLPB/PM*
NAME	DRoth	GGeorge	NOtto
DATE	07/13/2023	07/28/2023	10/16/2023

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FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT ANP-10340P-A, REVISION 0, SUPPLEMENT 1, REVISION 0

“INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS”

PROJECT NO. 710; DOCKET NO. 99902041

EPID L-2021-TOP-0015

1.0 INTRODUCTION AND BACKGROUND

By letter dated June 28, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21187A198), as supplemented by letter dated April 11, 2022 (ADAMS Accession No. ML22105A047), Framatome Inc. (Framatome) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval Topical Report (TR) ANP-10340P-A, Revision 0, Supplement 1, Revision 0, “Incorporation of Chromia-Doped Fuel Properties in Framatome PWR [Pressurized Water Reactor] Methods” (Ref. 1). The TR is a supplement to the base approved TR (Ref. 2) for the incorporation of chromia-doped fuel in Framatome approved methods, which dealt only with boiling water reactor (BWR) methodologies. This supplement documents the effects of the use of chromia-doped fuel and its implementation in Framatome PWR methodologies.

During this review, a regulatory audit was conducted (Refs. 3 and 19). After conclusion of the audit, a request for additional information was issued (Ref. 4) and responses were received (Ref. 5).

2.0 REGULATORY EVALUATION

The NRC staff used the guidance in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” (SRP), Section 4.2, “Fuel System Design,” for the review of ANP-10340P-A, Revision 0, Supplement 1, Revision 0. SRP Section 4.2 acceptance criteria are based on meeting the requirements of General Design Criteria (GDC) 10 of Appendix A of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, “Reactor Design.” Specifically, GDC 10 establishes specified acceptable fuel design limits that should not be exceeded during any condition of normal operation, including the effects of AOOs.

In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

a. The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs),

b. Fuel system damage is never so severe as to prevent control rod insertion when it is required,

c. The number of fuel rod failures is not underestimated for postulated accidents, and

d. Coolability is always maintained.

The regulation at 10 CFR Part 50, Appendix A, GDC 28, "Reactivity Limits," requires reactivity control systems to be designed with appropriate limits on potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than local yielding nor (2) sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to impair significantly the capability to cool the core.

In addition, the following paragraphs of 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," (b) require in part that:

(1) "Peak cladding temperature." The calculated maximum fuel element cladding temperature shall not exceed 2200°F [degrees Fahrenheit].

(2) "Maximum cladding oxidation." The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.

(3) "Maximum hydrogen generation." The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

(4) "Coolable geometry." Calculated changes in core geometry shall be such that the core remains amenable to cooling.

3.0 TECHNICAL EVALUATION

The NRC staff reviewed ANP-10340P-A, Revision 0, Supplement 1, Revision 0 to: (1) ensure that the material properties and in-core behavioral characteristics of chromia-doped fuel, as analyzed using the GALILEO and other Framatome PWR methodologies (ARCADIA, ARITA, AREA, and Westinghouse and Combustion Engineering (W&CE) loss-of-coolant accident (LOCA), which are discussed in Section 3.5 of this safety evaluation (SE)), are capable of accurately (or conservatively) ensuring the fuel system safety criteria, (2) identify any limitations on the behavioral characteristics of the additive fuel, and (3) ensure compliance of fuel design criteria with licensing requirements of fuel designs.

3.1 Applicability of Base Topical Report

The subject TR (Ref. 1) is a supplement to the approved base TR, ANP-10340-PA, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods," May 2018 (Ref. 2), which covers the material properties of chromia-doped fuel along with the implementation of chromia-doped fuel in Framatome approved methods for BWRs. As stated in the base TR, the material properties, behavioral assessment, qualification database, and operating experience are generic for both BWR and PWR applications. The base TR describes the database that is used to qualify the models in GALILEO for chromia-doped fuel. Since Reference 2 was approved, **[[**

]]

In the subject TR (Ref. 1), Framatome did not repeat the parts of the approved base TR that are applicable to both BWRs and PWRs, and only presented specific changes needed for implementation into the PWR methods. Therefore, this review is focused specifically on the code specific implementation of chromia-doped fuel in the Framatome PWR methodologies. Any items previously approved in the base TR that have not changed when implementing in the PWR methodologies were not reviewed again.

3.2 Impacts of Chromia-Doped Fuel During Accidents

3.2.1 Loss-of-Coolant Accident

The performance of the emergency core cooling system is judged relative to the performance of the reactor fuel under postulated LOCA conditions. The regulations at 10 CFR 50.46 and Appendix K provide analytical requirements and prescriptive limits (2,200 degrees Fahrenheit (°F) peak cladding temperature (PCT) and 17 percent equivalent cladding reacted maximum cladding oxidation) applicable to uranium dioxide (UO_2) fuel pellets within cylindrical zircaloy or ZILRO cladding. These analytical limits preserve a coolable rod bundle array by ensuring adequate post-quench cladding ductility. The introduction of chromia-doped fuel pellets does not directly alter the applicability of the 10 CFR 50.46 analytical requirements and prescriptive limits associated with maintaining adequate cladding ductility; however, changes in fuel properties and performance may alter the accident progression and influence PCT and oxidation calculations.

The fuel properties including thermal conductivity, gaseous swelling, and FGR impacts the fuel rod internal pressures and fuel temperatures and has the potential to influence the LOCA cladding response. **[[**

]]

A change in fuel thermal conductivity will impact the amount of stored energy in the fuel pellet. Section 4.1, “Material Properties - Thermal Conductivity,” of the TR (Ref. 1) describes the impact of chromia addition on fuel thermal conductivity and Section 5.1, “GALILEO Thermal Conductivity Model for Chromia-doped Fuel,” describes changes in the GALILEO thermal conductivity model. See Section 3.3.1, “Thermal Conductivity,” of this SE for further assessment of fuel thermal conductivity. In general, the addition of chromia **[[** **]]** This potential impact is being explicitly addressed in the GALILEO calculated stored energy and initial fuel conditions (input) to the downstream LOCA calculations.

Ceramography data show that larger intragranular bubbles exist in the case of chromia-doped fuel, which corroborates with the observed larger cladding deformation. Standard fuel exhibits very low intragranular gaseous swelling and has not been modelled previously in GALILEO. Section 5.3, “GALILEO Intragranular Gaseous Swelling Model for Chromia-doped Fuel,” of the TR describes the GALILEO Intragranular Gaseous Swelling Model. See Section 3.3.4, “Intragranular Gaseous Swelling,” of this SE for further assessment of gaseous swelling. In general, the larger intragranular bubbles are a consequence of enhanced intragranular gaseous swelling, which in turn contributes to larger pellet deformation and therefore larger cladding deformation. This potential impact is being explicitly addressed in the GALILEO initial fuel conditions (input) to the downstream LOCA calculations.

A change in FGR will impact rod internal pressure which, in turn, will impact the probability of fuel rod ballooning and rupture. Section 5.2, "GALILEO Fission Gas Release Model for Chromia-doped Fuel," of the TR (Ref. 1) describes the GALILEO FGR model for chromia-doped fuel. Section 3.3.3, "Fission Gas Release," of this SE describes further assessment of the FGR model. In general, **[[**

]] These potential impacts are being explicitly addressed in the GALILEO fuel conditions which are used in the LOCA methodologies.

Therefore, the NRC staff finds that chromia-doped fuel will behave **[[** **]]** to that of standard fuel during LOCAs and that any impact is explicitly assessed with GALILEO.

3.2.2 Reactivity Initiated Accidents

The regulation at 10 CFR Part 50, Appendix A, GDC 28, "Reactivity Limits," requires reactivity control systems to be designed with appropriate limits on potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than local yielding nor (2) sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to impair significantly the capability to cool the core. For PWRs, Regulatory Guide (RG) 1.236, "Pressurized-Water Reactor Control Rod Ejection and Boiling-Water Reactor Control Rod Drop Accidents," identifies the postulated control rod ejection accident (CREA) as the limiting reactivity initiated accident. In addition, RG 1.236 provides fuel cladding thresholds for fuel rod cladding failure and allowable limits on radiological dose, reactor coolant system (RCS) pressure, and core coolability. With the exception of radiological dose, these thresholds and allowable limits are addressed by the AREA methodology (Ref. 6).

Framatome stated that the chromia doping of the fuel **[[**
]] As discussed in the TR as well as the base TR (Ref. 2), test results and code calculations have indicated that specific heat, enthalpy, thermal conductivity, and fuel pellet cracking **[[** **]]**

Framatome states that any interaction between chromia-doped fuel and fission products may alter the amount or chemical species released during a design basis accident or a severe accident. However, the presence of chromia in the fuel **[[**
]]

Framatome states that the chromia-doped fuel is not expected to have a significant impact on the maximum RCS pressure. This is due to the fact that the reactor coolant pressure calculation is based on heat transfer from the fuel. While there are minor differences expected in the pin powers and local flow conditions for a core with chromia-doped fuel, the overall heat transfer would be expected to remain essentially the same as that with standard undoped fuel.
[[
]] The inclusion of chromia-doped fuel in the reactor design has no impact on the RG 1.236 reactor coolant pressure allowable limit. In addition, the reactor coolant pressure allowable limit is specifically addressed as part of the AREA methodology (Ref. 6).

As discussed in Section 4.2, "Behavioral Assessment – Fuel Melting," of the TR (Ref. 1), the melting point of chromia-doped fuel was found to be **[[** **]]** than standard UO_2 fuel.

Framatome states that the limited amount of chromia in the fuel does not result in a significantly different radial average fuel enthalpy threshold for incipient melting verses standard UO_2 fuel.

Based on test results and code calculations, Framatome found that **[[**

]] In addition, the AREA methodology (Ref. 6) includes the chromia-doped properties, and therefore, any change to the average fuel enthalpy threshold for incipient melting is explicitly addressed, which confirms that the coolability criterion is not violated.

Test data and code calculations have shown that **[[**

]]

The NRC staff reviewed the test data for fuel specific heat, thermal conductivity, and fuel melting as well as code calculations provided in both the TR (Ref. 1) and base TR (Ref. 2) and finds that the inclusion of chromia-doped fuel in the fuel assemblies does not violate or alter the limits established by RG 1.236 used as a basis to evaluate a postulated CREA with chromia-doped fuel and is therefore acceptable.

3.3 Qualification of GALILEO for Chromia-Doped Fuel

GALILEO is Framatome's best-estimate fuel rod performance code approved for PWR fuel design and licensing analyses with standard UO_2 and gadolinia-bearing UO_2. The GALILEO code models the thermal-mechanical behavior of the fuel rods during normal operation and transient scenarios. The following sections detail changes made to GALILEO to accommodate the properties and behavior of chromia-doped fuel.

3.3.1 Thermal Conductivity

Fuel thermal conductivity is essential to the modeling of both steady state and transient phenomena, as it directly impacts fuel temperature and stored energy. Higher thermal conductivity results in lower fuel temperatures and less stored energy in the fuel.

As described in Section 4.5, "Thermal Conductivity," of the base TR (Ref. 2), Framatome conducted two in-house thermal diffusivity measurement campaigns, one each in 2006 and 2015. In both cases Framatome also sent a sub-set of samples to the Joint Research Center-Institute for Transuranium Elements (JRC-ITU) for confirmation and complementary measurements. **[[**

]]

After thermal diffusivity values are obtained, the thermal conductivity is calculated as a function of diffusivity, density, and specific heat.

As stated by Framatome in the TR (Ref. 1), GALILEO's thermal conductivity model consists of **[[**

]]

Based on the conclusion from the base TR (Ref. 2), **[[**

]] The final adjusted model parameters of the chromia-doped thermal conductivity are presented in Equations 5-1 to 5-6 of the TR (Ref. 1). During the regulatory audit, the NRC staff asked how the coefficients in the new term (Equation 5-6) were determined. Framatome responded that the new term was fine-tuned to envelope all chromia-doped data **[[**

]] Figures 5-1, “Chromia-doped GALILEO Model against 2006 Campaign Data,” and 5-2, “Chromia-doped GALILEO Model against 2015 Campaign Data,” of the TR (Ref. 1) show good agreement with the test data from both the 2006 and 2015 campaigns.

One of the conclusions from the base TR (Ref. 2) is **[[**

]]however,**[[**

]] This will result in GALILEO computing a different thermal conductivity for chromia-doped gadolinia fuel than gadolinia fuel without the chromium. During the regulatory audit, the NRC staff asked Framatome why **[[**

]] Framatome responded that **[[**

]]

Framatome subsequently provided confirmation (Ref. 5) that the concentration of gadolinia will always be **[[**

]] Framatome stated that their low leakage fuel management requires the power of the fresh fuel assemblies be depressed, which is achieved by their usage of gadolinia fuel. In addition, gadolinia as a burnable absorber is 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. Given that very low levels of gadolinia concentration are essentially not effective for power distribution control, the GALILEO methodology (Ref. 7) has only an upper limit and is approved for gadolinia concentrations of **[[** **]]**. Framatome also states that the Framatome Richland manufacturing facility is qualified to fabricate gadolinia pellets with gadolinia concentration ranging from **[[** **]]**. In about 30 years of history of PWR neutronics cycle design using gadolinia in the United States, the minimum gadolinia concentration used has been **[[** **]]**.

Standard UO_2 fuel experiences degradation of thermal conductivity with increased burnup. To validate that this effect is also present in chromia-doped fuel, Framatome benchmarked GALILEO to the REMORA2 test, where a pellet centerline temperature was measured online using thermocouples after achieving **[[** **]]** In Ref. 5, Framatome stated that the main purpose of the REMORA2 test was 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, and to study the FGR during the power transient for chromia-doped fuel at high burnup. In addition, the post-irradiation examinations also recorded gas components, fuel density, and microstructure from ceramography examinations. Framatome provided some details on the test rod dimensions and described **[[**

]] Framatome agreed with NRC staff that the test does not validate thermal conductivity directly and that the REMORA2 test is an integral test that demonstrates the validity of the thermal models, including fuel thermal conductivity. During the regulatory audit, the NRC staff examined the calculation notebook for the REMORA2 benchmark. As seen in Figure 5-3, "Calculated and Measured Temperatures in the REMORA2 Test," of the subject TR (Ref. 1), GALILEO demonstrates good agreement over the whole range of test powers and **[[**
]] as shown in Figure 4-2, "Predicted vs. Measured Fuel Centerline Temperature (Validation Database)," of Reference 7.

Framatome validated the applicability of the standard fuel thermal conductivity uncertainty on the chromia-doped fuel using the approach as described in Section 5.4.5, "Transient Model Uncertainties," of Reference 7. The uncertainty was confirmed for the chromia-doped UO_2 model over the whole range of measured fuel centerline temperatures from the REMORA2 experiment. As shown in Figure 5-4, "Calculated and Measured Temperatures Using Lower Bound FTC Uncertainty," of the TR (Ref. 1), **[[**
]]

Given the experimental measurements and satisfactory benchmarking of GALILEO, the NRC staff finds Framatome's thermal conductivity models for chromia-doped fuel and chromia-doped $(U\text{-}Gd)O_2$ in GALILEO to be acceptable.

3.3.2 Fuel Melting

Framatome has previously measured the melting point of standard UO_2, chromia-doped UO_2, and chromia-doped $(U\text{-}Gd)O_2$ fuel using laser heating and fast multi-channel pyrometry at the JRC-ITU as described in detail in Section 5.2, "Fuel Melting," of the base TR (Ref. 2). Framatome found that the fuel melting temperature of chromia-doped UO_2 is **[[**
]] in comparison to standard UO_2 fuel and that **[[**
]]

The standard UO_2 fuel melting temperature in GALILEO **[[**
]] In Reference 5, Framatome stated that **[[**

]] In the base TR (Ref. 2), the same **[[** **]]** was applied, however, the RODEX4 methodology uses a constant melting temperature that is not burnup dependent where the constant value reflects the minimum over the anticipated burnup range. Therefore, using a **[[** **]]** over all burnup values is consistent with the base TR (Ref. 2).

Section 8.2.1, "ARITA Methodology," of the TR (Ref. 1) states "In addition, **[[**

]] Section 4.2.4.7.1, "Criteria for FCM and TCS," of Reference 9 shows the **[[** **]]** uncertainty in the equation for UO_2 melt temperature, however, Equation 4-2 in the TR (Ref. 1) does not include this value as it is the best estimate fuel melt temperature and the lower bound is applied as part of ARITA.

When implementing in GALILEO, Framatome used Equation 4-2 in the TR where the chromia-doped UO_2 melting point is **[[** **]]** from the non-doped UO_2 melting point. By **[[** **]]**, GALILEO is appropriately capturing the results from the JRC-ITU experiments, therefore, the NRC staff finds this acceptable. **[[** **]]** which is consistent with the experimental data, therefore, the NRC staff finds this acceptable.

3.3.3 Fission Gas Release

Framatome states that chromia-doped fuel is similar to standard fuel with an enlarged grain microstructure and the same phenomenological FGR model is applicable to both fuel types. **[[**

]] as described in Section 3.3.3.3, "FGR Processes," of Reference 7. In this model, **[[**

]]

However, Framatome notes that **[[**

]] In order to adjust to the experimental results, Framatome implemented the **[[** **]]** Framatome used **[[** **]]** During the regulatory audit, Framatome confirmed that the value is best-estimate and used in the predictions shown in Figure 5-5, "Fission Gas Release Predicted and Measured for Chromia-Doped Database," of the TR (Ref. 1). In addition, Framatome used **[[** **]]**

To validate the FGR model in GALILEO, Framatome compared code results to the experimental database. **[[**

]] The best estimate results, shown in Figures 5-5, "Fission Gas Release Predicted and Measured for Chromia-Doped Database," and 5-6, "Burnup Trend of FGR for Chromia-doped UO_2," of the TR (Ref. 1), show good agreement. Framatome validated the applicability of the standard fuel diffusion coefficient uncertainty for FGR on the chromia-doped fuel. As shown in Figure 5-7, "Predicted vs. Measured FGR – Upper Bound," of the TR (Ref. 1), **[[** **]]**

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 **[[** **]]** This document states **[[** **]]**

Framatome explained (Ref. 5) that 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 TR (Ref. 2), **[[** **]]** In addition, Framatome **[[** **]]**

Framatome described the changes to the base UO_2 FGR model as follows:

- **[[**
-
- **]]**

In Table 8-1, "Maximum Rod Internal Pressure Results," of the subject TR (Ref. 1), an example of the maximum rod internal pressure analysis is shown for UO_2 and chromia-doped UO_2. 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 Reference 5, Framatome performed the same calculations for a chromia-doped UO_2-Gd_2O_3 rod and obtained a maximum pressure of **[[ ]]**. In addition, when going from chromia-doped UO_2 to chromia-doped UO_2-Gd_2O_3, the FGR **[[ ]]** These changes in pressure and FGR are noticeably lower in the chromia-doped UO_2-Gd_2O_3 rods than for chromia-doped UO_2 rods. For rods containing gadolinia, the poison suppresses power early in life while the enrichment reduction limits power late in life. The lower power results in **[[ ]]** Given the lower power of the rods containing gadolinia, Framatome states that it is **[[ ]]**.

To further demonstrate the chromia-doped UO_2-Gd_2O_3 FGR model, Framatome performed a comparative analysis against standard (non-doped) UO_2-Gd_2O_3 fuel as discussed in Reference 5. The analysis is based on a **[[ ]]** This is a reasonable scenario where a **[[ ]]** Since the purpose of the analysis 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 the standard (non-doped) and chromia-doped fuel is the **[[ ]]** The results of this comparison showed the **[[ ]]** Based on the larger grain size in the chromia-doped fuel, and all other properties identical, the FGR reduction is expected. The pressure **[[ ]]** in the chromia-doped fuel due to the addition of the intragranular gaseous swelling model for chromia-doped fuel. Framatome states that **[[ ]]** for the standard UO_2-Gd_2O_3 fuel (as seen in Figures 4-10, "UO_2 and Gadolinia Transient FGR Calibration," and 4-11, "UO_2 and Gadolinia Steady-State FGR (Validation Database)," of Ref. 7) and that given the mechanism of FGR is the same for these types of fuel, it is expected that the FGR model for chromia-doped UO_2-Gd_2O_3 fuel would also have similar conservatism. The comparison demonstrates that GALILEO predicts **[[ ]]**

FGR measurements are used to calibrate and validate fuel models and quantify the uncertainty on these model predictions. Given the **[[ ]]** the NRC staff is including the following limitation and condition:

- Fuel licensing application of chromia-doped UO_2-Gd_2O_3 fuel is acceptable **[[ ]]** This limitation can be removed after sufficient FGR measurement data for chromia-doped UO_2-Gd_2O_3 fuel are available and the validity of the FGR model for chromia-doped UO_2-Gd_2O_3 is confirmed by NRC.

With **[[ ]]** Given the results from the Framatome calculations for UO_2-Gd_2O_3 and chromia-doped UO_2-Gd_2O_3, as described in Reference 5, there is significant margin to the rod internal pressure limitation for rods containing gadolinia. The **[[ ]]** compensates for any concern in FGR and rod internal pressure calculations and ensures that this issue remains low safety significance given rods containing gadolinia are not expected to be limiting.

Given the use of experimental measurements and satisfactory benchmarking of GALILEO, the NRC staff finds Framatome's FGR model for chromia-doped UO_2 with **[[ ]]** to be acceptable. In addition, the NRC staff finds the changes to the FGR model for chromia-doped UO_2-Gd_2O_3 suitable for use **[[**

]]

3.3.4 Intragranular Gaseous Swelling

In standard UO_2, fission gases collect and may form bubbles along the grain boundary, known as intergranular bubbles. As chromia-doped fuel has larger grains and enhanced creep and plasticity it has a propensity for forming intragranular bubbles instead, as the gases collect inside the grain instead of along the grain boundary. These bubbles lead to increased fuel pellet and cladding deformation, especially following a power ramp. Standard fuel exhibits very low intragranular gaseous swelling, so this phenomenon has not been modelled previously in GALILEO.

To accurately capture this phenomenon for chromia-doped fuel, Framatome added an intragranular swelling model to GALILEO. This model, which is described in detail in Section 7.3, "RODEX4 Intragranular Gaseous Swelling Model for Chromia-doped Fuel," of the base TR (Ref. 2), was modified with a new calibration over that from the base TR. During the regulatory audit, the NRC staff asked Framatome for details on the new calibration and why it was necessary. Framatome responded that because the FGR model is different in RODEX4, the model parameters f_{ig} and C_{gig} in the intragranular swelling model were varied to arrive at an appropriate prediction of transient cladding strain as shown in the best-estimate benchmark result in Figure 5-8, "Clad Diameter Change Predicted vs. Measured for Chromia-doped Database," of the TR (Ref. 1). The TR states "Figure 5-8 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."

Framatome stated (Ref. 5) that Figure 5-8 in the subject TR (Ref. 1) is a "best-estimate" comparison, and that it shows **[[ ]]** Framatome stated that **[[**

]]

Comparison between Figure 5-8 in the subject TR (Ref. 1) and Figures 4-25, "Rod Diameter Change for Pellets with L/D Ratio less than 1.4," through 4-30, "UO_2-Gd_2O_3 Ramps - Calculated vs. Measured Rod Diameter Increase," in Reference 7 show that the scattering band for the chromia-doped fuel is like that for standard fuel. In addition, Framatome provided Figures 4-2, "Clad Diameter Change Predicted vs. Measured - Upper Bound with Rod Q09_03," and 4-3, "Clad Diameter Change Predicted vs. Measured - Upper Bound," in Reference 5 which show the predicted versus measured clad diameter change using the upper bound model with and without inclusion of data from a ramp rod test labeled Q09_3. Framatome states that **[[**

]]

The upper bound model includes use of the following uncertainties: **[[**

]]

3.3.5 Rod Free Volume and Internal Pressure

The prediction of rod internal pressure is directly linked to the rod free volume along with the predictions for FGR and fuel temperatures and is dependent on the collective effects from other thermal and mechanical models. Framatome performed calculations to compare rod free volume and internal pressure to the available data. The validation database of free volume and rod internal pressure is a subset of the FGR database. The results for rod free volume, shown in Figures 5-11, "Predicted vs. Measured Free Volumes for Chromia-doped UO_2," and 5-12, "Burnup Trend of Free Volume for Chromia-doped UO_2," of the TR (Ref. 1), show good agreement and **[[** **]]**. The results for internal pressure, shown in Figures 5-13, "Predicted vs. Measured Internal Pressure for Chromia-doped UO_2," and 5-14, "Burnup Trend of Internal Pressure for Chromia-doped UO_2," of the TR (Ref. 1), also show good agreement and no bias versus burnup. The code predictions versus measured data for both rod free volume and internal pressure for chromia-doped fuel show similar agreement to that of standard fuel as seen in Figures 4-47, "Measured and Predicted Free Volumes for UO_2 and Gadolinia Fuel," and 4-49, "Measured and Predicted Internal Pressure for UO_2 and Gadolinia Fuel," of Reference 7. Therefore, based on the comparisons to experimental data, the NRC staff finds that rod free volume and internal pressure for chromia-doped UO_2 are adequately predicted in GALILEO.

3.4 Qualification of Rod Growth to Chromia-Doped Fuel

As a general fuel design requirement, the fundamental mechanical and hydraulic functions of a fuel assembly shall not be impaired due to irradiation growth of the fuel rods. In particular, the fuel assembly shall give sufficient space for differential rod growth to occur without it becoming restrictive. The clearance between the fuel rod top ends and the top nozzle is known as the shoulder gap.

As described in Section 11.2, "Fuel Rod Axial Growth," of Reference 10, an upper bound fuel rod axial growth model was defined from over **[[** **]]** To address applicability of this data set to chromia-doped fuel, Framatome stated (Ref. 5) that the database of M5$_{\text{Framatome}}$ fuel rod axial growth contains **[[** **]]** from fuel rods with chromia-doped fuel. The measurements include three different fuel designs: **[[** **]]** There are no measurements with chromia-doped gadolinia fuel rods, however, Framatome states that 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, "Axial Growth of Chromia-Doped Fuel Rods," of Reference 5 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. For those fuel types used in the US, the upper bound model **[[** **]]** When the AFA-3G fuel, which is not used in the US, is included, the upper bound model overpredicts **[[** **]]** of the measurements from chromia-doped fuel. Framatome stated that the upper bound fuel rod axial growth model is specific to M5$_{\text{Framatome}}$ cladding, and therefore, chromia-doped fuel for PWR applications will only use M5$_{\text{Framatome}}$ cladding.

Given that the upper bound fuel rod axial growth model overpredicts **[[** **]]** of the measurements from US fuel designs (GAIA and HTP) with chromia-doped fuel, the NRC staff finds this model acceptable for use with chromia-doped fuel.

3.5 Qualification of Framatome Methodologies to Chromia-Doped Fuel

Framatome states that chromia-doped fuel will be analyzed with the ARCADIA, ARITA, AREA, and W&CE LOCA methodologies as described in the associated TRs. Framatome does not plan to make any revisions to the existing NRC-approved TRs to specifically list chromia-doped fuel as an approved fuel material. This approach is being used as any operating PWR plant that would implement chromia-doped fuel would need to incorporate the subject TR (Ref. 1) into their licensing basis using an appropriate licensing change process. The NRC staff finds this approach acceptable.

3.5.1 ARCADIA Methodology

As described in Reference 8, ARCADIA is a code package that was developed for worldwide application and provides a converged code system for neutronic and thermal-hydraulic core design and safety evaluation. The main components of the ARCADIA system are the spectral/lattice code APOLLO2-A and the core simulator ARTEMIS. APOLLO2-A is a state-of-the-art lattice physics code that features several high-level physics enhancements and requires fewer approximations compared to the previous generation of lattice physics codes. The core simulator ARTEMIS is a 3D nodal multigroup reactor burnup code with pin power reconstruction for PWRs.

As stated by Framatome, the ability to model chromia-doped fuel is primarily dependent upon the accuracy of the cross-section data. The chromium data are part of the standard cross section libraries validated with APOLLO2-A and approved in the ARCADIA TR. During the regulatory audit, the NRC staff requested the licensee provide the reference to where the standard cross section libraries, including chromium, were approved. Framatome responded that the cross-section information for chromium is included in the nuclear data library JEFF3.1.1 used by APOLLO2-A and the data is processed by HERMES and used by the ARTEMIS neutronic solver. Framatome stated that this library was approved implicitly as part of the ARCADIA TR (Ref. 8). Framatome found that no changes are required to the approved neutronics codes or methodologies (Refs. 8 and 11).

Given that the effect of chromium on core reactivity has already been quantified through inclusion of chromium in the cross-section libraries, NRC staff finds that no changes are required to the approved neutronics codes or methodologies (Refs. 8 and 11) for chromia-doped fuel.

3.5.2 AREA Methodology

As described in Reference 6, the AREA methodology is used for the evaluation of a CREA in a PWR. The methodology is used to demonstrate compliance with the acceptance criteria specified in NUREG-0800, Section 4.2. The methodology makes use of several codes and methods. The ARCADIA code system is used to analyze the three-dimensional neutronics and thermal-hydraulics behavior during the transient. The GALILEO code provides the thermal-mechanical properties of the fuel pins. The S-RELAP5 code is used to model the RCS response for W&CE plants and the RELAP5/MOD2-B&W code is used for Babcock & Wilcox plants. The methodology provides compliance with the regulatory criteria for energy deposition, fuel rim melt, fuel centerline melt, minimum departure from nucleate boiling ratio (MDNBR), and RCS pressure response.

During the regulatory audit, the NRC staff questioned Framatome about any changes made to S-RELAP5 and RELAP5/MOD2-B&W. Framatome responded that the only updates to the S-RELAP5 code are the incorporation of the chromia-doped GALILEO adaptations into the GALILEO module within S-RELAP5. As part of the regulatory audit, the NRC staff reviewed the S-RELAP5 code changes to the GALILEO module and found it consistent with the changes to GALILEO described in the TR. In Reference 5, Framatome stated **[[**

]]

Framatome performed an analysis with an AREA Evaluation Model which included chromia-doped fuel that indicates **[[** **]]** The results of the AREA analysis are described in more detail in Section 3.6.2.2, "Control Rod Ejection Accident," of this SE. The Framatome results confirmed that all margins are preserved in a core design based on chromia-doped fuel and demonstrate the AREA methodology is not challenged by the inclusion of chromia-doped fuel in a core design.

As part of the AREA methodology, GALILEO is used to define the fuel thermal properties and fuel rod internal pressure. The NRC staff reviewed the use of GALILEO in the AREA methodology and finds that the inclusion of chromia-doped fuel properties and other model changes (i.e., FGR and intragranular gaseous swelling models) in GALILEO do not alter the overall workflow of the methodology. The revised GALILEO code w/chromia-doped modifications continues to interact with the ARCADIA and S-RELAP5 codes in the same manner, therefore, the NRC staff finds that the AREA methodology is acceptable for use with chromia-doped fuel.

3.5.3 ARTEMIS/RELAP Integrated Transient Analysis (ARITA) Methodology

As described in Reference 9, the ARITA methodology is intended to analyze the non-LOCA events defined in Chapter 15 of the SRP (with the exception of the control rod ejection event) using a statistical approach. In this methodology, S-RELAP5 is used for the system thermal-hydraulic analysis, ARTEMIS is used for core analysis, and GALILEO is used for thermal-mechanical analysis. The methodology allows running S-RELAP5 and ARTEMIS, either independently or in a coupled fashion, depending on the non-LOCA event being considered.

Framatome states that the ARITA methodology is not affected by the inclusion of chromia-doped fuel as the thermal conditions are dependent on pin powers and local flow conditions. It is expected that **[[**

]] During the regulatory audit, the NRC staff asked Framatome if the slight differences in **[[** **]]** are explicitly considered, or if they are assumed small and ignored. Framatome responded that the transient analysis considers the explicit representation of chromia-doped fuel with no approximations.

Framatome performed an analysis with the ARITA methodology for an uncontrolled bank withdrawal (UCBW). The results of the ARITA analysis are described in more detail in Section 3.6.2.1, "Uncontrolled Bank Withdrawal," of this SE. Framatome found that **[[** **]]** and that use of the ARITA methodology will be exercised or dispositioned as part of the reload analysis process when deploying core designs that include chromia-doped fuel. During the regulatory audit, the NRC staff asked Framatome what criteria would be used to determine if the ARITA methodology will be exercised or dispositioned during the reload analysis process. Framatome responded that the methodology will be exercised in its fullness during the first reload designed with chromia-doped fuel, however, subsequent reloads will assess the effect of chromia with respect to the previous cycle. Framatome stated that there is no change to the reload process analysis or the methodologies that will be used to analyze chromia-doped fuel and that Section 11, "Disposition of Event Process," of the ARITA TR (Ref. 9 (not approved yet)) defines the disposition process.

As part of the ARITA methodology, GALILEO is used for fuel thermal-mechanical analysis to compute fuel centerline melt and transient clad strain. The NRC staff reviewed the use of GALILEO in the ARITA methodology and finds that the inclusion of chromia-doped fuel properties and other model changes (i.e., FGR and intragranular gaseous swelling models) and in GALILEO do not alter the overall workflow of the methodology. The revised GALILEO code w/chromia-doped modifications continues to interact with the ARTEMIS and S-RELAP5 codes in the same manner, therefore, the NRC staff finds that the ARITA methodology is acceptable for use with chromia-doped fuel, provided the ARITA methodology (Ref. 9) is approved for use with the base GALILEO code (Ref. 7).

3.5.4 W&CE LOCA Methodology

Framatome's LOCA methodology is described in References 12 through 15. The small-break LOCA (SBLOCA) evaluation model uses a deterministic approach based on the requirements of 10 CFR Part 50, Appendix K, to determine the expected PCT, maximum local oxidation (MLO), and core-wide oxidation (CWO) response. The realistic large-break LOCA (RLBLOCA) EM uses a best-estimate approach based on statistical sampling of uncertainty contributors and propagation of uncertainty to determine the expected PCT, MLO, and total CWO response. The RLBLOCA EM is patterned after the Code Scaling, Applicability, and Uncertainty (CSAU) methodology and follows the recommendations of RG 1.203, "Transient and Accident Analysis Methods," Evaluation Model Development and Assessment Process (EMDAP).

The LOCA methodologies in References 12 through 15 discuss using either RODEX2 or COPERNIC as the fuel performance code, while Reference 16 implements the GALILEO fuel performance code into S-RELAP5 for use as part of the Framatome LOCA methodologies.

Framatome states that the chromia-doped fuel specific physical models and material properties are supplied by GALILEO and the implementation of these model adaptations will not change the current fuel rod analysis workflow or basic model capabilities of the current W&CE LOCA EMs. The S-RELAP5 code remains the thermal-hydraulic system code and no changes are made to the general capabilities of the code in terms of systems, components, phases, geometries, fields, and processes modeled. As discussed above in Section 3.5.2 of this SE, the only updates to the S-RELAP5 code are to incorporate the chromia-doped GALILEO adaptations into the GALILEO module within S-RELAP5.

Framatome performed a review of the SBLOCA and RLBLOCA EMs, as supplemented by GALILEO, with respect to chromia-doped fuel pellet properties and identified **[[**
]] This review also identified the important fuel-related LOCA phenomena that could potentially be affected by chromia-doped properties, including **[[**

]]

The NRC staff has examined the results of the LOCA calculations and find they are consistent with the expected changes using chromia-doped fuel. For the SBLOCA, the use of chromia-doped fuel resulted in **[[**
]] Therefore, the NRC staff finds that the Framatome LOCA methodology from Reference 16, using the revised GALILEO code with chromia-doped updates along with the S-RELAP5 code, is acceptable for use with chromia-doped fuel.

3.6 Licensing Criteria Assessment

Framatome performed sample design analyses for chromia-doped fuel. The results of those analyses were compared to standard fuel analyses to evaluate the impacts of the chromia dopant. These examples were examined in greater detail at the regulatory audit conducted by the NRC staff. No discrepancies were discovered.

3.6.1 Fuel Rod Thermal-Mechanical Evaluation

Framatome performed an analysis with GALILEO using the chromia-doped model options on a CE 14x14 fuel design with $\text{M5}_{\text{Framatome}}$ cladding. The sample calculations examined rod internal pressure, cladding collapse, and cladding fatigue. For rod internal pressure, the example analyses show that **[[** **]]** This is primarily because **[[** **]]** While the **[[** **]]** the results show there is significant margin to the limiting value as defined by the GALILEO methodology (Ref. 7).

Cladding collapse was historically observed due to high levels of densification of fuel pellets, which left gaps in the fuel column into which the cladding could ovalize and collapse. Current fuel designs have greatly reduced the likelihood of cladding collapse through the use of pressurized fuel rods and fuel pellets with high initial density and low in-reactor densification, thereby preventing the occurrence of gaps large enough to permit clad collapse. **[[** **]]** For cladding collapse, the CROV creep collapse analysis code was used in addition to GALILEO. The CROV methodology was limited to B&W Fuel Company cladding as described in Section 1.2, "Limits," of Reference 17. During the regulatory audit, the NRC staff asked Framatome why this methodology is applicable to $\text{M5}_{\text{Framatome}}$ cladding. Framatome responded that the CROV methodology was approved in Reference 18 to be applicable to $\text{M5}_{\text{Framatome}}$. Section 3.7, "Fuel Rod Cladding Creep Collapse," of Reference 18 states "Since the creep rate of M5 is considerably slower than the standard **[[** **]]** the creep collapse life of an M5 fuel rods is much greater than the standard rods and is not limiting at burnups up to 62 GWd/mtU." Reference 10, Section 10.3 states **[[** **]]**

The CROV methodology defines three criteria for cladding collapse as follows:

- **[[**
-
- **]]**

The results from the Framatome analyses show the **[[** **]]** with the chromia-doped fuel as expected.

For the cladding fatigue analysis, Framatome performed transient calculations with GALILEO using the methodology defined in Appendix C, "Fuel Rod Fatigue Initialization," of Reference 7. The GALILEO results are then used to calculate the cumulative usage factor (CUF) using the methodology described in Section 10.5, "Fuel Rod Fatigue," of Reference 10. The CUF design limit for $\text{M5}_{\text{Framatome}}$ cladding is **[[** **]]**. The results of the analysis show that standard (non-doped) fuel has a **[[** **]]** CUF than chromia-doped fuel. Framatome states that this is because fatigue usage is driven by the magnitude of stress fluctuations (i.e., stress amplitude), and not the magnitude of stress at any given moment. For the sample analyses, Framatome explains that the majority of fatigue usage comes from **[[**

]]

Given that the cladding fatigue is primarily driven by events with **[[** **]]** the sample analyses confirmed that the chromia-doped fuel is **[[** **]]** than standard fuel.

The NRC staff has examined the results of the fuel rod thermal-mechanical evaluation presented in the TR, as well as the detailed calculations made available at the regulatory audit. The NRC staff finds the results acceptable, as they demonstrate expected behavior of Cr-doped fuel including **[[** **]]**

3.6.2 Safety Analyses

Framatome performed calculations of AOOs and postulated accidents to demonstrate the methodologies work with the chromia-doped fuel. These sample analyses detail the results of comparisons between standard fuel and chromia-doped fuel using the ARITA methodology from Reference 9, a CREA using the AREA methodology in Reference 6, and a LOCA using the methodology in Reference 16.

3.6.2.1 Uncontrolled Bank Withdrawal

For a sample analysis using the ARITA methodology, Framatome selected an UCBW from part-power initial conditions (AOO transient). The analysis is based on a 4-loop Westinghouse plant with a 17x17 fuel assembly design. Specified acceptable fuel design limits considered for the UCBW include fuel centerline temperature, transient cladding strain, and departure from nucleate boiling (DNB).

The results for fuel centerline temperature, as shown in Table 8-4, “Fuel Centerline Temperature Comparison,” of the TR (Ref. 1), show that the chromia-doped fuel has **[[** **]]** The analysis for the chromia-doped fuel assumes the fuel melting temperature is **[[** **]]** In addition, both standard fuel and chromia-doped fuel take into account the **[[** **]]** when computing margin to the melting temperature.

The results for transient cladding strain, as shown in Table 8-5, “Transient Cladding Strain in AOO Comparison,” of the TR (Ref. 1), show that the chromia-doped fuel has a **[[** **]]** as expected.

The DNB calculations are performed with the COBRA-FLX thermal-hydraulic code module used by ARTEMIS. Given that the critical heat flux correlations implemented inside COBRA-FLX are not dependent on fuel pellet type or properties, Framatome states that the ability to use COBRA-FLX to calculate DNB will not be challenged by the inclusion of chromia in the fuel design. The DNB calculations are mainly dependent on water properties, local geometry, and local heat flux within the assembly. The local heat flux is dependent on the pin powers and local flow conditions. **[[**

]] However, Framatome states that the DNB evaluation will be performed for chromia-doped fuel as part of the reload analysis process.

The NRC staff has examined the results of the UCBW evaluation presented in the TR (Ref. 1), as well as the detailed calculations made available at the regulatory audit. The NRC staff finds the results acceptable, as they demonstrate expected behavior for chromia-doped fuel, including **[[** **]]**

3.6.2.2 Control Rod Ejection Accident

As described above in Section 3.5.2, "AREA Methodology," of this SE, the AREA methodology is used for the evaluation of a CREA in a PWR. The methodology is used to demonstrate compliance with the acceptance criteria specified in NUREG-0800, Section 4.2. For the CREA sample analyses, Framatome used the Westinghouse 4-loop plant described in Appendix A of Reference 6 and made modifications to include chromia-doped fuel. The results were then compared with the results from the sample problem in Appendix A of Reference 6.

Framatome provided an assessment of the limiting case for each of the limiting criteria presented in Table A-7 of Reference 6. The results for a core containing chromia-doped fuel is summarized in Table 8-6, "W 4-Loop, Measure of Conservatism for Limiting Result Cases," of the TR (Ref. 1). For each of the CREA limiting criteria, the power level, cycle burnup, **[[**

]] are provided.

Framatome provided a comparison between the conservatisms of the standard fuel (Table A-7 of Ref. 6) and chromia-doped fuel as presented in Table 8-7 of the TR (Ref. 1). The results of this comparison show that **[[**
]] and that there is ample conservatism for each criterion.

The comparisons provided by Framatome for the CREA analyses show that the margin to the criteria for a core design with chromia-doped pellets is **[[** **]]** with respect to a core design with standard fuel. The maximum observed change in margin is **[[**
]] as presented in Table 8-7 of the TR (Ref. 1).

The NRC staff has examined the results of the CREA evaluation presented in the TR, as well as the detailed calculations made available at the regulatory audit. The NRC staff finds the results acceptable, as they demonstrate expected behavior for chromia-doped fuel including **[[**

]]

3.6.2.3 Loss-of-Coolant Accident

For the LOCA, Framatome performed sample analyses representative of a Westinghouse 4-loop PWR plant. The sample problem calculations are similar to those presented in the LOCA methods with GALILEO (Ref. 16) and compare results from standard fuel with chromia-doped fuel.

For the small break LOCA analyses, Framatome performed **[[** **]]** as required by the SBLOCA methodology. Framatome found that the limiting case for both fuel types resulted in **[[** **]]** Therefore, Framatome concludes that the results demonstrate that the SBLOCA EM changes with chromia-doped fuel have **[[** **]]** on the results of the analyses.

For the large break LOCA, Framatome performed **[[** **]]** as required by the RLBLOCA methodology. As described above in Section 3.5.4 of this SE, the RLBLOCA EM uses a best-estimate approach based on statistical sampling of uncertainty contributors and propagation of uncertainty to determine the expected PCT, MLO, and total CWO response. Given the statistical sampling of parameters and phenomena, **[[** **]]** Framatome found that the results for the **[[** **]]** The results for PCT, MLO, and CWO are shown in Table 8-9 of the TR (Ref. 1) and demonstrate that the RLBLOCA EM changes with chromia-doped fuel have **[[** **]]** on the results of the analyses.

The NRC staff has examined the results of the LOCA evaluations presented in the TR. The NRC staff finds the results acceptable, as they are in line with expectations for the changes introduced by the chromia-doped fuel.

3.6.3 Impact on Nuclear Design Requirements

Framatome states that the observations made in Section 9.3 of the approved base TR (Ref. 2) remain valid and applicable to analyses of PWRs, except that the APOLLO2-A code with corresponding cross section libraries is used in place of the CASMO-4 lattice code that is used for BWR analyses. Framatome further states that no other changes to existing neutronics codes or methodologies will be required.

Given that the chromium cross sections are already included in the nuclear data library as part of the APOLLO2-A code, the addition of chromia to the fuel will require no changes to existing neutronics codes or methodologies. Therefore, the NRC staff finds that any impact of chromia addition on core physics predictions is explicitly accounted for in the APOLLO2-A code.

3.6.4 Fuel Design Criteria

Section 4.2 of the SRP discusses the acceptance criteria needed for fuel system damage, fuel rod failure, and fuel coolability in order to meet the requirements of GDC 10. Framatome stated that there is no change to cladding materials, structural materials, or fuel assembly design with the use of chromia-doped fuel. When modeling chromia-doped fuel versus standard fuel, the significant changes needed are in the physical properties of the fuel pellets. Table 3-1 of the TR provides a list of the individual criteria from Section 4.2 of the SRP along with the Framatome assessment of how each criterion is affected by use of chromia-doped fuel. Framatome found that, with the few exceptions noted below, the methodologies used to evaluate each criterion are not affected by the use of chromia-doped fuel. Based on the unique properties of the chromia-doped fuel pellets, the margin to a given acceptance criterion may be affected, however, Framatome provided sample analysis to demonstrate that the acceptance criteria are met with the use of chromia-doped fuel. NRC staff reviewed Table 3-1 of the TR and finds that Framatome appropriately categorized each item related to any required methodology changes. As an example, one of the fuel system damage criteria is rod internal pressure. The methodology used to compute the rod internal pressure does not change depending on the fuel type. What is changed are the physical properties of the selected fuel type. In this example, described in Section 8.1.1 of the TR and Section 3.6.1 of this SE, using the same methodology, the **[[** **]]** This is the expected result as **[[** **]]**

Changes to the methodologies include **[[** **]]** These changes are reviewed above in Sections 3.3.3, 3.3.4 and 3.4 of this SE and were all found to be acceptable to the staff.

Overall, NRC staff finds that the Framatome methodologies used to determine if the acceptance criteria of SRP Section 4.2 are met are acceptable for use with chromia-doped fuel and meet the requirements of GDC 10 related to specified acceptable fuel design limits.

4.0 LIMITATIONS AND CONDITIONS

Consistent with the final SE of the approved base TR (Section 4.0 of Ref. 2), the usage of chromia-doped fuel in PWR methods is subject to the same limitations and conditions (1 through 3 below). In addition, one new limitation has been added.

1. The limitation imposed on grain size of standard fuel in Reference 7 is unchanged. GALILEO is approved for **[[** **]]**
2. Chromia-doped fuel is limited to a rod average burnup limit of **[[** **]]**
3. Chromia concentration is limited to the range of **[[** **]]** The limit also applies to chromia-doped gadolinia fuel.
4. Fuel licensing application of chromia-doped UO_2-Gd_2O_3 fuel is acceptable up to a rod average burnup of **[[** **]]**

5.0 CONCLUSIONS

Framatome has presented data and analyses to support their request for approval of chromia-doped UO_2 fuel for use in PWRs, where the dopant is within the range **[[** **]]** Material property changes have been implemented in both the GALILEO thermal-mechanical fuel performance code and other Framatome PWR analysis methodologies as necessary. The impact of the chromia dopant on in-reactor fuel performance (such as reactivity initiated accident behavior, LOCA behavior, and FGR) has been adequately analyzed.

The NRC staff concludes that thermal-mechanical performance of the proposed chromia-doped fuel in PWRs is adequately addressed in the Framatome submittal with the application of the GALILEO fuel performance code. **[[**

]]

The NRC staff's SE of chromia-doped fuel is subject to the limitations and conditions listed in Section 4.0.

6.0 REFERENCES

1. ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods," Framatome, Inc., June 2021 (ADAMS Package Accession No. ML21187A202)

2. ANP-10340P-A Revision 0, "Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods," June 2018 (ADAMS Package Accession No. ML18171A107)

3. Letter from D. Morey (NRC) to G. Peters (Framatome), "November 18 and December 7, 2021, Regulatory Audit Plan for Framatome Inc. Topical Report, ANP-10340P, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods" (EPID L-2021-TOP-0015), November 5, 2021 (ADAMS Package Accession No. ML21302A116)

4. Letter from N. Otto (NRC) to G. Peters (Framatome Inc.), "Request for Additional Information Regarding Framatome Topical Report, ANP-10340P, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods" (EPID L-2021-TOP-0015)," December 16, 2021 (ADAMS Package Accession No. ML21349A908)

5. Framatome Inc. submittal of "Response to Request for Additional Information Regarding ANP-10340, Revision 0, Supplement 1P, Revision 0 "Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods," April 11, 2022 (ADAMS Package Accession No. ML22105A049)

6. ANP-10338P-A, Revision 0, "AREA™ - ARCADIA® Rod Ejection Accident," February 2018 (ADAMS Package Accession No. ML18059A753)

7. ANP-10323P-A, Revision 1, "GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors," December 2020 (ADAMS Package Accession No. ML21005A028)

8. ANP-10297P-A, Revision 0, "The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results," February 2013 (ADAMS Package Accession No. ML14195A145)

9. ANP-10339P, Revision 0, “ARITA - ARTEMIS/RELAP Integrated Transient Analysis Methodology,” August 2018 (ADAMS Package Accession No. ML18242A480)

10. BAW-10227P-A, Revision 2, “Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel,” January 2023 (ADAMS Package Accession No. ML23037A928)

11. ANP-10297P-A, Revision 0, Supplement 1PA, Revision 1, “The ARCADIA Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” December 2020 (ADAMS Package Accession No. ML21071A062)

12. EMF-2328P-A, Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” March 2001 (ADAMS Package Accession No. ML011410426)

13. EMF-2328P-A, Revision 0, Supplement 1(P)(A), Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” December 2016 (ADAMS Package Accession No. ML16356A396)

14. BAW-10240P-A, Revision 0, “Incorporation of M5 Properties in Framatome ANP Approved Methods,” August 2004 (ADAMS Accession No. ML042800308)

15. EMF-2103P-A, Revision 3, “Realistic Large Break LOCA Methodology for Pressurized Water Reactors,” September 2016 (ADAMS Package Accession No. ML16286A579)

16. ANP-10349P-A, Revision 0, “GALILEO Implementation in LOCA Methods,” December 2021 (ADAMS Package Accession No. ML21354A136)

17. BAW-10084P-A, Revision 3, “Program to Determine In-Reactor Performance of BWFC Fuel Cladding Creep Collapse,” April 1995 (ADAMS Package Accession No. ML20086N796)

18. BAW-10227P-A, Revision 1, “Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel,” June 2003 (ADAMS Package Accession No. ML15162B043)

19. Audit Report for Framatome Topical Report ANP, 10340P, Revision 0, Supplement 1, Revision 0, “Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods” (ADAMS Package Accession No. ML22129A158)

Principal Contributors: Robert Beaton, Adam Rau

Date: October 16, 2023

Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods

ANP-10340NP-A
Revision 0
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Revision 0

Topical Report

June 2021

Nature of Changes

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

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Nomenclature

Acronym	Definition
AOO	Anticipated Operational Occurrence
AREA	ARCADIA Rod Ejection Analysis
AST	Alternate Source Term
BOC	Beginning of Cycle
BWR	Boiling Water Reactor
CHF	Critical Heat Flux
CFR	Code of Federal Regulations
CRDA	Control Rod Drop Accident
CREA	Control Rod Ejection Accident
CUF	Cumulative Usage Factor
CWO	Core-Wide Oxidation
CWSR	Cold-Worked Stress-Relieved
DNB	Departure from Nucleate Boiling
DNBR	Departure from Nucleate Boiling Ratio
ECCS	Emergency Core Cooling System
EFPD	Effective Full Power Days
EM	Evaluation Model
EOC	End of Cycle
FA	Fuel Assembly
FTC	Fuel Thermal Conductivity
FGR	Fission Gas Release
GDC	General Design Criteria
HBS	High Burnup Structure
JRC-ITU	Joint Research Centre – Institute for Transuranium Elements

Acronym	**Definition**
LBLOCA	Large Break LOCA
LHGR	Linear Heat Generation Rate
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LWR	Light Water Reactor
MDNBR	Minimum Departure from Nucleate Boiling Ratio
MLO	Maximum Local Oxidation
MOC	Middle of Cycle
PA	Postulated Accident
PCI	Pellet-Cladding Interaction
PCMI	Pellet-Cladding Mechanical Interaction
PCT	Peak Cladding Temperature
PIE	Post-Irradiation Examination
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RG	Regulatory Guide
RIA	Reactivity-Initiated Accident
RLBLOCA	Realistic LBLOCA
RXA	Recrystallized Annealed
SAFDL	Specified Acceptable Fuel Design Limit
SBLOCA	Small Break LOCA
TCS	Transient Cladding Strain
TD	Theoretical Density
W&CE	Westinghouse and Combustion Engineering
Zr4	Zircaloy 4 Alloy

ABSTRACT

As a supplement to the approved topical report for the incorporation of chromia-doped fuel in Framatome approved methods, which dealt only with BWR methodologies, this submittal documents the effects of the use of chromia-doped fuel and its implementation in Framatome PWR methodologies.

A discussion is presented of the applicable regulatory guidance related to fuel material. This guidance is found primarily in NUREG-0800 Sections 4.2 through 4.4. The effects of incorporation of chromia-doped fuel on the methods which support the applicable NUREG-0800 criteria are provided.

As stated in the approved topical report, the material properties, behavioral assessment, qualification database and operating experience are generic for both BWR and PWR applications. Therefore, those parts of the approved topical report are not repeated herein, only specific PWR features are presented as needed.

A description of modifications to Framatome's PWR fuel performance code to support the use of chromia-doped fuel is provided, along with documentation of code validation. Model adjustments were made to accommodate changes in the [ ] in order to capture chromia-doped fuel's specific properties. No changes to the current PWR fuel rod thermal-mechanical methodologies were necessary.

The qualification of ARCADIA, AREA, ARITA, and W&CE LOCA methodologies to accurately model chromia-doped fuel behavior are also presented. Finally, sample cases of design analyses that cover the fuel licensing evaluation for thermal-mechanical analyses, non-LOCA safety, LOCA, and CREA are provided.

1.0 INTRODUCTION

Framatome's application of chromia (Cr_2O_3)-doped UO_2 and (U-Gd)O_2 fuels in BWR fuel methods with RODEX4 fuel performance code was approved in 2018 (Reference 1). The material properties, behavioral assessment, qualification database and operating experience sections of the approved topical report are generic for both BWR and PWR applications. However, as stated in the approved topical report, the model adaptation to chromia-doped fuel is code specific.

In order to support the request for approval of chromia-doped UO_2 and (U-Gd)O_2 fuels for use in PWR methods this supplement describes the qualification of the GALILEO fuel performance code (Reference 2) for chromia-doped fuel, together with the related upstream and downstream codes and methods. Sample cases of design analyses are provided for the entire range of PWR fuel licensing analyses for thermal-mechanical, non-LOCA safety, LOCA, and CREA.

The purpose of this topical report supplement is to extend the applicability of existing topical reports to include chromia-doped fuel once it is approved by the NRC. [

] In cases where some modification is necessary to incorporate chromia-doped fuel, this topical report describes the updates necessary to model chromia-doped fuel and demonstrates that the chromia-doped fuel has been appropriately modeled. In all cases, no revisions will be made to the existing NRC-approved topical reports to specifically list chromia-doped fuel as an approved fuel material. This approach is appropriate since any operating PWR plant that would implement chromia-doped fuel would need to incorporate this topical report into their licensing basis using an appropriate licensing change process. The following sections define the applicability of chromia-doped fuel to existing NRC-approved licensing methodologies.

Consistent with the Final Safety Evaluation of the approved base topical report (Section 4.0 of Reference 1), the usage of chromia-doped fuel in PWR methods is subject to the following limitations and conditions:

1. The limitation imposed on grain size of standard fuel in Reference 2 is unchanged. GALILEO is approved for [ ]
2. Chromia-doped fuel is limited to a rod average burnup limit of [ ]
3. Chromia concentration is limited to the range of [ ] The limit also applies to chromia-doped gadolinia fuel.

2.0 SUMMARY

This report provides a description of the changes to Framatome's GALILEO fuel performance code and its validation to support the use of chromia-doped UO_2 and (U-Gd)O_2 fuel in PWRs. In addition, the associated neutronics and thermal-hydraulic codes and methods have been analyzed for any needed adaptation to adequately model chromia-doped fuel.

Section 4.0 of this supplement provides necessary updates related to PWR applications, based on Sections 4.0, 5.0, 6.0, and 10.0 of Reference 1.

Sections 5.0 through 8.0 describe how the general properties of chromia-doped fuel are modeled in the GALILEO based PWR methodology to generate sample licensing evaluations in support of typical core designs. The adaptation and qualification of GALILEO to chromia-doped fuel are described in Section 5.0. The discussion does not impose a limitation or restriction on the usage of the GALILEO code (Reference 2) on the standard (non-doped) fuels. Section 6.0 provides information regarding qualification of Framatome's ARCADIA (References 6 and 7), AREA (Reference 5), ARITA (Reference 4), and Small Break LOCA (SBLOCA) and Realistic Large Break LOCA (RLBLOCA) methodologies (References 8, 9, 10, and 11) for chromia-doped fuel. Section 7.0 describes the qualification of the growth model for chromia-doped fuel rods. Finally, for illustration purposes, Section 8.0 presents sample cases of design analyses that cover the full range of calculations for fuel licensing under GALILEO-based PWR methodologies and demonstrate compliance with the licensing criteria which are discussed in Section 3.0.

3.0 APPLICABLE REGULATORY GUIDANCE

This section maps the content of the topical report to the applicable regulatory guidance.

3.1 *Applicable Regulatory Guidance*

Regulatory guidance for the review of fuel system designs and adherence to applicable General Design Criteria is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", Section 4.2, “Fuel System Design” (Reference 3).

The Standard Review Plan (SRP) Section 4.3 is not discussed in this report because there are no changes required for the application of the neutronics codes and methods to chromia-doped fuel. Chromium neutron cross-sections are present in the lattice code (i.e., APOLLO2-A), and the neutronics methods accurately model this element as described in Section 8.3 of this report.

The SRP Section 4.4, which refers to the thermal and hydraulic design, is also not impacted by the chromia-doped fuel because the small change to fuel composition has no effect on any of the processes and phenomena related to thermal and hydraulic design of the core. However, the results of the analyses required by SRP Section 4.2 (which are also cross-referenced in SRP Section 4.4) are slightly modified by the specific properties of chromia-doped fuel. Therefore, the corresponding design basis topics are included in the following discussion of compliance with the applicable regulatory guidance.

As there is no change to cladding materials, structural materials, or fuel assembly design, only the SRP fuel design criteria from Section 4.2 that are germane to implementation of chromia-doped fuel are described in Table 3-1.

SRP Chapter 15 acceptance criteria for Anticipated Operational Occurrences (AOOs) and accidents are addressed in Section 8.2, where representative events are analyzed and the effect of employing chromia-doped fuel on margins to acceptance criteria limits are evaluated. Table 3-1 addresses the SRP Chapter 15 acceptance criteria for the Section 4.2 design criteria that apply.

Table 3-1
Standard Review Plan Section 4.2 Criteria

1. Design Bases	Item	Topic	Assessment	Location in this Report
A. Fuel System Damage	i	Stress, strain, or loading limits (fuel rod cladding)	[ ]	See row B.vi of this table for information on cladding strain.
	ii	Fatigue (fuel rod cladding)	[ ]	Section 8.1 provides sample analysis results.
	iii	Fretting wear (fuel rod cladding)	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.
	iv	Oxidation, hydriding, crud (fuel rod cladding)	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.
	v	Dimensional changes (fuel rod growth)	[ ]	The chromia-doped fuel rod growth correlation is addressed in Section 7.0.

1. Design Bases	Item	Topic	Assessment	Location in this Report
A. Fuel System Damage *(continued)*	vi	Rod internal gas pressure	[ ]	Section 5.2 discusses benchmarking the Fission Gas Release (FGR) model. Section 8.1 provides sample analysis results.
	vii	Assembly liftoff	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.
	viii	Control rod reactivity and insertability	[ ]	Since neither the method nor calculated results for control rod insertability are affected by the use of chromia-doped fuel, this topic is not included in the report. Neutronics methods are discussed in Section 6.0.

1. Design Bases	**Item**	**Topic**	**Assessment**	**Location in this Report**
B. Fuel Rod Failure	i	Hydriding (fuel rod cladding)	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.
	ii	Cladding collapse	[ ]	The material properties are provided in Reference 1 and Section 8.1 provides sample analysis results.
	iii	Overheating of cladding	[ ]	The material properties are provided in Reference 1. The impact on DNB is presented in Section 8.2.1.

1. Design Bases	**Item**	**Topic**	**Assessment**	**Location in this Report**
B. Fuel Rod Failure *(continued)*	iv	Overheating of fuel pellets	**[ ]**	The material properties are provided in Reference 1 and Section 8.2 provides sample analysis results.
	v	Excessive fuel enthalpy	**[ ]**	Section 4.3.2 discusses chromia-doped fuel behavior during RIA. Section 8.2.2 illustrates the impact of chromia-doped fuel on deposited enthalpy calculations.

1. Design Bases	**Item**	**Topic**	**Assessment**	**Location in this Report**
B. Fuel Rod Failure *(continued)*	vi	Pellet/ cladding interaction	[ ]	Section 4.0 of Reference 1 provides the material properties that affect PCMI and Section 10.2 of Reference 1 discusses the ramp test database. Section 8.2.1 provides sample analysis results.
	vii	Bursting	[ ]	Section 6.0 illustrates the effects of chromia-doped fuel on criteria dealing with this topic.
	viii	Mechanical fracturing	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.

1. Design Bases	**Item**	**Topic**	**Assessment**	**Location in this Report**
C. Fuel Cool-ability	i	Cladding embrittlement	[ ]	Section 6.0 illustrates the effects of chromia-doped fuel on criteria dealing with this topic.
	ii	Violent expulsion of fuel	[ ]	The methodology for evaluating this topic can be found in Reference 5. The effect of chromia-doped fuel on a severe reactivity insertion accident is exemplified in Section 8.2.2 of this report.
	iii	Generalized cladding melting	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.

1. Design Bases	**Item**	**Topic**	**Assessment**	**Location in this Report**
C. Fuel Cool-ability *(continued)*	iv	Fuel rod ballooning	[ ]	Section 6.0 illustrates the effects of chromia-doped fuel on criteria dealing with this topic.
	v	Structural deformation (fuel rod cladding)	[ ]	Since neither the method nor calculated results are affected by the use of chromia-doped fuel, this topic is not included in the report.

4.0 APPLICABILITY OF BASE TOPICAL REPORT

Section 4.0 of Reference 1 provides the material properties of chromia-doped fuel with the associated qualification dataset, which provides the basis for properties that are different from those of standard fuel. For the material properties that are not affected by the chromia dopant, experimental and/or theoretical justification is provided to support the continued use of the material property for chromia-doped fuel. Thermal conductivity is discussed below in Section 4.1. The following sections of Reference 1 are generic for both BWR and PWR applications.

- Section 4.1 Microstructure
- Section 4.2 Theoretical Density
- Section 4.3 Thermal Expansion
- Section 4.4 Specific Heat and Enthalpy
- Section 4.6 Grain Size and Growth
- Section 4.7 Elastic Moduli
- Section 4.8 Tensile Fracture Strength
- Section 4.9 Creep and Plastic Deformation
- Section 4.10 Fuel Pellet Cracking
- Section 4.11 In-reactor Densification
- Section 4.12 Effect of Additive on the High Burn-up Fuel Pellet Rim Structure

Section 5.0 of Reference 1 describes the chromia-doped fuel characteristics that are related to in-reactor behavior during normal operation, accident conditions, and following fuel failure. Section 5.1 of Reference 1 is generic for both BWR and PWR applications. Fuel melting is discussed below in Section 4.2. Behavior during accidental conditions is discussed below in Section 4.3.

Section 6.0 of Reference 1 describes the validation and verification (i.e., qualification) database that is required in order to qualify a fuel performance code for chromia-doped applications. Updates after the approval of Reference 1 are included in Section 4.4.

Section 10.0 of Reference 1 contains the operating experience with chromia-doped fuel in power reactors. This section also describes the comprehensive power ramp test program that is the basis for the quantification of the PCI performance improvement with chromia-doped fuel. This section applies to both BWR and PWR application and no update is necessary.

Sections 4.0, 5.0, 6.0 and 10.0 of Reference 1 are generally valid for both BWR and PWR applications. The following sub-sections describe minor changes due to the BWR and PWR fuel performance code differences and the addition of more measurement results.

4.1 *Material Properties - Thermal Conductivity*

Chromia-doped fuel thermal diffusivity measurement campaigns and database are described in Section 4.5 of Reference 1. After thermal diffusivity values are obtained using the laser flash technique, the thermal conductivity is calculated as a function of diffusivity, density, and specific heat as shown in Equation 4-1.

$$k(T) = \alpha(T).\rho(T).c_p(T) \tag{4-1}$$

where:

$k(T)$	-	thermal conductivity	[W/(m·K)]
$\alpha(T)$	-	diffusivity	[m^2/s]
$\rho(T)$	-	density	[kg/m^3]
$c_p(T)$	-	specific heat	[J/(kg·K)]
T	-	temperature	[K]

The thermal conductivity data in this report have been processed with the specific heat formulation in GALILEO code (Reference 2).

The general observations and conclusions stated in Section 4.5.2 of Reference 1 are not changed. Two important conclusions are reiterated here.

Figure 4-1, Figure 4-2, Figure 4-3, and Figure 4-4 display the results (all conductivity values normalized to 95% TD) of the measurement campaigns performed in Framatome facilities and independently at JRC-ITU.

4.2 *Behavioral Assessment – Fuel Melting*

The fuel melting temperature measurement technique, using laser heating and fast multi-channel pyrometry, is described in detail in Section 5.2 of Reference 1. Statistical evaluation of the experimental data concludes the impact of chromia dopant on the melting temperature of doped uranium dioxide and chromia-doped (U-Gd)O_2 in Reference 1 as the following:

- The fuel melting temperature of chromia-doped UO_2 is **[ ]** in comparison to standard UO_2 fuel.

[ ]

Therefore, the chromia-doped UO_2 melting point in GALILEO is given by Equation 4-2, which is simply **[ ]** from the non-doped UO_2 melting point. **[ ]**

[ ]

4.3 *Behavior During Accidental Conditions*

The following two sections justify the conclusion that the anticipated behavior of chromia-doped fuel during the LOCA and CREA design basis accidents is **[ ]**

4.3.1 Loss of Coolant Accidents

Fuel behavior, such as thermal conductivity, gaseous swelling, and fission gas release impacts the fuel rod internal pressures and fuel temperatures, which have a potential to influence the LOCA cladding response. Nevertheless, **[ ]**

[

]

[

]

4.3.2 Reactivity Initiated Accidents

A Reactivity-Initiated Accident (RIA) is a nuclear reactor accident that involves an unwanted increase in fission rate and reactor power. The immediate consequence of an RIA is a fast rise in neutron power and fuel temperature. The power excursion may lead to failure of the nuclear fuel rods with a release of radioactive material into the primary reactor coolant.

Section 10 of the Code of Federal Regulations (10 CFR) Part 50, Appendix A, GDC 28 requires reactivity control systems to be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of an RIA cannot result in:

- damage to the reactor coolant pressure boundary greater than local yielding nor

- sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to impair significantly the capability to cool the fuel within the core.

Regulatory Guide (RG) 1.236 (Reference 16) identifies the postulated Control Rod Ejection Accident (CREA) as the limiting RIA in a PWR.

In order to satisfy 10 CFR Part 50 Appendix A, GDC 28, RG 1.236 provides fuel cladding thresholds and limits that must be satisfied to avoid:

- Fuel rod cladding failure (ductile, brittle, PCMI)
- Radiological dose
- Reactor coolant system pressure failure
- Core coolability failure

These are addressed by the AREA methodology (Reference 5) except for the radiological dose analysis.

The impact of chromia-doped fuel on the requirements of RG 1.236 is discussed in the following sub-sections.

4.3.2.1 Impact of Chromia-Doped Fuel Inclusion on Fuel Rod Cladding

The chromia doping of the fuel [ ] As discussed in this report; test results have indicated that specific heat, enthalpy, thermal conductivity, and fuel pellet cracking [ ]

4.3.2.2 Impact of Chromia-doped Fuel Inclusion on Radiological Accidents

Any interaction between chromia-doped fuel and fission products may alter the amount or chemical species released during a design basis accident or a severe accident. The presence of chromia in the fuel [

]

The Framatome AREA methodology does not address radiological consequences for a rod ejection. However, RG 1.183 and RG 1.195 (References 17 and 18, respectively) can be used to determine the Alternate Source Term (AST) for chromia-doped fuel as it does for standard fuel.

4.3.2.3 Impact of Chromia-doped Fuel Inclusion on Reactor Coolant System Pressure

Chromia doping in standard fuel has no significant impact on the maximum reactor coolant system pressure. The reactor coolant pressure calculation is based on a conventional heat transfer from the fuel. Heat flux is directly related to the ability to calculate pin powers and local flow conditions. During normal operation and transients, the pin powers for cores with chromia-doped fuel are essentially the same as a core without chromia-doped fuel. [

] Thus, the inclusion of chromia-doped fuel in the reactor design has no impact on the RG 1.236 reactor coolant pressure criterion. The impact on reactor coolant pressure criterion is addressed as part of the AREA methodology (Reference 5).

4.3.2.4 Impact of Chromia-doped Fuel Inclusion on Core Coolability

The melting point of standard fuel and chromia-doped fuel has been documented in Section 4.2. In general, the addition of chromia [ ] with respect to standard fuel. The limited amount of chromia in the fuel [ ]

[ ] The thermal-mechanical methodology used to analyze each reload cycle includes the chromia-doped properties, and therefore any change to the average fuel enthalpy threshold for incipient melting is explicitly addressed. This ensures that the coolability criterion will not be violated. The coolability criterion is addressed within the AREA methodology (Reference 5).

4.3.2.5 Conclusion

The addition of chromia to standard fuel based on the specification from Section 4 of Reference 1 is small. Thus, [

] The ability to calculate heat flux is directly related to the ability to calculate pin powers and local flow conditions. It is expected that during normal operation and a rod ejection transient that [

] Thus, the inclusion of chromia-doped fuel in the fuel assemblies does not violate the limits established by RG 1.236 used as a basis to evaluate a postulated CREA with chromia-doped fuel.

Furthermore, the effect of chromia on fuel rod performance has been assessed using GALILEO. The results indicate that [

] as detailed in Section 8.2.2 of this report.

Thus, the RG 1.236 fuel cladding thresholds and limits to fuel rod cladding failure remain consistent with the criteria for the standard fuel.

4.4 *Qualification Data*

A large set of irradiation data in both power reactors and research reactors in steady-state and power ramp operational modes and in conditions specific to both BWR and PWR reactors has been acquired in the last fifteen years. Cladding for the chromia-doped pellets has included recrystallized M5$_{\text{Framatome}}$, Cold-Worked Stress-Relieved (CWSR) Zr4 in PWRs, and Zircaloy-2 (liner and non-liner). Maximum rod burn-up of approximately [ ] has been obtained.

Detailed description of cladding materials, fuel rod designs, and PIE measurements are described in Section 6.0 of Reference 1. After Reference 1 was approved, [

] These ramp testing rods were discussed in Section 10.2 of Reference 1.

[

]

Table 4-1
Chromia-Doped Fuel Irradiation Database

[ ]

Figure 4-1
Thermal Conductivity Measurements at AREVA in 2015

Figure 4-2
Thermal Conductivity Measurements at JRC-ITU in 2015

Figure 4-3
Thermal Conductivity Measurements at AREVA in 2006

Figure 4-4
Thermal Conductivity Measurements at JRC-ITU in 2006

5.0 QUALIFICATION OF GALILEO FOR CHROMIA-DOPED FUEL

The GALILEO fuel performance code was approved for PWR fuel rod design and licensing analyses in conjunction with its associated statistical methodology (Reference 2). The unique properties of chromia-doped fuel, which have been described in Section 4.0 in this supplement and Section 4.0 in Reference 1, necessitate minor adaptation of select code models so that GALILEO can be applied to chromia-doped fuel for PWR analyses using the same statistical methodology.

The verification and validation of GALILEO for chromia-doped fuel used the qualification database presented in Section 4.4 and consists of the following:

[ ]

The following describes the model adaptations or additions that were required, as well as the benchmarking of the qualification database. [ ]

5.1 *GALILEO Thermal Conductivity Model for Chromia-doped Fuel*

The adaptation of the GALILEO thermal conductivity model and its subsequent validation is discussed below.

5.1.1 Adaptation of GALILEO Thermal Conductivity Model to Unirradiated Chromia-doped Fuel

GALILEO's thermal conductivity model consists of [

]

Based on the conclusion from Reference 1, reiterated in Section 4.1, [

]

For completeness, the final adjusted model parameters of the chromia-doped thermal conductivity are listed below in Equations 5-1 to 5-6 and displayed in Figure 5-1 and Figure 5-2:

[

]

5.1.2 Validation of GALILEO Thermal Conductivity Model to Irradiated Chromia-doped Fuel

The thermal conductivity model adaptation to chromia-doped fuel in Section 5.1.1 was based on unirradiated fuel studies and accounts for the generic impact of the chromia dopant. It was anticipated that the burnup degradation impact on thermal conductivity, as described by Equation 5-1 for standard fuel, is valid for chromia-doped fuel as it was previously shown to be valid in the case of gadolinia fuel.

This was confirmed by the benchmarking of the REMORA2 test in which the pellet centerline temperature was measured online by a central thermocouple that was inserted in the drilled section of the refabricated rodlet. The rodlet was irradiated in the OSIRIS test reactor after the father rod achieved a [ ] in a power reactor.

Figure 5-3 compares calculated and measured temperatures of the REMORA2 tests and demonstrates good agreement over the whole range of test powers. [ ], as shown in Figure 4-2 of Reference 2.

5.1.3 Validation of GALILEO Fuel Thermal Conductivity Uncertainty

The applicability of the standard fuel thermal conductivity uncertainty on the chromia-doped fuel is confirmed by using the same approach as described in Section 5.4.5 of Reference 2. As shown in Figure 5-4, [ ] Measurements of the fuel centerline temperature with [ ] in the REMORA2 test are considered in the assessment.

5.2 *GALILEO Fission Gas Release Model for Chromia-doped Fuel*

Chromia-doped fuel is similar to standard fuel with an enlarged grain microstructure and the same phenomenological FGR model is applicable to both fuel types. [ ]

[ ] (Section 3.3.3.3 of Reference 2). In this model, [ ]

[ ]

[

]

[

]

The model extension for fission gas release of chromia-doped fuels implemented in GALILEO is well calibrated and validated for chromia-doped UO_2 fuel as displayed in Figure 5-5 and Figure 5-6. The applicability of the standard fuel diffusion coefficient uncertainty for FGR on the chromia-doped fuel is confirmed as shown in Figure 5-7.

[ ]

5.3 *GALILEO Intragranular Gaseous Swelling Model for Chromia-doped Fuel*

Ceramography data show that larger intragranular bubbles exist in the case of chromia-doped fuel, which corroborates with the observed larger cladding deformation. These larger bubbles are interpreted to be a consequence of enhanced intragranular gaseous swelling, which in turn contributes to larger pellet deformation and hence larger cladding deformation, especially during power ramps. Standard fuel exhibits very low intragranular gaseous swelling, so this has not been modelled previously in GALILEO. The difference in intragranular gaseous swelling can be observed in hot-cell PIE images indicating a low gas precipitation on grain boundaries and a significant gas precipitation into intragranular bubble form. Section 7.3 of Reference 1 has described the full theory of intragranular gaseous swelling model. Consequently, the intragranular gaseous swelling model developed in Reference 1 for chromia-doped fuel is used in GALILEO with new calibration as shown in Figure 5-8.

Related to the fuel deformation, Figure 5-9 and Figure 5-10 show the GALILEO predicted versus measured fuel density and dish filling, respectively. The comparisons demonstrate a best-estimate code response for the chromia-doped fuel. These figures show that the scattering band for the chromia-doped fuel is similar to that for the standard fuels, as shown in Figure 4-19 and Figure 4-22 of Reference 2. Furthermore, Figure 5-8 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.

5.4 *Validation of Rod Free Volume and Internal Pressure*

Fuel rod free volume is dependent on the collective effects from other thermal and mechanical models. The prediction of rod internal pressure is directly linked with free volume along with the quality of predictions for FGR and fuel temperatures. Therefore, the integral test of rod free volume and internal pressure is demonstrated in this section.

Figure 5-11 shows the predicted and measured rod free volumes. Figure 5-12 demonstrates that [

]. The results of predicted rod internal pressure compared to the measurement is shown in Figure 5-13. Likewise, no bias versus burnup is shown in Figure 5-14 for rod internal pressure prediction. Overall, these figures for the chromia-doped fuel have demonstrated the agreement between predicted and measured parameters is as satisfactory as those for the standard fuel, shown in Figure 4-47 and 4-49 of Reference 2.

Figure 5-1
Chromia-doped GALILEO Model against 2006 Campaign Data

Figure 5-2
Chromia-doped GALILEO Model against 2015 Campaign Data

Figure 5-3
Calculated and Measured Temperatures in the REMORA2 Test

[

]

Figure 5-4
Calculated and Measured Temperatures Using Lower Bound FTC Uncertainty

Figure 5-5
Fission Gas Release Predicted and Measured for Chromia-Doped Database

Figure 5-6
Burnup Trend of FGR for Chromia-doped UO_2

Figure 5-7
Predicted vs. Measured FGR - Upper Bound

Figure 5-8
Clad Diameter Change Predicted vs. Measured for Chromia-doped Database

Figure 5-9
Predicted vs. Measured Density for Chromia-doped UO_2

Figure 5-10
Predicted vs. Measured Dish Filling for Chromia-doped UO_2

Figure 5-11
Predicted vs. Measured Free Volumes for Chromia-doped UO_2

Figure 5-12
Burnup Trend of Free Volume for Chromia-doped UO_2

Figure 5-13
Predicted vs. Measured Internal Pressure for Chromia-doped UO_2

[

]

Figure 5-14
Burnup Trend of Internal Pressure for Chromia-doped UO_2

6.0 QUALIFICATION OF FRAMATOME METHODOLOGIES TO CHROMIA-DOPED FUEL

Chromia-doped fuel will be analyzed with the ARCADIA, ARITA, AREA, and W&CE LOCA methodologies. The qualification of these methodologies is presented in the following sub-sections.

ARCADIA Methodology

The ARCADIA code package (References 6 and 7) has received NRC approval for use in analyzing core designs for normal operation and transients. The validation provided in References 6 and 7 demonstrates that the models and equations in APOLLO2-A (the deterministic 2D neutron transport code designed for lattice physics calculations) can accurately predict the reactivity of fuel pin lattices. The ability to model chromia-doped fuel is primarily dependent upon the accuracy of the cross section data. The chromium data are part of the standard cross section libraries validated with APOLLO2-A and approved in the ARCADIA topical report. The effect of chromium on core reactivity has been quantified. Thus, no foreseeable changes are required to the approved neutronics codes or methodologies (References 6 and 7).

Furthermore, the inclusion of chromia to the fuel rod as a doping agent is independent of the U-235 enrichment of the fuel pellet.

AREA Methodology

The AREA methodology (Reference 5) is NRC approved for evaluation of control rod ejection accidents. The methodology couples the ARCADIA code system and S-RELAP5 for the system pressure analysis. This coupling allows the AREA methodology to provide a more realistic representation of the reactor pressure response during a CREA. The methodology provides compliance with the regulatory criteria for energy deposition, fuel rim melt, fuel centerline melt, MDNBR, and RCS pressure response.

Results from an AREA Evaluation Model (EM) (See Section 8.2.2) which included chromia-doped fuel indicate that [

] The results confirm that all margins are preserved in a core design based on chromia-doped fuel. Thus, the AREA methodology is not challenged by the inclusion of chromia-doped fuel in a core design.

ARITA Methodology

The ARTEMIS/RELAP Integrated Transient Analysis (ARITA) topical report (Reference 4) defines a methodology to analyze the non-LOCA events defined in Chapter 15 of the SRP using a statistical approach (with the exception of the Control Rod Ejection event). In this context, S-RELAP5 is used to calculate the system thermal-hydraulic response, ARTEMIS is used for core neutronic and thermal-hydraulic analysis, and GALILEO is used for thermal-mechanical response.

The methodology allows running S-RELAP5 and ARTEMIS, either independently or in a coupled fashion, depending on the non-LOCA event being considered.

The ARITA methodology is not affected by the inclusion of chromia-doped fuel. The thermal conditions are dependent on pin powers and local flow conditions. It is expected that [

] The system thermal-hydraulic response is not dependent on the inclusion of chromia-doped fuel.

Therefore, [

] Use of the ARITA methodology will be exercised or dispositioned as part of the reload analysis process when deploying core designs that include chromia-doped fuel.

W&CE LOCA Methodology

The scope of the evaluation of implementing chromia-doped fuel in the Framatome Westinghouse and Combustion Engineering (W&CE) LOCA EMs focuses on the direct effects that a change to the chromia-doped properties would have on the LOCA methodologies, which include topical reports and the models and correlation embedded in the LOCA analysis codes. Framatome's SBLOCA EM is defined in References 8, 9, and 10. Framatome's RLBLOCA EM is defined in Reference 11. The RLBLOCA EM was developed using the Evaluation Model Development and Assessment Process (EMDAP) described in RG 1.203 (Reference 12). Therefore, a graded EMDAP approach was used to evaluate the impact of chromia-doped fuel on the RLBLOCA EM. The GALILEO fuel performance code is implemented in the W&CE LOCA EMs via Reference 13.

The SBLOCA and RLBLOCA methodologies rely on two computer codes: GALILEO (Reference 2) and S-RELAP5. The chromia-doped fuel specific physical models and material properties are supplied by GALILEO with the model adaptations described in Section 5.0. The implementation of these model adaptations will not change the current fuel rod analysis workflow or basic model capabilities of the current W&CE LOCA EMs. The S-RELAP5 code remains the thermal-hydraulic system code and no changes are made to the general capabilities of the code in terms of systems, components, phases, geometries, fields, and processes modeled. The only updates to the S-RELAP5 code are to incorporate the chromia-doped GALILEO adaptations into the GALILEO module within S-RELAP5.

The review of the SBLOCA and RLBLOCA EMs, as supplemented by GALILEO, with respect to chromia-doped fuel pellet properties identified [

] The review also identified the important fuel-related LOCA phenomena that could potentially be affected by chromia-doped properties. [

]

7.0 QUALIFICATION OF ROD GROWTH TO CHROMIA-DOPED FUEL

The design basis for fuel rod axial growth is that adequate clearance be maintained between the fuel rod ends and top and bottom nozzles to accommodate the difference in the axial growth of fuel rods and fuel assembly. The clearance between the fuel rod top ends and the top nozzle is known as the shoulder gap.

In Reference 15, Section 11.2 an updated upper bound fuel rod axial growth model was defined from over [

]

The fuel rod axial growth model prediction versus the fuel rod axial growth measurements in Reference 15, Figure 11-1 shows that the model is conservative.

As noted above, the allowable rod growth is dictated by the shoulder gap criterion. This is primarily a function of initial shoulder gap, fuel rod growth, and fuel assembly growth. In the evaluation of shoulder gap, inputs are chosen to assure a conservative analysis. This includes [

] Therefore, no fuel rods in the core are expected to violate the shoulder gap criterion during the design lifetime of the fuel assembly.

8.0 LICENSING CRITERIA ASSESSMENT

Sections 5.0 and 6.0 described the adaptation and qualification of the PWR codes and methods for application to chromia-doped fuel. In addition to this, no changes are necessary to any of the design or licensing criteria.

The following sub-sections illustrate examples of design analyses performed for the chromia-doped fuel. The results of those analyses are compared to standard fuel analyses to evaluate the impacts of the dopant. Representative manufacturing statistics for chromia-doped fuel are included in the analysis based on the pre-industrialization manufacturing runs and fuel pellet specifications. The following pellet characteristics are modified for the chromia-doped fuel:

[ ]

The uncertainty ranges of the gas diffusion coefficient and thermal conductivity are the same as for the non-doped fuels. The consistent prediction (same scatter band) of the chromia-doped and non-doped FGR allows use of the same uncertainty for both fuel types. With regards to the thermal conductivity, the bounding character of the model adaptation for chromia-doped fuel compensates for the reduced dataset.

8.1 *Fuel Rod Thermal-Mechanical Evaluation*

The example fuel rod thermal-mechanical analyses presented in this section represent a CE 14X14 fuel design with M5$_{\text{Framatome}}$ cladding. The calculations are performed with the GALILEO fuel code with the chromia-doped model options activated by specifying the corresponding input parameters in the GALILEO input files.

8.1.1 Maximum Rod Internal Pressure

Maximum rod internal pressure is evaluated with the GALILEO methodology from Reference 2. The rod internal pressure is limited to a value [ ] above the reactor system pressure (Reference 2, p. 3-2). For the CE 14x14 sample analyses, the limit is [ ]. Maximum rod pressures are shown in Table 8-1.

This example shows that [ ] This is primarily the result of two phenomena:

[ ]

8.1.2 Cladding Collapse

Collapse of M5$_{\text{Framatome}}$ cladding is evaluated with GALILEO (Reference 2) and CROV (Reference 14). The likelihood of cladding collapse has been greatly reduced in contemporary PWR fuel designs through the use of pressurized fuel rods and fuel pellets with high initial density and low in-reactor densification. [ ]

The CROV methodology defines three criteria for cladding collapse (Reference 14, Section 3.4).

[ ]

[ ]

Results for each of the cladding collapse criteria are shown in Table 8-2. As expected, [ ] with the chromia-doped fuel.

8.1.3 Cladding Fatigue

For the cladding fatigue analysis, transient calculations are performed with GALILEO using the methodology defined in Appendix C of Reference 2. The GALILEO results are then used to calculate the Cumulative Usage Factor (CUF) using the methodology described in Reference 15, Section 10.5. The CUF design limit for M5$_{\text{Framatome}}$ cladding is [ ].

Table 8-3 shows the fatigue results for the CE 14x14 fuel design with M5$_{\text{Framatome}}$ cladding. For this sample problem, standard fuel was shown to have a [ ] cumulative fatigue usage. This is explained by the fact that fatigue usage is driven by the magnitude of stress fluctuations (i.e., stress amplitude), not the magnitude of stress at any given moment. [ ] The majority of fatigue usage for this sample problem comes from [ ] Although the disparity in alternating stress difference between the fuel types is [ ], this causes a larger relative difference in CUF due to the logarithmic relationship between alternating stress and allowable cycles.

[ ] For PWR fuel rods, the fatigue is primarily driven by events with [ ] Consequently, the chromia-doped fuel is [ ] for fatigue as explained above.

Table 8-1
Maximum Rod Internal Pressure Results

[ ]

Table 8-2
Cladding Collapse Results

[ ]

Table 8-3
Cladding Fatigue Results

[ ]

8.2 *Safety Analyses*

Safety Analyses evaluate the fuel and plant behavior during AOOs and Postulated Accidents (PA) described in Chapter 15 of the Standard Review Plan (NUREG-0800). The following sub-sections detail the results of comparative analyses between standard fuel and chromia-doped fuel using the ARITA methodology from Reference 4, a CREA using Reference 5, and a LOCA using Reference 13.

8.2.1 ARITA Methodology

AOO transients and a subset of PA are analyzed using the ARITA methodology described in Reference 4. For this sample analysis, an Uncontrolled Bank Withdrawal (UCBW) from part-power initial conditions (AOO transient) is selected. The event is modeled for a 4-loop Westinghouse type plant with a 17x17 fuel assembly design. Specified Acceptable Fuel Design Limits (SAFDL) for the UCBW include fuel centerline temperature, transient cladding strain, and Departure from Nucleate Boiling (DNB).

The fuel temperature and cladding strain calculations are performed with the GALILEO fuel performance code with the chromia-doped model options activated by specifying the corresponding input parameters in the GALILEO input files.

Fuel Centerline Temperature

Besides the model adaptations and changes necessary to represent chromia-doped fuel behavior, the lower melting temperature of chromia-doped fuel is taken into account. As described in Section 4.2, a bounding correction for the chromia-doped fuel was developed such that the fuel melting temperature of chromia-doped UO_2 is [

] in comparison to standard UO_2 fuel.

In addition, [ ] Table 8-4 shows the maximum predicted fuel temperatures and the margin to fuel melt for the AOO transient. [ ]

Transient Cladding Strain

The transient induced strain limit for M5$_{\text{Framatome}}$ cladding is 1% (Reference 15, Section 10.4). Table 8-5 lists the predicted transient cladding strain and margin to the 1% strain limit for standard (non-doped) fuel and chromia-doped fuel during the AOO transient. The chromia-doped fuel [ ]

Table 8-4
Fuel Centerline Temperature Comparison

[ ]

Table 8-5
Transient Cladding Strain in AOO Comparison

[ ]

Departure from Nucleate Boiling

COBRA-FLX is the thermal-hydraulic code module used by ARTEMIS to perform both the nodal and detailed sub-channel DNB calculation. CHF correlations implemented inside COBRA-FLX are not dependent on fuel pellet type. Therefore, the ability to use COBRA-FLX within ARCADIA to calculate DNB will not be challenged by the inclusion of chromia in the fuel design.

The DNB calculations are mainly dependent on water properties, local geometry, and local heat flux within the assembly. Water properties are not impacted by the inclusion of chromia-doped fuel in the core design. Furthermore, the ability to calculate heat flux is directly related to the ability to calculate pin powers and local flow conditions. It is expected that during normal operation and transients that [

] however, the DNB evaluation will be performed for chromia-doped fuel as part of the reload analysis process.

8.2.2 Control Rod Ejection Accident

This section summarizes the impacts of chromia-doped fuel on regulatory safety criteria using the AREA methodology (Reference 5). The Westinghouse 4-Loop plant described in Appendix A of Reference 5 was modified to include chromium-doped fuel. Event results with the chromia-doped fuel are then compared to results and data generated in the Reference 5, Appendix A sample problem.

8.2.2.1 Conservatism of Biasing Method

An assessment of the limiting case for each of the limiting criteria presented in Table A-7 of Reference 5 is summarized in Table 8-6 for a core design containing chromia-doped fuel. For each of the CREA limiting criteria, the power level, cycle burnup, [

] are provided. The results indicate that there is ample conservatism for each criterion.

A comparison between the conservatisms of the standard fuel (Table A-7 of Reference 5) and chromia-doped fuel is presented in Table 8-7. The results of this comparison indicate that [ ]

8.2.2.2 Peak Reactor Coolant System Pressure Assessment

The maximum integrated power to the coolant for the chromia-doped fuel sample problem is the same as the sample problem using standard fuel presented in Appendix A of Reference 5. Thus, [

] The conclusions from the CREA over-pressurization analysis found in Section A.4 of Reference 5 remains applicable for over-pressurization for core designs based on chromia-doped fuel.

8.2.2.3 Sample Problem Conclusion

For a core design that includes chromia-doped fuel, the CREA results [

] A chromia-doped fuel pin limiting value comparison with the standard fuel is presented in Table 8-8. [

]

These results indicate that the integration of a chromia-doped fuel in a core design [ ] using the Reference 5 CREA methodology. Chromia-doped fuel can be introduced in core reloads without consequence to the rod ejection analysis.

Comparisons provided in this sample problem analyses show that the margin to the control rod ejection criteria for a core design with chromia-doped pellets is [ ] with respect to a core design with standard fuel. The maximum observed change in margin is [ ] as presented in Table 8-7. When implementing chromia-doped fuel into a core covered by an AREA based analysis, [ ]

Table 8-6
W 4-Loop, Measure of Conservatism for Limiting Result Cases

Table 8-7
Conservatism % Difference

[

]

Table 8-8
Rod Ejection Analysis Limiting Parameter Comparison

8.2.3 Loss of Coolant Accident

This section summarizes a sample problem analysis representative of a Westinghouse 4-loop PWR plant that illustrates the impacts of chromia-doped fuel on LOCA analyses. The sample problem calculations are similar to those presented in the LOCA methods with GALILEO (Reference 13). The results are discussed below and compared to the same sample problem with standard UO_2 fuel.

SBLOCA Sample Problem Analysis

As required by the SBLOCA EM, [ ] The results show that the general trend in PCT with break size [ ] for both sets of SBLOCA sample problems. The limiting case for both fuel types results [ ] However, SBLOCA events are not affected by this difference as PCTs occur late in the transient at a time when decay heat dictates the energy content of the fuel and initial internal energy does not affect clad temperature response. In conclusion, the results demonstrate that the SBLOCA EM changes with chromia-doped fuel have [ ] on the results of the SBLOCA evaluations and are in line with expectations for the changes introduced by the chromia-doped fuel.

RLBLOCA Sample Problem Analysis

As required by the RLBLOCA EM, [ ] Because of the nature of the statistical sampling of parameters and phenomena in the RLBLOCA analysis, [ ] The results show that the [ ] The upper tolerance limit (UTL) comparisons between the two fuels, [ ] In conclusion, the results demonstrate that the RLBLOCA EM changes with chromia-doped fuel have [ ] on the results of the LBLOCA evaluations and are in line with expectations for the changes introduced by the chromia-doped fuel.

Table 8-9
Comparison of Chromia-Doped UO_2 Fuel and Non-Doped UO_2 Fuel Analyses – LOCA W4 Sample Problem, Limiting PCT, MLO and CWO

8.3 *Impacts on Nuclear Design Requirements*

The observations made in Section 9.3 of Reference 1 remain valid as applicable to the analyses in PWRs except that the code APOLLO2-A, with the corresponding chromium cross section libraries, is now used in the analyses. No other changes to existing neutronics codes or methodologies will be required.

8.4 *Licensing Criteria Conclusion*

The general conclusions of the selected sample cases presented above are:

[

]

The CREA sample problem analyses show that the margin to the control rod ejection criteria for a core design with chromia-doped pellets is [

] The SBLOCA and RLBLOCA sample problem analyses show that the figures of merit (PCT, MLO, and CWO) are within expectation for the changes introduced by the chromia-doped fuel.

Overall, representative sample cases have been selected and analyzed; the results of the analyses are as expected given the performance of chromia-doped fuel.

9.0 REFERENCES

1. ANP-10340P-A Revision 0, “Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods,” May 2018.
2. ANP-10323P-A Revision 1, “GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” November 2020.
3. NUREG-0800, Standard Review Plan, Chapter 4, U.S. Nuclear Regulatory Commission, March 2007.
4. ANP-10339P-A Revision 0, “ARITA - ARTEMIS/RELAP Integrated Transient Analysis Methodology,” October 2023.
5. ANP-10338P-A Revision 0, “AREA™ - ARCADIA® Rod Ejection Accident,” December 2017.
6. ANP-10297P-A Revision 0, Supplement 1PA, Revision 1, “The ARCADIA Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” December 2020.
7. ANP-10297P-A, Revision 0, “The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” February 2013.
8. EMF-2328P-A, Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” March 2001.
9. EMF-2328P-A, Revision 0, Supplement 1(P)(A), Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” December 2016.
10. BAW-10240P-A, Revision 0, “Incorporation of M5 Properties in Framatome ANP Approved Methods,” May 2004.
11. EMF-2103P-A, Revision 3, “Realistic Large Break LOCA Methodology for Pressurized Water Reactors,” June 2016.

12. Regulatory Guide 1.203, “Transient and Accident Analysis Methods, (ADAMS Accession No ML053500170), U.S. Nuclear Regulatory Commission, December 2005.

13. ANP-10349P-A, Revision 0, “GALILEO Implementation in LOCA Methods,” November 2021.

14. BAW-10084P-A, Revision 3, “Program to Determine In-Reactor Performance of BWFC Fuel Cladding Creep Collapse,” April 1995.

15. BAW-10227P-A, Revision 2, “Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel,” January 2023.

16. Regulatory Guide 1.236, Revision 0, “Pressurized-Water Reactor Control Rod Ejection and Boiling-Water Reactor Control Rod Drop Accidents,” (ADAMS Accession No ML20055F490), U.S. Nuclear Regulatory Commission, June 2020.

17. Regulatory Guide 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors,” (ADAMS Accession No ML003716792), U.S. Nuclear Regulatory Commission, July 2000.

18. Regulatory Guide 1.195, “Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors,” (ADAMS Accession No ML031490640), U.S. Nuclear Regulatory Commission, May 2003.

Correspondence

framatome

June 28, 2021
NRC:21:024

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Request for Review and Approval of ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods"

Framatome Inc. (Framatome) requests the NRC's review and approval of the topical report ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods" for referencing in licensing actions. The enclosed topical report provides a justification for implementation of chromia-doped fuel modeling in Framatome PWR methodologies.

NRC's approval of this supplement supports Framatome's Enhanced Accident Tolerant Fuel (EATF) Program's near term solution for PWRs. NRC's approval of chromia-doped pellets for PWRs is a prerequisite for submittal of a topical report for the combined product of chromium-coated M5$_{\text{Framatome}}$ cladding with chromia-doped pellets, planned in 2023. Therefore, Framatome requests NRC approval of this topical report by December 2022.

Framatome considers some of the material contained in Enclosure 1 to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support withholding of information from public disclosure.

There are no regulatory commitments within this letter or its enclosures.

If you have any questions related to this submittal please contact Mr. Morris Byram, Licensing Manager. He may be reached by telephone at 434-221-1082 or by e-mail at Morris.Byram@framatome.com.

Sincerely,

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: N. Otto
Project 728

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Enclosures:

1 ANP-10340P-A, Revision 0, Supplement 1, Revision 0 (PROPRIETARY)
2 ANP-10340NP-A, Revision 0, Supplement 1, Revision 0 (NON-PROPRIETARY)
3 Affidavit

From: Otto, Ngola <Ngola.Otto@nrc.gov>
Sent: Thursday, July 29, 2021 10:53 AM
To: PETERS Gary (FRA-CORP) <gary.peters@areva.com>
Cc: Morey, Dennis <Dennis.Morey@nrc.gov>; Lukes, Robert <Robert.Lukes@nrc.gov>; Beaton, Robert <Robert.Beaton@nrc.gov>; BYRAM Morris (FRA-CORP) <morris.byram@areva.com>; Panicker, Mathew <Mathew.Panicker@nrc.gov>
Subject: Acceptance for Review of the Framatome TR, ANP-10340P, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods" EPID L-2021-TOP-0015; Docket No. 99902041

Mr. Gary Peters, Director
Licensing and Regulatory Affairs
Framatome, Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: ACCEPTANCE FOR REVIEW OF THE FRAMATOME INC. TOPICAL REPORT ANP-10340P, REVISION 0, SUPPLEMENT 1, "INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS" (EPID: L-2021-TOP-0015)

Dear Mr. Peters:

By letter dated June 28, 2021 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML21187A202), Framatome, Inc. (Framatome) submitted for review and approval, Topical Report (TR), ANP-10340P, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome Pressurized Water Reactor (PWR) Methods." Framatome stated in part that TR, ANP-10340P, Rev. 0, Supplement 1 provides a justification for implementation of chromia-doped fuel modeling in Framatome PWR methodologies and supports Framatome's Enhanced Accident Tolerant Fuel (EATF) Program's near term solution for PWRs. Framatome is also requesting an approval of ANP-10340, Supplement 1 by December 2022. The NRC staff have found that the material presented is sufficient to begin our review. The NRC staff plan to issue requests for additional information by December 17, 2021, and draft safety evaluation by June 21, 2022.

This schedule information takes into consideration the NRC's current review priorities and available technical resources and may be subject to change. If modifications to these dates are deemed necessary, we will provide appropriate updates to this information. The NRC staff estimates that the review will require approximately 900 staff-hours including project management. The review schedule milestones and estimated review costs were discussed and agreed upon between Morris Byram and the NRC staff on July 29, 2021. This email will be placed in ADAMS and made Official Agency Records and declared public. Section 170.21 of Title 10 of the *Code of Federal Regulations* requires that topical reports are subject to fees based on the full cost of the review. You did not request a fee waiver; therefore, NRC staff-hours will be billed accordingly.

If you have any questions or require any additional information, please feel free to contact me at (301) 415-6695 or by email.

Sincerely,

Ngola Otto
Project Manager, Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation
US Nuclear Regulatory Commission
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 16, 2021

Mr. Gary Peters, Director
Licensing and Regulatory Affairs
Framatome, Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING FRAMATOME TOPICAL REPORT, ANP-10340P, REVISION 0, SUPPLEMENT 1, REVISION 0, “INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS” (EPID L-2021-TOP-0015)

Dear Mr. Peters:

By letter dated June 28, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML21187A198), Framatome Inc. (Framatome) submitted to the U.S. Nuclear Regulatory Commission (NRC), Topical Report (TR) ANP-10340P, Revision 0, Supplement 1, Revision 0, “Incorporation of Chromia-Doped Fuel Properties in Framatome [Pressurized Water Reactor] PWR Methods,” (ADAMS Accession No. ML21187A197) for review and approval. The NRC staff has reviewed the proposed TR and determined that additional information is needed to complete the review. Enclosed is the NRC staff’s request for additional information (RAI) questions.

If you have any questions, please contact me at 301-415-6695 or by e-mail to Ngola.Otto@nrc.gov.

Sincerely,

/RA/

Ngola Otto, Project Manager
Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 99902041
Project No. 728

Enclosure:
RAI Questions (Proprietary)

NOTICE: Enclosure transmitted herewith contains proprietary information. When separated from Enclosure, this transmittal document is decontrolled.

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING FRAMATOME TOPICAL REPORT, ANP-10340P, REVISION 0, SUPPLEMENT 1, REVISION 0, "INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS" (EPID L-2021-TOP-0015) DATED DECEMBER 16, 2021

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ML21349A902 (Letter)
ML21349A903 (RAI Questions - Proprietary)

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REQUESTS FOR ADDITIONAL INFORMATION

FRAMATOME TOPICAL REPORT ANP-10340P-A, REVISION 0, SUPPLEMENT 1, REVISION 0, "INCORPORATION OF CHROMIA-DOPED FUEL PROPERTIES IN FRAMATOME PWR METHODS"

PROJECT NO. 99902041

EPID L-2021-TOP-0015

1.0 INTRODUCTION

By letter dated June 28, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21187A198), Framatome Inc. (Framatome) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval Topical Report (TR) ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods," June 2021 (ADAMS Accession No.ML21187A197). The TR is a supplement to the base approved TR for the incorporation of chromia-doped fuel in Framatome approved methods, which dealt only with boiling water reactor (BWR) methodologies. This supplement documents the effects of the use of chromia-doped fuel and its implementation in Framatome pressurized water reactor (PWR) methodologies.

During this review, a virtual regulatory audit for understanding was conducted on November 18, 2021, and December 7, 2021 (ADAMS Package Accession No. ML21302A117). The NRC staff requests for additional information from the review of ANP-10340P are provided below.

2.0 REGULATORY BASIS

The NRC staff used the guidance in Standard Review Plan (SRP), NUREG-0800, Section 4.2, "Fuel System Design," for the review of ANP-10340P-A, Revision 0, Supplement 1, Revision 0. SRP Section 4.2 acceptance criteria are based on meeting the requirements of General Design Criteria (GDC) 10 of Appendix A of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Reactor Design." GDC 10, Reactor design, states:

> The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

a. The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs),
b. Fuel system damage is never so severe as to prevent control rod insertion when it is required,

c. The number of fuel rod failures is not underestimated for postulated accidents, and
d. Coolability is always maintained.

In addition, the following paragraphs of 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," (b) require in part that:

(1) "Peak cladding temperature." The calculated maximum fuel element cladding temperature shall not exceed 2200°F [degrees Fahrenheit].
(2) "Maximum cladding oxidation." The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.
(3) "Maximum hydrogen generation." The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.
(4) "Coolable geometry." Calculated changes in core geometry shall be such that the core remains amenable to cooling.

3.0 REQUEST FOR ADDITIONAL INFORMATION

1) 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 [[
   ]]

2) 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.

3) 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.

4) 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.

5) 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.

6) 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.

7) 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.

framatome

April 11, 2022
NRC:22:007

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Response to Request for Additional Information Regarding ANP-10340, Revision 0, Supplement 1P, Revision 0 "Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods"

Framatome Inc. (Framatome) requested the NRC's review and approval of the topical report ANP-10340P-A, Revision 0, Supplement 1, Revision 0, "Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods" in Reference 1. The NRC provided a Request for Additional Information (RAI) in Reference 2. This letter submits the response to the RAI questions.

Framatome considers some of the material contained in the enclosure to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the RAI response are provided.

There are no commitments within this letter or its enclosures.

If you have any questions related to this information please contact Mr. Morris Byram, Licensing Manager, Licensing & Regulatory Affairs, by telephone at (434) 221-1082, or by e-mail at Morris.Byram@framatome.com.

Sincerely,

Gary Peters

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: N. Otto
Project 728

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References:

Ref. 1: Letter, Gary Peters (Framatome Inc.) to Document Control Desk (NRC), “Request for Review and Approval of ANP-10340P-A, Revision 0, Supplement 1, Revision 0, ‘Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods’,” NRC:21:024, June 28, 2021.

Ref. 2: Letter, Ngola Otto (NRC) to Gary Peters (Framatome Inc.), “Request for Additional Information Regarding Framatome Topical Report, ANP-10340P, Revision 0, Supplement 1, Revision 0, ‘Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods’ (EPID L-2021-TOP-0015),” December 16, 2021, ML21349A902.

Attachments:

1. Proprietary report (ANP-10340P-A, Revision 0, Supplement 1, Revision 0, Q1P, Revision 0)
2. Non-proprietary report (ANP-10340P-A, Revision 0, Supplement 1, Revision 0, Q1NP, Revision 0)
3. Affidavit for Withholding of Proprietary Information

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

Topical Report

ANP-10340,
Revision 0,
Supplement 1,
Revision 0,
Q1NP,
Revision 0

April 2022

Nature of Changes

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

Contents

List of Tables

List of Figures

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 $M5_{\text{Framatome}}$ 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$_{\text{Framatome}}$ 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(ΔT/ΔX); 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.

Summary of Changes

Page Number, Section Number, and/or Reference	Description of Change
Section 4.1, Page 4-2	Typo. Equation 4-1, Changed “J/kg” to “J/(kg·K)”.
Section 4.1, Page 4-2	Typo. Equation 4-1, Changed “W/mK” to “W/(m·K)”.
Section 5.1.2, Page 5-4	Typo. Changed “SILOE” to “OSIRIS”.
Section 9.0 (References), Reference 1	Typo. Changed “ANP-10340-PA” to “ANP-10340P-A”
Section 9.0 (References), Reference 4	Updated “ANP-10339P, Revision 0, August 2018” to current approval status: “ANP-10339P-A, Revision 0”. Reference date was updated with new approval date.
Section 9.0 (References), Reference 13	Updated “ANP-10349P, Revision 0, October 2020” to current approval status: “ANP-10349P-A, Revision 0”. Reference date was updated with new approval date.
Section 9.0 (References), Reference 15	Updated “BAW-10227P, Revision 2, December 2019” to current approval status: “BAW-10227P-A, Revision 2”. Reference date was updated to correspond with new approval date.

Summary of Changes – Marked-up Pages

Section 6.0 of Reference 1 describes the validation and verification (i.e., qualification) database that is required in order to qualify a fuel performance code for chromia-doped applications. Updates after the approval of Reference 1 are included in Section 4.4.

Section 10.0 of Reference 1 contains the operating experience with chromia-doped fuel in power reactors. This section also describes the comprehensive power ramp test program that is the basis for the quantification of the PCI performance improvement with chromia-doped fuel. This section applies to both BWR and PWR application and no update is necessary.

Sections 4.0, 5.0, 6.0 and 10.0 of Reference 1 are generally valid for both BWR and PWR applications. The following sub-sections describe minor changes due to the BWR and PWR fuel performance code differences and the addition of more measurement results.

4.1 *Material Properties - Thermal Conductivity*

Chromia-doped fuel thermal diffusivity measurement campaigns and database are described in Section 4.5 of Reference 1. After thermal diffusivity values are obtained using the laser flash technique, the thermal conductivity is calculated as a function of diffusivity, density, and specific heat as shown in Equation 4-1.

$$k(T) = \alpha(T).\rho(T).c_p(T) \tag{4-1}$$

where:

$k(T)$	-	thermal conductivity	[W/(m·K)]
$\alpha(T)$	-	diffusivity	[m^2/s]
$\rho(T)$	-	density	[kg/m^3]
$c_p(T)$	-	specific heat	[J/(kg·K)]
T	-	temperature	[K]

This was confirmed by the benchmarking of the REMORA2 test in which the pellet centerline temperature was measured online by a central thermocouple that was inserted in the drilled section of the refabricated rodlet. The rodlet was irradiated in the OSIRIS~~SILOE~~ test reactor after the father rod achieved a [

] in a power reactor.

Figure 5-3 compares calculated and measured temperatures of the REMORA2 tests and demonstrates good agreement over the whole range of test powers. [

], as shown in Figure 4-2 of Reference 2.

5.1.3 Validation of GALILEO Fuel Thermal Conductivity Uncertainty

The applicability of the standard fuel thermal conductivity uncertainty on the chromia-doped fuel is confirmed by using the same approach as described in Section 5.4.5 of Reference 2. As shown in Figure 5-4, [

] Measurements of the fuel centerline temperature with [ ] in the REMORA2 test are considered in the assessment.

5.2 *GALILEO Fission Gas Release Model for Chromia-doped Fuel*

Chromia-doped fuel is similar to standard fuel with an enlarged grain microstructure and the same phenomenological FGR model is applicable to both fuel types. [

]

9.0 REFERENCES

1. ANP-10340~~-~~P-A Revision 0, “Incorporation of Chromia-Doped Fuel Properties in AREVA Approved Methods,” May 2018.
2. ANP-10323P-A Revision 1, “GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” November 2020.
3. NUREG-0800, Standard Review Plan, Chapter 4, U.S. Nuclear Regulatory Commission, March 2007.
4. ANP-10339P-A Revision 0, “ARITA - ARTEMIS/RELAP Integrated Transient Analysis Methodology,” October 2023~~August 2018~~.
5. ANP-10338P-A Revision 0, “AREA™ - ARCADIA® Rod Ejection Accident,” December 2017.
6. ANP-10297P-A Revision 0, Supplement 1PA, Revision 1, “The ARCADIA Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” December 2020.
7. ANP-10297P-A, Revision 0, “The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” February 2013.
8. EMF-2328P-A, Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” March 2001.
9. EMF-2328P-A, Revision 0, Supplement 1(P)(A), Revision 0, “PWR Small Break LOCA Evaluation Model, S-RELAP5 Based,” December 2016.
10. BAW-10240P-A, Revision 0, “Incorporation of M5 Properties in Framatome ANP Approved Methods,” May 2004.
11. EMF-2103P-A, Revision 3, “Realistic Large Break LOCA Methodology for Pressurized Water Reactors,” June 2016.

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AFFIDAVIT

1. My name is Morris Byram. I am Product Manager, Licensing & Regulatory Affairs for Framatome Inc. (Framatome) and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the topical report ANP-10340, Revision 0, Supplement 1P-A, Revision 0, entitled "Incorporation of Chromia-doped Fuel Properties in Framatome PWR Methods," and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

(a) The information reveals details of Framatome’s research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.

(e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in this Document is considered proprietary for the reasons set forth in paragraph 6(c) and 6(d) above.

7. In accordance with Framatome’s policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: (1/11/2024)

BYRAM Morris
Digitally signed by BYRAM Morris
Date: 2024.01.11 10:04:59 -08'00'

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