

ENCLOSURE 2:

Comments on Draft Safety Evaluation for ANP-10323, Revision 0 Supplement 1P, Revision 0, "One GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors."

(NON-PROPRIETARY)

U. S. NUCLEAR REGULATORY COMMISSION
DRAFT SAFETY EVALUATION
FOR FRAMATOME INC. TOPICAL REPORT
ANP-10323 REVISION 1, SUPPLEMENT 1P, REVISION 0,
“ONE GALILEO FUEL ROD THERMAL-MECHANICAL METHODOLOGY FOR
PRESSURIZED WATER REACTORS”
DOCKET NO. 99902041
EPID: L-2025-TOP-0015

1.0 INTRODUCTION

By application dated April 1, 2025 (Ref. 1), as supplemented by letter dated January 12, 2026 (Ref. 2), Framatome Inc., submitted Topical Report (TR) ANP-10323, Revision 1, Supplement 1P, Revision 0, “One GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” for U.S. Nuclear Regulatory Commission (NRC) staff review and approval. This TR is a supplement to the NRC approved ANP-10323P-A, Revision 1, “GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors (GALILEO)” (Ref. 3). GALILEO is a Framatome fuel thermal-mechanical performance code. As outlined in ANP-10323, Revision 1, Supplement 1P, Revision 0 (also referred to as the One GALILEO TR, or the TR), Framatome proposes to update the following four GALILEO application methodologies to [[

]] in ANP-10323P-A, Revision 1:

1. Fuel rod internal pressure
2. Cladding oxide thickness
3. Fuel centerline melt limits
4. Transient cladding strain limits

While the One GALILEO TR changes the application methodology for the four analyses, the TR does not change the GALILEO code models described in ANP-10323P-A, Revision 1 (Ref. 3).

2.0 REGULATORY EVALUATION

Regulatory guidance for the review of fuel system materials and designs are intended to ensure adherence to Title 10 of the Code of Federal Regulations (10 CFR) Part 50, Appendix A, General Design Criteria (GDC)-10, “Reactor Design,” GDC-27, “Combined Reactivity Control Systems Capability,” GDC-28, “Reactivity Limits,” and GDC-35, “Emergency Core Cooling.” Additional guidance is provided in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants” (SRP), Section 4.2, “Fuel System Design” (Ref. 4).

Enclosure

In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide assurance that: (1) the fuel system is not damaged as a result of normal operation and AOOs, (2) fuel system damage is never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for postulated accidents, and (4) coolability is always maintained. A “not damaged” fuel system is defined as fuel rods that do not fail, fuel system dimensions that remain within operational tolerances, and functional capabilities that are not reduced below those assumed in the safety analysis. Objective 1 is consistent with GDC-10, and the design limits that accomplish this are called specified acceptable fuel design limits. “Fuel rod failure” means that the fuel rod leaks, and the first fission product barrier (the cladding) has therefore, been breached. However, the NRC staff recognizes that it is not possible to avoid all fuel rod failures during normal operation, and reactor coolant cleanup systems are installed to deal with a small number of leaking rods.

3.0 TECHNICAL EVALUATION

While the One GALILEO TR changes the application methodology for the analysis of fuel rod internal pressure, cladding oxide thickness, fuel centerline melt limits, and transient cladding strain limits, the TR does not change the GALILEO code models described in ANP-10323P-A, Revision 1 (Ref. 3). As such, the NRC staff find that the limitations and conditions described in ANP-10323P-A Revision 1 remain applicable. The NRC staff thus includes the following limitation and condition for the TR:

Limitations and conditions and the code range of applicability described in ANP-10323P-A Revision 1 shall be met, other than the fuel enrichment applicability limit, which was extended to **[[** uranium-235 in ANP-10353P-A, Increased Enrichment for PWRs” (Ref. 11).

3.1 Rod Internal Pressure and Cladding Oxide Thickness

In Table 4-1, “Rod Internal Pressure and Corrosion Methodology and Technical Basis,” of the TR, Framatome outlines the rod internal pressure (RIP) and the cladding oxide thickness methodologies. The normal operation RIP limit is defined in ANP-10358P, “Increased Burnup for PWRs” (Ref. 5). The steps in the RIP and corrosion methodologies are summarized as follows:

[[

]]

Aspects of the methodology above are evaluated in the subsequent subsections.

3.1.1 Rod Power Histories

In Section 4.0, "Rod Internal Pressure and Cladding Oxide Thickness," of the TR, Framatome states that [[

]], as discussed in the response to request for additional information (RAI) 1. The [[]] rods analyzed for a 3-cycle core are as follows:

- [[

]]

For a 2-cycle core, the [[]] rods analyzed would include all of the above except for the rods designated above with N-2 since there would be no third cycle rods.

The NRC staff finds [[

]]

3.1.2 Power Uncertainty Application

The power uncertainties are described in [[]] above in Section 3.1 of this SE and discussed in Section 4.1, "Power Uncertainty Application," of the TR. The power uncertainties include the reactor power measurement uncertainty and the local power uncertainty. The core power uncertainty primarily comes from the uncertainty in feedwater flow instrument measurements. 2 percent is the standard for core power uncertainty and is expected to be conservative based on old feedwater flow instrumentation (e.g., see *10 CFR* Part 50, Appendix K Section I.A., which specifies a 1.02 factor on power). As feedwater flow instrumentation has gotten better, licensees have been able to reduce their core power uncertainties. If 2 percent is used it would be conservative, but for a plant that upgraded their feedwater flow meters, they may use an uncertainty that is representative of their specific instrument. In that case, it would be a representative uncertainty.

Consistent with ANP-10323P-A, Revision 1 (Ref. 3), the reactor power measurement uncertainty is **[[**
]]. The NRC staff finds this acceptable because the reactor power measurement uncertainty is conservative or representative of the plant feedwater flow instrumentation error and is consistent with that approved in ANP-10323P-A, Revision 1.

The local power uncertainty consists of the **[[**

]] The NRC staff finds the **[[**
]] treatment to be acceptable because it reasonably captures the 95/95 upper bound uncertainty.

Regarding the **[[**

]]

Similarly, for the oxide thickness, **[[**
]]The NRC staff conducted sensitivity studies with the Fuel Analysis under Steady-state and Transients (FAST) fuel performance code (Ref. 8), to verify **[[**
]] The NRC staff applied uncertainties similar to those in Reference 3. **[[**

]]

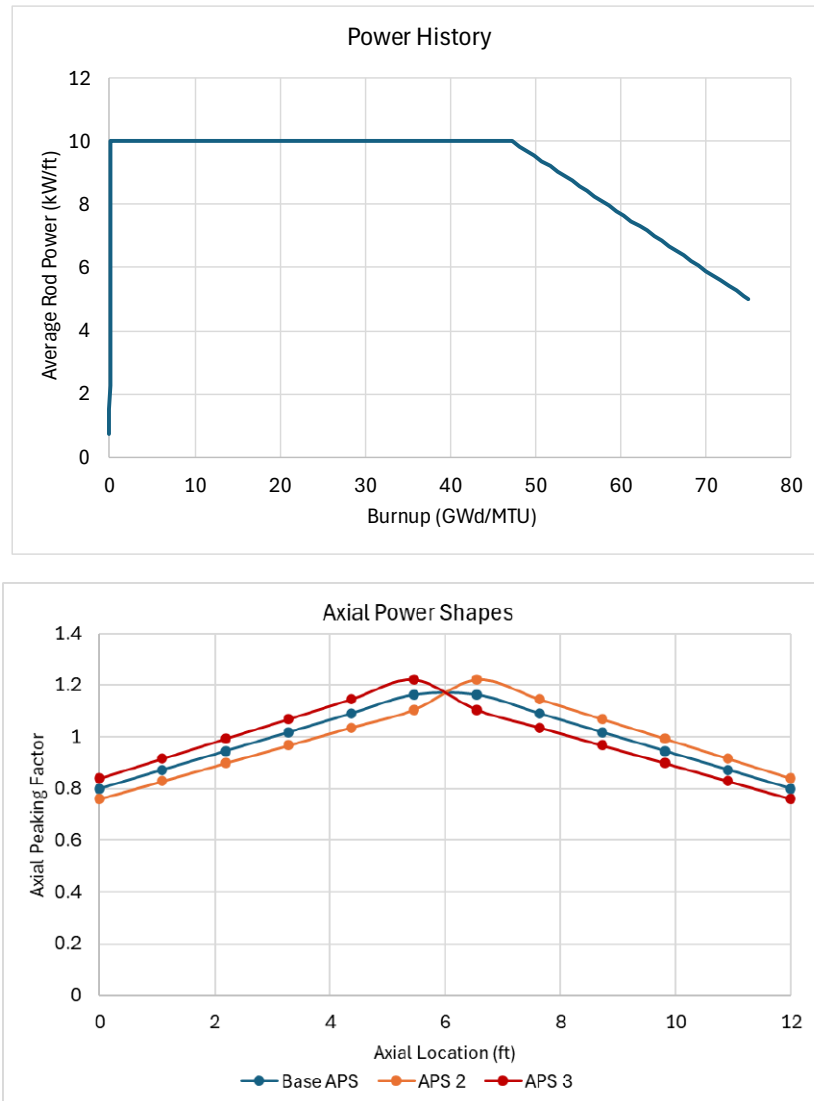


Figure 1: Power history and axial power shapes assumed for NRC sensitivity study

The RIP and oxide thickness results are presented as a function of burnup for the 3 FAST runs with the 3 APSs in the figures below.

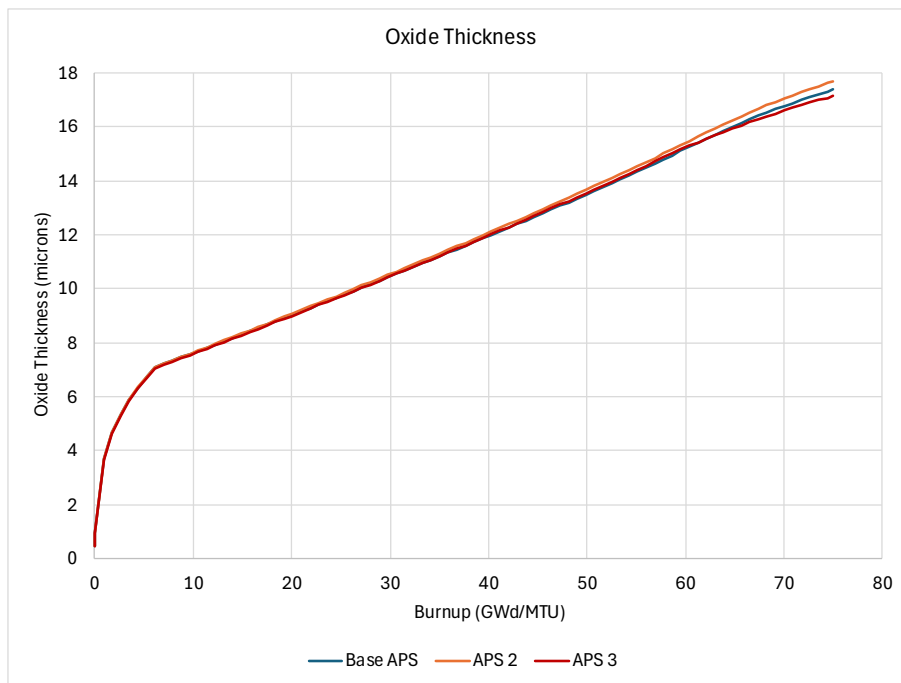
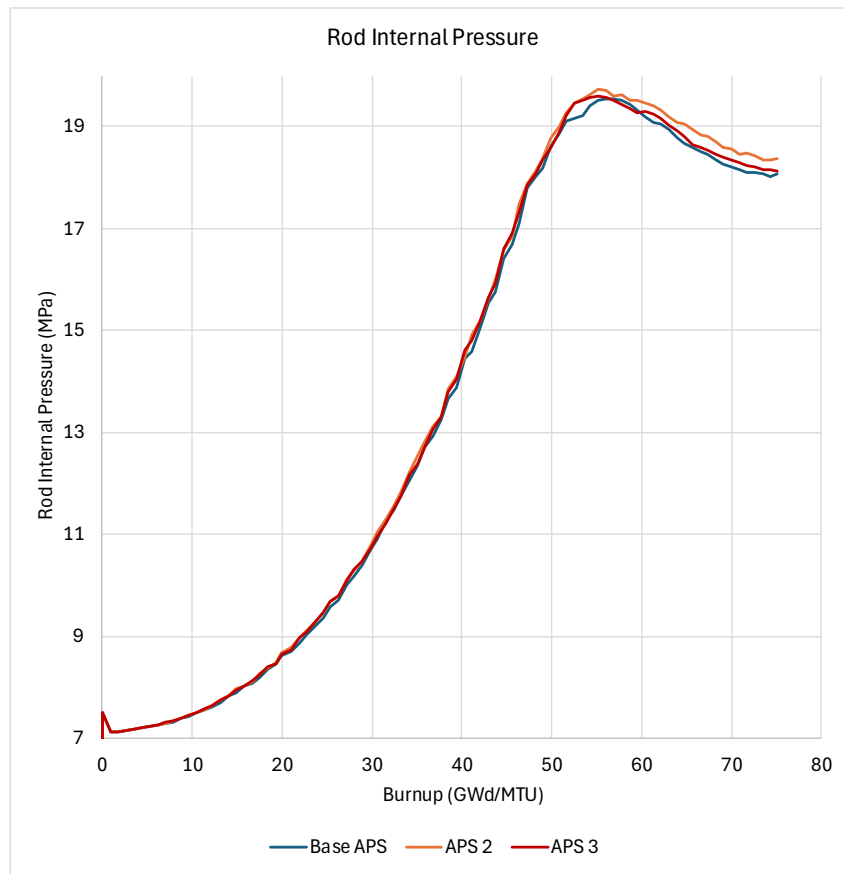


Figure 2: NRC APS sensitivity study results as function of burnup for RIP (top) and oxide thickness (bottom)

These results are presented in tabular form below:

Parameter	Base APS	APS 2		APS 3	
	Result	Result	Difference Relative to Base Result	Result	Difference Relative to Base Result
Peak RIP (Mega Pascal (MPa))	19.544	19.726	0.9 percent	19.584	0.2 percent
EOL Oxide Thickness (microns)	17.393	17.698	1.8 percent	17.148	-1.4 percent

The NRC sensitivity study results above show that for the case that the NRC staff analyzed, had a negligible effect on RIP and oxide thickness, helping to confirm Framatome’s assertion and sensitivity study. The NRC staff notes that for some other FAST cases not reported above with more top peaked APSs and/or larger uncertainties, a larger impact was observed on RIP and oxide thickness. Despite this, the NRC finds Framatome’s treatment of to be acceptable because the uncertainties of ARCADIA (Ref. 6) are expected to be in line with the sensitivity study, and a top peaked APS is not expected to occur for the entirety of rod’s residence time in the reactor as the NRC assumed in the simple FAST exploratory runs. Therefore, the NRC staff finds the treatment to be acceptable because it is not expected to have a large impact on RIP and oxide thickness.

As stated in Section 4.1.3, “Total Power Uncertainty Allowance,” of the TR, the total power uncertainty is calculated using The NRC staff finds this to be acceptable because

3.1.3 Upper Bound Fission Gas Release Model Combined with Power Uncertainties

In Section 4.2, “Upper Bound FGR Model Combined with Power Uncertainties,” of the TR Framatome states that One GALILEO will use the upper bound value of the FGR model via the code variable ADIFF123. Figure 4-2, “C-M RIP with ADIFF123 and Power Uncertainty,” of the TR shows that the calculated minus measured results where both the upper bound (UB) FGR ADIFF123 is used and the power uncertainty is applied is conservative. Therefore, the NRC staff finds the use of UB FGR ADIFF123 values and the power uncertainty acceptable.

3.1.4 Fuel Rod Design Parameters

In Section 4.3, “Fuel Rod Design Parameters,” of the TR, Framatome stated that The NRC staff performed a sensitivity study using FAST to examine the effect of

[[

NRC staff finds the [[]] Based on the NRC's sensitivity study, the
because [[]] to be acceptable

]]

Regarding the use of [[

]]
Framatome performed a sensitivity study in TR Section 4.3, "Fuel Rod Design Parameters," to demonstrate that the [[]] would not cause the One GALILEO results to be nonconservative. Specifically, the sensitivity study examined the effect of [[

]] on RIP. These parameters were chosen due to their importance on RIP. The RIP was calculated by [[]] The result of the sensitivity study is presented in Table 4-3, "Comparison of RIP (MPa): Applying Individual Uncertainty and One GALILEO," of the TR and compared to the One GALILEO application example. One GALILEO was shown to produce a [[]] in the sensitivity study. The NRC staff finds the use of [[]] to be acceptable for the One GALILEO methodology because Framatome demonstrated that the method will produce equivalent or higher results for RIP than the [[]] on RIP.

3.1.5 Departure of Nucleate Boiling Propagation

In Section 4.5, "DNB Propagation," of the TR, Framatome discusses Departure of Nucleate Boiling (DNB) propagation. Framatome referenced that their DNB propagation methodology is described in Section 4.5 of ANP-10339P-A, Revision 0, "ARITA – ARTEMIS/RELAP Integrated Transient Analysis Methodology" (Ref. 14). This DNB propagation methodology assumes that [[

]] This method is [[]] and is separate from the GALILEO and One GALILEO methodology. Since Framatome's DNB propagation methodology is independent of One GALILEO and has been previously reviewed and approved, the NRC staff finds the treatment of DNB propagation to be acceptable. If different DNB propagation methods are employed, the NRC staff will review them in a license amendment request.

3.1.6 Review of Rod Internal Pressure and Oxide Thickness Application Examples

Framatome provides RIP and oxide thickness calculation application examples in TR Section 4.4 for Framatome's Advanced Fuel Management (AFM) Westinghouse (W) 17x17, Combustion Engineering (CE) 14x14, CE 16x16, and W 17x17 fuel designs. Table 4-4, "UO₂ Rod Internal Pressure Results," of the TR compares the One GALILEO RIP results with that of the GALILEO Statistical method (Ref. 3). The results showed that One GALILEO produced results that were [[]] These examples provide

assurance that the One GALILEO RIP method overall is reasonable; thus, the NRC staff finds One GALILEO acceptable for calculating RIP.

Similarly, the One GALILEO corrosion results are provided for the application examples in TR Table 4.5, "UO₂ Rod Cladding Oxide Thickness Results." Framatome compared these oxide thickness results with those calculated with the GALILEO Statistical method in response to RAI 3 (Ref. 2), which showed that One GALILEO produced []

]] Accordingly, the NRC staff finds One GALILEO acceptable for calculating oxide thickness because it produces conservative results.

3.2 Fuel Centerline Melt

In Section 5.0, "Fuel Centerline Melt," of the TR, Framatome describes how One GALILEO will be used to calculate LHGR limits to preclude fuel centerline melting (FCM). The following subsections describe the NRC evaluation of specific aspects of the FCM method.

3.2.1 Steady State Power History and Transient Power Ramp

In Section 5.1 of the TR Framatome states that a power history []

the steady-state power history treatment to be acceptable because []]] The NRC staff finds

]]

The steady-state []

]] The NRC staff finds the treatment of transients to be acceptable in the FCM analysis because it is similar to that previously approved in the COPERNIC TR, BAW-10231P-A, Revision 1 (Ref. 9).

3.2.2 Fuel Design and Thermal-Hydraulic Conditions

In Section 5.2, “Fuel Design and Thermal-Hydraulic Conditions,” of the TR, Framatome states that [[]] will be employed in the One GALILEO fuel centerline melt analyses. This is consistent with the fuel centerline melt analysis approved in Framatome’s COPERNIC methodology (BAW-10231P-A, Revision 1, “COPERNIC Fuel Rod Design Computer Code” (Ref. 9), Section 12.3.1). Framatome stated that [[]]

[[]] The NRC staff performed a sensitivity study with FAST and confirmed that [[]] did not significantly affect the fuel temperature prediction. Similarly, in Figure 5-8, “Comparison of UO₂ FCM Limits,” FCM limits calculated with the One GALILEO method are presented for both AFM GAIA 17x17 fuel and CE 14x14 fuel, [[]] are unlikely to significantly affect the FCM limit calculation.

The NRC staff finds the use of [[]] to be acceptable because [[]] are not expected to significantly affect the LHGR to melt limits and because of the conservatism in the FCM calculation, as discussed in Section 3.2.3, “Fuel Melt Temperature and Uncertainty Application,” of this SE.

3.2.3 Fuel Melt Temperature and Uncertainty Application

In Section 5.4, “Fuel Melt Temperature,” of the TR, Framatome states that fuel melt temperature correlations are consistent with those already in the GALILEO, as expected, and thus acceptable.

In Section 5.5, “Uncertainty Application,” of the TR Framatome discusses the uncertainty factors applied in the FCM limits. There is a [[]] discussed in existing Framatome methods (e.g. ANP-10338, “AREA-ARTEMIS Rod Ejection Accident” (Ref. 10)), so the uncertainty, is therefore, acceptable. Additionally, [[]]

[[]] The conservatism in this FCM uncertainty is seen in Figure 5-4, “Comparison to Fuel Melt Experiment (UO₂),” and Figure 5-5, “Comparison to Fuel Melt Experiment (Gad),” of the TR, which compare the measured and predicted fuel melt radii for UO₂ and Gad fuel, respectively. These figures show that the GALILEO best-estimate prediction is [[]]

[[]] The NRC staff finds the fuel melt temperature uncertainties to be acceptable because Framatome demonstrated that they result in conservative fuel melt predictions.

3.2.4 Evaluation of Fuel Centerline Melt Application Examples

In Section 5.6, “Application Examples,” of the TR, Framatome performed sample FCM limit calculations for the various Framatome fuel designs. The examples show that the FCM LHGR limits decrease as a function of burnup, which the NRC staff finds is the expected trend due to burnup effects in the fuel pellet (e.g., decreasing fuel melt temperature and thermal conductivity as burnup increases).

Based on its review, the NRC staff finds the One GALILEO FCM limit calculation method to be acceptable because it conservatively accounts for uncertainties and is shown to produce conservative melt predictions when compared to experimental data.

3.3 Transient Cladding Strain

As discussed in Section 6, “Transient Cladding Strain,” of the TR, the transient cladding strain (TCS) methodology in One GALILEO uses [[

]]. The approach is designed to meet NRC SRP Section 4.2 Acceptance Criteria 1.B.vi (as discussed in TR Section 3.4), which limits uniform cladding strain to less than and equal to (\leq) 1 percent to limit fuel failures from pellet-cladding interaction (PCI) and pellet-cladding mechanical interaction (PCMI). In cases where fuel melting is more restrictive than cladding strain, the fuel melt limit governs the analysis. The key aspects of the One GALILEO TCS methodology are described in Subsections 3.3.1, “Steady State Power History and Transient Power Ramp,” 3.3.5, “Evaluation of TCS Limit Application Examples,” of this SE below.

3.3.1 Steady State Power History and Transient Power Ramp

Similar to the COPERNIC TCS methodology, the One GALILEO approach applies [[

]]. This [[]] ensures that the transient analysis conservatively considered rods that have experienced the most challenging conditions during normal operation. This methodology also includes [[

]]

Section 6.3, “Transient Power Ramp,” of the TR describes the methodology for using transient power ramps for the TCS analysis in the One GALILEO method. Consistent with the FCM limit method previously described, [[

]]

[[

]] This approach ensures that the analysis accounts for variations in axial power distribution under different initial conditions. If fuel melt occurs before the strain limit is reached, the fuel melt criterion governs, which is conservative and satisfies NRC SRP Section 4.2 for PCI, PCMI, and fuel melt.

The NRC staff finds that the One GALILEO power history selection and transient ramp assumptions used in TCS limit development are acceptable because a range of different power

histories are analyzed and several limiting transient power shapes are analyzed, which provides reasonable assurance that the limiting transient cladding strain limit is calculated.

3.3.2 Fuel Design and Thermal-Hydraulic Conditions

Consistent with the methodology applied for fuel centerline melt in TR Section 5.2, "Fuel Design and Thermal-Hydraulic Conditions," and as described in SE Section 3.2, the One GALILEO approach for TCS limits uses [[

]] Framatome justified these methodologies by stating [[

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The NRC staff finds the use of [[
]] to be acceptable because [[
]] in the fuel rod design parameters and the thermal-hydraulic conditions are not expected to significantly affect the TCS and because of the conservatism in the TCS calculation, as discussed in Sections 3.3.3, "TCS Limit," and 3.3.4, "Uncertainty Application," of this SE.

3.3.3 TCS Limit

[[

]]. For some combinations of burnup and initial power, the fuel melt limits are more restrictive than the cladding strain limits discussed in this section. When the fuel melt limits are more restrictive, the [[
]] limits are conservatively based on the LHGR melt limits instead.

The TCS equation provided in Section 6.4, "TCS Limit," of the TR [[

]] During the audit (Ref. 13), the NRC staff discussed the use of the [[

]] Framatome showed that the use of [[

]] strain uncertainty (as discussed in Section 6.4 of the TR). Furthermore, the cladding diameter will decrease initially (i.e., creep down) until it makes contact with the fuel pellet, then increases, expanding with the pellet, eventually becoming greater than the initial diameter. [[

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Therefore, the NRC staff concludes that the One GALILEO approach is acceptable for calculating TCS limits.

3.3.4 Uncertainty Application

Like the FCM method in Section 5.5, "Uncertainty Application," of the TR, the uncertainty application for the TCS limits is based on the GALILEO code prediction uncertainty. [[

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3.3.5 Evaluation of TCS Limit Application Examples

The Framatome TR, Framatome provides a walkthrough of the TCS methodology used in One GALILEO to ensure the TCS limits remain below the [[]] criterion across the licensed burnup range. Example results are given in the form of graphs provided within the TR from Figure 6-3, "AFM UO₂ TCS Limits," to Figure 6-7, "Comparison of UO₂ TCS Limits at End of Life."

The initial step in the methodology by calculating the FCM [[]] is described in Section 5.6 of the TR. [[

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Figure 6-3 through Figure 6-7 of the TR illustrates how the TCS limits [[]] Framatome explained during the August 28, 2025, audit (Ref. 13) that the different TCS limit curves in Figure 6-7 of the TR had different [[]] which accounted for some of the differences in the curves of Figure 6-7. Additionally, Framatome stated that the different fuel designs had significantly different outside cladding diameters that would account for much of the difference between curves when accounting for TCS limits at EOL between the different fuel types.

Similarly, during the audit (Ref. 13), Framatome provided [[]]. Framatome explained that

with [[

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Based on its review, the NRC staff finds the One GALILEO TCS limit method to be acceptable because it (1) analyzes a wide range of rods to ensure that the most limiting TCS limits are determined, (2) acceptably accounts for uncertainty, and (3) accounts for the relevant phenomena affecting TCS.

4.0 LIMITATIONS AND CONDITIONS

Based upon its review of ANP-10323, Revision 1, Supplement 1, Revision 0, the NRC staff imposes the following limitation and condition upon the proposed methodology to ensure acceptable implementation.

1. Limitations and conditions and the code range of applicability described in ANP-10323P-A Revision 1 shall be met, other than the fuel enrichment applicability limit, which was extended to [[]] uranium-235 in ANP-10353P-A, Increased Enrichment for PWRs” (Ref. 11).

5.0 CONCLUSION

The NRC staff completed its review of Framatome’s One GALILEO methodology for evaluating PWR fuel and cladding performance, covering four areas during normal operation and AOOs:

1. Rod internal pressure
2. Cladding oxide thickness
3. Fuel centerline melt limits
4. Transient cladding strain

The NRC staff assessed each method in detail and performed confirmatory sensitivity analyses (using the FAST fuel-performance code). The review also verified the methodology’s conservative uncertainty treatment [[]] and its use of [[]] and [[]] and therefore, finds the overall methodology acceptable. Based on the NRC staff’s evaluation, the NRC staff concludes that the One GALILEO TR is acceptable for referencing in licensing application for Framatome PWR fuel design to the extent specified and under the limitations and conditions delineated in Section 4.0 of this SE.

6.0 REFERENCES

- [1] Framatome, “ANP-10323, Revision 1, Supplement 1P, Revision 0, ‘One GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” April 2025 (ML25092A022).
- [2] Framatome, “Response to Request for Additional Information - One GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” January 2026 (ML26013A062).

- [3] Framatome, Publication of “ANP-10323P-A, Revision 1, ‘GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” December 2020 (ML21005A028).
- [4] U.S. NRC, “NUREG-0800 Standard Review Plan, Section 4.2, Revision 3, ‘Fuel System Design,” 2007 (ML070740002).
- [5] Final Safety Evaluation for Framatome, “ANP-10358P, Revision 0, “Increased Burnup for PWRs,” March 2026 (ML26050A038).
- [6] Publication of Framatome, “ANP-10297P-A, Revision 0, “The ARCADIA Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” July 2014 (ML14195A145).
- [7] Publication of Framatome, “ANP-10297P-A, Revision 0, Supplement 1, ‘The ARCADIA Reactor Analysis System for PWRs Methodology Description and Benchmarking Results,” March 2021 (ML21071A062).
- [8] Pacific Northwest National Laboratory, “PNNL-35701, FAST-1.1.1: A Computer Code for Thermal-Mechanical Nuclear Fuel Analysis under Steady-state and Transients,” 2024 (ML24177A227).
- [9] Framatome, “BAW-10231P-A, Revision 1,” ‘COPERNIC Fuel Rod Design Computer Code,” 2004 (ML042930233).
- [10] Framatome, “ANP-10338P-A, ‘AREA-ARTEMIS Rod Ejection Accident,” 2018 (ML18059A753).
- [11] Framatome, “ANP-10353P, ‘Increased Enrichment for PWRs,” 2023 (ML23139A272).
- [12] Framatome, “ANP-10340P-A, Revision 0, Supplement 1P-A, Revision 0, ‘Incorporation of Chromia-Doped Fuel Properties in Framatome PWR Methods,” 2024 (ML24011A252).
- [13] U.S. NRC, “August 28, 2025, Regulatory Audit Report for Framatome Inc. Topical Report ANP-10323, Revision 1, Supplement 1P, Revision 0, “One GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors,” 2025 (ML25324A022).
- [14] Framatome, Publication of “ANP-10339P-A, Revision 0, ‘ARITA – ARTEMIS/RELAP Integrated Transient Analysis Methodology,” 2023 (ML24026A139).

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Date: April 6, 2026