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Response to Request for Additional Information – ANP-10323P

ANP-10323, Rev. 1, Q4NP
Revision 0

GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors

September 2019

Nature of Changes

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

Contents

List of Tables

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Nomenclature

Acronym	**Definition**
HPUF	Hydrogen Pick-Up Fraction
LHGR	Linear Heat Generation Rate
MOX	Mixed Oxide
NRC	U.S. Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RAI	Request for Additional Information
RXA	Recrystallized Annealed
SAFDLs	Specified Acceptable Fuel Design Limits
SRA	Stress Relief Annealed
UO_2	Uranium Dioxide
V&V	Verification and Validation

1.0 RAI-1

RAI-1 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

2.0 RAI-2

RAI-2 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

3.0 RAI-3

RAI-3 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

4.0 RAI-4

RAI-4 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

5.0 RAI-5

RAI-5 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

6.0 RAI-6

RAI-6 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

7.0 RAI-7

RAI-7 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

8.0 RAI-8

RAI-8 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

9.0 RAI-9

RAI-9 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

10.0 RAI-10

RAI-10 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

11.0 RAI-11

RAI-11 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

12.0 RAI-12

RAI-12 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

13.0 RAI-13

RAI-13 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

14.0 RAI-14

RAI-14 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

15.0 RAI-15

RAI-15 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

16.0 RAI-16

RAI-16 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

17.0 RAI-17

RAI-17 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

18.0 RAI-18

RAI-18 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

19.0 RAI-19

RAI-19 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

20.0 RAI-20

RAI-20 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

21.0 RAI-21

RAI-21 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

22.0 RAI-22

RAI-22 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

23.0 RAI-23

RAI-23 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

24.0 RAI-24

RAI-24 was addressed in the following report:

ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.

25.0 RAI-25

RAI-25 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

26.0 RAI-26

RAI-26 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

27.0 RAI-27

RAI-27 was addressed in the following report:

ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.

28.0 RAI-28

RAI-28 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

29.0 RAI-29

RAI-29 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

30.0 RAI-30

30.1 *Request*

The following are related to the modeling and calibration/verification of the code to low stress cladding creep data for normal operation.

a. Please identify the burnup levels at which the gap typically closes for different PWR rod designs with Zr-4 SRA and M5 RXA cladding types. How is it determined that the gap is open such that the rod may be used to assess the creep model? Provide the data used to determine the open gap assumption for each cladding type and design. Identify those commercial fuel rods used for creep comparisons where the gap is assumed to be open identifying the design, burnup and cladding type. Also identify those data that are creep specimens (no active fuel present).

b. Please provide more information on the number of measurements per rod for the data that were used in the clad diameter change model validation summarized in Figures 4-43, 4-44, 4-49, 4-52, and 4-53 of the methodology document.

c. Please provide P-M versus axial position and P-M versus burnup for the cladding diameter change comparisons in Figures 4-43, 4-44, 4-49, 4-52, and 4-53 of the methodology document.

d. It appears that the [ ] Please provide a comparison of the fast flux (greater than 1 MeV) of this calibration Zr-4 creep data to the average fast flux in a commercial PWR. Please justify the applicability of this data for application to commercial PWRs.

e. Is the Zr-4 model applicable to both low tin and standard tin Zr-4 cladding? If so, please justify applicability because tin is known to have a significant impact on zirconium alloy cladding creep. If not what cladding type (low tin or standard) creep data were used to verify the Zr-4 creep model?

f. Figure 10-47 of the V&V document and Figure 5-11 of the methodology document appear to demonstrate that the GALILEO M5 creep model [ ] Are these data included in the uncertainty for M5 creep? If not, why not?

g. The uncertainty for M5 cladding creep is [

]

h. Please provide plots of P-M and ratio of P/M in-reactor creepdown versus stress (only in-reactor creep specimens unless stress was relatively constant for a commercial rod), versus fast flux, versus fast fluence, and versus temperature for each cladding type. For these plots distinguish between commercial fuel rods and in-reactor creep specimens. Provide the same but separate plots for those data with a positive stress for each alloy. Please provide the one sided upper and lower 95/95 bounds on these same plots for both compressive and tensile (positive) stress creep data.

i. Please provide plots of P-M and ratio of P/M steady-state (secondary) creep rate versus stress, versus fast flux, and versus temperature for in-reactor (commercial rods and creep specimens) data for each alloy. Identify those creep specimen data with a positive stress.

j. Please provide one of the following for the Zr-4 SRA creep data from IFA-585.1, IFA-585.4 (HWR-413 Figures 6 and 7, HWR-532 Figure 8) and IFA-699, and the M5 creep data from IFA-699 (HWR-882 Figure 13(a) and 13(b)).

    i. Comparison of the measured cladding creep strains in the GALILEO V&V database with the measured cladding creep strains in the experiments or

    ii. GALILEO predictions of creep strains for these experiments plotted as a function of full power hours.

k. Creep specimens are usually much better characterized (in terms of both operation and fabrication) than commercial fuel rods, therefore, having a much lower uncertainty than creep data from the latter. The use of the creep specimens for determining the best estimate coefficients appears to be justified but the uncertainties from these data appear to not be prototypical of commercial fuel application. Please justify the use of the creep specimens in determining the uncertainties in creep for commercial fuel applications.

l. Please provide the distributions for each cladding type in terms of P-M and ratio of P/M excluding any closed gap data (similar to Figures 5-8, 5-11, 5-14, and 5-17 of the methodology document) and include any new data comparisons requested (identifying this data by different colors). Identify those rods with a positive stress (strain). Please provide the one sided upper and lower 95/95 bounds on these distribution plots.

30.2 *Response*

In the development of the response to RAI 30, [ ]

[ ]

a. The pellet-to-clad gap in the PWR rod design for both Zr-4 and M5 cladding typically starts to close around a rod burnup of [ ] GWd/tM. The gap is considered open if there is no pellet-cladding contact and [ ] These criteria ensure free creep of the cladding due to external pressure effects. For most cases, [ ]

   In the calibration dataset (both Zr-4 and M5), [ ]

Table 30-1 presents the commercial fuel rods used for creep comparison (rods used in the calibration database) with their final burnup and design.

Table 30-1: Commercial Rods (Zr-4 and M5) with Expected Open Gap

b. The request for additional information on Figures 4-43, 4-44, 4-49, 4-52 and 4-53 in Revision 0 of the methodology document (Reference 1) is partially obsolete. The MOX fuel and Zircaloy-2 cladding alloy are no longer part of the scope in Revision 1 of the methodology document (Reference 2).

   Table 30-2 presents the figure correspondence between the two revisions of the methodology document. Table 30-3 presents the number of measurements for each rod used in Figure 4-32 in Revision 1 of the methodology document (Reference 2). Table 30-4 presents the number of measurements for each rod of each dataset used in Figure 4-37 in Revision 1 of the methodology document (Reference 2).

Table 30-2: Figure Number Equivalence between Revision 0 and 1 of the Methodology Document

[ ]

Table 30-3: Rod List for Figure 4-32 in Revision 1 of the Methodology Document with Number of Measurements

[ ]

Table 30-4: Rod List for Figure 4-37 in Revision 1 of the Methodology Document with Number of Measurements

[ ]

c. As in RAI 30.b, the request for additional information on Figures 4-43, 4-44, 4-49, 4-52 and 4-53 in Revision 0 of the methodology document (Reference 1) is partially obsolete. The MOX fuel and Zircaloy-2 cladding alloy are no longer part of the scope in Revision 1 of the methodology document (see Table 30-2 for details).

   Figures 30-1 and 30-2 present the P-M versus axial position and P-M versus burnup for the Zr-4 cladding with the rod set corresponding to Figure 4-32 of the methodology document (Reference 2, see Table 30-3 for details). Figures 30-3 and 30-4 present the P-M versus axial position and P-M versus burnup for the M5 cladding with the rod set corresponding to Figure 4-37 of the methodology document (Reference 2, see Table 30-4 for details).

Figure 30-1: Predicted minus Measured Rod Diameter vs Axial Position UO2/Zircaloy-4

Figure 30-2: Predicted minus Measured Rod Diameter vs Burnup UO2/Zircaloy-4

[ ]

Figure 30-3: Predicted minus Measured Rod Diameter vs Axial Position M5 Cladding

[ ]

Figure 30-4: Predicted minus Measured Rod Diameter vs Burnup M5 Cladding

[ ]

d. The fast flux levels (average between two measurements) of the creep specimens of the calibration database ranged from [ ] The average fast flux levels of the commercial rods of the calibration database ranged from [ ] For these rods, only one fluence measurement was taken. Therefore, an average fast flux level is provided for each fluence measurement. The calibration database is comprised of both creep specimens and PWR rods. There are [ ] creep specimens with measurements at various time steps and [ ] PWR commercial rods with measurements [ ]

The fast flux levels (average between two measurements) of the validation database ranged from [ ] The analysis of test data with fast neutron flux as low as [ ] did not show any significant drift, therefore the fast flux band was extended to [ ] encompassing the range for commercial PWRs.

e. The Zr-4 model is applicable [ ]

The Zr-4 model has been calibrated with measurements on [ ] in-reactor creep specimens and [ ] PWR rods. All in-reactor creep specimens (see Table 30-6, Zr-4 cladding) were [ ] PWR rods (see Table 30-1, Zr-4 cladding rods) were [ ] Figure 30-5 presents the P versus M data for the low stress creep calibration database [ ] and shows good prediction [ ]

Figure 30-5: Predicted versus Measured Strain of the Zr-4 Calibration Database

[ ]

f. Figure 10-47 of Revision 2 of the V&V document (Reference 4) is now listed as Figure 10-39 in Revision 4 (Reference 5). Figure 10-50 of Revision 2 of the V&V document (Reference 4) is now replaced by Figure 10-42 in Revision 4 (Reference 5) where MOX rod data has been removed from the figure and [ ] Figure 10-51 in Revision 2 of the V&V document (Reference 4) has no equivalent in Revision 4. Figure 5-11 in Revision 0 of the methodology document (Reference 1) has been replaced by Figure 5-8 in Revision 1 (Reference 2).

The M5 calibration and validation database for low stress creep model can be separated into [ ] groups regarding this subject:

- The M5 calibration database used to determine the model uncertainties is made of [ ] PWR rods of [ ] (see Table 30-1, M5 cladding). This database is a sub-part of the data used in Figure 5-11 in Revision 0 of the methodology document (Reference 1) which uses [ ] creep data.
- [ ] This database is used in Figure 10-47 in Revision 2 of the V&V document (Reference 4).
- The M5 PWR rods [ ] designs. This database is used in Figures 10-50 and 10-51 in Revision 2 of the V&V document (Reference 4).

Regarding the M5 calibration database, there is [ ] as seen in Figure 30-6 below. However, the model is [ ] for M5 low stress creep model, see Section 5.4.3.2 of Reference 2 [ ]

Figure 30-6: P versus M Rod Diameter Change, M5 Calibration Database

[ ]

Regarding the M5 in-reactor creep specimens validation database, as explained in RAI 20.a and 20.c of Reference 6, all of these tests [

]

Regarding the PWR rods validation database, Figures 30-3 and 30-4 show [

]

Figure 30-7: Predicted versus Measured Strain of the M5 Validation Database (16x16 and 15x15 Designs Only)

[

]

The impact of the creep model [

]

g. The low stress cladding creep uncertainties for Zr-4 SRA and M5 cladding are provided in Reference 2, Sections 5.4.3.1 and 5.4.3.2, respectively. Table 30-5 lists the upper and lower bound model uncertainty parameters for the low stress creep models. Also, included in Table 30-5 is the standard deviation of [ ] for each model. The uncertainties for Zr-4 and M5 are very similar, [ ] As discussed above in the response to RAI 30.e, the Zr-4 model [ ]

Table 30-5: Low Stress Cladding Creep (ACREEPL) Bounding Parameters

[ ]

h. [ ] Commercial rods used for those plots are presented in Table 30-1. Creep specimens are presented in Table 30-6 below. In an effort to align the dataset between RAIs, responses to RAI 30.h, 30.i and 30.l use the same dataset for in-reactor creep specimens and responses to RAI 30.h and 30.l will use the same dataset for PWR rods (RAI 30.i does not use PWR rods).

Table 30-6: Low Stress Cladding Creep Specimen Parameters

[ ]

In Figures 30-8 to 30-31:

[ ]

[ ]

Figures 30-8 through 30-19 present the results for both compressive and tensile stress creep data. Figures 30-20 through 30-31 present the results for tensile stress creep data only.

Figure 30-8: Zr-4 Cladding, P-M Strain versus Stress

[ ]

Figure 30-9: Zr-4 Cladding, P-M Strain versus Fast Fluence

Figure 30-10: Zr-4 Cladding, P-M Strain versus Temperature

Figure 30-11: M5 Cladding, P-M Strain versus Stress

[ ]

Figure 30-12: M5 Cladding, P-M Strain versus Fast Fluence

[ ]

Figure 30-13: M5 Cladding, P-M Strain versus Temperature

[ ]

Figure 30-14: Zr-4 Cladding, P/M Strain versus Stress

[ ]

Figure 30-15: Zr-4 Cladding, P/M Strain versus Fast Fluence

[ ]

Figure 30-16: Zr-4 Cladding, P/M Strain versus Temperature

[ ]

Figure 30-17: M5 Cladding, P/M Strain versus Stress

[ ]

Figure 30-18: M5 Cladding, P/M Strain versus Fast Fluence

[ ]

Figure 30-19: M5 Cladding, P/M Strain versus Temperature

[ ]

Figure 30-20: Zr-4 Cladding, Tensile Stress, P-M Strain versus Stress

[ ]

Figure 30-21: Zr-4 Cladding, Tensile Stress, P-M Strain versus Fast Fluence

[ ]

Figure 30-22: Zr-4 Cladding, Tensile Stress, P-M Strain versus Temperature

[ ]

Figure 30-23: M5 Cladding, Tensile Stress, P-M Strain versus Stress

[ ]

Figure 30-24: M5 Cladding, Tensile Stress, P-M Strain versus Fast Fluence

[ ]

Figure 30-25: M5 Cladding, Tensile Stress, P-M Strain versus Temperature

[ ]

Figure 30-26: Zr-4 Cladding, Tensile Stress, P/M Strain versus Stress

[ ]

Figure 30-27: Zr-4 Cladding, Tensile Stress, P/M Strain versus Fast Fluence

[ ]

Figure 30-28: Zr-4 Cladding, Tensile Stress, P/M Strain versus Temperature

[ ]

Figure 30-29: M5 Cladding, Tensile Stress, P/M Strain versus Stress

[ ]

Figure 30-30: M5 Cladding, Tensile Stress, P/M Strain versus Fast Fluence

[ ]

Figure 30-31: M5 Cladding, Tensile Stress, P/M Strain versus Temperature

[ ]

i. In order to align and keep consistency with the RAI 30.h response, the hypothesis for this response is kept very similar to the RAI 30.h response hypothesis. The main difference is [ ]

The analysis of the creep rate is [ ]

In all the figures included in this response:

[ ]

Figures 30-32 through 30-43 present the steady-state creep rate versus stress, fast flux, and temperature for in-reactor creep specimens (Zr-4 and M5 cladding).

Figure 30-32: Zr-4 Cladding, P-M Creep Rate versus Stress

[ ]

Figure 30-33: Zr-4 Cladding, P-M Creep Rate versus Average Fast Flux

[ ]

Figure 30-34: Zr-4 Cladding, P-M Creep Rate versus Temperature

[ ]

Figure 30-35: M5 Cladding, P-M Creep Rate versus Stress

[ ]

Figure 30-36: M5 Cladding, P-M Creep Rate versus Average Fast Flux

[ ]

Figure 30-37: M5 Cladding, P-M Creep Rate versus Temperature

[ ]

Figure 30-38: Zr-4 Cladding, P/M Creep Rate versus Stress

[ ]

Figure 30-39: Zr-4 Cladding, P/M Creep Rate versus Average Fast Flux

[ ]

Figure 30-40: Zr-4 Cladding, P/M Creep Rate versus Temperature

[ ]

Figure 30-41: M5 Cladding, P/M Creep Rate versus Stress

[ ]

Figure 30-42: M5 Cladding, P/M Creep Rate versus Average Fast Flux

[ ]

Figure 30-43: M5 Cladding, P/M Creep Rate versus Temperature

[ ]

j. The mentioned Halden experiments are [ ] The database already contains experiments with main parameter ranges covering, in most cases, the parameter ranges of the Halden experiments. The main difference in parameter ranges with the Halden experiment [ ] (in absolute value). Some of the mentioned Halden experiments [ ] in the GALILEO database. As can be seen in the following comparison (Table 30-7), all other main operational parameter ranges are close or fully covered by the GALILEO database.

Table 30-7: HWR Zr-4 Experiments Main Parameters

[ ]

Table 30-8: Selection of Zr-4 PWR Rods and Creep Specimens from the Calibration and Validation Database

[ ]

For Zr-4, [ ]

Regarding the M5 cladding Halden experiment, the main parameters are presented in Table 30-9.

Table 30-9: HWR M5 Experiment Main Parameters

[ ]

Table 30-10: Selection of M5 PWR Rods and Creep Specimens from the Calibration and Validation Database

[ ]

k. The creep model uncertainties include the effects of:

[ ]

Ideally, the model uncertainty [ ] Inclusion of creep specimens in the model uncertainty databases does not diminish the overall conservative nature of the application methodology because [ ]

l. The request for additional information on Figures 5-8, 5-11, 5-14 and 5-17 in Revision 0 of the methodology document (Reference 1) is partially obsolete. The MOX fuel and Zircaloy-2 cladding alloy are no longer part of the scope in Revision 1 of the methodology document (Reference 2). Figures 5-8 and 5-11 in Revision 0 of the methodology document (Reference 1) are now Figures 5-5 and 5-8 in Revision 1 of the methodology document (Reference 2). Figures 5-14 and 5-17 in Revision 0 of the methodology document (Reference 1) do not exist in Revision 1 (Reference 2).

In order to align and keep consistency with the RAI 30.h response, the hypothesis for this response is kept very similar to the RAI 30.h response hypothesis.

In this response, [

] therefore, no additional separation of the data points between positive and negative stress is necessary. Commercial rods used for those plots are presented in Table 30-1. Creep specimens are presented in Table 30-6. This is exactly the same dataset (PWR rods and creep specimens) provided in the RAI 30.h response.

In all tables and figures of this response:

[

]

Table 30-11 presents the low stress Zr-4 cladding P-M and P/M normal distribution parameters.

Table 30-11: Zr-4 Normal Distribution Parameters

[

]

Figures 30-44 and 30-45 present the P-M and P/M distributions for the selected dataset of Zr-4 cladding PWR rods and in-reactor creep specimens.

Figure 30-44: Zr-4 Cladding, P-M Distribution, Lower and Upper Bound Normal Distributions

[ ]

Figure 30-45: Zr-4 Cladding, P/M Distribution, Lower and Upper Bound Normal Distributions

[ ]

Table 30-12 presents the low stress M5 cladding P-M and P/M normal distribution parameters.

Table 30-12: M5 Normal Distribution Parameters

[ ]

Figures 30-46 and 30-47 present the P-M and P/M distributions for the selected dataset of M5 cladding PWR rods and in-reactor creep specimens.

Figure 30-46: M5 Cladding, P-M Distribution, Lower and Upper Bound Normal Distributions

Figure 30-47: M5 Cladding, P/M Distribution, Lower and Upper Bound Normal Distributions

30.3 *References for RAI-30*

1. ANP-10323(P), Revision 0, Fuel Rod Thermal-Mechanical Methodology for Boiling Water Reactors and Pressurized Water Reactors.
2. ANP-10323(P), Revision 1, GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors.
3. ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.
4. FS1-0004683-2.0, GALILEO Fuel Rod Performance Code Verification and Validation Report.
5. FS1-0004683-4.0, GALILEO Fuel Rod Performance Code Verification and Validation Report.
6. ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

31.0 RAI-31

RAI-31 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

32.0 RAI-32

RAI-32 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

33.0 RAI-33

RAI-33 was addressed in the following report:

ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

34.0 RAI-34

34.1 *Request*

The Zr-4 hydrogen pickup model is based on a [

] if the data are applicable to current PWR operation. Of concern is the applicability of this [

]

a. Please provide the cladding tin level, fuel design, plant core average power, primary inlet and outlet temperatures, cycle lengths, and power histories (nodal LHGR) for the [ ] Zr-4 data points used to calibrate the hydrogen pickup model. Provide the same information on any Zr-4 rods used in the validation but not used to calibrate the Zr-4 pickup model.

b. Please provide a P-M hydrogen versus burnup and effective full-power day for the Zr-4 data identifying the fuel rod design geometry.

c. Please provide P-M versus axial location for the Zr-4 data identifying the fuel rod design geometry.

d. Please provide a demonstration that the hydrogen pickup model can provide bounding hydrogen predictions when uncertainties in the corrosion model and hydrogen pickup model are combined according to your statistical methodology.

34.2 *Response*

In the development of the response to RAI 34, [

] Additional justification [

] for Zr-4 is provided in the Response to RAI 34.b.

[ ]

Appendix C contains markup corrections for each of these items with the updated information.

a. Tables 34-1 and 34-2 provide the requested data for the Zr-4 data points used for the hydrogen pickup model calibration and validation, respectively. Data is grouped by reactor and the number of measurements taken from each reactor is also provided. The reactor operating parameters in these tables are considered generally representative and are provided for information only.

   Figures 34-1 and 34-2 provide the power histories (nodal LHGR versus nodal burnup) for the Zr-4 data points used for the hydrogen pickup model calibration and validation, respectively.

Table 34-1: Zr-4 Calibration Data

[ ]

Table 34-2: Zr-4 Validation Data

[ ]

Figure 34-1: Zr-4 Calibration Data Power Histories

[ ]

Figure 34-2: Zr-4 Validation Data Power Histories

[ ]

b. In Figures 34-3 and 34-4, the predicted minus measured (P-M) hydrogen content for Zr-4 is plotted versus burnup and irradiation time. The predictions are based on best estimate models. In Figure 34-4, data is plotted against irradiation time instead of effective full power days since the hydrogen measurements and code calculations are based on irradiation time. On average the Zr-4 hydrogen concentration predictions are conservative and justify the selection of the [ ] for Zr-4 cladding. This conclusion along with Figures 34-3 and 34-4 also respond to RAI 6 previously deferred in Reference 2.

All Zr-4 measurements are taken from commercial PWR [ ]

Figure 34-3: Zr-4 P-M Hydrogen vs. Burnup

[ ]

Figure 34-4: Zr-4 P-M Hydrogen vs. Irradiation Time

[ ]

c. In Figure 34-5, P-M hydrogen content for Zr-4 is plotted versus axial elevation. The predictions are based on best estimate models.

All Zr-4 measurements are taken from commercial PWR [ ]

Figure 34-5: Zr-4 P-M Hydrogen vs. Axial Elevation

[ ]

d. Figures 34-6 and 34-7 show the P-M hydrogen pickup for Zr-4 and M5, respectively, when using the GALILEO "best estimate" and "upper bound" corrosion models. The plots show [ ]

Figure 34-6: Zr-4 Predicted Minus Measured Hydrogen Pickup vs. Burnup

[ ]

Figure 34-7: M5 Predicted Minus Measured Hydrogen Pickup vs. Burnup

[ ]

34.3 *References for RAI-34*

1. ANP-10323(P), Revision 1, GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors.
2. ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

APPENDIX A ADDITIONAL REQUESTS

A.1. REQUEST

In addition to the RAIs, the NRC also requested [

]

[

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A.2. RESPONSE

Fuel rod internal pressure is a specified acceptable fuel design limit (SAFDL) while fuel rod free volume is not a SAFDL. [

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Therefore, this response [

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The nominal predictions for fuel rod free volume and rod internal pressure are shown in Figure 4-47, Figure 4-48, Figure 4-49 and Figure 4-50 of Reference 1. Figure A-1 below shows the upper and lower bound rod internal pressure using upper and lower bound values [

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Figure A-1: 95/95 Uncertainty Assessment on Calculated-Measured Rod Internal Pressure

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The above figure confirms the conservatism of the GALILEO fuel performance code in the fuel rod internal pressure prediction. This figure also shows that there is no significant prediction bias on the burnup range.

A.3. REFERENCES FOR ADDITIONAL REQUESTS

1. ANP-10323(P), Revision 1, GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors.
2. ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

APPENDIX B TOPICAL REPORT MARKUPS (RAI 30)

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APPENDIX C TOPICAL REPORT MARKUPS (RAI 34)

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APPENDIX D ADDITIONAL TOPICAL REPORT MARKUPS

Below are additional markup pages for the GALILEO topical report (Reference 1) which supplement previously documented markup pages in References 2, 3, 4, and Appendices B and C of this report. These markup corrections will be included in the final approved version of Reference 1.

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D.1. REFERENCES

1. ANP-10323(P), Revision 1, GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors.
2. ANP-10323, Rev. 1, Q1P, Revision 0, Response to Request for Additional Information – ANP-10323P, December 2018.
3. ANP-10323, Rev. 1, Q2P, Revision 0, Response to Request for Additional Information – ANP-10323P, January 2019.
4. ANP-10323, Rev. 1, Q3P, Revision 0, Response to Request for Additional Information – ANP-10323P, June 2019.

APPENDIX E RAI 10 RESPONSE MARKUPS

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