ENCLOSURE 2

REGULATORY AUDIT SUMMARY PERFORMED VIRTUALLY ON

JANUARY 18, 2023, TO SUPPORT REVIEW OF THE

PRESSURIZED WATER REACTOR OWNERS GROUP

TOPICAL REPORT PWROG-21001-P/NP, REVISION 0,

HYDROGEN-BASED TRANSIENT CLADDING STRAIN LIMIT

DOCKET NO. 99902037

EPID L-2022-TOP-0043

(NON-PROPRIETARY)

Proprietary information pursuant to Section 2.390 of Title 10 of the *Code of Federal Regulations* has been redacted from this document.

Redacted information is identified by blank space enclosed within double brackets.

REGULATORY AUDIT SUMMARY PERFORMED VIRTUALLY ON

JANUARY 18, 2023, TO SUPPORT REVIEW OF THE

PRESSURIZED WATER REACTOR OWNERS GROUP

TOPICAL REPORT PWROG-21001-P/NP, REVISION 0,

HYDROGEN-BASED TRANSIENT CLADDING STRAIN LIMIT

DOCKET NO. 99902037

EPID L-2022-TOP-0043

1.0 BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) staff is currently engaged in a review of submitted Pressurized Water Reactor (PWR) Owners Group (PWROG) Topical Report (TR) PWROG-21001-P/NP, Revision 0, “Hydrogen-Based Transient Cladding Strain Limit.” By letter dated July 28, 2022 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML22209A254), the PWROG requested NRC review and approval for referencing in regulatory actions per NRC TR program. The purpose of this TR is to establish a new, alternative fuel performance design limit for transient cladding strain. The TR will facilitate PWROG licensees in using a data-driven, performance-based design limit when performing transient cladding strain analyses. This is an alternative limit which, after NRC approval, can be used in lieu of the current 1 percent transient cladding strain limit established in Section 4.2, “Core Design,” of the NRC Standard Review Plan, NUREG-0800.

This TR is applicable to Westinghouse nuclear steam supply system (NSSS) and Combustion Engineering NSSS PWROG members that use PAD5 fuel performance models for ZIRLO® and/or Optimized ZIRLO™ high performance fuel cladding material.

The NRC staff conducted a virtual regulatory audit on January 18, 2023, in accordance with the audit plan provided to the PWROG (ADAMS Accession No. ML22361A156), and to increase review efficiency. The audit was held in accordance with the Office of Nuclear Reactor Regulation Office Instruction LIC 111, “Regulatory Audits,” dated October 31, 2019 (ADAMS Accession No. ML19226A274).

2.0 AUDIT OBJECTIVE

The objective of this audit was to increase review process efficiency through interaction with the PWROG’s technical experts. More specifically, the NRC staff asked questions of the PWROG’s personnel to narrow the scope of the future request for additional information (RAI) questions. A more detailed narrative on the topics covered is included in the discussion section of this audit report. The details of the audit are discussed in Section 4.0 of this summary.

3.0 AUDIT TEAM

The following NRC staff members participated in the virtual audit:

- Siva Lingam (Project Manager)
- Joseph Messina (Technical Reviewer)
- Patrick Raynaud (Technical Reviewer)

The following PWROG personnel and its consultants supported the audit:

- James Andrachek
- Tim Crede
- Chad Holderbaum
- Christopher Logan
- Yum Long
- Dave Mitchell
- Brian Mount (Services 6)
- Guirong Pan
- Dave Rumschlag

4.0 AUDIT REPORT

4.1 Information Needs

The PWROG was requested to have the presentations and documents related to the areas of focus listed. The documentation was provided by presentations, documents, and calculation details. The following were the planned major areas of focus for detailed discussion and document review.

The deliberations during the audit, along with the original contents of the TR will be used to generate RAI questions and eventually prepare a safety evaluation by the NRC staff to complete the comprehensive review of the TR. Upon NRC approval, the PWROG's TR will facilitate PWROG licensees in using a data-driven, performance-based design limit when performing transient cladding strain analyses.

4.2 Topics Discussed during the Audit

Topic 1: Experimental Database

Question: Pellet-cladding mechanical interaction (PCMI) is established to be a biaxial phenomenon (i.e., the cladding is placed under both axial and radial stress). **[[**

]].

Response: The PWROG pointed to the PAD5 TR, which uses axial tensile tests and ring tensile tests to develop Westinghouse stress/strain models. These tests provide material tensile properties in the axial and hoop directions, respectively. The PWROG TCS limit is based on cladding uniform elongation (UE). The PWROG stated that in order to get accurate UE data, tests that introduce uniaxial loading are needed (e.g., axial tensile tests or ring tensile tests). With the current state of technology related to irradiated material testing in hot cells, it is difficult to get accurate UE data for experimental testing methods, which introduce biaxial loading.

Topic 2: Range of Operating Temperatures

Question: In the proposed hydrogen-based transient cladding strain limit, **[[**

]].

Response: The PWROG provided clarification on the "breakpoint" used in the TCS limit model. The PWROG stated that assuming lower cladding temperature for the breakpoint while keeping the fit for the data would result in a less conservative model at lower hydrogen concentrations. Further discussion occurred on the lack of data for samples below **[[** **]]** hydrogen content, but with excess hydrogen content (as opposed to soluble hydrogen). The PWROG discussed that the time when gap closure occurs is limiting for the cladding. Gap closure happens early in life when the cladding would have the least amount of hydrogen and temperatures would typically be high. TSS increases with temperature. As a result, it is not expected that hydrogen would precipitate at low hydrogen contents such as those observed early in life when gap closure occurs (i.e. the limiting time in life for cladding transient strain).

Topic 3: Measurement Accuracy

Question: It is stated on page 6-2 that **[[**

]]?

Response: The PWROG acknowledged that the hydrogen measurements may have been inaccurate but showed that if the two datapoints in question are omitted, it results in a less conservative model than proposed.

Topic 4: Model Variables: Temperature

Question: Section 4.1 describes states that "Specifically, the UE limit is a function of both the hydrogen content and cladding temperature…." Please clarify how the proposed TCS limit is a function of temperature.

Response: The PWROG clarified that temperature is used to determine TSS, which is used to **[[**

]].

Topic 5: Model Temperature Assumption

Question: Section 4.2 describes that the cladding outer temperature is used to determine TSS. **[[**

]]. Please elaborate on where this assumption is employed.

Response: The PWROG clarified that the outer cladding temperature is used in the calculation of TSS, which is used as described in the previous audit question.

Topic 6: Hydride Rim Effect

Question: Section 4.2 states that **[[**

]].

Response: The PWROG stated that using the outer surface cladding temperature should bound the hydride rim effect. The PWROG stated that the samples were taken from irradiated fuel rods, therefore the hydride rim effect would be implicitly accounted for in the test results used to develop the TCS limit.

Topic 7: Operation After Anticipated Operational Occurrence (AOO)

Question: When restarting after an AOO where cladding plastic strain was accumulated as a result of the AOO, how are the cladding strain hardening and possible opening of the fuel-cladding gap taken into account? In addition, how is further cladding strain accounted for or measured? Is the accumulated strain during the AOO subtracted from the proposed limit, such that the new transit cladding strain limit would be reduced for subsequent AOOs?

Response: The PWROG stated that the cladding plasticity models in PAD5 would be used to account for any effects of permanent strain or the opening of the pellet-cladding gap. They also stated that the effects of such changes on the thermal behavior of the rod, and thus fission gas release, are also accounted for in PAD5.

Topic 8: Terminal Solid Solubility

Question: The TSS changes when the hydrogen in the cladding is undergoing precipitation and when it is undergoing dissolution. Please explain how PWROG is accounting for this difference.

Discussion: The PWROG provided the 1967 JJ Kearns publication, “Terminal Solubility and Partitioning of Hydrogen in the Alpha Phase of Zirconium, Zircaloy-2 and Zircaloy-4,” from the *Journal of Nuclear Materials* for staff review and discussed that the Kearns TSS correlation is a dissolution correlation (TSS_d), which is conservative relative to the TSS under precipitation (TSS_p). For any given temperature, TSS_d is higher than TSS_p, which results in more calculated precipitated hydrogen when TSS_d is employed as the terminal solid solubility.

Topic 9: Integration with Existing Methods

Question: Please elaborate on how the proposed TCS limit integrates with existing methodologies (e.g., PAD5).

Response: The PWROG stated that all transient cladding strain calculations are the same as those discussed in the PAD5 TR, except for the design limit. Specifically, the following models in PAD5 are used:

- PAD5 corrosion model (originally approved in WCAP-12610-P-A & CENPD-404-P-A Addendum 2-A)
- PAD5 film temperature drop model to calculate cladding surface temperature
- PAD5 cladding strain
  PAD5 method for modelling of Condition II overpower transients

Topic 10: 10 CFR 50.59

Question: Please elaborate on the justification of the use of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59(c)(2)(viii) to implement the proposed TCS limit. Specifically, please walk the staff through the assessment that would be performed per NEI 96-07 and highlight which sections of the NEI guidance this would fall under.

Response: The PWROG responded to the question, but the staff did further independent research into the 10 CFR 50.59 bases and determined that the question was immaterial.

Topic 11: Condition II Events

Question: Please clarify which specific Condition II events the proposed TCS limit is planned to be applied to.

Response: The PWROG provided the list of Condition II transients that is in the PAD5 TR.

Documents Reviewed

During the audit, the staff reviewed the following documents, provided electronically for the duration of the audit:

- "PWROG-21001-P NRC Audit Reponses (FINAL for 1-18-23)"
- JJ Kearns, "Terminal Solubility and Partitioning of Hydrogen in the Alpha Phase of Zirconium, Zircaloy-2 and Zircaloy-4," *Journal of Nuclear Materials*, 1967.
- Kimberly Colas, et al., "Mechanisms of Hydride Reorientation in Zircaloy-4 Studied in Situ," *Zirconium in the Nuclear Industry: 17th International Symposium*, 2014.

Audit Summary Table

Table 1: Audit of PWROG-21001-P Revision 0: Closures, Action Items, and RAIs

Topic Number	Subject	Response	Acceptable / Action Item	RAI Needed (Yes/No/TBD)
1	Prototypicality of experimental database	UE data cannot be accurately retrieved from biaxial tests	RAI	Yes
2	Impact of range of operating temperatures	May be non-conservative to move breakpoint to lower total hydrogen	RAI	Yes
3	Measurement accuracy	Including the Almaraz data results in a more conservative limit compared to excluding it	Yes	Yes
4	Model variables (temperature)	Temperature is used to determine H solubility, which is then used to determine if UE_0 or UE_{Hex} is used	Yes	No
5	Model temperature assumption	Cladding outside temperature used to calculate TSS, which is used as discussed in Item 4	Yes	No

Topic Number	Subject	Response	Acceptable / Action Item	RAI Needed (Yes/No/TBD)
6	Hydride rim-effect	Used irradiated samples, so effect is inherently included in data	Yes	No
7	Operation after AOO	Plasticity and its effects are accounted for in PAD5	Yes	Yes
8	TSS during precipitation and dissolution	TSS_d is conservative compared to TSS_p	Yes	No
9	Integration with existing methods	Stated how PAD5 is used	Yes	No
10	10 CFR 50.59	50.59 discussed more	N/A	N/A
11	Condition II events	Condition II events from PAD5 TR	Yes	Yes

The final RAI questions were issued on February 14, 2023, and can be found in ADAMS Package Accession No. ML23038A047.

5.0 CONCLUSION

Through the audit, the NRC staff obtained an enhanced understanding of the PWROG's submittals and the details of the included safety analyses and their results. There was open communication throughout the audit, and this helped the NRC staff to communicate concerns about the submittals and have them answered by PWROG. The audit accomplished the objectives listed in Section 2.0. The NRC staff has issued RAI questions in conjunction with this audit report to resolve items that remain open.