**REQUEST FOR ADDITIONAL INFORMATION**

**NEDC-33353(P), REVISION 0,**

**"APPLICATION OF GNF-ZIRON TO GNF FUEL DESIGNS"**

**(TAC NO. ME5254)**

1. Please provide additional data that has been collected since publication of the submitted licensing topical report (LTR) such as from Plants V and F or additional post irradiation examinations (PIE) from Plants G and K. Please also provide any additional channel data from Plants P and N.

2. Please compare the GNF-Ziron channel bow data to current Zircaloy-2 (Zr-2) channel bow data noting differences and analysis of why the differences exist. What are the assumed uncertainties applied to the analysis of GNF-Ziron channel bow. How do these compare to those used for current generation Zr-2 [ ]. Please provide an analytical example of how channel bow due to growth is subtracted from the bow measurement data to determine bow due to shadow corrosion (hydriding). This should include justification for the GNF-Ziron channel growth correlation. Have hydrogen measurements been performed on channel faces to confirm differences in hydrogen and the influence on bow?

3. Corrosion at the inner diameter (ID) cladding is important for loss-of-coolant accident (LOCA) embrittlement criteria. Please provide measured oxide thickness of ID cladding corrosion for high burnup fuel rods.

4. The discussion of shadow corrosion on page 2-8 only discusses one set of symmetrical Zr-2 and GNF-Ziron clad rods in Plant V, however, there were several sets of symmetrical rods in the different lead use assemblies (LUAs) in Plants V, K, and G. Please provide similar details and discussion of the shadow corrosion in other rod pairs. Are there any all-Inconel spacers in US plants?

5. What is the range of primary coolant chemistry in US plants, specifically for O, H, Zn, sulfates, and pH? What is the range of chemistry tested for GNF-Ziron cladding? Provide this for each testing program.

6. Please provide comparison of hydrogen distribution and orientation between Zr-2 and GNF-Ziron in fuel rod cladding, spacers, end plugs, and channels. Will the changes between Zr-2 and GNF-Ziron impact the stress level at which hydride reorientation will be experienced? Please provide data to verify this response?

7. The discussion in the LTR regarding GNF-Ziron in-reactor behavior demonstrates that cladding texture and second phase particles (SPPs) are both important components of behavior. The subject LTR includes a brief discussion on texture and SPPs for GNF Ziron stating [ ].

ENCLOSURE 1

a. What are the texture and SPP size distributions for the different LUA's cladding, spacer grids, water rods, and channels with GNF-Ziron?

b. What fabrication specifications will be applied to texture and SPPs for GNF-Ziron in production and how do these compare to current generation Zr-2 specifications for each of the assembly components?

c. Are there different compositions or texture or SPP specification differences between the various assembly components and if so, how does this impact material performance?

8. The LTR states that an In-Process Heat Treatment (IPHT) will [ ]. Has the IPHT been applied to LUAs? If so, what was the resulting performance? If this IPHT process has not been demonstrated with the proposed ZIRON cladding how can it be assured the performance will be satisfactory using this process for GNF-Ziron?

9. Please provide the design basis linear heat generation rate limit (limiting design in terms of rod average power) versus peak pellet exposure for designs with GNF-Ziron.

10. What uncertainty is applied to GNF-Ziron predicted oxide thickness considering the amount of data available?

11. The following are related to the mechanical properties of GNF-Ziron.

    a. Please provide the sample geometry of mechanical test specimens discussed in Section B.3.b. Please provide additional justification for the applicability of these tests as indicators of failure strains in service applications of full size components.

    b. Strain data has been provided in terms of total elongation in Figure B-5. It has been shown that total elongation is not a good estimate of ductility at failure due to its stochastic behavior. Please provide the data (tabulated and plotted) in terms of uniform elongation, identifying the test temperature, fluence, hydrogen level, and test specimen geometry.

12. The following are related to GNF-Ziron irradiated creep.

    a. Section B.3.f provided the results of only one creep specimen (creep measured at four levels of fluence) to characterize the GNF-Ziron creep rate at one pressure level. Are there other GNF-Ziron irradiated creep tests at other stress levels? Is the pressure level quoted in this section a hoop stress rather than an internal pressure as stated? The level is high for an internal pressure value? Please provide a comparison of the GNF-Ziron creep data to the Zr-2 creep model. What uncertainty is assumed for GNF-Ziron creep given the very small amount of irradiated creep data used to verify the GNF-Ziron creep model?

    b. Has cladding creepdown been measured on the LUAs with GNF-Ziron? This should be a standard measurement? If so, please provide PRIME comparisons to these data.

13. The following are related to irradiation growth.

    a. Provide a detailed discussion of how the data in Figure B-11 is adjusted based on the basal F-factor in the longitudinal direction considering data with different F-factors.

    b. Please provide GNF-Ziron growth data for fuel rods, tie rods (if used in current designs) and channels. Which assembly component that utilizes GNF-Ziron has the largest axial stress - tie rods, water rods or another component? Please compare axial growth for the GNF-Ziron component with greatest axial stress to the component with the least stress. Recent experience with other zirconium alloys has suggested that growth may be stress dependent even when including creep effects.

14. The following are related to the impact of GNF-Ziron response to LOCA and associated analyses.

    a. Have Equivalent Cladding Reacted tests been performed on high burnup GNF-Ziron cladding with hydrogen present and oxide on ID?

    b. Does the addition of iron impact the $\alpha \rightarrow \alpha + \beta$ transformation temperature?

    c. Please compare the rupture strains compiled from the rupture tests associated with Figure B-6 to those measured for Zr-2 [ ]. Also, please describe how assembly flow blockage is determined from predicted rupture strains for GNF-Ziron.

    d. How does the introduction of GNF-Ziron for fuel rod design impact the Emergency Core Cooling System performance?

15. Please provide a detailed surveillance program, including PIEs, for the use of GNF-Ziron material in fuel rod and assembly design in reload applications. The PIE should include, but is not limited to, the following elements in order to verify acceptable performance: visual, oxide thickness, hydrogen level, cladding creepdown; fuel rod and water rod growth, channel growth, channel bow, and shadow corrosion.

16. The data on shadow corrosion appears to be based on [ ]. This will underestimate the level of shadow corrosion due to the Inconel grids. There appears to be a small improvement compared to Zr-2 but this is based on only 2 rod comparisons such that the evidence is weak.

    Please provide better measurements of shadow corrosion (such as micrographs or [ ]) at the spacer grids that provide a more accurate measurement of shadow corrosion.

17. The micrograph in Figure 6.1 of the response to RAI-6 that provides hydride distribution and orientation is from an unpressurized cladding from Plant K. Plant K also had cladding that was pressurized for cladding creep.

Were micrographs taken on the pressurized cladding from Plant K or any other plant? If so did these pressurized tubes show hydride reorientation? Provide the micrographs that illustrate hydride orientation?

18. The information in the LTR suggests that profilometry data were taken on GNF-Ziron and Zr-2 rods (some of these appear to be equivalent rods) from Plant V.

    Please compare creepdown from the profilometry measurements from equivalent GNF-Ziron and Zr-2 rods from Plant V after one and two cycles. Also provide predictions of creepdown for these rods using the Zr-2 creep model.

19. In the LTR supporting the irradiation of LUAs in Hatch 2 (GNF-0000-0079-7396NP, DRF Section 0000-0079-7396 R6, January 2013), there is a comparison of the ASTM Zr-2 (UNS R60802) specification composition, with GNF's proprietary Controlled Chemistry (CC) Zr2 and GNF-Ziron. It is understood that GNF's CC Zr-2 contains a tighter range on the alloying elements, **[ ]** and this would be representative of GNF's experience. Various references (1 - 8) refer to a High Fe/Zry-2 or High-Fe Improved Zircaloy by 2000, and ultimately GNF-Ziron by 2006. The most common nominal composition (in wt%) was given as 1.46 Sn, 0.26 Fe, 0.10 Cr, and 0.05 Ni, with balance Zr, although Lutz and Lin (Ref. 1) report a High Fe Zr-2 with 1.5 Sn, 0.25 Fe, 0.10 Cr, and 0.05 Ni.

    The LTR provides the range of Fe content as **[ ].** The ranges of Sn, Cr, Ni and O are also provided, however the nominal values of Sn, Ni and O in GNF-Ziron are not provided, although it is expected that they would probably be near the mid-range values, e.g., **[ ]**, which is cited in the LTR.

    The O content does have an influence on phase transformation ($\alpha \rightarrow \alpha + \beta$ and $\alpha + \beta \rightarrow \beta$) as well as strength. In LTR section B.3.b, Tensile Properties, GNF states that the apparent **[ ]** than normally used in GNF's Zr-2.

    a. What is the nominal value for Sn and O in GNF-Ziron? What are the anticipated ranges during manufacturing?

    b. Are there any tests of irradiated GNF-Ziron with Fe at the upper limit **[ ],** or higher?

    c. Please indicate the nominal composition and heat treatment (e.g., IPHT) of the GNF-Ziron alloy irradiated in each program, this will provide information on the alloy range tested.

20. In Table 2 of the LTR supporting the irradiation of LUAs in Hatch 2 (GNF-0000-0079-7396NP, DRF Section 0000-0079-7396 R6, January 2013), GNF identifies "number of properties or characteristics for GNF-Ziron were obtained through testing."
    Are there any additional properties or characteristics that have been obtained through testing or measurement not provided in the LTR.

21. The performance of a fuel rod is highly dependent on its integral power. Please provide the exposure/burnup and effective full power days (EFPDs) at the end of each cycle, or the cumulative burnups and EFPDs at discharge for the various LUA programs (Plants G, P, N, V, F, and H).

22. In the LTR for GNF-Ziron (Figure B-1), GNF provided limited data on the thermal conductivity of Zr-2 and GNF-Ziron. The NRC staff agrees that the data show that the thermal conductivity measurements show that GNF-Ziron and Zr-2 have essentially the same conductivity, and given the small increase in Fe content, PNNL would expect the thermal conductivities to be essentially equal. PNNL compared the measured data with the correlation for Zr-2 provided in the GNF LTR, “The PRIME Model for Analysis of Fuel Rod Thermal – Mechanical Performance,” NEDC-33256P that demonstrates the data is lower than the correlation. In addition, the data were compared with the IAEA correlation (from IAEA TECDOC 1496 (Ref. 9) and MATPRO Ref. 10). The PRIME correlation agrees well with the IAEA and MATRPRO correlations, although the IAEA correlation is slightly lower over the temperature range from 500 to 1000 K.
    Please comment on the measured data for Zr-2 and GNF-Ziron thermal conductivity and the difference with the correlations used in PRIME and MATPRO, and the IAEA recommended correlation.

REFERENCES

1. D. R. Lutz, C. C. Lin, "BWR Zircaloy Corrosion and Water Chemistry Tests," TR-106830, EPRI, December 1996.

2. Etoh, Y., Shimada, S., Yasuda, T., Ikeda, T., Adamson, R. B., Chen, J.-S. F., Ishii, Y., and Takei, K., "Development of New Zirconium Alloys for a BWR," Zirconium in the Nuclear Industry: Eleventh International Symposium, ASTM STP 1295, E. R. Bradley and G. P. Sabol, Eds., American Society for Testing and Materials, 1996, pp. 825-849.

3. Shinji Ishimoto, Toshio Kubo, Ronald B. Adamson, Yoshinori Etoh, Kunio Ito, Youjiro Suzawa, "Development of New Zirconium Alloys for Ultra-High Burnup Fuel," Proceedings of the ANS International Topical Meeting on LWR Fuel Performance, Park City, 2000, pp. 31-42.

4. K. Une and S. Ishimoto, "Heat Capacity of hydrogenated Zircaloy-2 and high Fe Zircaloy-2," Journal of Nuclear Materials 323 (2003) 101-107.

5. K. Une and S. Ishimoto, "Dissolution and precipitation behavior of hydrides in Zircaloy-2 and high Fe Zircaloy," Journal of Nuclear Materials 322 (2003) 66-72.

6. Shinji Ishimoto et al., "Improved Zr Alloys for High Burnup BWR Fuel, "Proceedings of Top Fuel 2006, Salamanca, Spain (2006).

7. Hideo Soneda, Yutaka Iwata, Mitsuo Ebisuya, et al, "BWR Core and Fuel Development for Highly-economical Power Generation," Hitachi-GE Nuclear Ltd, 2009 (Hitachi-r2009_02_104.pdf)

8. K. Une, K. Sakamoto, M. Aomi, J. Matsunaga, Y. Etoh, I. Takagi, S. Miyamura, T. Kobayashi, K. Ito, "Hydrogen Absorption Mechanism of Zirconium Alloys Based on Characterization of Oxide Layer," Journal of ASTM International (JAI102950), Vol. 8, No. 5, 2011.

9. IAEA-TECDOC-1496, “Thermophysical properties database of materials for light water reactors and heavy water reactors,” Final report of a coordinated research project 1999–2005, IAEA, Vienna, June 2006.

10. SCDAP/RELAP5-3D© Code Manual, “Volume 4: MATPRO - A Library of Materials Properties for Light-Water-Reactor Accident Analysis,” INEEL/EXT-02-00589, Volume 4, Revision 2.2, October 2003.