Edwin I. Hatch Nuclear Plant – Unit 2
Submittal of Additional Information to Support Proposed Exemption to 10 CFR 50.46 and 10 CFR 50 Appendix K to Allow Ziron Fuel Cladding

Enclosure 4

GNF-0000-0088-6047NP,
“Impact of GNF-Ziron Cladding on Thermal-Mechanical Licensing Limits” - July 2008
(Nonproprietary)

Global Nuclear Fuel

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Non-Proprietary Information

Impact of GNF-Ziron Cladding on Thermal-Mechanical Licensing Limits

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This document is a non-proprietary version of GNF-0000-0088-6047P which has the proprietary information removed. The information removed is shown as blank between double brackets [[ ]].

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Impact of GNF-Ziron Cladding on Thermal-Mechanical Licensing Limits

GE/GNF currently perform fuel rod thermal-mechanical design and licensing analyses with the GESTR-Mechanical (GSTRM) code and its associated application methodology. A key part of the statistical methodology is the inclusion of model uncertainty based upon the GSTRM qualification results. This prediction uncertainty, couched in terms of a corresponding uncertainty in linear heat generation rate (LHGR), is [[ ]]. In addition to this model uncertainty GSTRM application methodology explicitly addresses uncertainties in [[ ]].

Moreover, the fuel rods are designed such that if each rod type is operated within its specific thermal-mechanical operating limits of power versus exposure (LHGR limits), all licensing and design criteria, including those which address response to anticipated operational transients, are explicitly satisfied and fuel rod integrity will be maintained. The LHGR limits are specified to ensure compliance with the primary fuel rod thermal-mechanical licensing and design constraints.

The primary thermal-mechanical licensing parameters that may be impacted by the introduction of a new cladding material such as GNF-Ziron are

Fuel Melting
Fuel Rod Internal Pressure
Cladding Plastic Strain
Cladding Stress/Strain
Cladding Fatigue
Cladding Creep Collapse
Metal Thinning

An assessment of the impact of the Ziron cladding for each of these parameters is discussed below.

Fuel Melting

The design and licensing limit on fuel temperature is that the maximum fuel centerline temperature cannot exceed the fuel melting temperature during normal operation, including anticipated operational occurrences (AOOs). This fuel temperature limit is applied to ensure that sudden shifting of molten fuel in the interior of the fuel rods, and subsequent potential cladding damage, is precluded.

The GSTRM application methodology determines the Thermal Overpowers (TOP) limit in terms of LHGR to assure with 95% confidence (~1.645 standard deviations) that fuel melting will not occur. Except the fuel pellet properties,

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[1] The figure and table numbers refer to the figures in the companion document "Properties of GNF-Ziron" GNF-0000-0088-6043NP

cladding corrosion performance has the potential of impacting fuel melt margin. If the cladding is oxidized at a faster rate then the thick oxide layer at cladding outer surface will act as a barrier for heat transfer from the cladding to the coolant. As a consequence, fuel temperature will be higher and margin to fuel melting will be lower. However, Figure 15[1] demonstrates [[ ]] corrosion performance for GNF-Ziron and Zircaloy-2 (Zr-2) and the available Ziron liftoff measurements are [[ ]] GNF's Zr-2 experience base. It is noted that fuel melting is limiting at low exposure (~16 GWd/MTU), usually at the knee of LHGR limit curve, where GNF-Ziron's corrosion performance is [[ ]] Zr-2. Thus, this assessment concludes that GNF-Ziron [[ ]] on fuel melting.

Fuel Rod Internal Pressure

The design and licensing limit on fuel rod internal pressure is that it cannot exceed the value for which the cladding creepout rate becomes equal to the fuel pellet (solid) fission product swelling rate. If the fuel rod internal pressure exceeds the coolant pressure, the resulting cladding tensile hoop stress causes the cladding to deform outward (cladding creepout). If the rate of this cladding outward deformation exceeds the irradiation swelling rate, the pellet-cladding gap will begin to open. An increase in the pellet-cladding gap would reduce the pellet-cladding thermal conductance, thereby increasing fuel temperatures. The increased fuel temperatures would result in further fuel pellet fission gas release, greater fuel rod internal pressure, and, correspondingly, a faster rate of cladding outward deformation and gap opening. A limit on fuel rod internal pressure is applied to prevent this adverse feedback condition.

Conformance to the fuel rod internal pressure design and licensing criterion is performed through the evaluation of a fuel rod internal pressure design ratio, defined as

$$\text{Design Ratio} = \frac{\text{Fuel Rod Internal Pressure}}{\text{Fuel Rod Critical Pressure}}$$

where the fuel rod critical pressure corresponds to the pressure that would cause the fuel rod to creep out at a rate equal to the instantaneous fuel pellet irradiation swelling rate. The design ratio is evaluated statistically and formulated in such a way that a value of 1.0 provides 95% confidence that the fuel rod internal pressure will not exceed the critical pressure. Therefore, the value of the fuel rod internal pressure design ratio should be maintained $\leq$ 1.0.

Based on the available in-reactor creep test data as shown in Figure 5[1], a slower creepout rate can be anticipated for GNF-Ziron than for Zr-2. As a result, the potential for a positive feedback condition for fuel with GNF-Ziron cladding is relatively lower. As the Zr-2 creep correlation in GSTRM bounds the GNF-Ziron

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creep behavior no adverse effect on fuel rod internal pressure design ratio for fuel with GNF-Ziron cladding is expected.

Cladding Plastic Strain

The design and licensing limit on cladding strain is that the calculated cladding plastic strain at the pellet mid-height location cannot exceed [[ ]] during normal operation, including AOOs. This limit is applied to ensure that fuel rod failure due to pellet-cladding mechanical interaction will not occur.

Like the thermal overpower (TOP) limit, a mechanical overpower limit (MOP) is defined to protect against the [[ ]] plastic strain. This overpower limit (MOP) is applied at the most limiting exposure ([[ ]] GWd/MTU) to calculate the cladding permanent strain (plastic plus creep) and compared against the licensing limit. All the evaluations for cladding permanent strain are performed using [[ ]] basis for fuel rod design parameters as opposed to the [[ ]] used for other criteria. It is noted that stress/strain relationship for GNF-Ziron material is [[ ]] to Zr-2 as summarized in Table 2[1]. Moreover, cladding ductility is a function of fluence and hydrogen content. Figure 14[1] clearly indicates a lower hydrogen pickup for GNF-Ziron, even at lower fluences. Thus, this assessment concludes that GNF-Ziron [[ ]] plastic strain limit.

Cladding Stress/Strain

The fuel assembly components are evaluated to ensure that the fuel will not fail due to stresses or strains exceeding the fuel assembly component mechanical capability. The fuel rod stress analysis was performed using a Monte Carlo statistical method to calculate the effects of pressure differential, cladding ovality, radial thermal gradients, spacer contact, thermal bow and circumferential thermal gradients. The calculated stresses are compared with the appropriate design limit to produce a design ratio. Design ratios of less than 1.0 provide 95% confidence that the fuel will not fail due to stresses or strains exceeding the fuel assembly component mechanical capability.

As reported in Table 2[1], GNF-Ziron ductility [[ ]] Zr-2 as represented by the total elongation and reduction in area. As a result, the microscopic or local strain to failure for GNF-Ziron could be [[ ]] for Zr-2. Therefore, [[ ]] on cladding stress/strain limit is expected for GNF-Ziron.

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Cladding Fatigue

Fuel rod cladding is evaluated to ensure that strains due to cyclic loadings will not exceed the fatigue capability of the cladding material. The cladding strain cycles are analyzed using the rain flow cycle counting method. The fractional fatigue life expended for each strain cycle is determined and summed over the total number of cycles to determine the total fatigue life expended over the fuel design lifetime. The calculated upper 95% total fatigue life expended are compared with the design limit which requires that the total accumulated fractional fatigue life expended be <1.0.

Figure 6 and 7[1] show no significant difference in fatigue behavior between Zr-2 and GNF-Ziron. Also, for a given strain amplitude the number of cycles to failure is larger for GNF-Ziron than that expected from the GE/GNF design curve. Therefore, for fuel with GNF-Ziron cladding loss of mechanical integrity due to cladding fatigue is not expected.

Cladding Creep Collapse

The fuel rod is evaluated to ensure that fuel rod failure due to cladding collapse into a fuel column axial gap will not occur. Such collapse occurs due to a slow increase of cladding initial ovality caused by creep from the combined effect of reactor coolant pressure, temperature and fast neutron flux on the cladding over the axial gap. This condition occurs at cladding stress levels far below that required for elastic buckling or plastic deformation.

As noted before, GNF-Ziron creep strength appears to be higher than that of Zr-2. Thus, it can be concluded that failure due to cladding collapse is not expected for fuel rods with Ziron cladding.

Metal Thinning

The fuel rod is evaluated to ensure that the cladding temperature increase and cladding metal thinning due to cladding oxidation and the buildup of corrosion products do not result in fuel rod failure due to reduced cladding strength.

As mentioned before, GNF-Ziron corrosion behavior [[ ]] Zr-2. The increase in stress due to metal thinning by corrosion is more than offset by the increase in material strength due to irradiation. GSTRM application methodology explicitly addresses the metal thinning due to corrosion in the fuel rod stress and fatigue analyses. Thus, it is concluded that metal thinning due to corrosion are [[ ]].

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Conclusion

Based on the available data as reported in Table 1-2[1] and Figure 1-23[1], it is concluded that there is [[ ]] between GNF- Ziron and Zr-2 properties. Also the in reactor performance of both materials are similar. Ziron data are [[ ]] Zr-2 and can be adequately addressed by the [[ ]]. Therefore, GNF-Ziron behavior can be adequately modeled by [[ ]] on thermal-mechanical licensing limits is expected.

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