September 1, 2015

Mr. Jerald G. Head
Senior Vice President, Regulatory Affairs
General Electric-Hitachi
Nuclear Energy Americas, LLC
P.O. Box 780, M/C A-18
Wilmington, NC 28401-0780

SUBJECT: FINAL SAFETY EVALUATION FOR GLOBAL NUCLEAR FUEL – AMERICAS, LLC LICENSING TOPICAL REPORT NEDE-33798P, "APPLICATION OF NSF TO GNF FUEL CHANNEL DESIGNS" (TAC NO. MF0742)

Dear Mr. Head:

By letter dated February 13, 2013 (Agencywide Documents Access and Management System Accession No. ML13045A460), Global Nuclear Fuel – Americas (GNF) submitted NEDE-33798P, "Application of NSF [niobium (Nb), tin (Sn), iron (Fe)] to GNF Fuel Channel Designs," to the U.S. Nuclear Regulatory Commission (NRC) staff for review.

By letter dated August 13, 2015, an NRC draft safety evaluation (SE) regarding our approval of Topical Report (TR) NEDE-33798P was provided for your review and comment. The NRC staff's disposition of the GEH comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter. Please note that even though TR NEDE-33798P is proprietary, the enclosed SE is non-proprietary and will be publicly available.

The NRC staff has found that TR NEDE-33798P is acceptable for referencing in licensing applications for nuclear power plants to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that GEH publish approved proprietary and non-proprietary versions of TR NEDC-33798P within three months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The approved versions shall include an "-A" (designating approved) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, GEH and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RA/

Mirela Gavrilas, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 710

Enclosure: Safety Evaluation

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Sincerely,

/RA/

Mirela Gavrilas, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 710

Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE

OFFICE OF NUCLEAR REACTOR REGULATION

LICENSING TOPICAL REPORT

NEDE- 33798P, "APPLICATION OF NSF TO GNF FUEL CHANNEL DESIGNS"

GLOBAL NUCLEAR FUEL - AMERICAS

(TAC NO. MF0742)

1.0 INTRODUCTION

By letter dated February 13, 2013 (Reference 1), as supplemented by a letter dated June 10, 2015 (Reference 2), Global Nuclear Fuel - Americas (GNF) requested review and approval of an advanced zirconium alloy, NSF, for application to existing boiling water reactor (BWR) fuel channel designs. NSF derives its name from its primary alloying elements: niobium (Nb), tin (Sn), and iron (Fe). Recent operating experience has shown that channel distortion and associated control blade interference continues to be a major problem in the U.S. BWR commercial fleet. The goal of introducing NSF channel material is to resolve this issue. In addition, GNF requested a minor modification of the core-average, cell-average bow input to the channel-bow dependent critical power ratio (CPR) calculations.

In 2013 the U.S. Nuclear Regulatory Commission (NRC) staff approved GNF's expanded lead use channel (LUC) program for the NSF zirconium alloy (Reference 3). The purpose of the expanded LUC program was to allow greater numbers of NSF channels to be exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry, in order to gain experience and gather data for batch application.

The NRC staff's review was assisted by Pacific Northwest National Laboratory (PNNL). The staff's conclusions on the acceptability of NSF for batch application is supported by PNNL's Technical Evaluation Report (TER) (Reference 4).

2.0 REGULATORY EVALUATION

Regulatory guidance for the review of fuel system materials and designs and adherence to General Design Criteria (GDC)-10, GDC-27, and GDC-35 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" (Reference 5). In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

- The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs),
- Fuel system damage is never so severe as to prevent control rod insertion when it is required,

- The number of fuel rod failures is not underestimated for postulated accidents, and
- Coolability is always maintained.

The main focus of the limited SRP guidance with respect to BWR fuel bundle channels is control blade interference and insertability. SRP Section 4.2.II.1.A.v states:

> Control blade/rod, channel, and guide tube bow as a result of (1) differential irradiation growth (from fluence gradients), (2) shadow corrosion (hydrogen uptake results in swelling), and (3) stress relaxation, which can impact control blade/rod insertability from interference problems between these components. For BWRs, the effects of shadow corrosion should be considered for new control blade or channel designs, dimensions (e.g., the distance between control blade and channel is important), or materials. The effects of channel bulge should also be considered for interference problems for BWRs. Design changes can alter the pressure drop across the channel wall, thus necessitating an evaluation of such changes. Channel material changes can also impact the differential growth, stress relaxation, and the amount of bulge and therefore must be evaluated. If interference is determined to be possible, tests are needed to demonstrate control blade/rod insertability consistent with assumptions in safety analyses. Additional in-reactor surveillance (e.g., insertion times) may also be necessary for new designs, dimensions, and materials to demonstrate satisfactory performance.

With respect to ensuring control blade insertability under externally applied loads (i.e., safe shutdown earthquake (SSE) and loss-of-coolant accident (LOCA)), SRP 4.2 Appendix A, Section IV states:

> For a BWR, several conditions must be met to demonstrate control blade insertability – (1) combined loads on the channel box must remain below the allowable value defined above for components other than grids (otherwise, additional analysis is needed to show that the deformation is not severe enough to prevent control blade insertion) and (2) vertical liftoff forces must not unseat the lower tieplate from the fuel support piece such that the resulting loss of lateral fuel bundle positioning could interfere with control blade insertion.

The NRC staff's review of NEDE-33798P is to ensure that the introduction of NSF does not adversely impact the ability of existing BWR channel designs to satisfy these requirements.

3.0 TECHNICAL EVALUATION

The staff's review of the NEDE-33798P is summarized below:

- Verify that the fuel channel design requirements are consistent with regulatory criteria identified in SRP 4.2 or otherwise acceptable and justified.
- Verify NSF material properties based on existing material property databases and supporting mechanical testing database.
- Verify that the NSF channel designs satisfies regulatory requirements.

- Verify that the GNF experience database (in-reactor residence, post-irradiation examinations, and out-of-pile testing) supports the operating limits being requested and provides reasonable assurance that no anomalous behavior will occur during batch implementation.
- Verify that the impact of the GNF channel designs on the reload design methodology, safety analyses, and setpoints has been properly addressed.
- Define the range of applicability and allowed manufacturing tolerances/variances (e.g., alloy composition, microstructure).
- Define future surveillance and reporting requirements, as necessary.

The staff's review builds upon the NSF enhanced LUC program (Reference 3) and the operating experience and data collected from past and ongoing surveillance programs.

3.1 BWR Channel Design Requirements

In Section 1 of NEDE-33798P (Reference 1), GNF defines the design requirements for BWR channels under normal operating conditions as follows: (1) provides a guide for control blade insertion, (2) directs reactor coolant flow over the fuel rods effectively defining the flow envelope, and (3) controls the coolant flow leakage at the channel/lower tie plate interface. In addition, for transients and accident conditions, the channel (1) provides the structural stiffness for the fuel bundle to withstand fuel drop and seismic/LOCA loads and (2) transmits fuel assembly seismic loads to the top guide and fuel support. To perform these functions the channel must (1) maintain structural dimensions (i.e., avoid excessive channel distortion) and (2) maintain structural integrity (i.e., avoid failure due to stress and fatigue, avoid excessive metal thinning from corrosion). These design requirements are consistent with the SRP and, therefore, are acceptable.

3.2 NSF Composition and Microstructure

In Section 2.2 of NEDE-33798P (Reference 1), GNF describes the composition and microstructure of NSF. Zirconium metal is comprised of a hexagonal close-packed (HCP) crystalline structure at room temperature up through operating conditions (288 °C). When alloying elements are added, they either go into a solid solution or precipitate out as a second phase depending on the concentration and temperature. The alloying elements in NSF, like Zry-2 and Zry-4, result in a two-phase microstructure. In NSF, the Sn, O and portions of Nb will be in solid solution with the α-Zr matrix at operating temperatures while the remainder of the Nb and essentially all of the Fe combine with Zr to create small second phase particles (SPPs) that are distributed uniformly within an α grain structure. The SPPs in NSF have been identified to be of the $Zr(Nb,Fe)_2$ type at low and intermediate temperatures.

As with existing Zry-2 and Zry-4 channels, the standard microstructure of NSF (except in weld-zones) in channels is a fully recrystallized grain structure with uniform distribution of SPPs. The normal manufacturing process to produce channel strip begins with an ingot that is triple melted for homogeneity. The ingot is then forged, hot rolled, and beta

quenched. The beta quench dissolves all of the SPP's into solid solution at temperature to precipitate them into finer, more dispersed particles upon cooling. After beta quenching, the final thickness of the strip is then produced by a sequence of hot and cold rolling to final size with intermediate and final anneals. The cumulative annealing after beta quenching determines the SPP size while the final anneal fully recrystallizes the grain structure.

The development of NSF builds upon decades of nuclear experience with Zr-Nb-Sn-Fe alloys. NSF's nominal composition by weight percent (wt%) is: Zr (base) with 1.0% Nb, 1.0% Sn, and 0.35% Fe.

Table 2-1 of NEDE-33798P provides a comparison of nominal composition between NSF, ZIRLO™, and E635. Examination of this table reveals similar alloying composition. The specific concentrations of the major alloying elements are controlled during the ingot melting process. The allowable range of major alloying elements is provided in Table 2-2 of NEDE-33798P. Control of impurities is described in Section 2.2.3 of NEDE-33798P. In response to a request for information (RAI) regarding the range in allowable alloy composition (RAI-1, Reference 2), GNF stated that the allowable range is analogous to the composition ranges defined for Zry-2 and Zry-4 in ASTM B352/352M-11 and that quality controls similar to American Society for Testing and Materials (ASTM) and in accordance with 10 CFR Part 50 Appendix B would be maintained.

PNNL's technical assessment of NSF's composition and microstructure is provided in Section 2.0 of the TER (Reference 4). PNNL had concerns regarding the impact of variation in Sn and O content on channel performance. In response to RAI-1c (Reference 2), GNF described the impact on ultimate tensile strength (UTS), creep rate, and channel distortion. As described in further detail below, PNNL found the response acceptable. PNNL concluded that the allowable range in alloying was acceptable. Based upon this assessment, the staff finds the NSF composition, allowable range in alloying content, and microstructure acceptable.

A limitation on allowable alloying content and microstructure will be included in the staff's approval to ensure future NSF channels exhibit the same thermal, mechanical, and nuclear properties and performance as described in NEDE-33798P and in response to RAIs.

3.3 NSF Material Properties

In Sections 2.3 through 2.15 of NEDE-33798P (Reference 1), GNF describes the thermal, mechanical, and nuclear properties of NSF. PNNL's technical assessment of NSF's material properties is provided in Section 3 of the TER (Reference 4). For a majority of the material properties, GNF demonstrated that the NSF and Zry-2 properties are equivalent and the use of Zry-2 properties in design calculations is reasonable. For a few key properties, NSF showed improvement relative to Zry-2. However, this improvement was not always credited in mechanical design calculations. Table 3-1 of Reference 4 summarizes the material properties used in downstream design calculations.

In response to an RAI regarding the impact of changes in Sn and O content on NSF's UTS and yield strength (YS) (RAI-1c, Reference 2), GNF stated that design strength of NSF or any zirconium alloy is actually controlled in the material specification and requires objective evidence that the material lots meet the strength requirement. This accounts for any variability in the material strength from variation in chemistry. In Section 3.4 and 3.5 of Reference 4, PNNL reviewed the modified stress-strain models for NSF along with the design values. PNNL found these models acceptable.

In response to an RAI regarding the impact of changes in Sn and O content on NSF's creep rate (RAI-1c, Reference 2), GNF stated no significant difference in creep rate would be expected over the allowable composition range. This conclusion was supported by experimental data. PNNL found this response acceptable.

In response to an RAI regarding differences in channel growth between NSF and Zry-2 shown on Figure 2-13 of NEDE-33798P (RAI-5, Reference 2), GNF described the bases of the growth database and further evidence that NSF does not experience the breakaway growth exhibited by Zry-2. PNNL found this response acceptable.

In response to an RAI regarding differences in corrosion and hydrogen uptake between NSF and Zry-2 (RAI-3, Reference 2), GNF provided oxide thickness and hydrogen measurements from samples at nearly identical operating conditions. Examination of this database reveals that NSF has a higher corrosion rate, but significantly lower hydrogen pickup fraction relative to Zry-2. Based upon the information provided in NEDE-33798P and in response to RAI-3, PNNL found the corrosion performance of NSF channels acceptable.

In response to an RAI regarding differences steam oxidation under accident conditions between NSF and Zry-2 (RAI-3f, Reference 2), GNF provided data on oxidation measurements of NSF with and without a pre-oxidation film at 1000 ºC and compared the results with a Zr-2 specimen, which was not pre-oxidized. The NSF material with and without the pre-oxidation film behaved better than Zry-2. All of the specimens tested exhibited oxidation rates less than the Cathcart-Pawel (CP) relationship. PNNL found this response acceptable.

Based upon PNNL's assessment of NEDE-33798P and responses to applicable RAIs, the staff finds the material properties used in the mechanical design calculations for NSF channels acceptable.

3.4 NSF Operating Experience

In 2013, the NRC staff approved GNF's expanded LUC program for the NSF zirconium alloy (Reference 3). The purpose of the expanded LUC program was to allow greater numbers of NSF channels to be exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry, in order to gain experience and gather data for batch application. In response to an RAI regarding the status of the enhanced LUC

program (RAI-9, Reference 2), GNF provided details of past, ongoing, and future NSF LUCs. Upon its completion, the NSF LUC program will have amassed a significant channel performance empirical database.

The enhanced LUC program includes a monitoring program which is designed to provide a reasonable level of assurance against unanticipated channel distortion. In addition, the enhanced LUC program includes a post-irradiation inspection plan which is designed to gather data during subsequent reload cycles to identify negative trends and confirm expected performance. The inspection plan dictates specific requirements on the number and type of inspections to be performed on NSF LUCs. It is expected that the data being collected in accordance with this inspection plan on the vast quantity of NSF LUCs will provide reasonable assurance of in-reactor performance and model validation. This data will continue to be collected and will lead batch application of NSF channels.

The NSF channel operating experience database includes C-, D-, and S-Lattice plants up to a maximum of 52 GWd/MTU assembly average burnup, 2,796 days (residence), and 43,600 inch-days (effective control blade exposure (ECBE). In addition, the largest number of NSF LUCs monitored and inspected will have operated in S-Lattice plants, which are more susceptible to channel interference (due to smallest gap between blade and channel).

PNNL's technical assessment of NSF's channel surveillance program is provided in Section 5 of the TER (Reference 4). Based upon the information in NEDE-33798P and in response to RAI-9, PNNL states that the operational experience in this LUC phase supports the conclusions that NSF is resistant to fluence gradient-induced bow, resistant to shadow corrosion-induced bow, and similar to Zircaloy in creep corrosion performance.

In response to an RAI regarding the need for a future NSF surveillance and reporting requirement (RAI #10, Reference 2), GNF cited the monitoring, surveillance, and reporting requirements of the ongoing NSF LUC program. GNF identified the number of past, present, and expected future NSF channels included in this program and the large quantity of data collection. Based upon the information presented in response to RAI-9 and RAI-10, the staff finds the NSF LUC monitoring, surveillance, and reporting requirements acceptable with respect to providing sufficient confirmatory information ahead of batch applications. In addition to collecting and reporting the channel performance data, the NRC agrees with GNF that certain empirically-based models should be re-calibrated as more data becomes available. Section 5 lists conditions and limitations of the staff's approval of NSF channels. Included are requirements that the NSF LUC irradiation and data collection program continue, annual reports are provided to NRC staff, and GNF notify and provide the bases of changes in channel performance models.

3.5 NSF Performance Evaluation

GNF has requested use of NSF material on existing approved GNF channel designs. Except as described below, existing approved mechanical design requirements and calculational methods will be used to confirm the performance of GNF channels manufactured with NSF material. The staff finds the continued use of these design requirements and methods, along with the material properties described in Section 3.3, acceptable for NSF channels.

Recent operating experience has shown that channel distortion and associated control blade interference continues to be a major problem in the U.S. BWR commercial fleet. The goal of introducing NSF channel material is to resolve this issue. Contributing factors for channel distortion include (1) creep bulge, (2) fluence gradient-induced bow, and (3) shadow corrosion-induced bow. Each will be addressed below.

Creep Bulge:
Creep bulge in channels occurs because of the differential pressure between the inside and outside of the bundle. At a given axial position, the pressure drop is effectively a constant stress on the channel face that induces an elastic bulge that over time results in permanent strain. Channel deformation due to creep bulge has not been a major concern in the industry and, by itself, has not lead to control blade interference issues. The purpose of this review is to provide reasonable assurance that the use of NSF does not exacerbate creep bulge and/or introduce a new problem.

In Section 2.9 of NEDE-33798P (Reference 1), GNF describes the creep bulge mechanics and measured bulge database. PNNL's technical assessment of NSF's creep bulge model and supporting database is provided in Section 5.3 of the TER (Reference 4). In response to an RAI regarding comparable NSF and Zry-2 measured bulge (RAI-4b, Reference 2), GNF stated that the data depicted in Figure 2-11 of NEDE-33798P for both materials is from the same channel design and plant type. PNNL concluded that the creep rate of NSF channels is comparable to Zry-2 channels.

Based upon the measured creep data and PNNL's assessment, the staff finds NSF channel performance with respect to creep bulge acceptable.

Fluence Gradient-Induced Bow:
Irradiation growth is mainly attributed to the anisotropic redistribution of irradiation-induced vacancies and interstitials into dislocation loops on preferred crystallographic planes. Channel bowing occurs when a flux gradient across the channel box induces differential growth on opposite faces of the channel box. In bundles located toward the core periphery, a higher neutron flux would be experienced on the channel face toward the core interior, relative to the face toward the core periphery. Channel deformation due to fluence gradient-induced bow has been a major concern in the industry and, coupled with shadow corrosion-induced bow, has resulted in control blade interference issues. The purpose of this review is to provide reasonable assurance that NSF channels provide improved or equivalent performance or, at least, do not exacerbate fluence gradient-induced bow and/or introduce a new problem.

In Section 2.11 of NEDE-33798P (Reference 1), GNF describes the irradiation growth mechanics, model, and measured growth database. PNNL's technical assessment of NSF's irradiation growth model and supporting database is provided in Section 5.1 of the TER (Reference 4). In response to an RAI regarding the growth database (RAI-6c, RAI-6d, Reference 2), GNF provided additional data for NSF channels with EBCE > 4500 inch-days and clarified the ECBE weighting factor. Based upon the growth database, PNNL concluded that NSF channels exhibits lower and more controlled growth than Zry-2 channels. In addition, PNNL reviewed the fluence gradient-induced bow model and found it acceptable.

The database supporting the fluence gradient-induced bow performance and model is limited. As described in Section 3.4, ongoing and future NSF LUC programs are expected to provide a significant amount of new data to confirm performance and validate models. A condition on the staff's approval has been developed to document and report the NSF LUC data as it is collected. See Section 5.

Based upon the irradiation growth database, ongoing and future LUC data collection, and PNNL's assessment, the staff finds NSF's fluence gradient-induced bow performance and models acceptable. Revisions to the bow model based upon future data collection are allowed under the provisions described in Section 5.

Shadow Corrosion-Induced Bow:
Shadow corrosion is an enhanced irradiation corrosion mechanism that occurs on zirconium alloys when a dissimilar material (such as a stainless steel control blade) is near the zirconium surface (such as a BWR channel) and the water chemistry is oxygenated. When a fuel bundle is controlled early in life, the increased corrosion on the blade side relative to the non-blade side results in a difference in hydrogen absorbed in channel material. Hydrogen is absorbed into the metal as part of the corrosion process and causes a volume change resulting in channel bow.

Because direct measurement of shadow corrosion-induced bow is only possible when the fluence gradient is zero, shadow bow is generally observed by accounting for the fluence gradient induced bow. After accounting for fluence bow in the data, the end-of-life channel bow correlates well with the total effective control blade exposure (ECBE).

Prediction of shadow bow involves two parts. The first part is calculation of ECBE for each channel (this is a measure of the susceptibility to shadow-corrosion induced bow). The second part is using an empirical correlation to convert the ECBE to a corresponding shadow-induced bow.

In Sections A.2.3 and A.2.4 of NEDE-33798P (Reference 1), GNF describes the shadow corrosion-induced bow mechanics, model, and supporting database. PNNL's technical assessment of NSF's shadow corrosion bow model and supporting database is provided in Section 5.2 of the TER (Reference 4). In response to an RAI regarding the inferred shadow bow database (RAI-4, Reference 2), GNF provided additional data for NSF and Zry-2 channels operated under similar conditions. Based upon the shadow corrosion

database, PNNL concluded that NSF channels exhibits lower and more controlled shadow bow than Zry-2 channels. In addition, PNNL reviewed the shadow corrosion-induced bow model and found it acceptable.

The database supporting the shadow corrosion-induced bow performance and model is limited. As described in Section 3.4, ongoing and future NSF LUC programs are expected to provide a significant amount of new data to confirm performance and validate models. A condition on the staff's approval has been developed to document and report the NSF LUC data as it is collected (see Section 5.0 below).

Based upon the shadow corrosion bow database, ongoing and future LUC data collection, and PNNL's assessment, the staff finds NSF's shadow corrosion-induced bow performance and models acceptable. Revisions to the bow model based upon future data collection are allowed under the provisions described in Section 5.0 below.

NSF Corrosion:
As with any in-reactor material the first and foremost performance requirement is that the material withstands corrosion to the extent that it maintains structural integrity, and thus, maintains its ability to perform its design requirements. For channels, maintaining structural integrity is the only corrosion performance requirement, which in practice means that the component must maintain a minimum thickness of metal.

In Section 2.10 of NEDE-33798P (Reference 1), GNF describes the NSF corrosion model and supporting database. PNNL's technical assessment of NSF's corrosion model and supporting database is provided in Section 5.4 of the TER (Reference 4). In response to an RAI regarding the potential effect of alloying composition (RAI-1a, RAI-1b, Reference 2), GNF cited several technical papers investigating alloying composition on corrosion rates. GNF concluded that the significant margin between the measured corrosion and the design value would likely account for all variation in nominal corrosion caused by variation in ingot chemistry or from other variables such as location on the channels.

In response to an RAI regarding the NSF corrosion database (RAI-3, Reference 2), GNF provided a comparison of corrosion and hydrogen content for Zry-2, Zry-4, and NSF channels. Based upon a review of the additional data, PNNL found the oxidation performance of NSF channels acceptable.

GNF has requested approval of NSF channels with and without a pre-oxidized surface finish, which has been done in the past with Zry-4 channels. PNNL concluded that the pre-oxidized surface finish will have no detrimental impact on corrosion performance.

In response to an RAI regarding the high temperature corrosion under accident conditions (RAI-3f, Reference 2), GNF provided high temperature steam oxidation data for NSF channel material (with and without pre-oxidized surface finish) along with Zry-2 channel material. The test results show acceptable performance for the NSF material. Note that the data demonstrates the applicability of the CP correlation to NSF material. Based upon the data presented in response to RAI-3f, PNNL found the high temperature corrosion performance of NSF acceptable.

Based upon the information presented in the TR, in response to RAI-1 and RAI-3, and PNNL's assessment, the staff finds the corrosion performance of NSF acceptable.

Calculating CPR with NSF Channels:
In Section 3 of NEDE-33798P (Reference 1), GNF describes the current method for calculating CPR, specifically highlighting the dependence of R-factor on channel bow. This section is provided for information only and is intended to provide clarification on the previously approved method for establishing dependence of bundle R-factors and CPRs on channel bow. As described in Section 3.1.5, the current procedure for determining BOWAVE considers effects of initial as-manufactured channel bow and fluence-induced bow. For cores with NSF channels, a revised value of BOWAVE was requested.

PNNL's technical assessment of NSF's BOWAVE and core-average, cell-average bow (CACABO) is provided in Section 4 of the TER (Reference 4). In response to an RAI regarding further information on CACABO calculations (RAI-6, Reference 2), GNF provided sample calculations over a broad range of operating conditions. In addition, GNF provided sample calculations for channel bow and CACABO in response to RAI-7 (Reference 2).

In response to an RAI regarding uncertainties applied to R-factor calculations (RAI-7b, Reference 2), GNF responded that the same uncertainties used for Zry-2 channels, which generally show greater bow and greater scatter in the magnitude of bow, will be applied to NSF channels. PNNL found this approach acceptable.

Based upon the information provided in the TR, response to RAI-6 and RAI-7, and PNNL's assessment, the staff finds the approach for calculating CPR with NSF channels acceptable. Revisions to the R-factor uncertainty based upon NSF channel distortion measurements are allowed under the provisions described in Section 5.0 below.

3.6 Range of Applicability

In Section 4 of NEDE-33798P (Reference 1), GNF states that upon approval of this TR, NSF may be incorporated into GNF fuel designs in channels by inclusion in the GESTAR new fuel compliance reports for a specific fuel design, as supported by appropriate analysis using the properties described herein. This section did not systematically identify limitations on design and/or operation based upon the extent of data or experience. In response to an RAI regarding the range of applicability (RAI-4,

Reference 2), GNF proposed limitation on residence time, channel fluence, fuel burnup, and ECBE.

During subsequent meetings between GNF, PNNL, and NRC, the response to RAI-2 was discussed and it was determined that further limitations were required. Based upon a review of the NSF experience and database, the following limitations were identified:

1. The fully recrystallized Zr-Nb-Se-Fe alloy channel material, referred to as NSF, is restricted to the alloy composition range provided in Table 2-2 of NEDE-33798P.
2. The fully recrystallized NSF alloy channel material is approved for batch application to BWR channel designs based on currently approved design methodologies. The GESTAR II compliance report for each fuel product line describes the channels and confirms that the design meets the requirements for mechanical design, and seismic and LOCA conditions.
3. The fully recrystallized NSF alloy channel material is approved for batch application to BWR/2, BWR/3, BWR/4, BWR/5, and BWR/6 designs. NSF is also approved for batch application to ABWR and ESBWR designs.
4. The lifetime of NSF channels is restricted to the following limitations. Any fuel channel projected to exceed any of these limitations during the upcoming reload cycle shall not be loaded into the reactor, except as allowed in accordance with GNF's approved lead use program. Extended life LUC shall be limited to less than 2 percent of the channels in the core. The extended life LUC program will be exclusive of the 2 percent provision of GESTAR II for the testing of new design features in lead use assemblies. The notification and inspection requirements of this program will be consistent with the approved GESTAR II lead use program.
    a. Residence time shall not exceed 8 years.
    b. End of Life (EOL) fast fluence (>1.0 MeV) shall not exceed 1.2E22 n/cm^2 (channel average). NRC accepts the use of the surrogate 70 GWd/MTU peak pellet burnup limit to satisfy this fluence limit. Future changes in fuel assembly lattice design, fuel rod design, and/or fuel loading patterns which may invalidate this relationship needs to be evaluated and reported to the NRC.
    c. EOL ECBE shall not exceed 55,000 inch-days except to suppress power for unanticipated, emergent operational issues. If a channel exceeds 55,000 inch-days because of suppressing power for unanticipated, emergent operational issues, it shall be considered a LUC if reinserted in a following cycle.
    d. Channels shall not be re-used on different assemblies.

3.7 Incorporation of NSF into GESTAR II

By letter dated March 24, 2015 (Reference 6), GNF requested staff approval to incorporate NSF into GESTAR II. Change pages to GESTAR II (NEDE-24011-P-A) contain a brief description of NSF along with reference to NEDE-33798P. The approval date and "-A" version of the NSF TR will be updated in the future. The staff has reviewed these changes and finds them acceptable.

4.0 CONCLUSION

By letter dated February 13, 2013 (Reference 1), as supplemented by a letter dated June 10, 2015 (Reference 2), GNF requested review and approval of an advanced zirconium alloy, NSF, for application to existing BWR fuel channel designs. Recent operating experience has shown that channel distortion and associated control blade interference continues to be a major problem in the U.S. BWR commercial fleet. The goal of introducing NSF channel material is to resolve this issue. In addition, GNF requested a minor modification of the core-average, cell-average bow input to the channel-bow dependent CPR calculations.

In 2013, the NRC staff approved GNF's expanded LUC program for the NSF zirconium alloy (Reference 3). The purpose of the expanded LUC program was to allow greater numbers of NSF channels to be exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry, in order to gain experience and gather data for batch application. The data being collected in the NSF expanded LUC program provides confirmation of NSF channel performance and data to validate performance models. The NRC staff has completed its review of NEDE-33798P and finds it acceptable. Licensees referencing NEDE-33798P will need to comply with the conditions listed in Section 5.0 below.

With regard to the use of NSF channels, the staff has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the commission's regulations, and (3) issuance of this safety evaluation will not be inimical to the common defense and security or to the health and safety of the public.

5.0 CONDITIONS AND LIMITATIONS

Licensees referencing NEDE-33798P must ensure compliance with the following conditions and limitations:

1. The range of applicability of NSF channels is limited to those items described in Section 3.6 of this safety evaluation (SE).
2. The expanded NSF LUC program monitoring and inspection plan, detailed in Section 3.2 of the staff's SE (MFN 12-074 Supplement 2-A), must be completed.
3. The quantity of LUCs, exposures achieved, and post-irradiation examinations and data collection shall be consistent with GNF's response to RAI-9 and RAI-10 of NEDE-33798P.
4. To ensure continued in-reactor performance and applicability of NSF models, GNF must provide an annual report, addressed to the Director, Division of Safety Systems, Office of Nuclear Reactor Regulations, documenting the ongoing experience with the enhanced NSF LUC program, post-irradiation examinations and data collection, and validation of NSF models. At a minimum, the annual report must contain the following information:

a. Plot of NSF channel irradiation database, expressed as ECBE versus exposure.
b. Plot of measured channel growth versus fast neutron fluence data, along with NSF growth model predictions.
c. Plot of measured channel bulge versus exposure data.
d. Plot of measured channel bulge data versus NSF channel bulge model predictions.
e. Plot of measured channel distortion (total) versus exposure data, segregating low and high ECBE data.
f. Plot of inferred shadow corrosion bow versus ECBE data, along with NSF shadow bow model predictions.

Data collected within the prior annual period should be clearly delineated. The annual report is no longer required once all of the NSF enhanced LUCs have achieved the program EOL exposure and data has been reported. Note that item 6 below may necessitate a future report beyond the LUC program lifetime.

5. Based upon post-irradiation examinations and data collection, as described in items 2, 3, and 4, above, GNF may alter the NSF channel growth model, bow and bulge models, and shadow corrosion model to achieve an improved fit to the database. These channel distortion models will be a nominal fit to the data. The model uncertainty is defined as a standard deviation calculated using standard mathematical formulas. Any data eliminated from the model calibration should be identified and justified. Any changes to these models must be documented within the annual report described in item 4 above.
6. BWR channel distortion – control blade interference counter measures, including fuel management guidelines and augmented monitoring and inspection programs as described in MFN 10-245 (most recent version), will continue to be applied for cores containing NSF channels. These counter measures may be eliminated once a full core of NSF channels has experienced no observations of control blade-to-channel interference (e.g., slow to settle, no settle, delayed scram) for 3 consecutive years within an S-lattice design. Elimination of the counter measures should be documented in the annual report similar to that described in item 4 above.
7. Any future change in the R-factor uncertainty based upon incorporation of NSF channel distortion measurements must be justified and documented in the annual report similar to that described in item 4 above.

6.0 REFERENCES

1. GNF Letter MFN 13-008, “Application of NSF to GNF Fuel Channel Designs,” NEDC-33798P, February 13, 2013, ADAMS Accession No. ML13045A456.
2. GNF Letter MFN 15-040, “Response to Request for Additional Information Regarding Review of Licensing Topical Report NEDE-33798P, ‘Application of NSF to GNF Fuel Channel Designs’ (TAC No. MF0742),” June 10, 2015, ADAMS Accession No. ML15161A508.
3. GNF Letter MFN 12-074, Supplement 2-A, “Enhanced LUC Program for NSF Channels,” April 15, 2013, ADAMS Accession No. ML13106A067.

4. PNNL Technical Evaluation Report, “NEDE-33798P, Revision 0, Application of NSF to GNF Fuel Channel Designs, February 2013,” ADAMS Accession No. ML15211A015.
5. NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants” (SRP), Section 4.2, “Fuel System Design,” Revision 3, March 2007, ADAMS Accession No. ML070740002.
6. GNF Letter MFN 13-008, Supplement 2, “Incorporation of the Approved Topical Report NEDE-33798P, ‘Application of NSF to GNF Fuel Channel Designs’, into GESTAR II,” March 24, 2015, ADAMS Accession No. ML15083A301.

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Date: September 1, 2015

Comment Resolution
Summary for Draft Safety Evaluation for NEDE-33798P,
"Application of NSF to GNF Fuel Channel Designs"

Location in MFN 15-071 Markup	**Comment**	**NRC Disposition**
Section 3.3 NSF Material Properties	Page 6 (2nd to last paragraph in Section 3.3 GNF suggests the following changes: "The NSF material with and without the pre-oxidation film behaved better than Zry-2"	Comment accepted. Change incorporated in final SE.
Section 3.4 NSF Operating Experience	Page 6 (2nd paragraph in Section 3.4) GNF suggests the following changes: "In addition, **the enhanced LUC program includes** a post-irradiation plan which is designed to gather data during subsequent reload cycles to identify negative trends and confirm expected performance."	Comment accepted. Change incorporated in final SE.