ENCLOSURE 2

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Revision 7 of NEDO-33798 Supplement 1, "NSF Channel Annual Experience Summary Report"

Non-Proprietary Information

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Global Nuclear Fuel

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NEDO-33798 Supplement 1
Revision 7
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Non-Proprietary Information

NSF Channel Annual Experience Summary Report

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REVISION SUMMARY

Revision	Revision Description
0	2016 Initial Release
1	2017 Initial Release
2	2018 Initial Release
3	2019 Initial Release
4	2020 Initial Release
5	2021 Initial Release
6	2022 Initial Release
7	2023 Initial Release

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SUMMARY

This annual report for 2023 provides a summary of the ongoing experience with Global Nuclear Fuel's (GNF's) NSF channels as required by the Nuclear Regulatory Commission's (NRC's) conditions and limitations that are stipulated as a condition for the licensing of NSF channel material in reload quantities.

New poolside inspections of NSF reload channels from one United States (US) Boiling Water Reactor (BWR) have been completed since the 2022 annual report. These new measurements of channel bow and bulge add to the experience base and continue to demonstrate the expected low distortion behavior for NSF channels.

All NSF mini-batches that are available for inspection have now had their required inspections completed. The NSF mini-batch inspection for one host mini-batch BWR D-lattice plant was unable to be completed due to the early, permanent shutdown of the host plant before the planned irradiation period for the NSF channels was completed. However, a limited number of NSF channels from a reload batch in a different D-lattice plant have been inspected and reported in 2023 as a like-kind replacement to validate the performance of NSF in D-lattice plants.

All conditions and limitations of the NSF Licensing Topical Report (LTR) Safety Evaluation (SE) that require annual reporting are met by this report.

ACRONYMS

Acronym	Explanation
BWR	Boiling Water Reactor
CHAM	CHAnnel bulge Measurement system
ECBE	Effective Control Blade Exposure
GNF	Global Nuclear Fuel
GNF-A	Global Nuclear Fuel - Americas
LTR	Licensing Topical Report
LUA	Lead Use Assembly
LUC	Lead Use Channel
NRC	Nuclear Regulatory Commission
NSF	Zr-Sn-Nb-Fe Alloy
R-factor	Weighted rod power local peaking for critical power calculations
SE	Safety Evaluation
SimCHAD	Simplified ChAnnel Dimensional measurement system
US	United States

1.0 INTRODUCTION

Global Nuclear Fuel (GNF) proposed the use of its NSF[1] channel material as a material solution that could mitigate channel to control blade interference that emerged in the early 2000s as an operational concern. The benefit of NSF arises from its resistance to both fluence gradient-induced bow and shadow corrosion-induced bow. GNF loaded NSF Lead Use Channels (LUCs) in several United States (US) and European Boiling Water Reactor (BWR) plants starting in 2002 to gain experience with the material. An expanded LUC program that allowed up to 8% LUCs was approved by the Nuclear Regulatory Commission (NRC) in 2013 (MFN 12-074 Supplement 2-A, Reference 1).

Approval of the 8% LUC program included Condition and Limitation 3 to visually inspect and measure the length[2] of [[ ]] of the LUCs during each outage, and upon discharge to visually inspect and measure the length of [[ ]] of the LUCs and to measure the distortion (bow and bulge) of [[ ]] of the LUCs. The NRC approved the batch application of NSF channels in September 2015 (MFN 15-076, Reference 2). The expanded NSF LUC program monitoring and inspection plan, detailed in Section 3.2 of the MFN 12-074 Safety Evaluation (SE) report, must be completed as a requirement of the batch application approval. In addition, the batch approval requires the submittal of an annual NSF experience report to the NRC, until the conditions specified in MFN 15-076 (Reference 2) are met, to ensure continued in-reactor performance and applicability of NSF models.

The NSF mini-batch inspections for one host mini-batch BWR D-lattice plant were unable to be completed due to the early, permanent shutdown of the host plant before the planned irradiation period for the NSF channels was completed. However, a limited number of NSF channels from a reload batch in a different D-lattice plant have been inspected and reported in 2023 to validate the performance of NSF in D-lattice plants.

1.1 PURPOSE

The purpose of this report is to provide an annual NSF experience report to satisfy NRC requirements set forth in the SE report as a condition for the licensing of GNF's NSF channel material in reload quantities as specified in MFN 15-076 (Reference 2).

1.2 SCOPE

The scope of this NSF annual experience report provides a summary of the specific items that are required to be reported as set forth in the SE in Condition and Limitation 4 (Reference 2). These required items are the following:

a. Plot of NSF channel irradiation database, expressed as Effective Control Blade Exposure (ECBE) versus exposure.

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[1] NSF derives its name from the alloying elements used in a new channel material developed by GNF; Zr-Nb-Sn-Fe.

[2] Length measurements are used to determine the channel growth.

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 bow versus ECBE data, along with NSF shadow bow model predictions.

Since the 2022 annual report was issued (Reference 3), the new data available for items a through f, above, are channel distortion measurements (bow and bulge) of 20 reload channels from one US BWR/4 D-Lattice plant. These are reload channels so there are no specific, formal inspection or reporting requirements for them as there are with the mini-batch LUCs; however, they do supplement required inspections of D-lattice mini-batch channels that were unable to be completed for one plant that was permanently shutdown before the planned irradiation could be completed. All plots for items a through f are provided in this annual report regardless of whether they have been updated with new data since the 2022 annual report.

SE Condition and Limitation 5 (alterations to distortion models), 6 (elimination of channel-control blade interference counter measures), and 7 (changes in R-factor uncertainty) specified in Reference 2 require reporting when changes have been made. Because no changes were made in this annual reporting cycle, they are not included herein.

2.0 NSF CHANNEL INSPECTIONS AND PERFORMANCE

2.1 INSPECTIONS

New US poolside inspections of NSF reload channels from one US BWR/4 D-Lattice plant have been completed since the 2022 annual report (Reference 3). Inspection of these channels included bow and bulge measurement using GNF's Simplified CHAnnel Dimensional measurement system (SimCHAD) on all 20 channels and length measurement of one of the channels.

Details of the inspection included in this report are summarized in Table 2-1 and Table 2-2. The inspected channels represent a range of exposure and ECBE conditions. Currently, the irradiated NSF bow, bulge, and length measurement data encompasses the burnups and ECBEs shown in Figure 2-1 (Condition and Limitation 4.a). The database is bounded with [[ ]] channel exposure and [[ ]] ECBE.

2.2 PERFORMANCE

The measured growth, creep bulge, total distortion, and inferred shadow corrosion bow for NSF channels are summarized in the following sections. Comparisons are made to Zircaloy-2 in some cases to show the broader context in which the data exist.

2.2.1 NSF Channel Growth

Consistent with Condition and Limitation 4.b, NSF channel growth measurements, based on a calibrated tape measure, are shown in Figure 2-2 as a percentage change from the nominal original length. There is one new growth measurement since the 2022 annual report. The data shows that NSF growth is trending with fluence above and below the current model line and does not indicate that NSF's distortion model requires modification. At high fluence, the population of NSF channels continues to [[ ]] channels that start to exhibit signs of breakaway growth initiation between [[ ]] fast fluence.

2.2.2 NSF Channel Creep Bulge

Consistent with Condition and Limitation 4.c, the measured channel creep bulge based on SimCHAD as a function of exposure is shown in Figure 2-3 for 100/65/50 mil NSF channels, in Figure 2-4 for 120/75 mil NSF channels, and in Figure 2-5 for GNF3 Lead Use Assembly (LUA) 93/60 mil NSF channels. Data are plotted for the [[ ]] inch elevations. The new 100/65/50 mil NSF channel bulge measurements made in 2023 are included. In addition, bulge measurements based on the CHAnnel bulge Measurement system (CHAM) for the [[ ]] inch elevations are included in Figure 2-5 for the GNF3 LUAs with 93/60 mil channel. NSF creep bulge is [[ ]] based on the available data. Maximum bulge is approximately [[ ]], with most bulges being less than [[ ]].

Consistent with Condition and Limitation 4.d, the measured bulges compared to predicted values at the [[ ]] inch elevations are shown in Figures 2-6 and 2-7 for 100/65/50 mil and 120/75 mil NSF contoured channels, respectively. The new 100/65/50 mil NSF channel bulge measurements made in 2023 are included. The model tends to predict bulge relatively well but tends to be overpredicted a small amount, especially for the thinner channel type. Bulge

uncertainty is currently set at [[ ]] for the thinner channel type, which covers some of the variation in the data.

2.2.3 NSF Channel Total Bow Distortion

Consistent with Condition and Limitation 4.e, the measured total bow distortion as a function of exposure for NSF channels is shown in Figure 2-8. The new bow measurements made in 2023 are included. NSF's total bow distortion is [[ ]] about the zero-distortion axis between [[ ]]. NSF total bow distortion is [[ ]] and less variable compared to that of Zircaloy-2 channels, for a wide range of plants and operating conditions.

2.2.4 NSF Channel Inferred Shadow Corrosion Bow

Consistent with Condition and Limitation 4.f, the inferred shadow corrosion bow data from NSF channels in S-Lattice and C-Lattice plants are plotted versus ECBE in Figure 2-9. The new data from the 2023 measurements are included. A comparison of NSF's inferred shadow corrosion bow data to its current S120/C100 NSF shadow corrosion bow model, shown in Figure 2-9, demonstrates that there is good agreement between the model and data and therefore no modifications to the NSF shadow corrosion bow model are warranted. A comparison of NSF's shadow corrosion bow data to Zircaloy-2 channels for exposures greater than [[ ]] is also provided in Figure 2-9, which demonstrates that NSF has superior shadow corrosion bow performance relative to Zircaloy-2.

NSF D-Lattice data is also shown in Figure 2-9, which includes four prior measurements and the 20 new measurements made in 2023. As with [[ ]], the NSF D-Lattice and S-Lattice/C-Lattice models are [[ ]]. The NSF D-Lattice model is [[ ]] D-Lattice model, and the NSF D-Lattice and S-Lattice/C-Lattice models are [[ ]] over most of the ECBE range due to the [[ ]]. Near the [[ ]] ECBE saturation point, the S-Lattice/C-Lattice and D-Lattice NSF models diverge about [[ ]] but are much closer to each other at [[ ]]. The NSF D-Lattice shadow bow is similar to the shadow bow of the other lattice types, and no modifications to the D-Lattice NSF shadow corrosion model are warranted.

Table 2-1 NSF 2022-2023 Reporting Period Channel Inspections (Plants and Classifications)

Plant	Plant Type	Number of Channels in Program	Use Classification	Last Operating Cycle #/Date	Inspection Date
[[					]]

Table 2-2 Operating History Summary of NSF Channels Inspected in 2022-2023 Reporting Period

Plant	Use Classification	No. of Inspected Channels	Inspection Scope	Range Bundle Exposure (GWd/MTU)	Range ECBE (inch-days)	Fuel Design
[[ ]]	Reload	20	SimCHAD	[[	]]	GNF2

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Figure 2-1 Range of Exposure and ECBE for Irradiated NSF Channel Distortion and Length Measurement Database

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Figure 2-2 GNF Channel Growth Data and NSF Irradiation Growth Data

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Figure 2-3 Measured Creep Bulge versus Exposure for NSF 100/65/50 mil Channels

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Figure 2-4 Measured Creep Bulge versus Exposure for NSF 120/75 mil Channels (no new data for 2023)

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Figure 2-5 Measured Creep Bulge versus Exposure for NSF 93/60 mil GNF3 Channels (no new data for 2023)

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Figure 2-6 Measured Creep Bulge versus Predicted Creep Bulge for NSF 100/65/50 mil Channels

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Figure 2-7 Measured Creep Bulge versus Predicted Creep Bulge for NSF 120/75 mil Channels (no new data for 2023)

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Figure 2-8 Measured Total Channel Distortion versus Exposure for NSF and Zircaloy-2 Channels

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Figure 2-9 Plot of Inferred Shadow Bow versus ECBE for NSF and Zircaloy-2 Channels

3.0 REFERENCES

1. Letter, Andrew A. Lingenfelter (GNF) to Document Control Desk (NRC), "Accepted Version of Enhanced Lead Use Channel (LUC) Program for NSF Fuel Bundle Channels," MFN 12-074 Supplement 2-A, April 15, 2013.

2. Letter, Brian R. Moore (GNF) to Document Control Desk (NRC), "Approved Version of NEDE-33798P Revision 0, 'Application of NSF to GNF Fuel Channel Designs'," MFN 15-076, September 30, 2015.

3. Letter, Brian R. Moore (GNF) to Document Control Desk (NRC), "NEDE-33798P Supplement 1, Revision 6, 'NSF Channel Annual Experience Summary Report'," M230003, January 6, 2023.