ENCLOSURE 2

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Revision 1 of NEDO-33798 Supplement 1, “NSF Channel Annual Experience Summary Report”

Non-Proprietary Information - Class I (Public)

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Global Nuclear Fuel

NEDO-33798 Supplement 1

Revision 1

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Non-Proprietary Information – Class I (Public)

NSF Channel Annual Experience Summary Report

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REVISION SUMMARY

Revision	Revision Description
0	2016 Initial Release
1	2017 Initial Release

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SUMMARY

This annual report for 2017 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 twenty NSF channels from seven different Boiling Water Reactors (BWRs) have been completed between October 2016 and May 2017. In addition, the results of an eighth inspection of four NSF channels that was completed in March 2016 but were not available for inclusion in the annual report issued in October 2016 are also included now. New measurements of growth and creep bulge add to the experience base and continue to demonstrate the expected behavior for NSF channels. There are no new measurements of total channel distortion or inferred shadow corrosion-induced bow; however plots of prior measurements are recapped which demonstrate the expected behavior of NSF channels. 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
ECBE	Effective Control Blade Exposure
EOC	End-of-Cycle
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
PWR	Pressurized Water Reactor
R-factor	Weighted rod power local peaking for critical power calculations
SE	Safety Evaluation
SIMCHAD	Simplified Channel Dimensional Measurement Device
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) 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 to ensure continued in-reactor performance and applicability of NSF models.

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.

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.

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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. This alloy is comparable to Zircaloy-2 (Zr-Sn-Fe-Cr-Ni) and Zircaloy-4 (Zr-Sn-Fe-Cr). It was developed based on applications in Pressurized Water Reactor (PWR) (Zirlo) and Russian (Zr-Nb) fuel components.

2 Length measurements are used to determine the channel growth.

f. Plot of inferred shadow bow versus ECBE data, along with NSF shadow bow model predictions.

Since the 2016 annual report (Reference 3), the only new data for the plots noted in items a through f, above, are channel growth measurements and very limited bulge measurements from a Lead Use Assembly (LUA) of a new fuel bundle design, GNF3. However, all plots noted in items a through f, above, are provided in this 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

Seven new poolside inspections of a total of twenty NSF channels have been completed since the October 2016 annual report (Reference 3). The inspections included fifteen channels categorized as part of the 8% expanded NSF LUC program, three channels categorized as a 2% LUC, one channel categorized as a GNF2 LUA, and one channel categorized as a GNF3 LUA. None of the 8% LUC channels were discharged and therefore their inspection requirements were to perform visual inspection and length measurements on [[ ]] of the NSF LUC batch size, or [[ ]] channels. In addition, length measurement results from an eighth inspection of four NSF channels in the 8% expanded LUC program that had been performed in 2016, but were unavailable for the 2016 annual report, are also included in this report.

The eight inspections included in this report are summarized in Table 2-1, and details of the inspected channels are summarized in Table 2-2, which include a range of exposure and ECBE conditions. Currently, the irradiated NSF Simplified Channel Measurement Device (SIMCHAD) and length measurement database 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, new 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. New growth measurements are also compared to prior measurements in Figure 2-2. 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.

Measurements of the Pilgrim channel length were not able to be performed by tape measure; however, visual inspection indicated that the channel growth relative to the fuel assembly was not excessive.

2.2.2 NSF Channel Creep Bulge

Consistent with Condition and Limitation 4.c, the measured channel creep bulge as a function of exposure is shown in Figure 2-3 for 100T NSF channels, in Figure 2-4 for 120T NSF channels, and in Figure 2-5 for GNF3 LUA 93/63 NSF channels. Data are plotted for the [[ ]] inch elevations. In addition, measurements for the [[ ]] inch elevations are included in Figure 2-5 for the GNF3 LUA. Within these three figures, only the GNF3 LUA bulge data shown in Figure 2-5 is new. NSF creep bulge at these elevations is [[ ]]. Maximum bulge is approximately [[ ]], with most bulges being less than [[ ]]. Consistent with Condition and Limitation 4.d, the measured bulges compared to predicted values are shown in Figures 2-6 and 2-7 for 100T and 120T NSF channels, respectively. The model tends to predict bulge well for the available data, with some over prediction mostly at [[ ]] inches. Bulge uncertainty is currently set at [[ ]] and covers much of the variation in the data, thus no changes to the NSF bulge model are warranted. The bulge model for the new GNF3 LUA has not been finalized and therefore its predictive comparison is not provided in this annual report. However, the GNF3 channel bulge is bounded by predictions for the 100T and 120T designs.

2.2.3 NSF Channel Total Distortion

Consistent with Condition and Limitation 4.e, the measured total distortion as a function of exposure for NSF channels is shown in Figure 2-8. No new distortion measurements have been performed since the 2016 annual report. NSF's total distortion is [[ ]] about the zero-distortion axis between [[ ]]. Maximum distortion for NSF channels with ECBE [[ ]] compared to NSF channels with ECBE [[ ]]. NSF total distortion is [[ ]] compared to that of Zircaloy-2 channels.

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 NSF data is segregated into exposures less than [[ ]] and greater than [[ ]]. No new shadow corrosion bow measurements have been performed since the October 2016 annual report. A comparison of NSF's inferred shadow corrosion bow data to its current S120T/C100T 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; however, there are only [[ ]]. As with [[ ]], the D-Lattice and S-Lattice/C-Lattice NSF 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 [[ ]] channels in the NSF D-Lattice population are bounded by either the [[ ]],

and with such [[
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Table 2-1 NSF 2016-2017 Channel Inspections (Plants and Classifications)

Plant	Plant Type	Number of Channels in Program	Use Classification	Operating History	Inspection Date and Cycle
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* The growth data field inspection report was not finalized at the time that the 2016 annual report was issued; therefore, the length data is included in this report..

Table 2-2 Summary of NSF Channels Inspected in 2016-2017

Plant	ID	Inspection Date and Cycle	Inspection Scope	Bundle Exposure (GWd/MTU)	ECBE (inch-days)	Fuel Design
[[	GER322	[[	Visual, Growth	[[		GNF2
	GER157		Visual, Growth			GNF2
	GER160		Visual, Growth			GNF2
	GER176		Visual, Growth			GNF2
	YLE900		Visual, Bulge			GNF3
	SGE142		Visual, Growth			GNF2
	SGE201		Visual, Growth			GNF2
	SGE206		Visual, Growth			GNF2
	14P199		Visual, Growth			GE14
	14P221		Visual, Growth			GE14
	14P223		Visual, Growth			GE14
	16P841		Visual, Growth			GNF2
	16P851		Visual, Growth			GNF2
]]	16P857	]]	Visual, Growth		]]	GNF2

Table 2-2: Summary of NSF Channels Inspected in 2016-2017 (continued)

Plant	ID	Inspection Date and Cycle	Inspection Scope	Bundle Exposure (GWd/MTU)	ECBE (inch-days)	Fuel Design
[[	YLF318	[[	Visual, Growth	[[		GNF2
	YLF323		Visual, Growth			GNF2
	YLF328		Visual, Growth			GNF2
	YLE510		Visual, Growth			GNF2
	YLE584		Visual, Growth			GNF2
	YLE585		Visual, Growth			GNF2
	JYP723		Visual, Growth			GNF2
	YLG419		Visual, Growth			GNF2
	YLG397		Visual, Growth			GNF2
]]	YLG459	]]	Visual, Growth		]]	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 100T Channels

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Figure 2-4 Measured Creep Bulge versus Exposure for NSF 120T Channels

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Figure 2-5 Measured Creep Bulge versus Exposure for NSF 93/63 Channels

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Figure 2-6 Measured Creep Bulge versus Predicted Creep Bulge for NSF 100T Channels

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Figure 2-7 Measured Creep Bulge versus Predicted Creep Bulge for NSF 120T Channels

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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, "NSF Channel Annual Experience Summary Report"," MFN 16-061, October 25, 2016.