ENCLOSURE 2

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Non-Proprietary Information

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Global Nuclear Fuel

NEDO-33798 Supplement 1
Revision 3
October 2019

Non-Proprietary Information

NSF Channel Annual Experience Summary Report

INFORMATION NOTICE

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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

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SUMMARY

This annual report for 2019 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 five Boiling Water Reactors (BWRs) operating in the United States (US) have been completed between September 2018 and June 2019. New measurements of channel growth add to the experience base and continue to demonstrate the expected behavior for NSF channels. There are two new channel bulge measurement datasets but there are no new measurements of total channel distortion or inferred shadow corrosion-induced bow. Where no new data exists, plots of prior measurements are recapped which demonstrate the expected behavior of NSF channels.

Pilgrim station permanently ceased power generation operations in May 2019. Pilgrim was hosting an NSF mini-batch program that ended its second cycle coincident with the plant closure, which disrupted plans to operate and inspect the mini-batch out to three cycles. As a result, there is no possibility to inspect the Pilgrim channels after a third cycle, and, likewise, plans to inspect 5% of the mini-batch after the second cycle were abandoned. GNF intends to fill the gap in NSF performance monitoring in D-lattice plants by completing the equivalent scope from inspections of NSF LUCs or reload channels in other BWR 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
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) 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 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.

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 2018 annual report was issued (Reference 3), the only new data available for items a through f, above, are channel growth measurements of twenty channels from five US plants and bulge measurements of three channels from two US plants. All plots for items a through f are provided in this annual report, however, only plots for items a, b, and c that have new data are updated.

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

Five new US poolside inspections that included a total of twenty NSF channels categorized as an 8% LUC "mini-batch", 2% LUC, or GNF3 LUAs have been completed since the September 2018 annual report (Reference 3). Inspection of these channels included visual and length measurements, as well as bulge measurements of some. 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.

The US 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 Dimensional Measurement Device (SIMCHAD), Channel Bulge Measurement (CHAM), and length measurement database encompasses the burnups and ECBEs shown in Figure 2-1 (Condition and Limitation 4.a). The database is now bounded with [[ ]] channel exposure and [[ ]] ECBE.

Eight of the inspected NSF 2% LUC program channels from Limerick 1 and Perry attained relatively high exposure (>47 GWd/MTU), three of which from Perry are slightly above the previous maximum exposure of an inspected NSF channel.

Pilgrim station permanently ceased power generation operations in May 2019. Pilgrim was hosting an NSF mini-batch program that ended its second cycle coincident with the plant closure, which disrupted plans to operate and inspect the mini-batch out to three cycles. As a result, there is no possibility to inspect the Pilgrim channels after a third cycle, and, likewise, plans to inspect 5% of the mini-batch after the second cycle were abandoned. GNF intends to fill the gap in NSF performance monitoring in D-lattice plants by completing the equivalent mini-batch inspection scope from inspections of NSF LUCs or reload channels in other BWR D-lattice plants.

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.

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 Lead Use Assembly (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 LUAs. 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 overprediction 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.

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 in US plants since the 2018 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 in US plants since the 2018 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 [[ ]]

Table 2-1 NSF 2018-2019 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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Table 2-2 Summary of NSF Channels Inspected in 2018-2019

Plant	ID	Inspection Date and Cycle	Inspection Scope	Bundle Exposure (GWd/MTU)	ECBE (inch-days)	Fuel Design
[[	YLE901	[[	Visual, Bulge	[[		GNF3
	YLE903		Visual, Bulge			GNF3
	14P198		Visual, Growth			GE14
	14P199		Visual, Growth			GE14
	14P221		Visual, Growth			GE14
	14P222		Visual, Growth			GE14
	14P223		Visual, Growth			GE14
	16P850		Visual, Growth			GNF2
	16P860		Visual, Growth			GNF2
	16P880		Visual, Growth			GNF2
	JYU102		Visual, Growth			GNF2
	JYU105		Visual, Growth			GNF2
	JYU108		Visual, Growth			GNF2
	YLF322		Visual, Growth			GNF2
]]	YLF336	]]	Visual, Growth		]]	GNF2

Table 2-2 Summary of NSF Channels Inspected in 2018-2019 (Continued)

Plant	ID	Inspection Date and Cycle	Inspection Scope	Bundle Exposure (GWd/MTU)	ECBE (inch-days)	Fuel Design
[[	YLF347	[[	Visual, Growth	[[		GNF2
	SGE142		Visual, Growth			GNF2
	SGE201		Visual, Growth			GNF2
	SGE206		Visual, Growth			GNF2
]]	SGE225	]]	Visual, Bulge		]]	GNF3

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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 93/60 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, Revision 2, 'NSF Channel Annual Experience Summary Report'," M180163, September, 2018.