ENCLOSURE 2

M200061

1Q20 GNF ATF Quarterly Meeting Presentation

Non-Proprietary Information

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1, from which the proprietary information has been removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[ ]].

Non-Proprietary Information

Global Nuclear Fuel

1Q20 GNF/NRC ATF Workshop

March 11, 2020

Agenda

Time		Topic	Who
2:00	15	Public: Introductions and Opening Remarks	Halac
2:15	10	Public: NRC Public Update on ATF	NRC ATF PM
2:25	5	Public: Opportunity for Public Comment	Public
2:30	50	ARMOR Testing Update	Lin
3:20	30	ARMOR SAFDL Treatments	Porter
3:50	20	ARMOR Upscaling Qualification Linkages	DeSilva
4:10	15	Integrated Schedule for Licensing (RIS-2019-03)	McCumbee
4:25	10	ATF LTA Update (Clinton / Hatch)	Halac
4:35	15	Public: Closing Summary and Comment	NRC ATF PM
4:50		Adjourn	

Introductions

Workshop Agenda Objectives

Workshop Outlook

- Informal Discussions
  - Non-binding information exchange
  - Results shared in an open/candid forum
  - Recommendations welcomed
  - Understanding that shared information is specific to ARMOR and is Confidential GNF-A Intellectual Property
- Primary Scope: Requirements to license new cladding/coating technologies in reload quantities
- Content/Agenda (Determined by mutual agreement)
  - Provide additional information on questions identified from previous meeting
  - Furnish focused project updates on aspects of interest

NRC Public Update on ATF

Public Comment

ARMOR Testing Update

Material Testing - Introduction

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Thermal Conductivity (Supporting Data)

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Thermal Conductivity (Summary Observations)

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Explicit Thermal Conductivity ([[ ]] and Literature)

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Specific Heat (Supporting Data)

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Specific Heat (Summary Observations)

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Thermal Expansion (Supporting Data)

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Thermal Expansion (Summary Observations)

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Explicit Thermal Expansion ([[ ]]) [[

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Enthalpy and Heat of Reaction (Supporting Data)

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Enthalpy and Heat of Reaction ([[ ]])

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Density (Supporting Data)

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Density (Summary)

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High Temperature Steam Oxidation Rate (Supporting Data)

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HTO – Post-Test Characterization

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Post HTO TEM

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High Temperature Ballooning Behavior (Supporting Data)

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Burst Temperature vs. Burst Stress

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Burst Opening Bulge and Strain Examples

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Post Burst Test Characterization

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Post Quench Ductility (Supporting Data)

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Cladding PQD/RCT Offset Strain Summary

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Emissivity (Supporting Data)

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Emissivity (Summary Observations)

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Eutectic Study (Supporting Data)

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Non-Proprietary Information

Eutectic Study (preliminary results)

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Global Nuclear Fuel

Poisson's Ratio (Supporting Data)

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Poisson's Ratio ([[ ]])

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Tritium Diffusion (Supporting Data)

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Tritium Diffusion ([[ ]])

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Tensile Properties (Supporting Data)

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Tensile Properties (Summary Observations)

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Thermal Creep (Supporting Data)

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Thermal Creep Out (Summary Observations)

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Thermal Creep Out (Summary Observations)

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Thermal Creep In (Summary Observations)

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Fatigue (Supporting Data)

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Fatigue (Summary Observations)

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Micro-scale testing (Supporting Data)

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[[Non-Proprietary Information

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Hatch LTA Inspection

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- LTA inspection after 1 Cycle operation completed in February 6-9, 2020
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- Segments successfully harvested

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LTA Inspection – Initial results

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Residual Stress (Supporting Data)

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Residual Stress – [[

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Residual Stress – [[ ]]

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Global Nuclear Fuel

PRIME Approach for Best-Estimate Modeling ARMOR

NRC ARMOR Workshop | 11 March 2020

PRIME Approach Option #1

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PRIME Approach Option #2

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Modeling of ARMOR

- PRIME does not allow for an explicit modeling of a coating layer.
- Therefore, [[ ]]
- Within PRIME, the oxide layer has two impacts on performance:
  - [[ ]]
- The oxide layer itself has no impact on the mechanical behavior
- To simulate any mechanical changes, [[ ]]

Modeling of ARMOR (Mechanical)

The following mechanical properties were updated for ARMOR by altering the approved Zirc-2 properties:

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Modeling of ARMOR (Thermal)

The thermal impact of ARMOR is being simulated by the following:

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Modeling of ARMOR (Crud / Corrosion)

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Modeling of ARMOR (Corrosion)

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ARMOR SAFDL Treatments

Non-Proprietary Information

Objective

- To provide a high level overview of the ARMOR LTR SAFDL approach

Area	SAFDL	ISG Concern?
Assembly Performance	Rod Bow	Yes
	Irradiation Growth	No
	Hydraulic Lift Loads	No
	Fuel Assembly Lateral Deflections	No
	Fretting Wear	Yes
Normal Operation + AOOs	Cladding Stress	No
	Cladding Strain	Yes
	Cladding Fatigue	Yes
	Cladding Oxidation, Hydriding, and CRUD	Yes
	Fuel Rod Internal Pressure	Yes
	Internal Hydriding	No
	Cladding Collapse	Yes
	Overheating of Fuel Pellets	No
	Pellet-to-Cladding Interaction	No
	Boiling Crisis	Yes
Accident Conditions	Overheating of the Cladding	Yes
	Excessive Fuel Enthalpy	Yes
	Bursting	Yes
	Mechanical Fracturing	No
	Cladding Embrittlement	Yes
	Violent Expulsion of Fuel	No
	Generalized Cladding Melting	Yes
	Fuel Rod Ballooning	Yes
	Structural Deformation	No
Coating Specific	Coating Cracking	Yes
	Coating Delamination	Yes
	ARMOR-Zr Interdiffusion	Yes
	Radiation Effects	Yes
	Subsurface Damage	Yes
	Residual Stress	Yes
	Galvanic Corrosion	Yes
	Defects	Yes
	Eutectic Formation	Yes

SAFDL Approach - Overview

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Example - Cladding Fatigue

PRIME LTR
NEDC-33258P-A

- SRP-4.2
  The cumulative number of strain fatigue cycles ... should be significantly less than the design fatigue lifetime, which is based on appropriate data and includes a safety factor of 2 on stress amplitude or a safety factor of 20 on the number of cycles. Other proposed limits must be justified.

- ISG
  Fatigue data from irradiated cladding that was produced using a representative process for the applicant in question is recommended to either confirm the O'Donnell and Langer irradiated fatigue curve or to develop a new fatigue design curve.

- GESTAR II 1.1.2.B.i
  The GE criteria for evaluating cladding fatigue is that the fuel rod and assembly component stresses, strains and fatigue life usage shall not exceed the material ultimate stress or strain and the material fatigue capability.

LTR Content

Section 3.1.2.3 – Cladding Fatigue

The addition of the ARMOR coating [[ ]] the requirement that the number of strain fatigue cycles be significantly less than the design fatigue lifetime. Therefore, the GESTAR basis that the fatigue life usage shall not exceed the material fatigue capability [[ ]].

- [[ ]]

Coating Specific SAFDLs

ISG: 9 New Degradation Mechanisms / Other Considerations

These may either be addressed by applicants through existing limits or as separate limits.

These damage mechanisms are physical mechanisms and should be addressed even if no credit for coating performance is credited in the fuel system safety review.

LTR Approach

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Assembly Performance

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SAFDL	Rod Bow	Irradiation Growth	Hydraulic Lift Loads	Fuel Assembly Lateral Deflections	Fretting Wear
ISG Concern?	Yes	No	No	No	Yes
GESTAR II	1.1.2.B.v	1.1.2.B.v	1.1.2.B.vii	1.1.2.B.vii	1.1.2.B.ii
SAFDL Type	Shall not fail by	Shall not fail by	Shall not fail by	Shall be limited	Shall be limited
Needs SAFDL Disposition?	[[				
Needs Methodology Disposition?					]]

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Normal Operation & AOOs

SAFDL	Cladding Stress	Cladding Strain	Cladding Fatigue	Cladding Oxidation, Hydriding, and CRUD	Fuel Rod Internal Pressure
ISG Concern?	No	Yes	Yes	Yes	Yes
GESTAR II	1.1.2.B.i	1.1.2.B.i	1.1.2.B.i	1.1.2.B.iii	1.1.2.B.vi
SAFDL Type	Shall not fail by	Shall not fail by	Shall not fail by	Shall not fail by	Shall not fail by
Needs SAFDL Disposition?	[[				
Needs Methodology Disposition?					]]

SAFDL	Internal Hydriding	Cladding Collapse	Overheating of Fuel Pellets	Pellet-to-Cladding Interaction	Boiling Crisis
ISG Concern?	No	Yes	No	No	Yes
GESTAR II	1.1.2.B.iv	1.1.2.B.viii	1.1.2.B.ix	1.1.2.B.x	1.2.5.B.v
SAFDL Type	Numerical Limit	Shall not fail by	Shall not fail by	Numerical Limit	Shall not fail by
Needs SAFDL Disposition?	[[				
Needs Methodology Disposition?					]]

Methodology Dispositions

- [[

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Cladding Strain

- ISG
  There is the additional concern that large strains in the cladding may lead to cracking of the coating
- GESTAR II 1.1.2.B.i
  The GE criteria for evaluating cladding strain is that the fuel rod and assembly component strains shall not exceed the material ultimate strain
- Impact of ARMOR
  The approved methodology in GESTAR and PRIME [[

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LTR will address the following:
-[[

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Cladding Oxidation, Hydriding, and CRUD

PRIME Input

- ISG

None of these limits are particularly relevant to Cr-coated cladding … limits are proposed and justified for the coatings to ensure cladding integrity.

- GESTAR II 1.1.2.B.iii

The GE criteria for evaluating cladding oxidation, hydriding and crud is that the fuel rod and assembly component evaluations include consideration of metal thinning and any associated temperature increase due to oxidation and the buildup of corrosion products to the extent that these effects influence the material properties and structural strength of the components. In addition, an upper bound [[ ]] corrosion thickness limit of [[ ]] and an upper bound cladding hydrogen content of [[ ]] … to prevent significant localized cladding ductility loss.

- Impact of ARMOR

LTR will discuss the following:

-[[

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The limits for ARMOR coated rods [[ ]].

Fuel Rod Internal Pressure

PRIME

- ISG

  It shall be confirmed that no cladding liftoff during normal operation remains the most limiting

- GESTAR II 1.1.2.B.vi

  The GE criteria for evaluating rod internal pressure is that the loss of fuel rod mechanical integrity will not occur due to excessive cladding pressure loading. [[

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- Impact of ARMOR

  The GE basis for fuel rod internal pressure evaluations is based on the no cladding liftoff criteria, which depends on [[ ]]. The application of the ARMOR coating will [[ ]]. As discussed in Section 3.1.2.4, the addition of the ARMOR coating [[

  ]]. In addition, [[ ]].

  The design basis that cladding liftoff shall be precluded [[ ]] to ARMOR coated rods, and [[ ]].

Pellet-to-Cladding Interaction

PRIME

- ISG
  The inner surface of the cladding will be the same and therefore the typical approach would also apply for Cr-coated Zr cladding.

- GESTAR II 1.1.2.B.x
  [[

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- Impact of ARMOR
  The application of the ARMOR coating [[
  ]].

  In addition, the LTR will discuss the following:
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Accident Conditions

SAFDL	Overheating of the Cladding	Excessive Fuel Enthalpy	Bursting	Mechanical Fracturing	Cladding Embrittlement
ISG Concern?	Yes	Yes	Yes	No	Yes
GESTAR II	4.3.1	2.2.2.6 / 4.0.b (US Supplement)	2.2.2.8 / 4.2.3.2.7 (US Supplement)	4.2.3.2.8 (US Supplement)	4.2.3.3.1 (US Supplement)
Needs SAFDL Disposition?	[[				
Needs Methodology Disposition?					]]

SAFDL	Violent Expulsion of Fuel	Generalized Cladding Melting	Fuel Rod Ballooning	Structural Deformation
ISG Concern?	No	Yes	Yes	No
GESTAR II	4.2.3.3.2 & 7.3 (US Supplement)	2.2.3.3	4.2.3.3.3 (US Supplement)	4.2.3.3.4 (US Supplement)
Needs SAFDL Disposition?	[[			
Needs Methodology Disposition?				]]

Excessive Fuel Enthalpy

- ISG
  Cladding failure is by PCMI exceeding the ductility limit.
- GESTAR – Awaiting Rev.30
  - PCMI criteria =>

Hydrogen Concentration (wppm)	Exposure (GWD/MTU)	Delta Enthalpy (Δcal/g)
0	0	150
75	49.3	150
150	57.9	75
300	64.9	50

  - The high temperature cladding failure criteria sets limits on maximum enthalpy deposited as a function of cladding pressure differential.
- Impact of ARMOR
  The LTR will discuss the following:
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Therefore, existing fuel enthalpy limits for determining fuel failure [[ ]] for ARMOR coated rods.

Cladding Embrittlement

- ISG

  It is not known if these limits (2200F, 17% ECR) will be acceptable. It is unknown if some other mechanism could cause embrittlement of the cladding (e.g., ZrCr2 brittle rim). Tests showing ductility would be useful. For these tests, irradiated cladding tubes are preferable.

- GESTAR II US Supplement 4.2.1.3.1

  To meet the requirements of 10 CFR 50.46 as it relates to cladding embrittlement for a LOCA, GE uses an acceptance criterion of 2200°F on PCT and 17% on maximum cladding oxidation.

Impact of ARMOR

LTR will discuss the following:

- [[

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The addition of the ARMOR coating [[ ]] the phenomena of cladding embrittlement caused by high temperature oxidation. In addition, [[ ]]. Therefore, the existing limits of 2200°F PCT and 17% ECR [[ ]].

Violent Expulsion of Fuel

- ISG

These limits relate more to the fuel than to the cladding and are expected to be appropriate for Cr-coated Zr cladding.

- Impact of ARMOR

These limits are not designed to protect the cladding from being breached during such an event, but rather to limit the severity of the fuel degradation and dispersal. As such, the impact of ARMOR on these limits is negligible and the existing limits [[ ]] to ARMOR coated rods.

Generalized Cladding Melting

- ISG

  The formation of a low temperature eutectic with a thin coating may not result in a loss of geometry such as generalized cladding melting, but the formation of the eutectic shall be considered under this damage mechanism or under overheating of the cladding.

- GESTAR

  The GE criteria for generalized cladding melting is that it is bounded by the cladding embrittlement criteria.

- Impact of ARMOR

  The LTR will address the following:

  - [[ ]]

  Therefore, the criteria of generalized cladding melting being bounded by cladding embrittlement limits [[ ]] to ARMOR coated rods.

ARMOR Upscaling Qualification Linkages

Upscaling – From Development to Product

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Facility Planning

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Upscaling Sequence

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Thickness Production Control

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ARMOR Equivalency Progression

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ARMOR Equivalency Progression

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ARMOR Equivalency Progression

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Upscaling Summary

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Integrated Schedule for Licensing (RIS-2019-03)

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ATF Licensing Timelines

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ATF LTA Update (Clinton / Hatch)

Hatch LTA and Advanced Test Reactor status

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Clinton LTA Description

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Summary & Next Steps

Summary

- ARMOR Testing Update
- ARMOR SAFDL Treatments
- ARMOR Upscaling Qualification Linkages
- Integrated Schedule for Licensing (RIS-2019-03)
- ATF LTA Update (Clinton / Hatch)

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