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Increased Burnup Topical Report

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Agenda

- Introduction
- Fuel Design
- Mechanical
- Nuclear Design
- Thermal-Hydraulics
- Accident Analyses
    - Non-LOCA
    - LOCA
    - Fuel Dispersal
- Summary and Next Steps

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Introduction

- Jerry Holm

Meeting Objectives

- Initiate review of high burnup umbrella topical report
- Identify key review areas
- Discuss review process (audits, RAIs, schedule)

Advanced Fuel Management Program

- Industry need for AFM
  - Inflation Reduction Act provides incentive for increased production of carbon-free power
  - 24-month cycles provide many benefits to nuclear operation
    - Many PWRs need increased enrichment and burnup for economical 24-month cycles
- Framatome Approach to AFM
  - Employ fuel components that have robust performance
  - Establish base of advanced code and methods

PWR AFM Building Blocks

[ ]

Impact of Burnup

- Increased burnup results in a change in the fuel isotopics and fluence due to an increase in the number of fissions.
  - The change in isotopics impacts:
    - Neutronics parameters (for example, power distributions, decay heat, delayed neutron fraction, boron worth, control rod worth, etc.)
  - The change in fluence impacts:
    - material properties (for example, fuel rod growth, guide tube growth, corrosion, and hydrogen content, etc.).
- Increased burnup does not affect models related to fluid conditions or the operation of safety systems.

Overview of Content

- Limited areas impacted due to previous approvals to target burnup
  - M5 cladding
  - GALILEO Fuel Performance Code (FPC)
- Structure and scope closely follows that of ANP-10353P-A (increased enrichment umbrella topical report)

In most instances, methods are justified as applicable to increased burnup level without any changes

Increased Burnup Focus Areas

- The following items are new for increased burnup:
  - Lower Design Limit for Q12 Fuel Assembly Growth Empirical Model (Section 5.1.2.5.1),
  - Spacer Grid Growth Empirical Model (Section 5.1.2.5.2),
  - Fuel Rod Internal Pressure Limit (Section 5.2.1),
  - LOCA Cladding Embrittlement Research (Section 7.2),
  - RLBLOCA Packing Factor (Section 7.3.2), and
  - Fuel Dispersal (Appendix B).

Additional Items

- Approval requested for both increased enrichment and burnup
  - Fluence methods
  - Approval to use CHF correlation in ANP-10311, Revision 1, Supplement 1P-A

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Schedule

- Submittal of ANP-10358P November 2024
- Requested Approval March 2026

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Fuel Design

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Fuel Design Applicability

- Westinghouse and Combustion Engineering Plants
  - Westinghouse 15x15 and 17x17 arrays
  - Combustion Engineering 14x14 and 16x16 arrays
- ANP-10342P-A (GAIA Fuel Assembly Mechanical Design) describes generic design approach and criteria applicable to all PWR designs
  - HTP in addition to GAIA
- Fuel assemblies comprised of:
  - M5 cladding
  - Q12 control rod guide tubes and instrument tubes
  - M5 and/or Q12 spacers, Alloy-718 end grids
  - Standard materials for other components

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Mechanical

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Topics

- Material Applicability
- Fuel Rod Thermal Mechanical Methodology
- Fuel Design Methodology
- External Loads
- Statistical Holddown
- Cladding Collapse
- Fuel Rod Bow

M5 Material

- M5 cladding already applicable to [ ] GWd/mtU
- M5 spacer grids – increase burnup applicability [ ]
  - Physical properties are structure-insensitive
  - Mechanical behavior saturates at burnups lower than currently approved values
  - Oxidation and hydrogen pickup models already validated
  - [ ]

M5 material behavior supports applicability for Spacer Grids to a fuel rod average burnup limit of [ ] GWd/mtU

Q12 Material

- Q12 (ANP-10334P-A) as a structural material for both guide tubes and spacer grids - increase burnup applicability [ ]
  - o Physical and mechanical properties
    - structurally insensitive or saturation at higher irradiation
  - o Oxidation, hydrogen pickup, free growth, and creep models
    - developed from data which [ ]
- Empirical assembly growth model is [ ]

Only modification is the assembly growth empirical models which has been extended based on additional data

Fuel Rod Thermal Mechanical

- GALILEO (ANP-10323P-A, Rev. 1) has been approved for a fuel rod average burnup of [ ] GWd/mtU
- A revision to the rod internal pressure limit [ ] is proposed and justified in the increased burnup topical report
  - No reorientation of the hydrides in the radial direction in the cladding
  - No clad liftoff during normal operation – Analytical GALILEO studies compared to experimental results
  - DNB propagation methodology is independent of the magnitude of fuel rod overpressure

No changes to GALILEO methodology
Rod Internal Pressure limit is increased to better support increased burnup operation

Fuel Design Methodology

- Criteria and methodology described within ANP-10243P-A, "GAIA Fuel Assembly Mechanical Design":
  - Generically applicable to PWR fuel designs
  - Mechanical properties of the applicable materials are valid
  - Methods based on conventual equations, ASME code, and/or finite element stress analysis codes are not dependent on burnup
  - Testing (FIV/wear, component) at EOL conditions
  - Oper. Exp. / PIE validate performance (i.e., GTRF, FA Bow, FA length)

Inputs may change due to burnup, but
Increased burnup does not impact criteria and methodology

External Loads

- ANP-10337P-A, Rev. 0 plus Supplement 1P-A, Rev. 0
  - Stresses and load limit criteria are not impacted by the increase in burnup
    - Spacer grids deformation – [ ]
    - Guide tube buckling – EOL material properties saturate at higher burnup
    - Fuel rod acceptance criteria in BAW-10227P-A, Rev. 2 to [ ] GWd/mtU
  - Methodologies involve numerical models which simulate the mechanical behavior of fuel assemblies - not dependent on burnup.

Increased burnup does not impact criteria, methodology, and inputs

Holddown, Creep Collapse, & Rod Bow

- Statistical Holddown (BAW-10243P-A, Rev. 1)
  - Conventional open-literature equations to obtain a balance of forces
  - Combination of deterministic and statistical methods accounts for uncertainties
  - Changes in material properties and dimensions due to burn (e.g., spring relaxation and empirical growth models) impact results

Increased burnup does not impact criteria and methodology

- Cladding Collapse
  - BAW-10227P-A Rev. 2 approved the use of CROV (BAW-10084P-A, Rev.3) up to **[ ]** GWd/mtU
- Fuel Rod Bow
  - BAW-10227P-A, Rev 2 provided a new gap closure ratio correlation to determine DNBR and LHGR penalties (XN-75-32P-A) for use up to **[ ]** GWd/mtU

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Nuclear Design - ARCADIA

- Michelle Guzzardo

Nuclear Design – ARCADIA

- ARCADIA is used for all reactor core physics calculations
- Currently approved for use up to a fuel rod average burnup of 71 GWd/mtU
- Justification basis for extension to **[ ]** GWd/mtU
  - Isotopic comparisons for increased burnup
  - Impact on uncertainty analysis (UA) evaluated

Isotopic Comparison

- Four samples from Vandellos Unit 2
  - Burnups between 63.8 and 78.2 GWd/mtU
  - Comparisons for a wide range of isotopics
- Comparisons are [

  ]

Results support extension of ARCADIA to a rod average burnup limit of [ ] GWd/mtU

Uncertainty Analysis Disposition

- ARCADIA is valid for moveable incore fission detectors, Rhodium SPNDs, and Aeroball incores
- Power distribution uncertainties depend on local and global power predictions
- Local peaking uncertainty contribution addressed by performing multi-assembly comparisons
  - Verifies the ARTEMIS dehomogenization model at higher burnups
- Inferred and Calculated power distribution uncertainties remain valid
  - Methodology and equations used in global reconstruction models are not burnup-dependent
  - Nuclear Reliability Factors are dependent on local prediction error and global predictions
  - Nuclear detector sensitivity remains consistent for higher burnups

Evaluation supports extension

Consistent with the ARCADIA TR, power distribution predictions will continue to be compared against measured data when available

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Thermal-Hydraulics

- Michelle Guzzardo

Thermal-Hydraulics

- CHF Correlations
  - Function of local T-H condition (e.g., pressure, enthalpy, local heat flux)

Valid within range of conditions for correlations, regardless of burnup

- COBRA-FLX
  - Code models fluid flow and heat transfer

Increased burnup does not impact COBRA-FLX calculations

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Accident Analysis

Lisa Gerken

Approach Overview

- Establish methodology basis for burnup extension
- Assessment of impacts from high burnup operation on:
  - Key phenomena for accident
  - Inputs
  - Assumptions
  - Modeling
  - Computational tools

Modifications to analysis methods support operation with high burnup fuel

Generic HBU Impacts

- Decay Heat
  - High importance to LOCA
  - Methods use generic models (i.e., not core-design specific)

Appendix A validates the existing models for application to high burnup

- Potential for fuel dispersal
  - Dispersal is assumed negligible up to 62 GWd/MTU
  - Methods do not model impacts of fuel dispersal

Appendix B provides the approaches for plant-specific validation of this assumption

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Non-LOCA

Lisa Gerken

Non-LOCA Methods

- Method Topical Reports
  - **AREA**: Analysis method for Control Rod Ejection accidents
    - ANP-10338P-A, Revision 0
  - **ARITA**: Analysis method of remaining non-LOCA events in Chapter 15
    - ANP-10339P-A, Revision 0

- Umbrella Topical Reports
  - **Increased Enrichment**: ANP-10353P-A, Revision 0 – Validation and update for **[ ]** wt% U235

The impacts of high burnup operation are addressed relative to these NRC-approved methods

Non-LOCA Methods

- Package of codes, and their ability to predict key parameters, are shown to be applicable for both methods
- ARITA
  - Several uncertainty parameters potentially affected by enrichment were identified by NRC during the increased enrichment TR review (L&C 1 of ANP-10353P-A)
  - Section 6.1.5 provides the validation of these parameters for both increased enrichment and increased burnup
- AREA
  - Methodology is fully compliant with RG 1.236 Rev. 0 (applicable to 68 GWd/MTU)
  - Section 6.2.6 extends the applicability of RG 1.236 to **[ ]** GWd/MTU for M5 cladding

The AREA and ARITA methods, without modification, are applicable to [ ] wt% U-235 and [ ] GWd/MTU rod average

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LOCA

Lisa Gerken

Applicable Methods

- Evaluation Model Topical Reports
  - **SBLOCA**: EMF-2328(P)(A), Rev. 0; EMF-2328(P)(A), Rev. 0, Supplement 1(P)(A)
  - **RLBLOCA**: EMF-2103P-A, Rev. 3
- Umbrella Topical Reports
  - **GALILEO Incorporation**: ANP-10349P-A, Rev. 0 - Incorporated fuel rod models approved up to [ ] GWd/MTU
    - LOCA-relevant fuel rod properties (e.g., thermal conductivity) addressed by use of GALILEO FPC
    - M5 properties and models (e.g., swelling and rupture model) extended in BAW-10227P-A, Rev. 2
  - **Increased Enrichment**: ANP-10353P-A, Revision 0

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LOCA Evaluation Models

[ ]

Packing Factor

[ ]

Cladding Embrittlement Research

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Fuel Dispersal

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Approach Overview

Approach Overview

[ ]

LOCA Approach

[ ]

LOCA Approach

[ ]

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Summary and Next Steps

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Thank you

Acronyms

AFM	Advanced Fuel Management	LTOM	Least Transient Oxidation margin
ASME	America Society of Mechanical Engineers	LOCA	Loss of Coolant Accident
CHF	Critical Heat Flux	MLO	Maximum Local Oxidation
CWO	Core Wide Oxidation	PCT	Peak Cladding Temperature
EOL	End of Life	PWR	Pressurized Water Reactor
EM	Evaluation Model	RAI	Request for Additional Information
FA	Fuel Assembly	RLBLOCA	Realistic Large Break Loss of Coolant Accident
FFRD	Fuel Fragmentation, Relocation, and Dispersal	SB	Small Break
FOM	Figure of Merit	SBLOCA	Small Break Loss of Coolant Accident
GTRF	Grid to Rod Fretting	SE	Safety Evaluation
HBU	High Burnup	UA	Uncertainty Analysis
LAR	License Amendment Request		
LB	Large Break		
LBLOCA	Large Break Loss of Coolant Accident		

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Framatome's AFM Codes and Methods

Enrichment	ANP-10353P-A Umbrella TR for increased enrichment
Neutronics	ARCADIA (ANP-10297P-A and S1P-A)
Thermal–Hydraulic	COBRA-FLX (ANP-10311P-A, Rev 1 and Supp 1P-A)
CHF	GAIA CHF (ANP-10341P-A)
Non-LOCA	ARITA (ANP-10339P) and AREA (ANP-10338P-A)
SB LOCA	SBLOCA (EMF-2328P-A and S1P-A)
LB LOCA	RLBLOCA Rev. 3 (EMF-2103P-A, Revision 3)
LOCA FPC Upgrade	LOCA-GAL (ANP-10349P-A)
Fuel Performance Code	GALILEO (ANP-10323P-A, Revision 1)
External Loads	(ANP-10337P-A and Supplement 1P-A)
Fuel Design	GAIA (ANP-10342P-A) with Q12 (ANP-10334P-A)
$M5_{Framatome}$	(BAW-10227P-A, Revision 2)
Liftoff	Statistical Holddown (BAW-10243P-A)
Cladding Collapse	CROV (BAW-10084P-A, Revision 3)
Bow	(XN-75-32P-A)

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