framatome

RODEX4 Supplement 3 Pre-Submittal Meeting

M. Anderson/K. Duggan

Remote Meeting, 09/04/2024

Content

1

Safety Message

Complacency is one of the biggest risks we face in terms of completing our day-to-day tasks safely. In our industry, complacency can kill.

Complacency is when someone becomes so comfortable or secure in a situation or task that it leads to unawareness of actual dangers or deficiencies. This state of overconfidence can cause us to disregard weak signals and take potentially dangerous shortcuts, resulting in serious consequences affecting safety, production and quality. If you find yourself saying, “it’s always been that way” or “we’ve always done it this way,” then complacency is your enemy. No activity is hazard-free.

Examples of how using error-prevention tools strengthens the use of this critical element and aids employees in being proactive in identifying, assessing and controlling hazards and preventing safety incidents:

Safety tool:	Reviewing the **job hazard analysis** regularly helps maintain awareness of hazards and risks.
Quality tool:	Looking for **weak signals** increases awareness of potential precursors to major events.
HU tool:	**STAR** Self-checking helps to focus attention on the task before performing a critical activity.

framatome

2

Objectives

Objectives

- Provide an overview of Supplement 3 to the RODEX4 Topical Report (BAW-10247PA)

[ ]

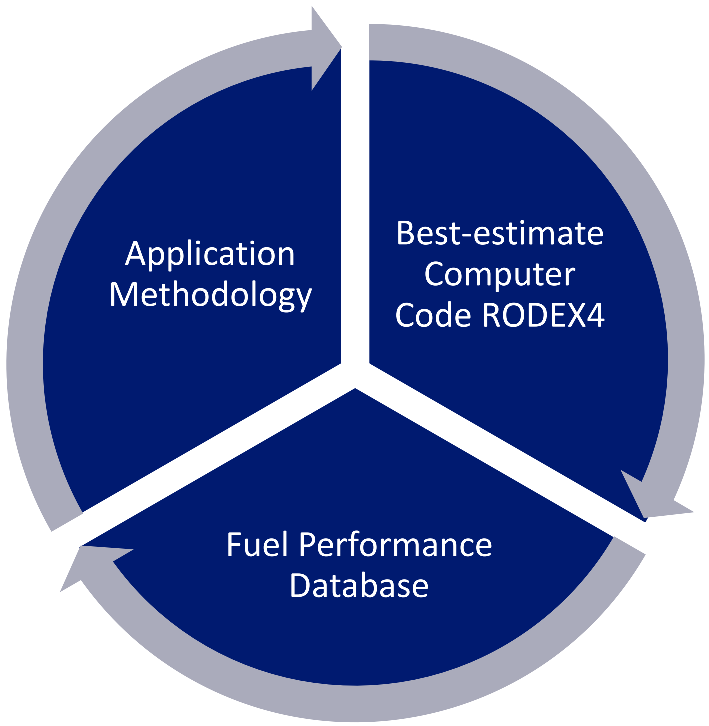
3

Background

Background

- RODEX4 is the approved Thermal-Mechanical Analysis Methodology for BWR Fuel Rods
  - A realistic methodology based on non-parametric order statistics
  - Currently limited to 5 wt% U-235 fuel and full-length fuel rod-average exposure of 62 MWd/kgU
- Extended in Supplement 1
  - RXA Zircaloy Cladding
  - Hydrogen Pickup Model

RODEX4 Methodology



Background

- Extended in Supplement 2
  - BWR fuel rod bow correlation
  - Axial irradiation growth correlations (fuel rod and other fuel assembly components)
  - Added Z4B validated for internal water channels
  - Fuel rod bow and fuel rod and fuel assembly growth models approved to [57 MWd/kgU]
- Extended to chromia-doped fuel in ANP-10340P

Schedule for Topical Report

- Pre-submittal meeting (strategy and scope) - today

[

]

[ ]

Driving Factors for AFM Implementation

- DOE Priority for AFM/EATF development
- Customer Economics
  - Provides significant operational flexibility
    - Longer cycles
    - Power uprates
  - Improved plant economics
    - Reduced fuel costs
- Safety
  - Reduced high-level waste

4

RODEX4 Thermal-Mechanical Extension

M. Anderson
Advisory Engineer, BWR Thermal-Mechanics

Review of RODEX4 Methodology

- Important phenomena identified in PIRT
  - Uses non-parametric order statistics process to sample the important input variables
    - Projected power operation
    - Manufacturing parameters
    - Model parameters
- Best estimate thermal-mechanical analysis
  - Validated against an extensive fuel performance database
- Approved for uranium enrichments up to 5 wt% and full-length fuel rod-average exposures up to 62 MWd/kgU

Necessary Topics to Extend RODEX4

- Based on PNNL-29368
  - Fuel Material Properties (§3.1)
  - Cladding Material Properties (§3.2)
  - SAFDL Limits for High Burnup Fuel (§3.3)
- Information Necessary for RODEX4 Extension
  - For many parameters, PNNL-29368 concludes that no additional information is needed
  - For other parameters, availability of Framatome proprietary data will be reviewed

PNNL-29368, *Fuel Performance Considerations and Data Needs for Burnup above 62 MWd/kgU, In Reactor Performance, Storage, and Transportation of Spent Nuclear Fuel,* November 2019.

Fuel Material Properties and Processes

Items from PNNL-29368 and BAW-10247PA

- PNNL-29668
  - F1 – thermal conductivity
  - F2 – thermal expansion
  - F3 – Emissivity
  - F4 – enthalpy and specific heat
  - F5 – melting temperature
  - F6 – densification
  - F7 – swelling
  - F8 – fission gas release
  - F9 – radial power profile
  - F10 – fuel radial relocation
  - F11 – high burnup rim formation
  - F12 – decay heat

- BAW-10247PA
  - F13 – young's modulus
  - F14 – Poisson's ratio
  - F15 – creep
  - The values for these items are from MATPRO, so additional testing is not needed

- Conclusions from PNNL-29368 (Table 3.1)
  - Items for which some action is recommended

    [ ]
  - No additional testing needed for other items from F1 through F12

Cladding Material Properties and Processes

Items from PNNL-29368 and BAW-10247PA

- PNNL-29668
  - C1 – thermal conductivity
  - C2 – thermal expansion
  - C3 – emissivity
  - C4 – enthalpy and specific heat
  - C5 – elastic modulus
  - C6 – yield stress
  - C7 – thermal and irradiation creep rate
  - C8 – axial irradiation growth
  - C9 – oxidation rate
  - C10 – hydrogen pickup
- PNNL-29688 (cont'd)
  - C11 – high temperature ballooning behavior
  - C12 – high temperature (800 – 1200°C) steam oxidation rate
- Conclusions from PNNL-29368 (Table 3.1)
  - No addition tests: C1 through C4
  - Tests recommended for fast fluence associated with extended exposure range: C5 through C10

[ ]

Data Gaps Identified in PNNL-29368

Based on publicly available data at time of publication (2019)

- PNNL-29668
  - G1 – fuel centerline temperature (significant data up to 70 MWd/kgU, sparse data to 85 MWd/kgU)
  - G2 – power ramp tests (significant data to 72 MWd/kgU, none beyond)
  - G3 – RIA test (significant data to 80 MWd/kgU, none beyond)
  - G4 – fission gas release (significant data to 70 MWd/kgU, moderate data to 100 MWd/kgU)
- PNNL-29688 (cont'd)
  - G5 – cladding corrosion and hydriding (significant data with power histories to 70 MWd/kgU, data without power histories to 85 MWd/kgU)
  - G6 – cladding mechanical properties (significant data to 72 MWd/kgU, sparse data to 85 MWd/kgU)
  - G7 – integral LOCA tests (reasonable data between 44 and 92 MWd/kgU)
- Assessment of Gaps

[ ]

N.B., these gap alphanumeric indices are not from PNNL-29368 but have been assigned by Framatome.

Fuel Centerline Temperature Coverage

[ ]

Data Gaps Identified in PNNL-29368 (cont'd)

Based on publicly available data at time of publication (2019)

- PNNL-29668
  - G1 – fuel centerline temperature (significant data up to 70 MWd/kgU, sparse data to 85 MWd/kgU)
  - G2 – power ramp tests (significant data to 72 MWd/kgU, none beyond)
  - G3 – RIA test (significant data to 80 MWd/kgU, none beyond)
  - G4 – fission gas release (significant data to 70 MWd/kgU, moderate data to 100 MWd/kgU)

- PNNL-29688 (cont'd)
  - G5 – cladding corrosion and hydriding (significant data with power histories to 70 MWd/kgU, data without power histories to 85 MWd/kgU)
  - G6 – cladding mechanical properties (significant data to 72 MWd/kgU, sparse data to 85 MWd/kgU)
  - G7 – integral LOCA tests (reasonable amounts of data between 44 and 92 MWd/kgU)

- Assessment of Gaps

[ ]

[ ]

Data Gaps Identified in PNNL-29368 (cont'd)

Based on publicly available data at time of publication (2019)

- PNNL-29668
  - G5 – cladding corrosion and hydriding (significant data with power histories to 70 MWd/kgU, data without power histories to 85 MWd/kgU)
  - G6 – cladding mechanical properties (significant data to 72 MWd/kgU, sparse data to 85 MWd/kgU)

- Gaps G5 & G6

- Assessment of Gaps

[ ]

framatome

Fuel Performance Concerns

Items from PNNL-29368

- PNNL-29668
  - HP1 – oxidation and hydriding (limits to these phenomena must be provided)
  - HP2 – strain and strain limits (continued ductility reduction with exposure and increasing swelling could induce more strain; the methodology must adequately predict such strain)
  - HP3 – fission gas release and fuel rod internal pressure (fission gas release increases markedly with increases exposure)
  - HP4 – empirical fuel assembly limits

- Addressing Fuel Performance Concerns

- Other Fuel Performance Concerns

[ ]

N.B., these fuel performance concern alphanumeric indices are not from PNNL-29368 but have been assigned by Framatome.

Fission Gas Release (FGR)

RODEX4 Models Valid to High Exposures

Fission Gas Release (FGR) (cont'd)

RODEX4 Models Valid to High Exposures

[ ]

Fission Gas Release (FGR) (cont'd)

RODEX4 Models Valid to High Exposures

Cladding Corrosion

RODEX4 Models Valid to High Exposures

Cladding Corrosion

RODEX4 Models Valid to High Exposures

Cladding Corrosion

RODEX4 Models Valid to High Exposures

Additional Considerations

Irradiation Effects on Cladding and Fuel Deformation

[ ]

Additional Considerations (cont'd)

[ ]

framatome

Changes to the RODEX4 Code

[ ]

5

Supplement 2 Extensions Validation of Fuel Rod Bow Model and Development of Growth Correlations

- K. Duggan
  Advisory Engineer, BWR Mechanics

Topics to Ensure Assembly Performance

- Based on PNNL-29368

Rod Bow Assessment

Updated Irradiation Growth Correlations

Updated n Growth Correlations (cont'd)

framatome

Updated Growth Correlations (cont'd)

Updated Growth Correlations (cont'd)

Updated Growth Correlations (cont'd)

Updated Growth Correlations (cont'd)

6

Next Steps

Next Steps

- Pre-submittal meeting - 09/04/24

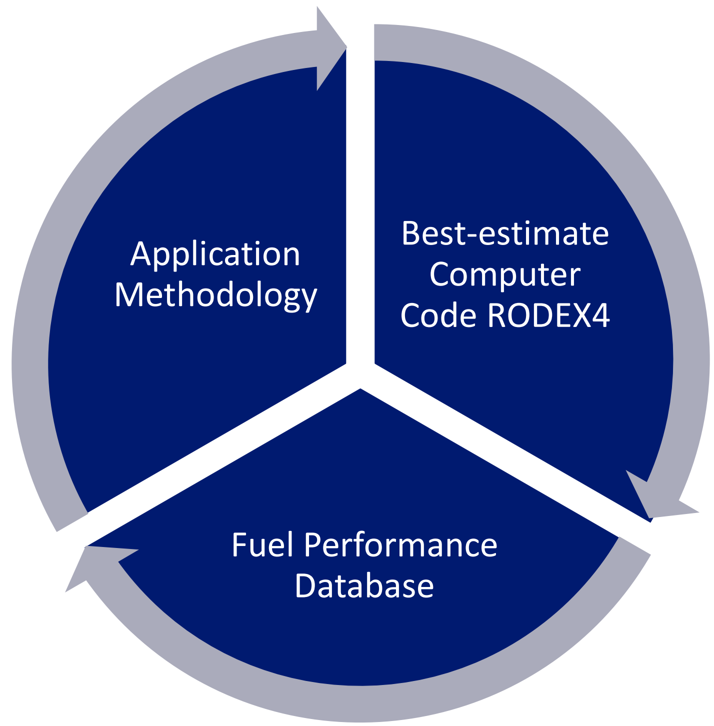
[ ]

Summary/Conclusions

[ ]

- NRC feedback on [process, methodology, schedule]?

RODEX4 Methodology



Acronyms/Nomenclature

Acronym/Nomenclature	
EC	Eddy Current
EOL	End of Life
FA	Fuel Assembly
FR	Fuel Rod
HBS	High-Burnup Structure
LOCA	Loss of Coolant Accident
MATPRO	A compilation of material property correlations and computer subroutines for use in reactor analysis
PIRT	Phenomenon Importance Ranking Table
PNNL	Pacific Northwest National Laboratory
RIA	Reactivity Insertion Accident
RXA	Recrystallized Annealed (also RX)

Acronyms/Nomenclature (cont'd)

Acronym/Nomenclature	
SRA	Stress Relief Annealed (also SR)
Z4B	A proprietary Framatome zirconium alloy

Trademarks

ATRIUM and Z4B are trademarks or registered trademarks of Framatome or its affiliates, in the USA or other countries.

Acknowledgement

This material is based upon work supported by the U.S. Department of Energy under award numbers DE-NE-0009034, DE-NE0008818 and previously DE-NE0008220.

Thank you