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EMF-93-177, Revision 1, Supplement 3, ATRIUM BWR Enhanced Accident Model (A-BEAM) Pre-Submittal Meeting

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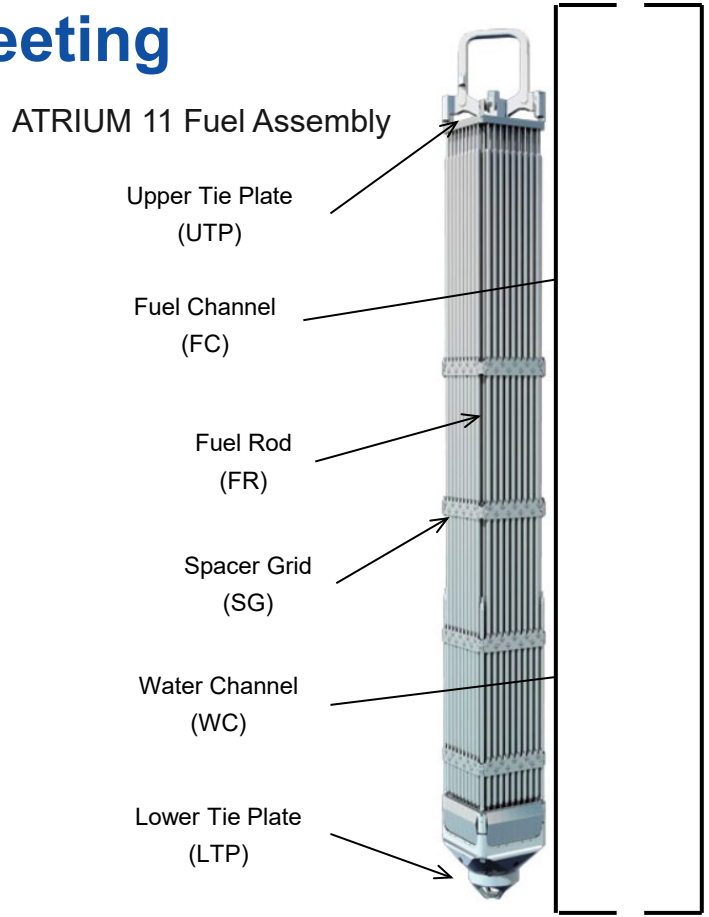
WebEx 11/19/2020

CONTENT

Objectives for Pre-Submittal Meeting

- Provide an overview of Framatome's upcoming submittal of a TR supplement to Mechanical Design for BWR Fuel Channels addressing accident analyses
  - *EMF-93-177, Revision 1, Supplement 3P ATRIUM BWR Enhanced Accident Model (A-BEAM)*
  - TR supplement provides an option for a more detailed horizontal dynamic model in order to get more refined accident analysis results for fuel assembly components.
  - No change to the TR sections related to the fuel channel design, design criteria, or normal operation analysis methods.
- Minimize follow-up needed prior to submittal
- Obtain NRC feedback



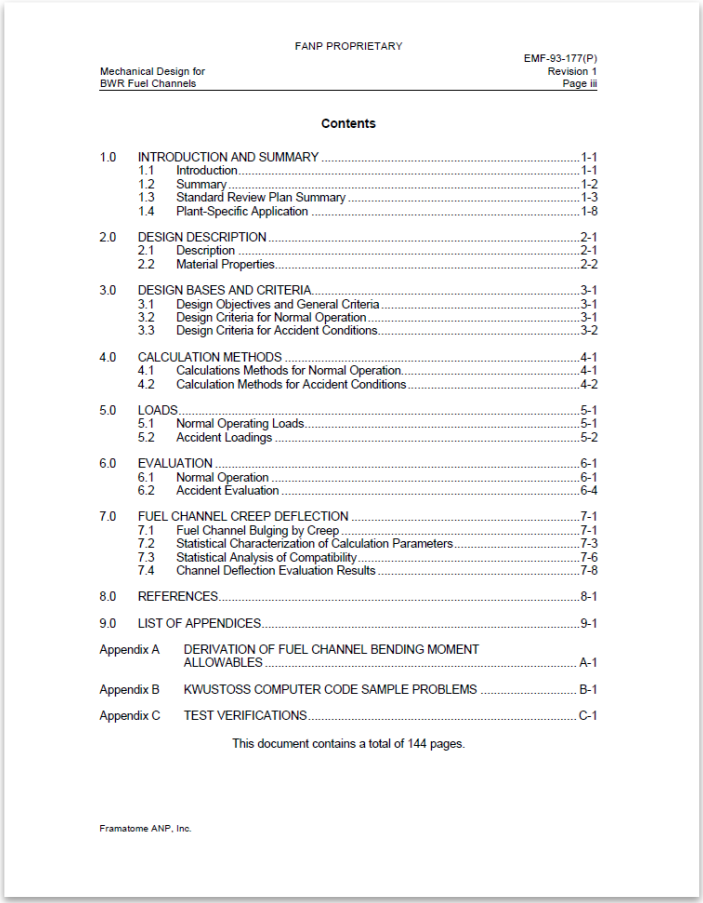
Adding Complexity in Response to Industry Changes

- Finite element methods, computing power, and test instrumentation capabilities have continually improved since 1993.
  - Why add complexity to the model now?

- Utilities have revisited and sometimes increased their design basis accidents loads to ensure they remain conservative.
- More plants have calculated acceleration time histories at the core support and upper end guide that can feed directly into a fuel bundle dynamic analysis.
- Fuel designs have evolved to improve thermal-hydraulic performance and neutronic efficiency, sometimes to the detriment of structural design margins.

Overview of Analytical Model Improvements

Scope of Submittal



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Contents

This document contains a total of 144 pages.

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Scope of Submittal

Scope of Submittal

- Section 4.2.3 Dynamic Analysis and Model Description

Sub Section Title	Methodology / Example Problem Updates
General Model Description	
Model Characteristics	
FC Stiffness	
Lower Fuel Support Condition	
FA Mass	
FA Stiffness	
SG Stiffness	
SG to FC Gap Size	
Structural Damping	
Amplitude, Frequency, and Time Step Sensitivity	
Fluid-Structure Interaction	

Scope of Submittal

- Structure of the Topical Report EMF-93-177 Supplement 3
  - Introduction and Summary
  - Calculation Methods for Accident Conditions
    - General Model Description
    - Model Characteristics
    - Fuel Assembly Stiffness
    - Lower Fuel Support Conditions
    - Fuel Assembly Mass
    - Spacer Grid Stiffness
    - Structural Damping
    - Amplitude, Frequency, and Time Step Sensitivity
    - Fluid Structure Interaction
  - Evaluation
    - Fuel Channel
    - Fuel Assembly Tie Structure (Water Channel)
    - Fuel Rods
  - References
  - Appendix A Test Verifications and Descriptions

Planned Schedule

BWR ATRIUM Design Changes

NRC's Prioritization Factors

- Classification
  - Emergent NRC technical Issue (IN 2012-09)
  - Supplement reflects current requirements or analytical methods
- Applicability
  - Potentially entire group of BWR Licensees
- Implementation Certainty
  - Currently no docketed intent
  - Needed for ATRIUM 11 implementation for some plants

Spacer grid characteristics for modern fuel designs require more refined models to determine margins accurately

ATRIUM BWR Enhanced Accident Model (A-BEAM)

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Analysis Engineer, Erlangen, Germany

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A-BEAM – Why Update the Model?

A-BEAM – Why Update the Model?

A-BEAM – Why Update the Model?

A-BEAM – Model Evolution

- The new fuel bundle model applies the lumped-mass method similar to the current model.

A-BEAM – Model Evolution

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A-BEAM – Model Evolution

A-BEAM – Model Evolution

A-BEAM – Model Evolution

A-BEAM – Model Evolution

A-BEAM – Full Model

A-BEAM – Animation

- KWUSTOSS
- SHP-1 Benchmarking

A-BEAM – Damping

A-BEAM – Benchmarking

- Benchmarking
  - Stiffness curve
  - Alpha and beta damping match resonance curve
  - Impact forces between SG and impact bars in full model
- Sensitivity Studies
  - +/-10% change in frequency (mass/stiffness) and excitation amplitude
  - Boundary conditions (pinned/pinned, fixed/pinned, etc.)

A-BEAM – Assessment for Accident Analysis

Spacer Grid Impact Spring Benchmark

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Spacer grid lateral dynamic load test

- The fuel assemblies can impact against the fuel channel wall during the movement in horizontal direction because a gap is present between the spacer and the fuel channel.
- This impact load is absorbed by the spacer grid.
- A lateral dynamic test is performed to determine the impact behavior of the spacer grids.
- The lateral dynamic test is performed on AH75, AH76 and AH77 spacer grids for BOL and EOL condition.
  - AH75 – Bottom spacer grids containing all rods
  - AH76 – Middle spacer grids without short part length fuel rods
  - AH77 – Top spacer grids with no part length fuel rods

Spacer grid lateral dynamic load test

Spacer grid lateral dynamic load test

Spacer grid lateral dynamic load test

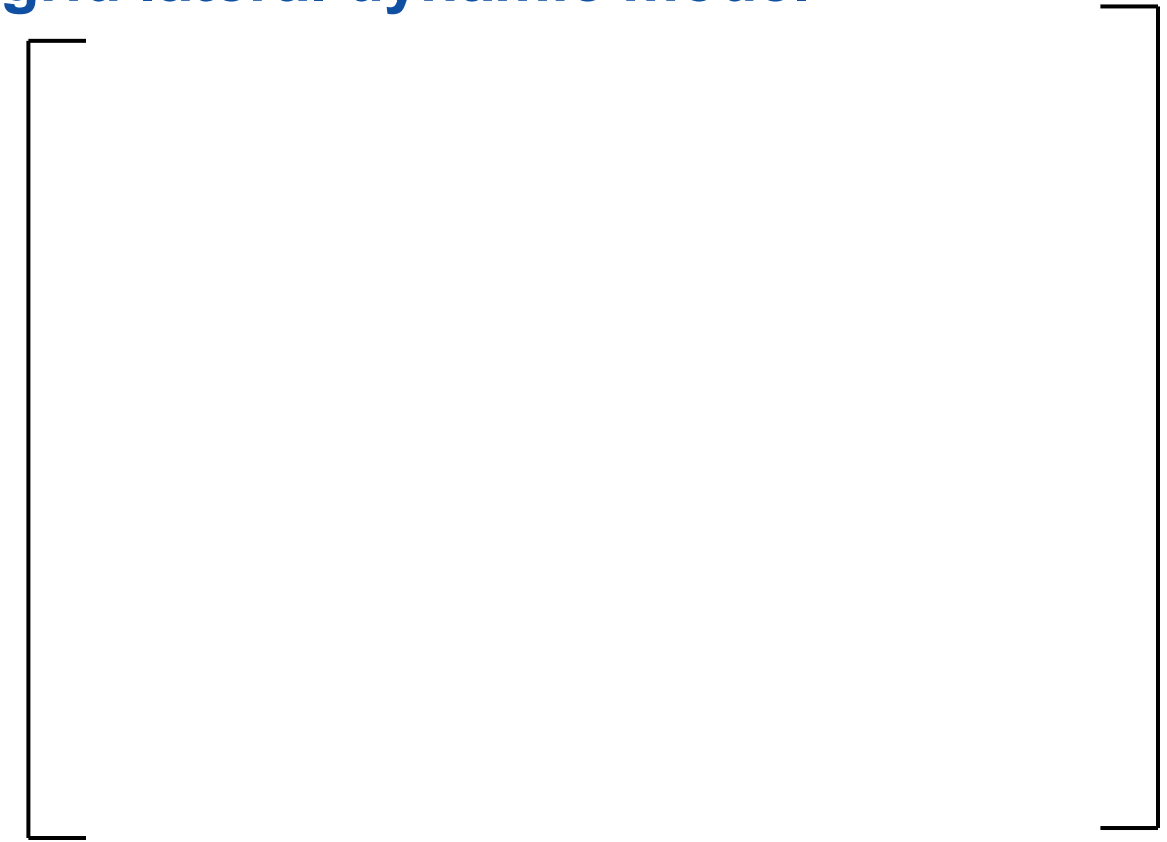
Spacer grid lateral dynamic model

Spacer grid lateral dynamic model

Spacer grid lateral dynamic model

Spacer grid lateral dynamic model

- KWUSTOSS
- Dynamic Model



Spacer grid lateral dynamic model benchmark

Spacer grid lateral dynamic model benchmark

Spacer grid lateral dynamic model benchmark

Fluid Structure Interaction

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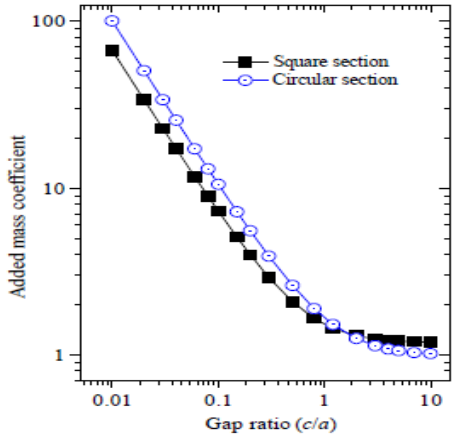
Fluid Structure Interaction (FSI)

Fluid Structure Interaction (FSI)

Fluid Structure Interaction (FSI)

- The gap or bypass between the channel and the test box wall has a large effect in the value of the geometric factor "f".
  - It is established in the literature.
    - e.g. : (Jeong, 2017)



Jeong, H. K., & Jhung, M. J. (2017). " Added Mass Estimation of Square Sections Coupled with a Liquid Using Finite Element Method." *Nuclear Engineering and Technology*. 49(1), 234–244.

Topical Report KWUSTOSS Sample Problems

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Software Verification

- KWUSTOSS continues to be used in the U.S. and EU
- KWUSTOSS was updated for the A-BEAM
  - All standard test suite cases have essentially the same results between the two releases

The code will continue to be maintained through our software control procedures

Conclusion

Summary/Conclusions

- Supplement 3 specifically updates Section 4.2.3 *Calculations Methods for Accident Conditions* of Topical Report EMF-93-177(P)(A) by separating the fuel bundle tie structure and fuel rod beams
- These modeling improvements allow Framatome BWR accident analysis to:
  - Position Framatome to address future design changes such as EATF and to be prepared for some plants with higher loads
  - Improve fuel assembly component margins while maintaining conservatism in the spacer grid strength and damping evaluations
  - Utilize [ ]
  - Evaluate stiffness changes of the fuel bundle inside the fuel channel as a result of end of life conditions
  - Increases understanding of the relationships and interactions between components:
    - Tie structure and fuel rods
    - Spacer grid and fuel channel
    - Fluid structure interaction between adjacent fuel channels

Next Steps

Acronyms/Nomenclature

- A-BEAM — ATRIUM BWR Enhanced Accident Model
- BOL — Beginning of Life
- BWR — Boiling Water Reactor
- CF — Channel Fastener
- EATF — Enhanced Accident Tolerant Fuel
- EOL — End of Life
- EU — European Union
- FA — Fuel Assembly
- FB — Fuel Bundle
- FC — Fuel Channel
- FEA — Finite Element Analysis
- FLFR — Full Length Fuel Rod
- FR — Fuel Rod
- FSI — Fluid Structure Interaction
- KWUSTOSS — Framatome (*KWU*) Impact (*STOSS*) Code
- LOOP — Loss of Offsite Power
- LPLFR — Long Part Length Fuel Rod
- LTP — Lower Tie Plate
- NRC — Nuclear Regulatory Commission
- SER — Safety Evaluation Report
- SG — Space Grid
- SHP-1 — Servo Hydraulic Test Facility 1 (*Fuel Assembly Vibration Machine*)
- SHP-6 — Servo Hydraulic Test Facility 6 (*Spacer Grid Transverse Dynamic Load Test Facility*)
- SPLFR — Short Part Length Fuel Rod
- SRP — Standard Review Plan
- SSE — Safe Shutdown Earthquake
- TBD — To Be Determined
- TR — Topical Report
- UTP — Upper Tie Plate
- WC — Water Channel

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Thank You