NRC Pre-Submittal Tactical Meeting - ARTEMIS™/RELAP Integrated Transient Analysis Method

Jerry Holm
Kevin Segard
Bill Walters
Ruxandra Bobolea
Philippe Bellanger
Roberto Rubilar

Rockville, MD
February 4, 2015

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Agenda

Safety and Operational Excellence	Jerry Holm
Objectives	Jerry Holm
U.S. PWR Advanced Methods Update	Kevin Segard
ARITA Methodology	
- Overview	Kevin Segard
- Non-LOCA	Bill Walters
- Setpoints	Ruxandra Bobolea
- Fuel Performance Code	Philippe Bellanger
- Power Distribution Control	Roberto Rubilar
Summary/Conclusion	Kevin Segard
Next Steps	Jerry Holm

Objectives

- Present a summary of the ARITA methodology
- Obtain NRC feedback on the ARITA methodology
- Discuss the schedule for NRC review and approval of AREVA's ARITA topical report

ARTEMIS™/RELAP Integrated Transient Analysis

Kevin C. Segard/Roberto Rubilar
Supervisor, Methods and Licensing
AREVA Expert - Neutronics
PWR Neutronics – Lynchburg

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Agenda

- Background
- ARITA Developments
- Topical Report Transitions

Background

- **In 2002, AREVA began the development of a new set of advanced PWR codes**
  - **ANP-10297PA: ARCADIA® Core Analysis System**
    - APOLLO2-A Lattice Code
    - ARTEMIS™ 3D Core Simulator
  - **ANP-10311PA: COBRA-FLX™ 3D Thermal-Hydraulics Code**
- **These and other auxiliary codes makeup the ARCADIA® code system (ANP-10297PA)**
- **ARTEMIS™, GALILEO™ and S-RELAP5 are the main codes in the ARITA methodology**

» **ARCADIA® and COBRA-FLX™ received NRC approval in 2013**

Background
Topical Report Development

- **Three ARCADIA® based topical reports are in development**
  - **ARCADIA® Code Supplement**
    - Changes made to support ARITA and AREA topical reports
    - Additional benchmarks to support safety criteria
    - Description and justification for basic transient capabilities will be provided in the supplement
    - Description and justification impacting transient calculations will be provided in either the ARITA or AREA topical reports
  - **AREA – AREVA Rod Ejection Analysis Methodology**
  - **ARITA – ARTEMIS™/RELAP Integrated Transient Analysis**
- **Provides a path to transition from legacy methods**

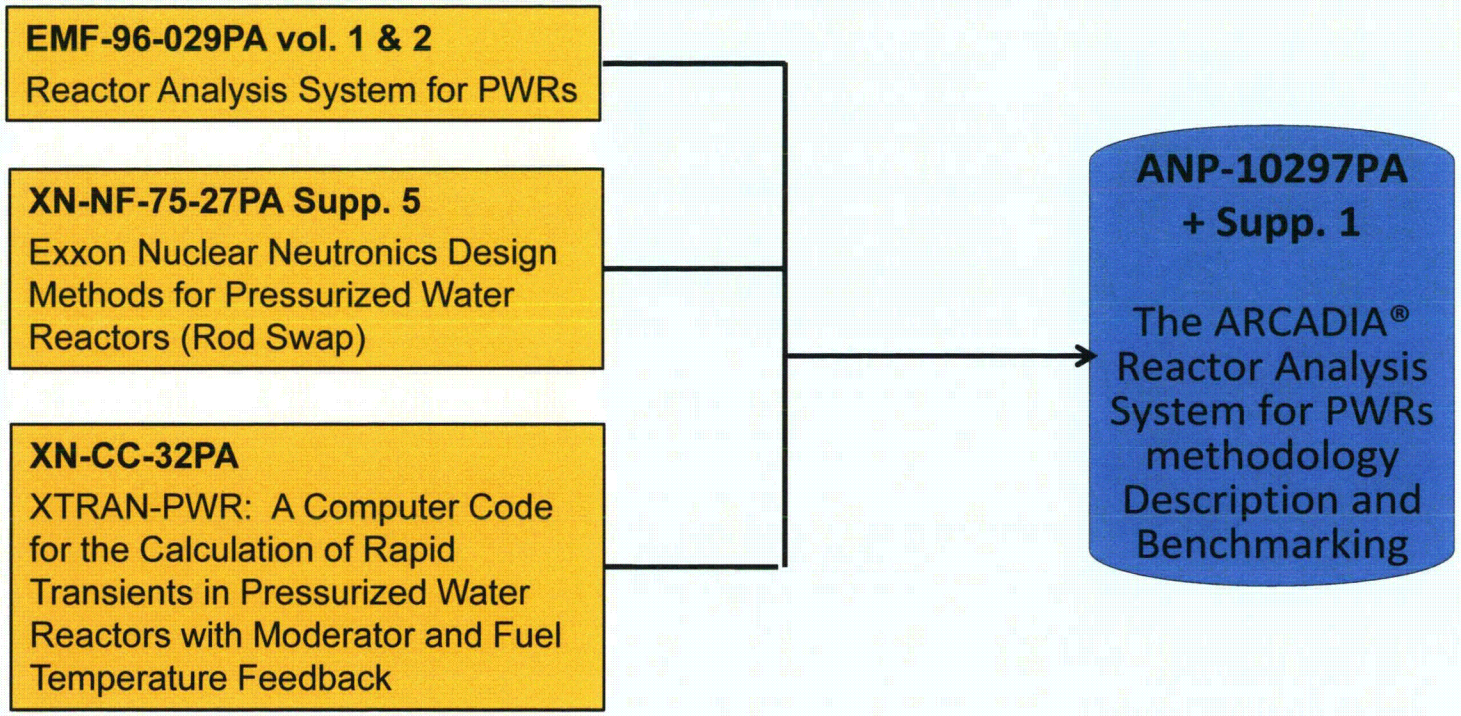
Background
Methodology Objectives

- **NUREG 0800, Standard Review Plan (SRP)**
  - **The ARITA Topical will be developed to be consistent with the criteria presented in Chapters 4.2, 4.3, 4.4, and 15.**
- **Regulatory Guide 1.203, Transient and Accident Analysis**
  - **EMDAP is used to establish the development of the ARITA Evaluation Model**

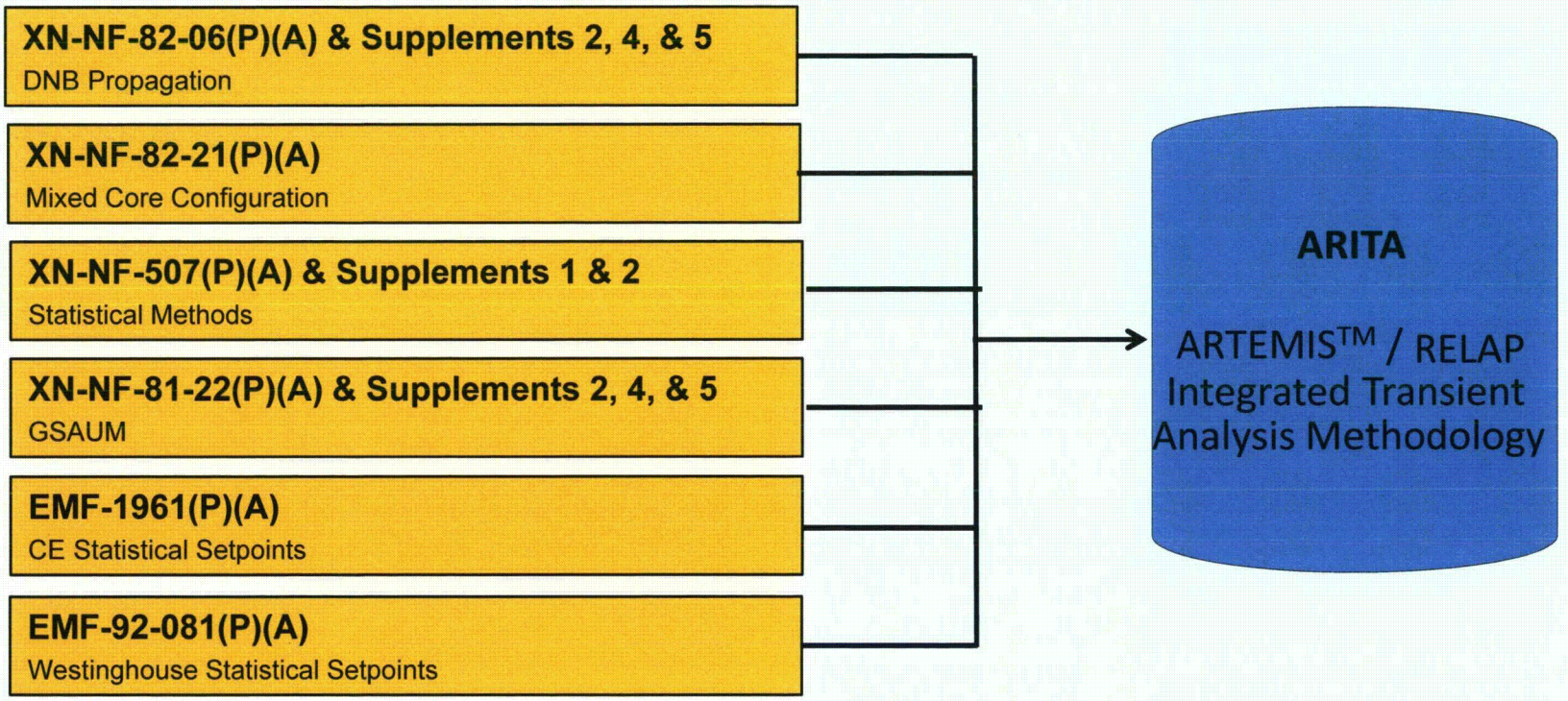
Background
Methodology Objectives

- **Provide opportunity to transition from current legacy methods to ARITA method**
  - **Requires NRC approval of the following associated topical reports:**
    - ANP-10323P, "Fuel Rod Thermal Mechanical Methodology for BWRs and PWRs," GALILEO™
    - ANP-10297P Supplement 1, "The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results"
- **Reduce the number of topical reports used for reload analyses in plant licensing bases**

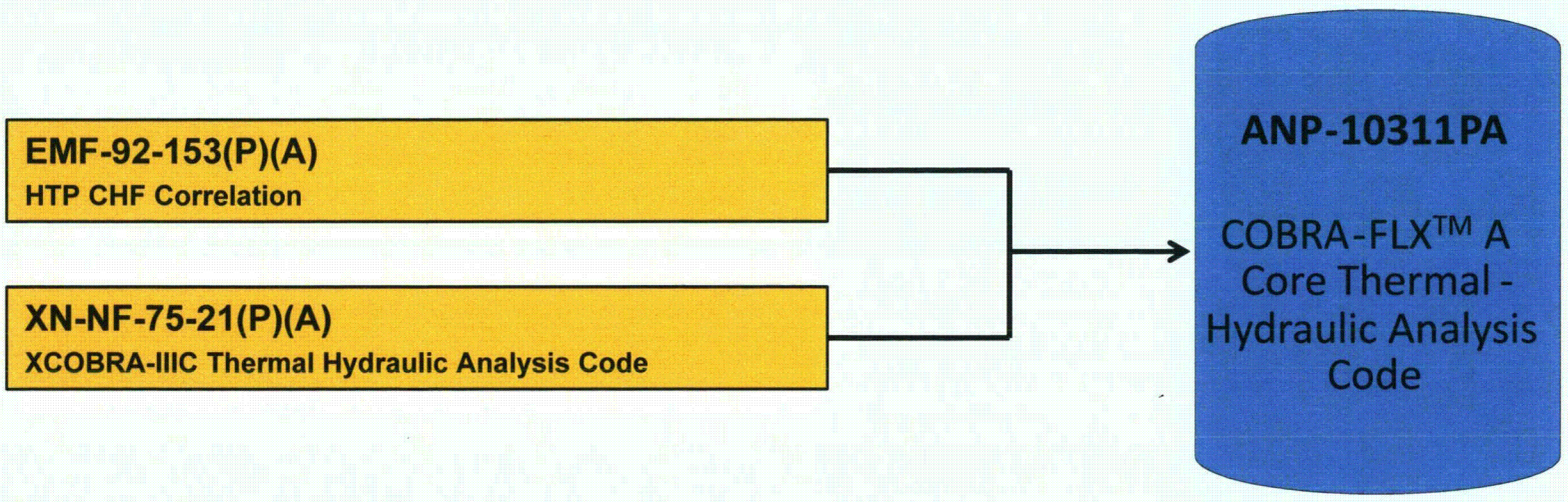
Neutronics Topical Reports Transition



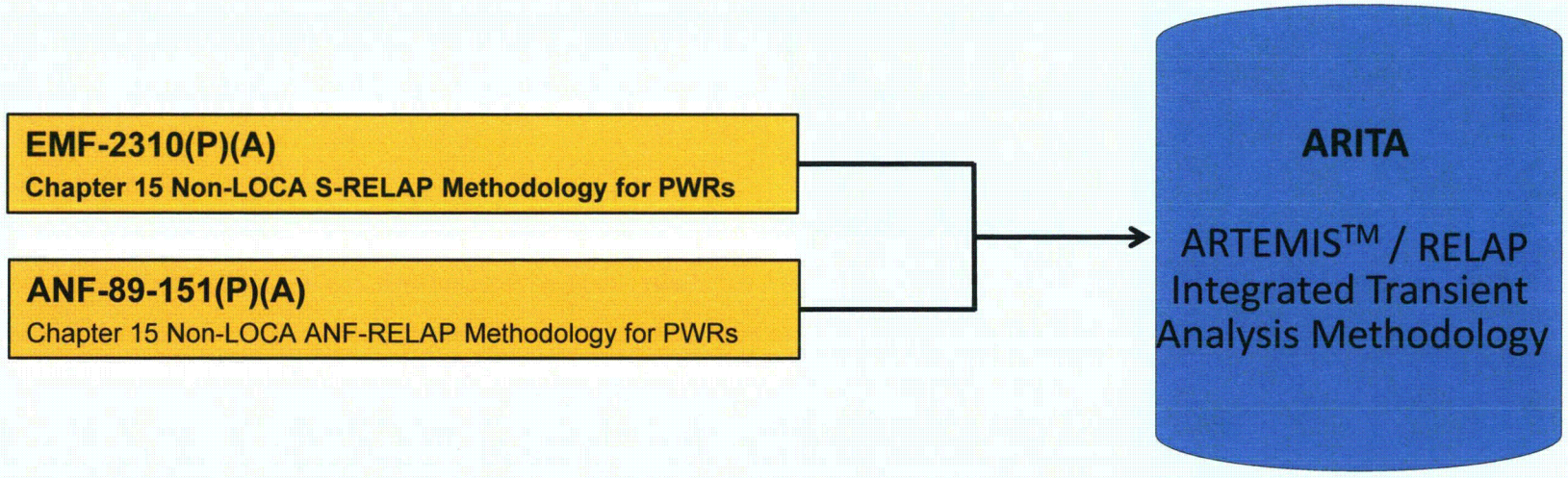
Thermal-Hydraulics Topical Report Transition (1 of 2)



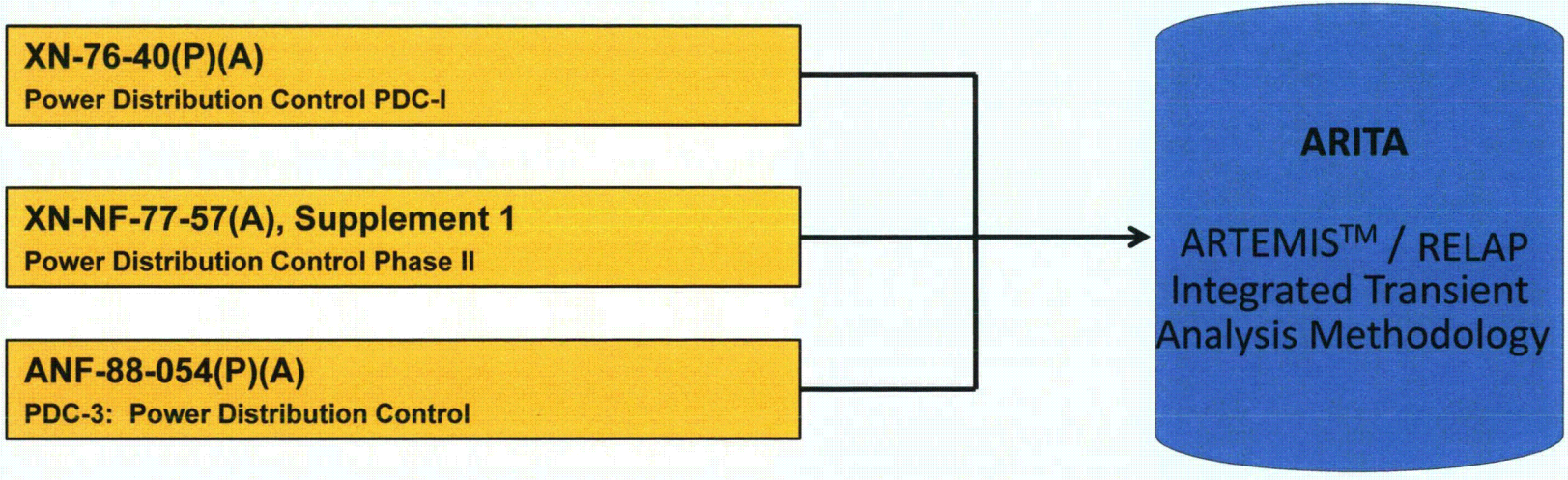
Thermal-Hydraulics Topical Report Transition (2 of 2)



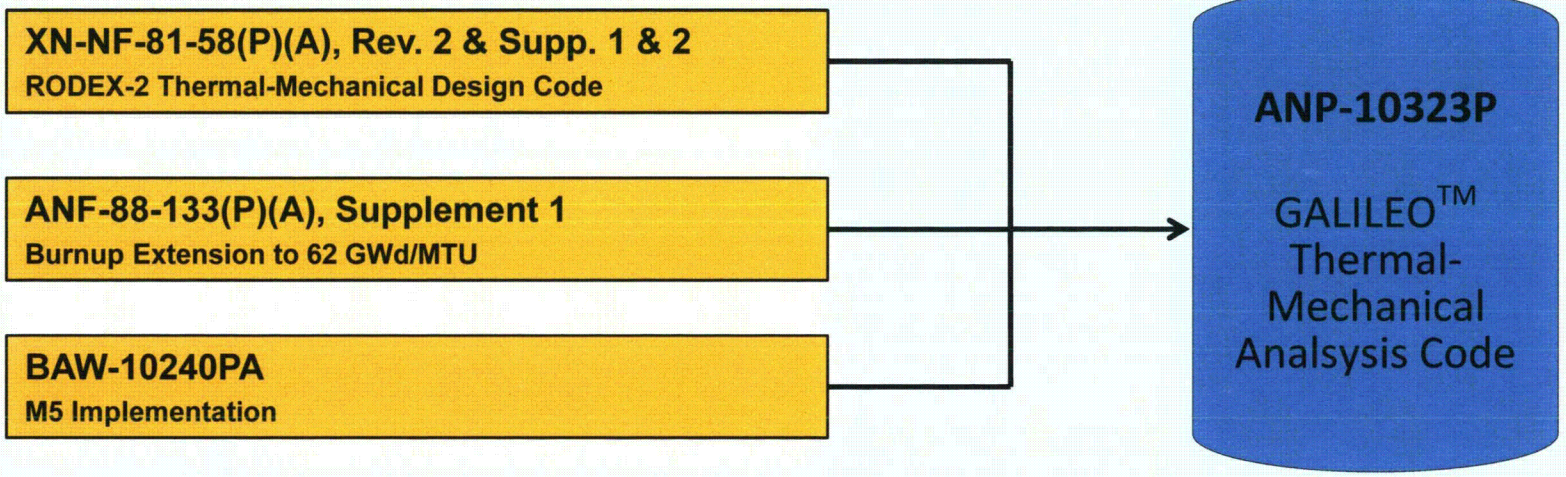
System Transient Analysis Topical Report Transition



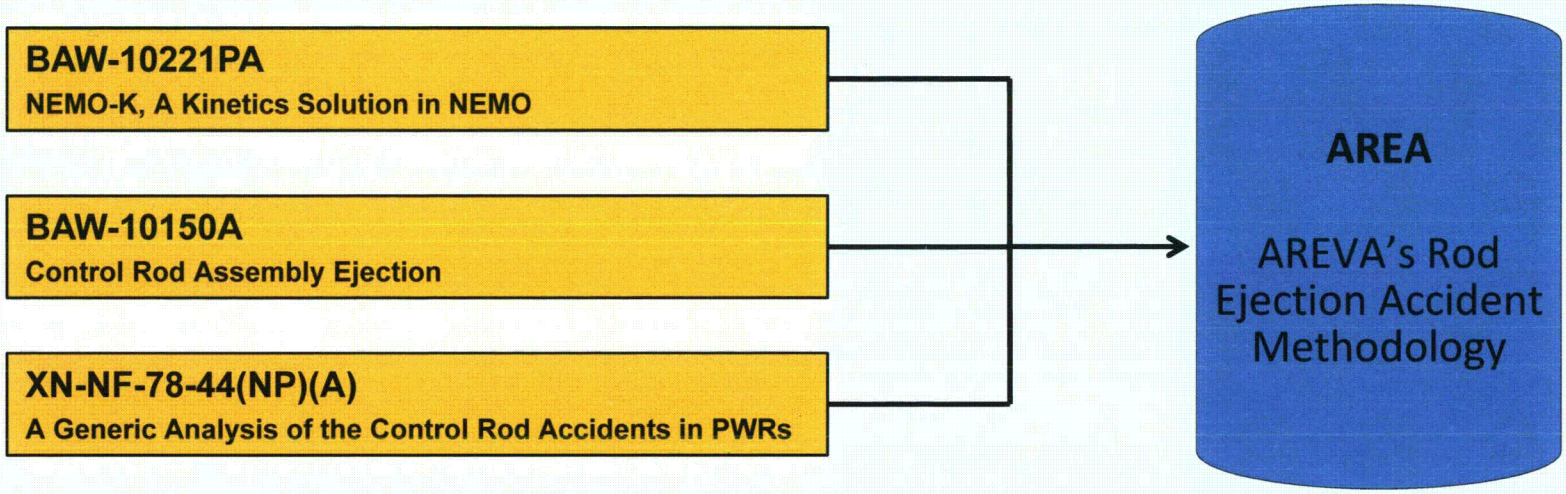
Power Distribution Control Topical Report Transition



Thermal-Mechanical Topical Report Transition



Control Rod Ejection Topical Report Transition



Topical Report Transition Summary

- **Reducing 22 legacy code and methodology topical reports to 5 topical reports**
  - **Approved**
    - ANP-10297P-A ARCADIA®
    - ANP-10311P-A, COBRA-FLX™
  - **Under active NRC review; NRC plans DSER in 2015**
    - ANP-10323P, GALILEO™
  - **Submittals in 2015**
    - ANP-10297P-A, ARCADIA® Supplement 1
    - AREA – Control Rod Ejection Methodology
    - ARITA – Transient Analysis Methods

Reduced number of topical reports will provide for a simpler plant licensing basis and more efficient NRC review.

Planned Schedule

- Pre-submittal tactical meeting — today
- Pre-submittal meeting — October 2015
- Topical submittal to NRC — December 2015
- Post-submittal meeting — 1st Quarter 2016
- Additional meetings/audits — 2016 - 2017
- Requested NRC approval — December 2017

ARITA Topical Structure (1 of 2)

- **ARITA Evaluation Model**
  - **PIRT**
  - **AMT**
  - **Benchmarks**
  - **Model Description (0D and 3D)**
  - **Event Description**
  - **Sensitivity Analysis**
  - **Sample Problems**
- **Thermal-Hydraulics Methods**
  - **Statistical Setpoints**
    - W & CE Plants
  - **Statistical DNB**
  - **DNB Propagation**

ARITA Topical Structure (2 of 2)

- **Thermal-Mechanical**
  - **Fuel Centerline Melt**
- **Power Distribution Control**

Methodology Objectives

- Applicable to W and CE PWR plants
- Applicable to UO_2 cores
- Addresses Non-LOCA issues
  - replaces EMF-2310PA Revision 1 Supplement 1, submitted December 2011
- Provides ability to analyze transients using either:
  - 0D kinetics
  - 3D kinetics

EMDAP

- Applied codes will be presented using the Evaluation Model Development and Assessment Process (EMDAP) guidance from RG 1.203
- EMDAP process was followed to identify the key phenomena and validate the codes used in the ARITA topical report
- Phenomena Identification and Ranking Table (PIRT) analysis
  - Defines important phenomena that must be considered in the transient analyses
- Assessment Matrix Table (AMT)
  - Defines the benchmarks required to qualify the codes used in the methodology
- Approach defining how to perform sensitivity studies
  - Based on PIRT bias and uncertainty parameters

EMDAP Process

- **Sample problem selection**
  - Considers events important to FCM, DNB
  - Considers events and the phenomena they support
- **Methods set will include:**
  - System transient analyses with S-RELAP5
  - Steady state decoupled methods for certain transients and for setpoint methods
  - 3D Core coupled transient methods
  - 3D Core and plant system coupled methods

Start of Proprietary Discussion

Proprietary meeting will begin with next slide

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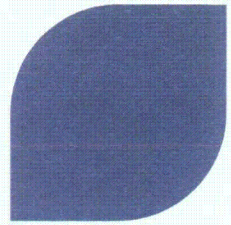
Method Description and Codes Used

- Methodology designed to support PWR reactor types with sample cases for W and CE plants
- Core analysis based on steady state and time dependent ARCADIA® calculations
  - ARTEMIS™ – A multi energy group nodal simulator code
  - COBRA-FLX™ – Approved core thermal hydraulics code
- System boundary conditions defined by the S-RELAP5 system code
- Time dependent core thermal solution uses an explicit full core-pin by-pin model.

ARITA Calculational Tools and Coupling Options



Associated Topical Reports

- **NRC's approval of the following associated topical reports is needed:**
  - **ANP-10323P, "Fuel Rod Thermal Mechanical Methodology for BWRs and PWRs," GALILEO™**
    - Needed for fuel pin thermal properties, gap conductivity, and corrosion model (oxide and/or hydrogen pickup model).
    - Status: Active NRC review.
  - **ANP-10297P Supplement, "The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results"**
    - Needed for additional benchmarks, upscatter Doppler model, and some ejected rod worth measurements.
    - Status: Planned for submittal to NRC in June 2015.

ARCADIA® Benchmarks

- **Core benchmarks**
  - 10 plants / 50+ cycles
  - W 157, W 193, CE 217, B&W 177, S 193 and S 157 plant types
  - Moveable fission chambers, fixed rhodium and Aeroball detectors
  - UO_2 and Enriched Reprocessed Uranium (new)
- **Additional benchmarks**
  - Plant G2 cold critical comparisons
  - Doppler Power Coefficient comparisons
  - Pseudo ejected rod worth comparisons

ARCADIA® Transient Benchmarks

- NEACRP Rod Ejection benchmark
  - Analytical benchmark against industry standard
- Rod Drop benchmark
  - 193 assembly plant
- SPERT-IIIE Rod Ejection benchmark (new)

Analytic Transient Benchmarks

- **NEACRP Bank Withdrawal**
  - Westinghouse 193 assemblies, 4 loop, 17x17 lattice
  - 3D ARTEMIS™ (no system coupling)
- **NEACRP MSLB (Exercise #3)**
  - B&W, 177 assemblies, 2X4 loop, 15x15 lattice
  - ARTEMIS™ fully coupled to S-RELAP5

Operational Transients

- **Shaft Break**
  - KWU 193 assemblies, 4 loop, 16x16 lattice
  - 3D ARTEMIS™ (no system coupling)
- **Load Rejection**
  - KWU 193 assemblies, 4 loop, 16x16 lattice
  - ARTEMIS™ fully coupled to S-RELAP5
- **Load Rejection with temporary loss of RCP**
  - KWU 193 assemblies, 4 loop, 16x16 lattice
  - ARTEMIS™ fully coupled to S-RELAP5

Summary

- ARITA method was developed based on RG 1.203 and SRP requirements in Chapters 4.2, 4.3, 4.4, and 15
- The method allows the flexibility of a 0D or 3D transient analysis for any of the Chapter 15 events supported
- Extensive validation of the codes both decoupled and coupled are provided
- Unique approach considers each pin and subchannel in the core during the transient
- 22 topical reports are consolidated into five topicals through the AREVA US PWR Codes and Methods development

ARTEMIS™/RELAP Integrated Transient Analysis – Non-LOCA

Bill Walters

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Non-LOCA AGENDA

- Overview of Evaluation Models (EM)
- Codes, Nodalization, and Methods for the 0D EM
- Codes, Nodalization, and Methods for the 3D EM
- Non-LOCA Sample Problems
- Summary

Evaluation Models

- **Two EMs are defined**
  - **0D EM - S-RELAP5 with point kinetics providing boundary conditions to steady-state ARTEMIS™ calculations**
    - Similar to currently approved methods
  - **3D EM – Coupled transient where ARTEMIS™ provides the 3D power distribution and S-RELAP5 calculates the system response**
- **Either EM is justified to evaluate non-LOCA Chapter 15 events**
  - **Rod Ejection Accident is covered by a different topical**

0D Analysis - Codes

- S-RELAP5 is used to calculate the system response with point kinetics
  - Same system code as used for currently approved methods
  - RELAP5 has been validated across numerous applications
  - Approved codes are used to generate the neutronics data
- Steady-state ARTEMIS™ is used to evaluate DNBR when required
  - DNBR Analysis will be discussed further in a later presentation
- GALILEO™ is used to evaluate FCM when required
  - FCM analysis will be discussed further in a later presentation

0D Analysis - Nodalization

- **Nodalization is similar to currently approved methodologies, with two changes:**

[ ]

0D Analysis - Methods

- Methods are similar to currently approved methodologies with the following changes:

[ ]

0D Analysis - Methods

3D Analysis - Codes

- S-RELAP5 is coupled with ARTEMIS™
  - S-RELAP5 is used to calculate the system response
  - ARTEMIS™ calculates the reactivity and power distribution
- ARTEMIS™ is used to evaluate DNBR when required
- GALILEO™ is used to evaluate FCM when required

3D Analysis - Nodalization

- S-RELAP5 nodalization is similar to 0D EM

[ ]

- ARTEMIS™ models the core using a nodal model
  - Typically 4 nodes per fuel assembly
  - Models the active fuel region
  - Open channel

3D Analysis - Methods

- **Similar Methods to 0D Evaluation Model:**

[ ]

3D Analysis - Methods

Coupling

- **Synchronous communication between S-RELAP5 and ARTEMIS™ using Message Passing Interface (MPI)**
- **S-RELAP determines core boundary conditions**
  - Core inlet temperature and flow
  - Core outlet pressure
  - Boron concentration
- **RPS and control systems also driven by S-RELAP5**
  - Control rod movement
  - SCRAM signal

3D Analysis - Methods

Coupling (continued)

- **ARTEMIS™ calculates the reactivity and power**
  - Fission power distribution
  - Thermal power distribution
  - Excore detector signals

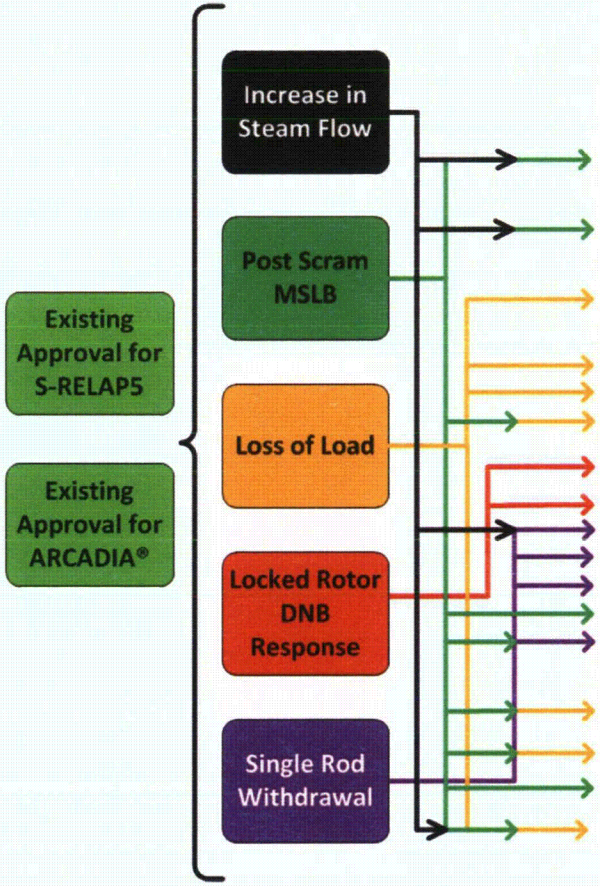
Sample Problems

- Five sample problems were selected to demonstrate the capability of the EMs and methodology
- Problems selected to address the key phenomena in SRP Chapter 15 Non-LOCA events
- Problems selected demonstrate the key aspects of the coupling
- Multiple plant types will be evaluated

Non-LOCA Sample Problems

Sample Problem	SRP Category	Event Type	Challenged Acceptance Criterion	Analysis Exposure	Initial Power	Plant Type to be Analyzed	Plant Response	EM
Increase in Steam Flow	15.1.3 Increase in Heat Removal	AOO	FCM DNB	EOC	HZP & HFP	CE	Prompt critical high-power spike NI response decalibration	0D & 3D
Post-Scram MSLB	15.1.5 Increase in Heat Removal	PA	DNB FCM	EOC	HZP	W-4	Core inlet temperature asymmetry Core power asymmetry Changing boron concentration	0D & 3D
Loss of Load	15.2.1 Decrease in Heat Removal	AOO	Over-pressure	BOC	HFP	W-4	Both primary and secondary over-pressure cases are analyzed.	0D
Locked Rotor	15.3.3 Decrease in RCS Flow	PA	DNB	BOC	HFP	W-3	Core inlet flow asymmetry Flow coast down	0D & 3D
Single Rod Withdrawal	15.4.3.2 Reactivity Insertion	PA	FCM DNB	BOC EOC	Partial Power	W-4	Augmented radial peaking Core power asymmetry Single rod motion	0D & 3D

Sample Problem Coverage Map



SRP #	Event Name	0D EM	3D EM
15.1.1 – 15.1.4	Decrease in Feedwater Temperature; Increase in Feedwater Flow; Increase in Steam Flow; Inadvertent Opening of a SGRV or SGSV	✓	✓
15.1.5	Main Steam Line Break	✓	✓
15.2.1 – 15.2.5	Loss of External Load; Turbine Trip; Loss of Condenser Vacuum; MSIV Closure; Steam Pressure Regulator Failure (Closed)	✓	✓
15.2.6	Loss of Non Emergency AC Power	✓	✓
15.2.7	Loss of Normal Feedwater Flow	✓	✓
15.2.8	Feedwater Pipe Break	✓	✓
15.3.1 – 15.3.2	Complete Loss of Coolant Flow; Partial Loss of Coolant Flow	✓	✓
15.3.3 – 15.3.4	RCP Shaft Seizure and RCP Shaft Break	✓	✓
15.4.1	UCBW from Subcritical or Low Power	✓	✓
15.4.2	UCBW at Power	✓	✓
15.4.3	Control Rod Misoperation	✓	✓
15.4.4	Startup of an Inactive Loop	✓	✓
15.4.6	Inadvertent Decrease in Boron Concentration	✓	✓
15.4.7	Loading of an FA in an Improper Location	✓	Not required
15.5.1 – 15.5.2	Inadvertent Operation of ECCS and CVCS Malfunction	✓	✓
15.6.1	Inadvertent Opening of Pressurizer PRV	✓	✓
15.6.2	Failure of Small Lines Carrying Primary Coolant Outside Containment	✓	✓
15.6.3	Steam Generator Tube Failure	✓	✓

Non-LOCA Summary (1 of 2)

- Defined a 0D EM and a 3D EM
- Uses the S-RELAP5 code
  - RELAP5 has been validated across numerous applications
- The 0D EM is similar to currently approved methods
  - Key nodalization changes and additions to the methodology were discussed
- The 3D EM uses synchronous coupling of S-RELAP5 and ARTEMIS™

Non-LOCA Summary (2 of 2)

- System response biasing considers analyzed criteria and the EM

[ ]

- The selected sample problems demonstrate that the EMs can be applied to any non-LOCA Chapter 15 transient
  - Control rod ejection covered by a different topical

ARTEMIS™/RELAP Integrated Transient Analysis – Setpoints and DNB Analyses

Ruxandra Bobolea

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Agenda

- Statistical Setpoints Verification
- Statistical DNB
- Core Model Considerations
- DNB Propagation
- Summary

Statistical Setpoints Verification

- Advanced statistical setpoints methods are applicable to W and CE plants.
- Consolidate NRC-approved topical reports:
  - EMF-1961(P)(A) (CE plants)
  - EMF-92-081(P)(A) (W plants)
  - XN-NF-81-22(P)(A) & Supplements 2, 4, & 5
  - XN-NF-507(P)(A) & Supplements 1 & 2.
- Advanced statistical setpoints methods will reflect the use of:
  - NRC-approved subchannel code COBRA-FLX™
  - The ARCADIA® system.

Statistical Setpoints Verification

- **DNB SAFDL protection will mainly consider the following changes to the current approved methods:**
  - **Use of NRC-approved subchannel code COBRA-FLX™.**
  - **ARTEMIS™-based axial power shapes.**

Statistical Setpoints Verification

- Retain CSLL verification process with the following changes to the current approved methods:
  - Use of NRC-approved subchannel code COBRA-FLX™.

[ ]

Statistical Setpoints Verification

- FCM SAFDL protection will mainly consider the following changes to the current approved methods:
  - Use of advanced codes GALILEO™ and ARTEMIS™.

Statistical Setpoints Verification Sample Problems

- **Statistical Setpoints verification sample problem will use:**
  - **NRC-approved subchannel code COBRA-FLX™**
  - **The ARCADIA® system**
  - **NRC-approved CHF correlations.**
- **Demonstrate SAFDLs protection for W and CE plants.**

Statistical DNB

Statistical DNB Methodology

- Use NRC-approved subchannel code COBRA-FLX™ and NRC-approved CHF correlations.
- The basis is the current NRC-approved methods described in EMF-1961(P)(A) (CE plants) and EMF-92-081(P)(A) (W plants).

[ ]

Core Model Considerations

- Use NRC-approved subchannel code COBRA-FLX™.

DNB Propagation

DNB Propagation Methodology

- DNB propagation methodology included in ARITA topical report.
- Similar DNB propagation method to currently NRC-approved DNB propagation methodology (XN-NF-82-06 (P)(A) Revision 1 & Supplements 2, 4, & 5).

Summary

- Use NRC-approved subchannel code COBRA-FLX™, the ARCADIA® system and NRC-approved CHF correlations.

[ ]

- DNB propagation methodology included in ARITA topical report.

ARTEMIS™/RELAP Integrated Transient Analysis – Fuel Rod Performance Analyses

Philippe Bellanger

AREVA

Fuel Rod Performance Models

- NRC-approved modern fuel rod performance codes will be used for FCM analyses
  - Modern codes explicitly model all known physical phenomena, including TCD
- ARITA topical report will reference the GALILEO™ code and models currently under review by the NRC (ANP-10323P)
  - NRC approval of AN-10323P is required for the review of the ARITA topical report

FCM Methodology for Statistical Setpoint Analyses

- GALILEO™ topical report describes AOO FCM methodology consistent with current setpoint verification methods
  - Output of analyses is a set of maximum allowable local linear heat generation rates (LHGRs) vs. burnup which ensure that FCM limits are met
  - Manufacturing, model, and power uncertainties are statistically sampled to achieve 95% confidence level
  - Compliance with LHGR limits is verified in downstream setpoint analyses
- AOO methodology currently under review will remain unchanged for statistical setpoint methodology

FCM Methodologies for Non-LOCA Safety Analyses

- ARITA topical report will extend the GALILEO statistical methodology to explicitly analyze FCM for all Chapter 15 events
  - FCM methodologies suited for each type of EMs (0D or 3D) will be presented
  - Excludes REA which is covered in a separate topical report
- GALILEO will be used to model the power and RCS parameters response during limiting events
- Manufacturing, model, and power uncertainties will be statistically sampled to achieve 95 confidence level

FCM Sample Problems

- **Sample problems will be presented in the topical report to demonstrate the suitability of the proposed FCM methods:**
  - **Cover all FCM methods (setpoint, 0D Non-LOCA, and 3D Non-LOCA)**
  - **Cover all targeted plants (Westinghouse and CE cores with fuel lattice sizes ranging from 14x14 to 17x17)**
  - **Focus on most limiting events (overcooling and reactivity events)**

Summary

- ARITA requires approval of GALILEO topical report
- Different FCM methods tailored to all ARITA methodologies
  - Setpoint analyses
  - Non-LOCA safety analyses based on 0D EM
  - Non-LOCA safety analyses based on 3D EM

ARTEMIS™/RELAP Integrated Transient Analysis – Power Distribution Control

Roberto Rubilar

AREVA

ARITA (Power Distribution Control)

- **PDC is used to verify that power peaking limits are not violated within the prescribed AO boundary**
  - **Used to support plants with infrequent In-core measurements**
  - **Penalty factors generated that are applied to measured FQ**
- **The new method will:**
  - **Consider PDC approaches used in France, Germany, and U.S.**
    - PDC-I, PDC-II, and PDC-3
    - Design Transient Analysis
    - Bounding Approach
    - Xe-Transient Approach
  - **Incorporate enhancements realized in other methods**
  - **Build in flexibility in anticipation of a need to address future challenges**
  - **Be applied to Westinghouse in the U.S. only**

Summary

- Provided an overview of the ARCADIA®/RELAP Integrated Transient Analysis.
- The ARITA Topical Report will be developed to be consistent with the criteria presented in SRP 4.2, 4.3, 4.4, and 15.
- AREVA plans to use RG 1.203
- AREVA informed NRC staff of:
  - the associated topical reports needing NRC approval
  - the method and models used
  - assessment of codes relative to available benchmarks
  - uncertainties, biasing, and limiting conditions and
  - planned scope of sample problems
- Additional NRC feedback?

Next Steps

Suite of Advanced topical reports schedule

ARCADIA pre-submittal meeting	March 2015
ARCADIA topical report	June 2015
AREA Methodology pre-submittal meeting	July 2015
AREA Methodology topical report	September 2015
ARITA pre-submittal meeting	October 2015
ARITA topical report	December 2015
ARITA post-submittal meeting	1st quarter, 2016
NRC DSER for ARITA topical report	December 2017

Acronyms/Nomenclature

- ARITA – ARTEMIS™/RELAP Integrated Transient Analysis
- ASME American Society of Mechanical Engineers
- AMT Assessment Matrix Table
- AO Axial Offset
- AOO Anticipated Operational Occurrences
- B&W Babcock and Wilcox
- BOC Beginning of Cycle
- BWR Boiling Water Reactor
- CE Combustion Engineering
- CSLL Core Safety Limit Line
- DNB Departure of Nucleate Boiling
- EOC End of Cycle
- EM Evaluation Model
- EMDAP Evaluation Model Development and Assessment Process
- HFP Hot Full Power
- HFT High Flux Trip
- HZP Hot Zero Power
- DNBR Departure from Nucleate Boiling Ratio
- FCM Fuel Center Melt
- LAR License Amendment Request
- LHGR Linear Heat Generation Rate
- LOCA Loss of Coolant Accident
- MDNBR Minimum Departure from Nucleate Boiling Ratio
- MPI Message passing Interface
- PDC Power Distribution Control
- PIRT Phenomenon Identification and Ranking Table
- PWR Pressurized Water Reactor
- P-T Pressure-Temperature
- REA Rod Ejection Accident
- RIA Reactivity-Initiated Accident
- RPS Reactor Protection System

Acronyms/Nomenclature

- **RV** Reactor Vessel
- **SAFDL** Specified Acceptable Fuel Design Limits
- **SG** Steam Generator
- **SRP** Standard Review Plan
- **TCD** Thermal conductivity Degradation
- **TFGR** Transient Fission Gas Release
- **TS** Technical Specifications
- **W** Westinghouse