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Core Thermal Hydraulic (TH) Methodology Update (Redacted)

July 26, 2012

Agenda

- Departure from Nucleate Boiling (DNB) Methodology Strategy
- VIPRE-01 use for B&W mPower^{TM} Analysis
- Critical Heat Flux Testing Update

Departure from Nucleate Boiling (DNB) Methodology Strategy

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Objectives

- Discuss B&W mPower^{TM} reactor unique TH needs relative to conventional PWRs
- Discuss general concept for DNB methodology for the B&W mPower reactor
- Discuss NRC staff feedback regarding proposed DNB methodology

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Nomenclature

AFS	Axial Flux Shape
AO	Axial Offset
AOO	Anticipated Operational Occurrence
CHF	Critical Heat Flux
CRA	Control Rod Assembly
DNB(R)	Departure from Nucleate Boiling Ratio
FCM	Fuel Centerline Melt
GDC	General Design Criteria
PZR	Pressurizer
RCS	Reactor Coolant System
RSM	Response Surface Model
SAFDL	Specified Acceptable Fuel Design Limits
SCD	Statistical Core Design
SDL	Statistical Design Limit
SRP	Standard Review Plan
TR	Topical Report

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10CFR50 – General Design Criteria

Crit. 10: The reactor core and associated coolant, control, and protections systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits (SAFDL) are not exceeded during any condition of normal operation including the effects of anticipated operational occurrences (AOO).

Crit. 12: The reactor core and associated coolant, control, and protections systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits (SAFDL) are not possible or can be reliably and readily detected and suppressed.

Core Specified Acceptable Fuel Design Limits (SAFDLs)

- The core SAFDLs focus on maintaining the primary barrier to fission product release – **the fuel clad integrity**
- SRP 4.2 provides guidance to meet the GDC requirements
- Overheating of Cladding → DNB
  - A rapid decrease in the heat transfer from the fuel rod surface to the coolant occurs when the critical heat flux (CHF) is exceeded
  - The decreased heat transfer leads to an increase in cladding temperature that can ultimately lead to a cladding rupture
- Overheating of Fuel Pellets → Fuel Centerline Melt (FCM)
  - Relocation of molten fuel could contact cladding leading to failure

Assurance of SAFDL Protection

Deterministic

- Conservative $F_{\Delta H}$ (e.g. tech. spec. limit)
- DNB Limiting AFS
- DNB Limiting P_{sys}, T_{hot}, core power, flow
- Compound uncertainties and engineering factors at their worst condition

- OR -

Statistical

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[CCI per Affidavit 4(a)-(d)]

Key Parameters to Consider for DNB

RCS Parameters

Pressurizer pressure
RCS hot temperature
Core flow
Core thermal power

Engineering Parameters

Hot channel factors
- Fuel rod bow
- Fuel assembly bow
- Manufacturing tolerances

Power distributions
- Radial peaking ($F_{\Delta H}$)
- Axial Flux Shape (F_Z)

CHF correlation uncertainty

Code Calculations
- TH and Neutronics
- Code Uncertainties
- Margins for Core Design

B&W mPower Unique Traits

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Fundamentally the B&W mPower reactor is a PWR

No soluble boron → reactivity control by control rods

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-] [CCI per Affidavit 4(a)-(d)]

Low average Linear Heat Generation Rate (LHGR)

- Favorable for preventing FCM
- Favorable for preventing DNB, but offset by low RCS flow (Power-to-Flow comparable to other PWR)

The unique B&W mPower core design affects the manner in which power distributions are handled.

Rodded Power Distributions

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[CCI per Affidavit 4(a)-(d)]

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Preliminary Statistical Core Design Methodology

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[CCI per Affidavit 4(a)-(d)]

Preliminary Statistical Core Design Methodology (cont)

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[CCI per Affidavit 4(a)-(d)]

Preliminary Statistical Core Design Methodology (cont)

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[CCI per Affidavit 4(a)-(d)]

Summary

- Deterministic and statistical methods are both being considered and the Topical Report will address where each method will be applied
- The B&W unique mPower design affects the manner in which power distributions are handled
- The methods proposed are similar to methods used for the analysis of existing PWR designs but will be modified to assure an appropriate level of protection for the B&W mPower reactor

VIPRE-01 Use For B&W mPower Analysis

- **Overall Objective:**
  - **Validating VIPRE-01 (`VIPRE-01MOD 02.4.0`) for B&W *mPower* analysis**

- **Objective of this presentation:**
  - **Discuss B&W's path to validating VIPRE-01 for the analysis of B&W *mPower* design through compliance with the VIPRE-01 SER**
  - **Discuss US NRC's feedback on B&W's approach to validation**

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B&W mPower Fuel Design

- **B&W *mPower* fuel design**
  - **Conventional 17x17 array, rod diameters, and rod pitch**

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[CCI per Affidavit 4(a)-(d)]

- **B&W *mPower* core composition**
  - **Conforms to the industry standards**

B&W *mPower* fuel design is simple and typical of the industry standards

B&W mPower TH Design

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[CCI per Affidavit 4(a)-(d)]

Compliance with VIPRE-01 SER

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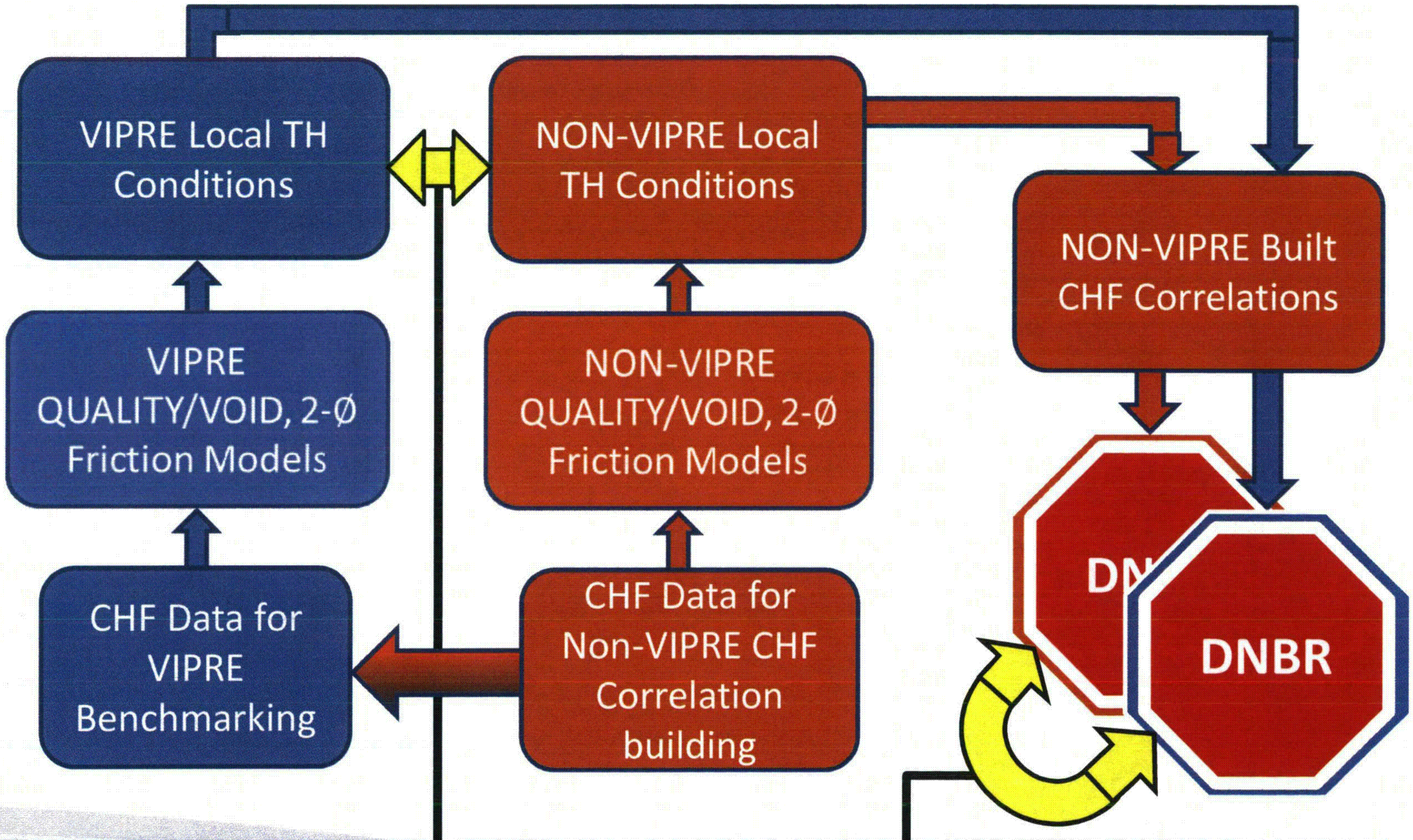
CHF Correlation Applicability

Previous benchmarking of VIPRE* to other TH Codes



- **NON-VIPRE built CHF Correlations are valid for use with VIPRE**
- **Validates the chosen combination of Quality-Void- 2-Ø friction correlations**

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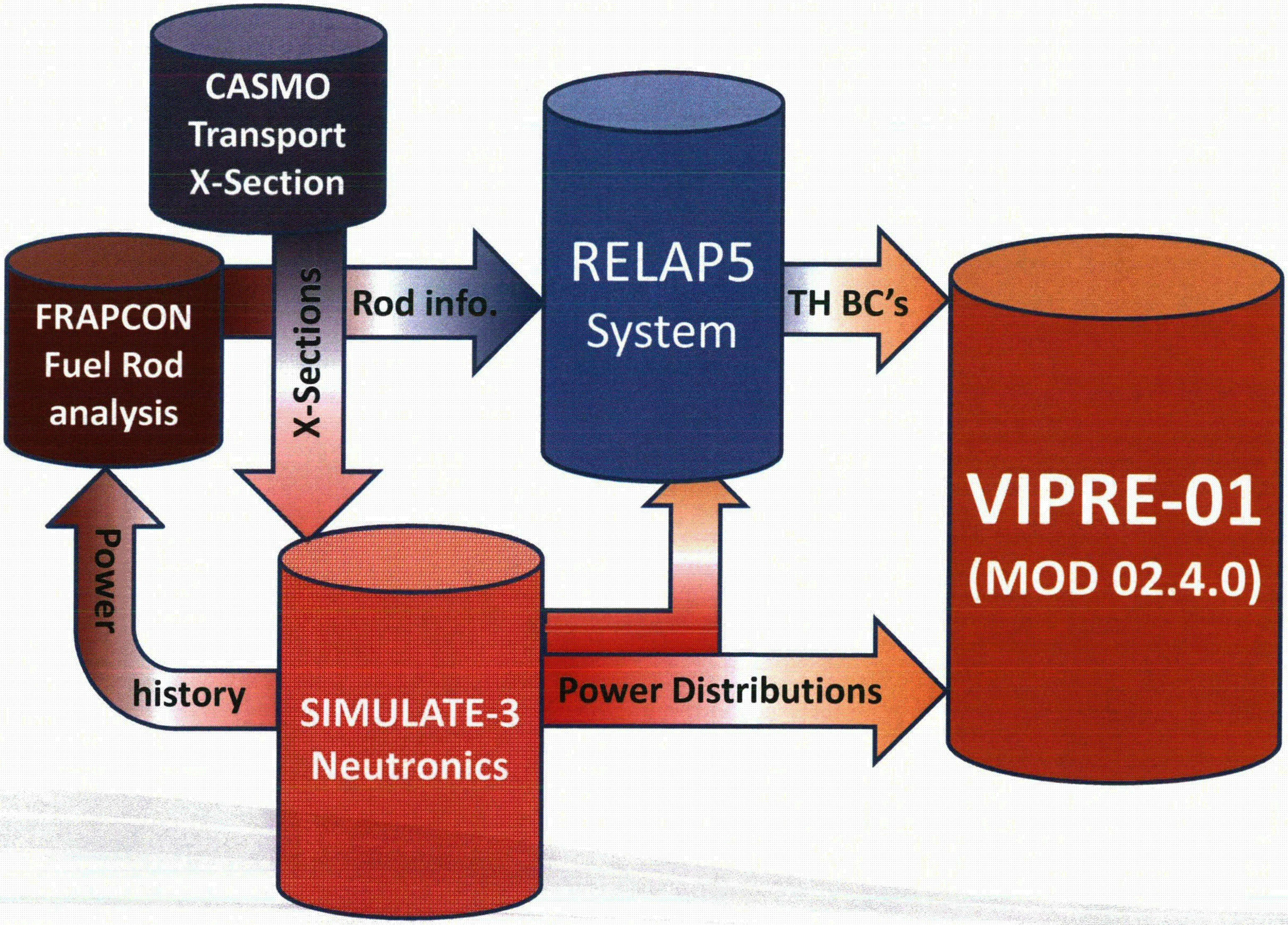
[CCI per Affidavit 4(a)-(d)]

Boundary Conditions



VIPRE-01 Fuel Rod Model

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Method Overview Discussion

Turbulent Momentum Factor - FTM

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[CCI per Affidavit 4(a)-(d)]

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[CCI per Affidavit 4(a)-(d)]

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[CCI per Affidavit 4(a)-(d)]

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[CCI per Affidavit 4(a)-(d)]

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[CCI per Affidavit 4(a)-(d)]

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Applications

- A B&W mPower CHF correlation Topical Report to be submitted for NRC review
- VIPRE-01 will be used for the analysis of:
  - CHF and mixing tests (typically 3x3 – 6x6 rod arrays)
  - prototypical fuel assemblies (typically 15x15 – 17x17 rod arrays)
- Transients to be analyzed with VIPRE-01 will be specified
- CHF correlations will be used for transient analysis, as permitted by the VIPRE-01 SER, only up to CHF
- VIPRE-01 modeling details for licensing calculations will be specified
- VIPRE-01 model behavior will be analytically justified

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Summary

- **B&W *mPower* fuel design is simple and typical of the industry standards**

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[CCI per Affidavit 4(a)-(d)]

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Discussion

- A path to achieve full compliance with the VIPRE-01 SER has been determined
- A systematic and structured effort is underway to perform the analyses supporting the Topical Report
- On course to submit the Topical Report for the NRC review on the first quarter of 2013

B&W mPower Critical Heat Flux Testing Update

Critical Heat Flux Testing Status

- Testing is being conducted at Stern Laboratories in Hamilton, Ontario, Canada

[ ] test series [ ] test configurations) have been completed [CCI per Affidavit 4(a)-(d)]

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[CCI per Affidavit 4(a)-(d)]

B&W mPower CHF Test Bundle

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Test Bundle (showing top end grid)

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[CCI per Affidavit 4(a)-(d)]

B&W mPower CHF Test Section

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Flow
Channel

Pressure
Boundary

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[CCI per Affidavit 4(a)-(d)]

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Example of Test Results

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[CCI per Affidavit 4(a)-(d)]

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Correlation Development

- Individual tests are modeled using VIPRE-01
- Local conditions from the model results and the CHF value from the test define the database for correlation development
- Parameters used in the correlation:

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[CCI per Affidavit 4(a)-(d)]

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Local Conditions for Completed Tests

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[CCI per Affidavit 4(a)-(d)]

Preliminary Correlation

Surface fit based on local conditions:

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[CCI per Affidavit 4(a)-(d)]

Preliminary Correlation Results

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[CCI per Affidavit 4(a)-(d)]

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Preliminary Correlation Ranges

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[CCI per Affidavit 4(a)-(d)]

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Preliminary Correlation Statistics

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[CCI per Affidavit 4(a)-(d)]

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- Additional testing is currently scheduled for November 2012

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[CCI per Affidavit 4(a)-(d)]

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CHF Topical Report

- To be based on the tests described here:
  - [ ]
  - [ ] test configurations
- To be submitted for NRC review in the third quarter of 2013

[CCI per Affidavit 4(a)-(d)]

Summary

- Successful tests on [ ]configurations have been completed

  [ ]more configurations will be tested
- Tests to date [are well correlated by a six parameter local conditions correlation]
- On-time submission of a CHF topical report is anticipated

[CCI per Affidavit 4(a)-(d)]

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Steam Generator Riser Design Basis
(Redacted Version)

July 26, 2012

Objectives

- Describe the design details of the riser
- Discuss materials, fabrication, assembly, and inspection
- Encourage NRC staff interaction on DSRS review guidance

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B&W mPower Reactor

Design Characteristics	
Reactor Type	PWR
Core Outlet	530 MWt
Reactor Height	88ft
Reactor Diameter	13ft (At the Flanges)
Reactor Dry Weight	1.4 Mlbm
Fuel Cycle	4 Years
Design Life	60 Years
RCP Quantity	8
Rail Shippable	Factory built

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B&W mPower Reactor

Design Characteristics	
Integral Vessel	No large primary piping
Internal CRDMs	No rod ejection
Passively Safe	Natural circulation for decay heat removal
CRDM Quantity	[ ] [CCI per Affidavit 4(a)-(d)]
Fuel Assembly Quantity	69
Fuel Assembly	17 x 17 fuel pin array
Design Pressure	2300 psi
Design Temperature	[ ] [CCI per Affidavit 4(a)-(d)]
Mass Flow Rate	31 Mlbm/hr

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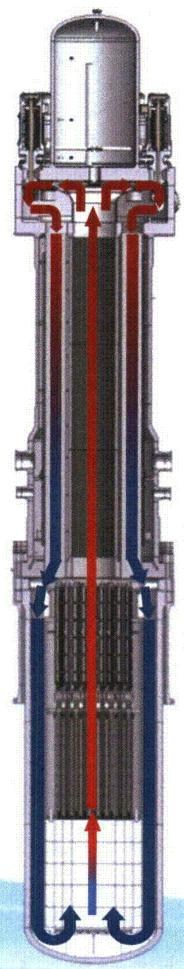
B&W mPower Reactor



2060 psia
606°F Core outlet
[ ] **[CCI per Affidavit 4(a)-(d)]**
31 Mlbm/hr

Primary Loop

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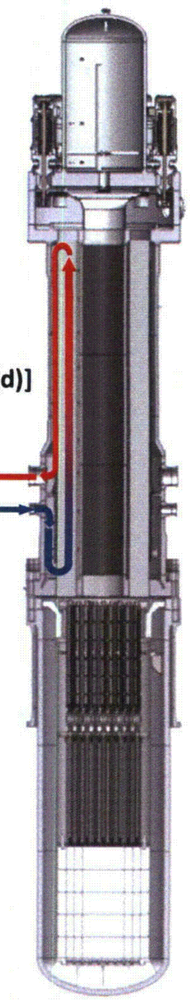
] **[CCI per Affidavit 4(a)-(d)]**



Steam
Feedwater

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[CCI per Affidavit 4(a)-(d)]

Secondary Loop

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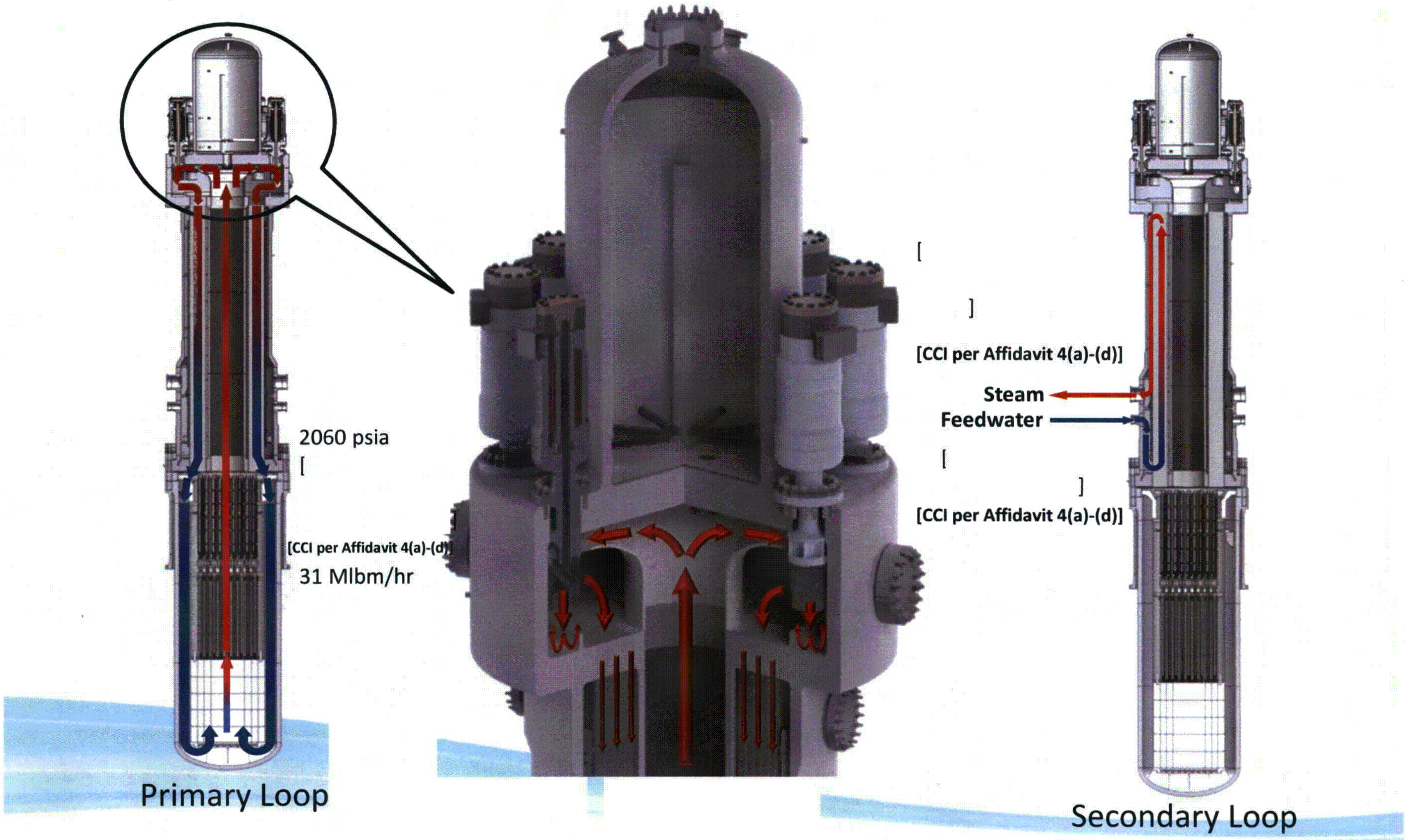
B&W mPower Reactor



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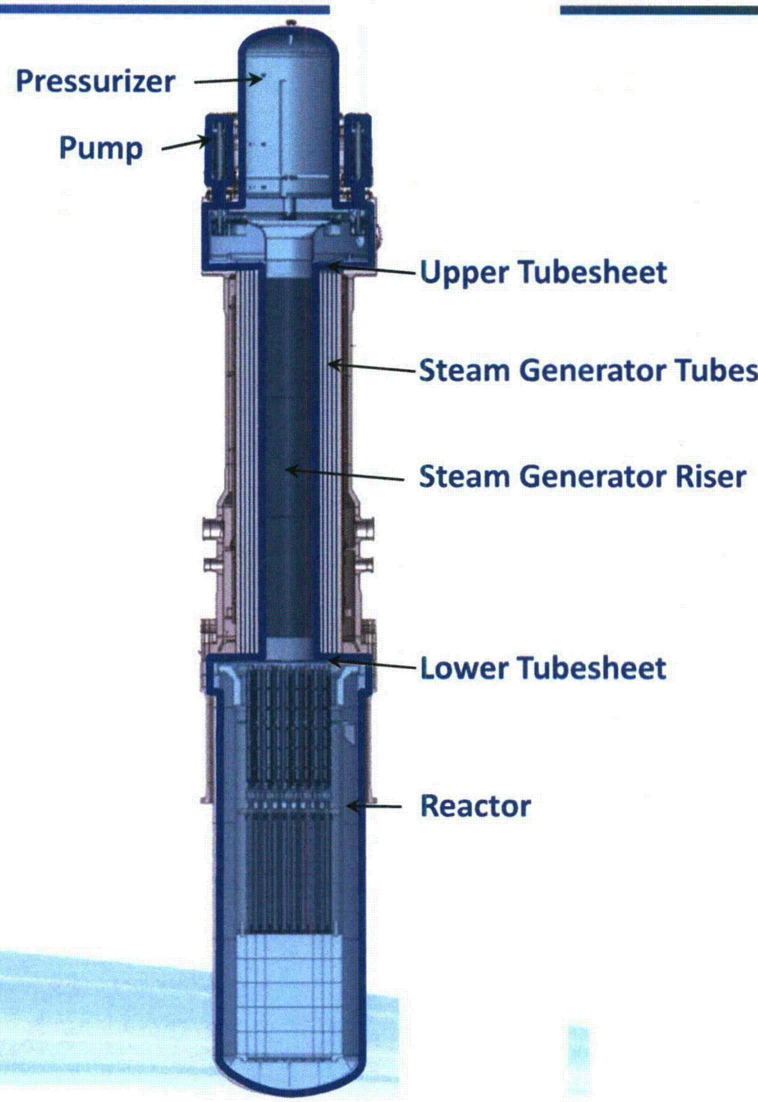
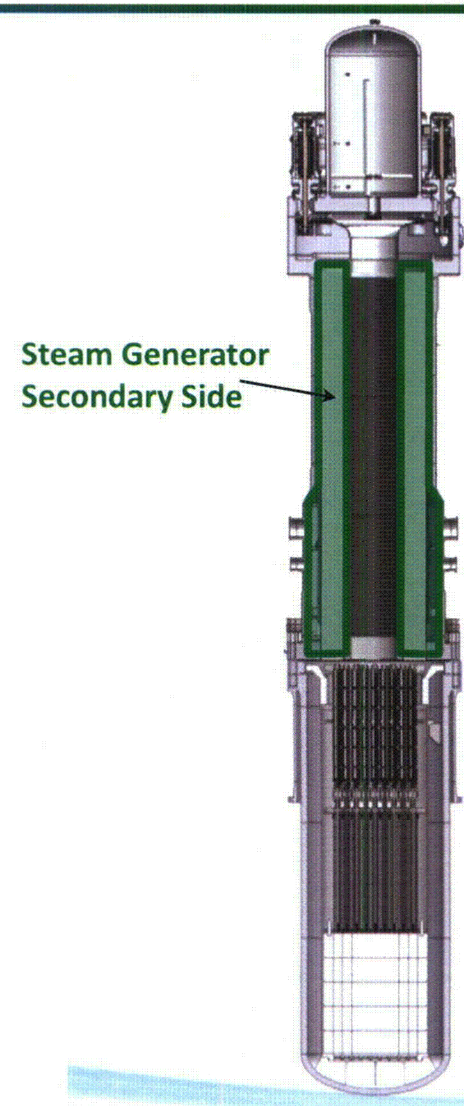
Pressure Boundary



Primary



Secondary

Reactor Breakdown

Reactor Breakdown

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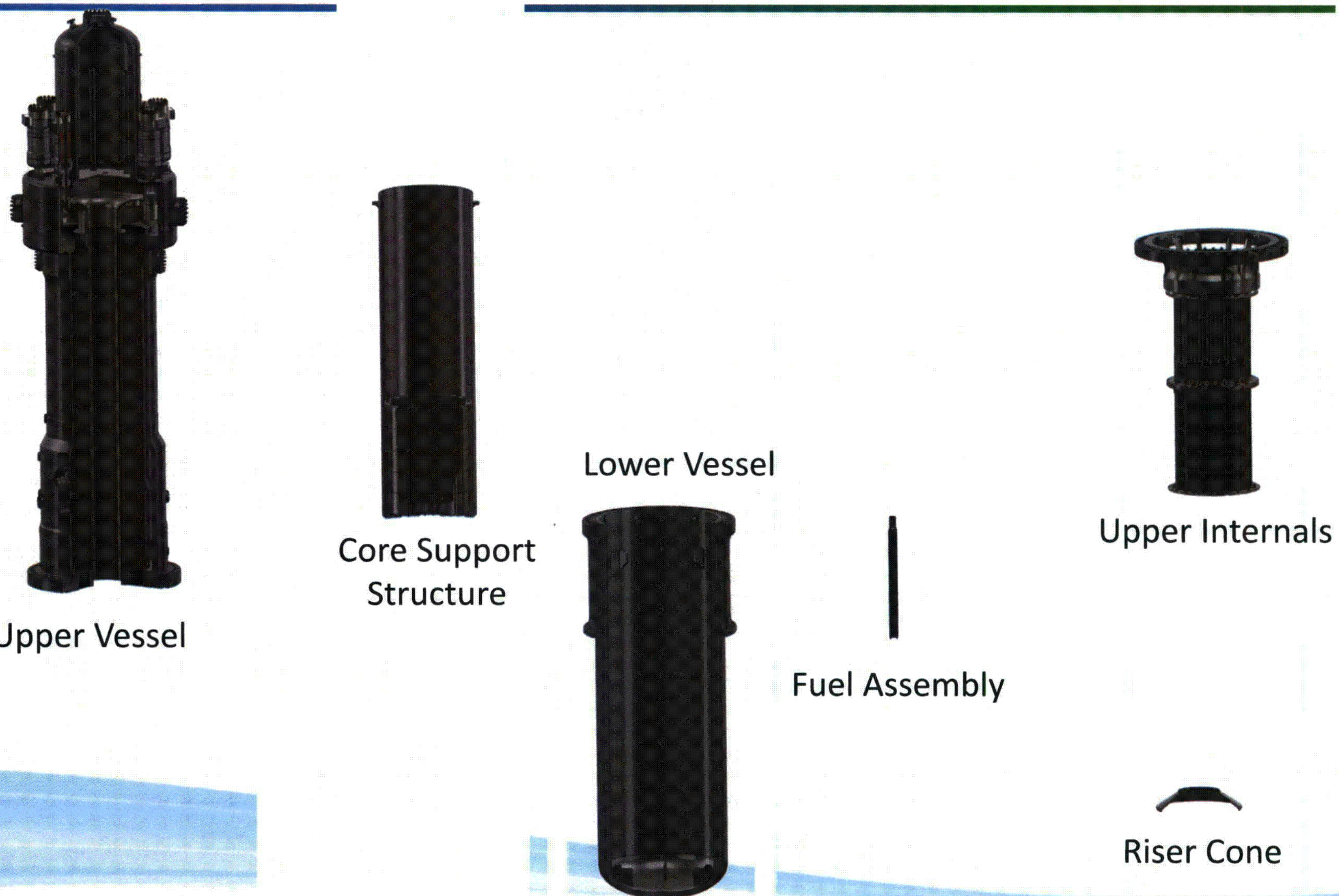
Reactor Breakdown



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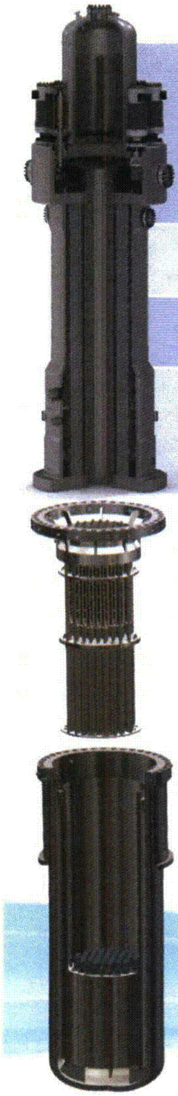
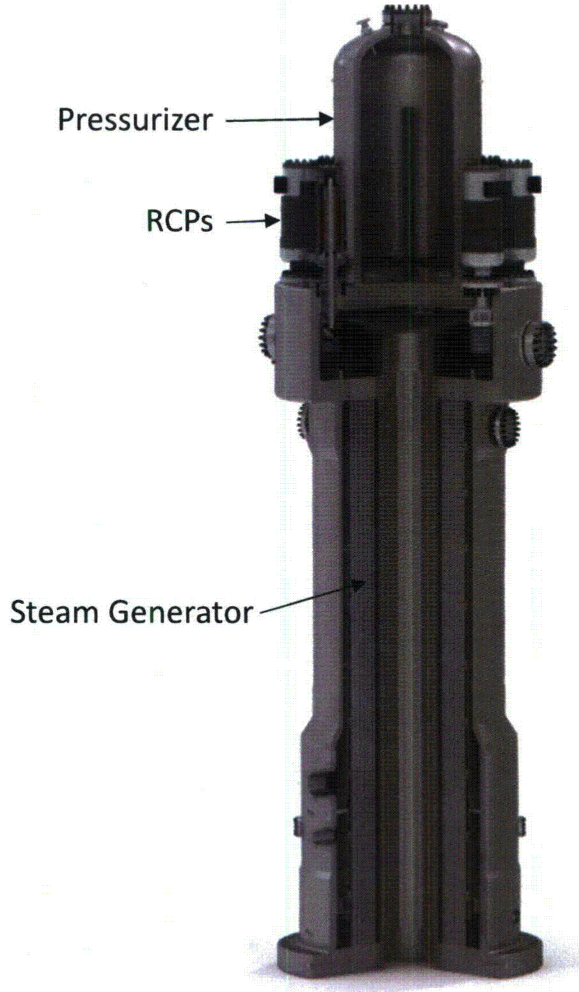
Upper Vessel Configuration



Configuration	Integral Pressurizer & Steam Generator (8) External motor RCPs
Vessel Diameter	13'
Height	[
Weight	] [CCI per Affidavit 4(a)-(d)]



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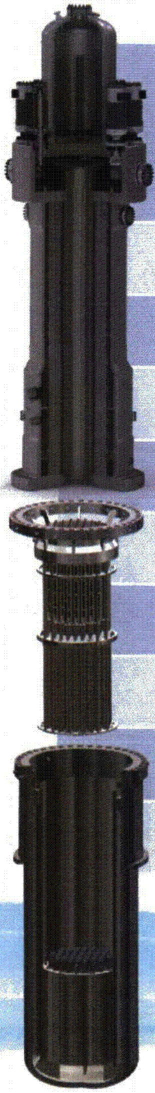
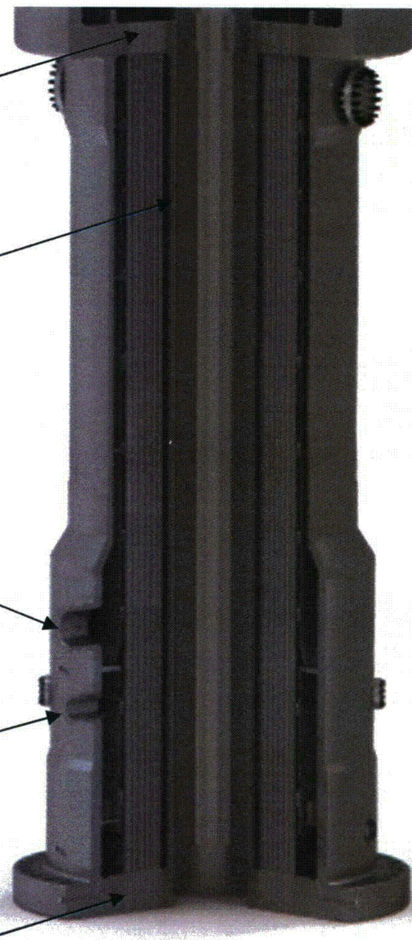
Steam Generator



Configuration	Integral Economizer Once Through Steam Generator (IEOTSG)
Vessel OD	13’
Riser ID	[
Number of tubes	
Active tube length	
Steam outlet nozzle	
Feedwater nozzle	
Shells	
Tubes	
Tube Supports	]

[CCI per Affidavit 4(a)-(d)]



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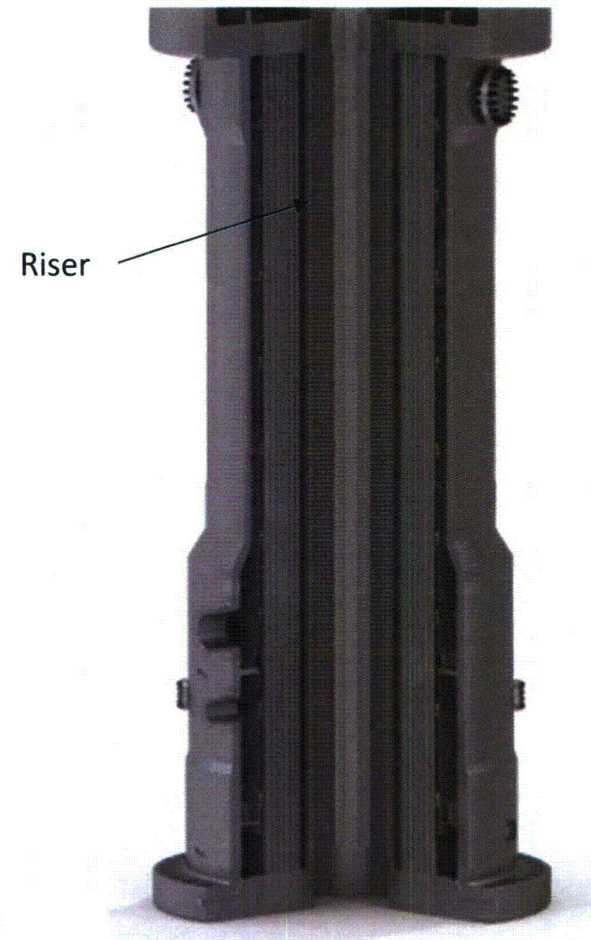
SG Riser

- Classification
  - ASME Section III, Div 1, Class 1 Vessel
    - SG is a multi-chambered vessel
- Design & Construction
  - NB-3300, vessel design
  - N-1 data report
  - N-Stamp
- Material
  - [
  -] [CCI per Affidavit 4(a)-(d)]
- Inspection
  - ASME Section XI, Subsection IWB
    - SG vessel welds (examination category B-B)



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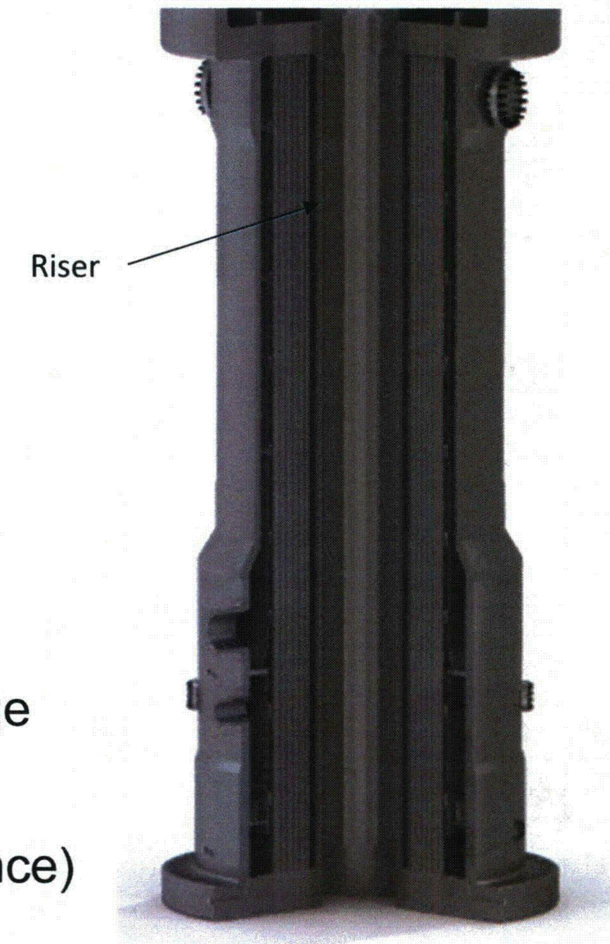
SG Riser

- Operating Stress State
  - Hoop Tension
  - Axial Compression
- Primary Pressure Sizing
  - [
  -] [CCI per Affidavit 4(a)-(d)]
- Seismic Stresses
  - Not typically controlling for vessel walls
- Thermal/Mechanical
  - Assessed preliminary 3Sm and fatigue usage
- Brittle Fracture
  - No radiation embrittlement (no neutron fluence)



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Fabrication Concept

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[CCI per Affidavit 4(a)-(d)]

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Upper Vessel Assembly

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[CCI per Affidavit 4(a)-(d)]

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Summary and Closing Discussions

- mPower SG Riser is designed as vessel
  - Consistent application of ASME Boiler and Pressure Vessel Code
  - Design and analysis is coupled to SG tubes and secondary shell
  - N-1 Data report and N-Stamp
- Typical SG fabrication and materials
- ASME Section XI SG vessel weld inspections
- No new vessel failure mechanisms
  - No neutron fluence, not susceptible to brittle fracture
  - Typical PWR environments (except no boron)