

**Enclosure 3**  
**Core Thermal Hydraulics Methodology Update Slides**  
**and**  
**Steam Generator Riser Design Basis Slides**  
**(Redacted)**



*Core Thermal Hydraulic (TH) Methodology Update  
(Redacted Version)*

*July 26, 2012*

© 2012 Babcock & Wilcox mPower, Inc. All Rights Reserved. This document is the property of Babcock & Wilcox mPower, Inc. (B&W mPower)

This is a pre-application document and includes preliminary B&W mPower Reactor design or design supporting information and is subject to further internal review, revision, or verification.

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

# *Departure from Nucleate Boiling (DNB) Methodology Strategy*



## Objectives

- Discuss B&W mPower™ 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

# 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

## 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  $P_{\text{sys}}$ ,  $T_{\text{hot}}$ , core power, flow
- Compound uncertainties and engineering factors at their worst condition

[

]

[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

- T-H and Neutronics
- Code Uncertainties
- Margins for Core Design

## B&W mPower Unique Traits

Fundamentally the B&W mPower reactor is a PWR

No soluble boron → reactivity control by control rods

[

]

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

DNB can be addressed in a manner similar to other PWRs but there are some unique requirements for the B&W mPower reactor

# Rodded Power Distributions

[

]

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



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



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

## Summary

- Deterministic[ ] methods are[ ] being considered and the Topical Report will address[ ]
- [ ]
- The methods proposed are similar to methods used for the analysis of existing PWR designs but will be modified and extended to assure an appropriate level of protection for the B&W mPower reactor[ ]

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

## *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**



# B&W mPower Fuel Design

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

[

]

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

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





# B&W mPower TH Design

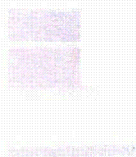
[

]

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



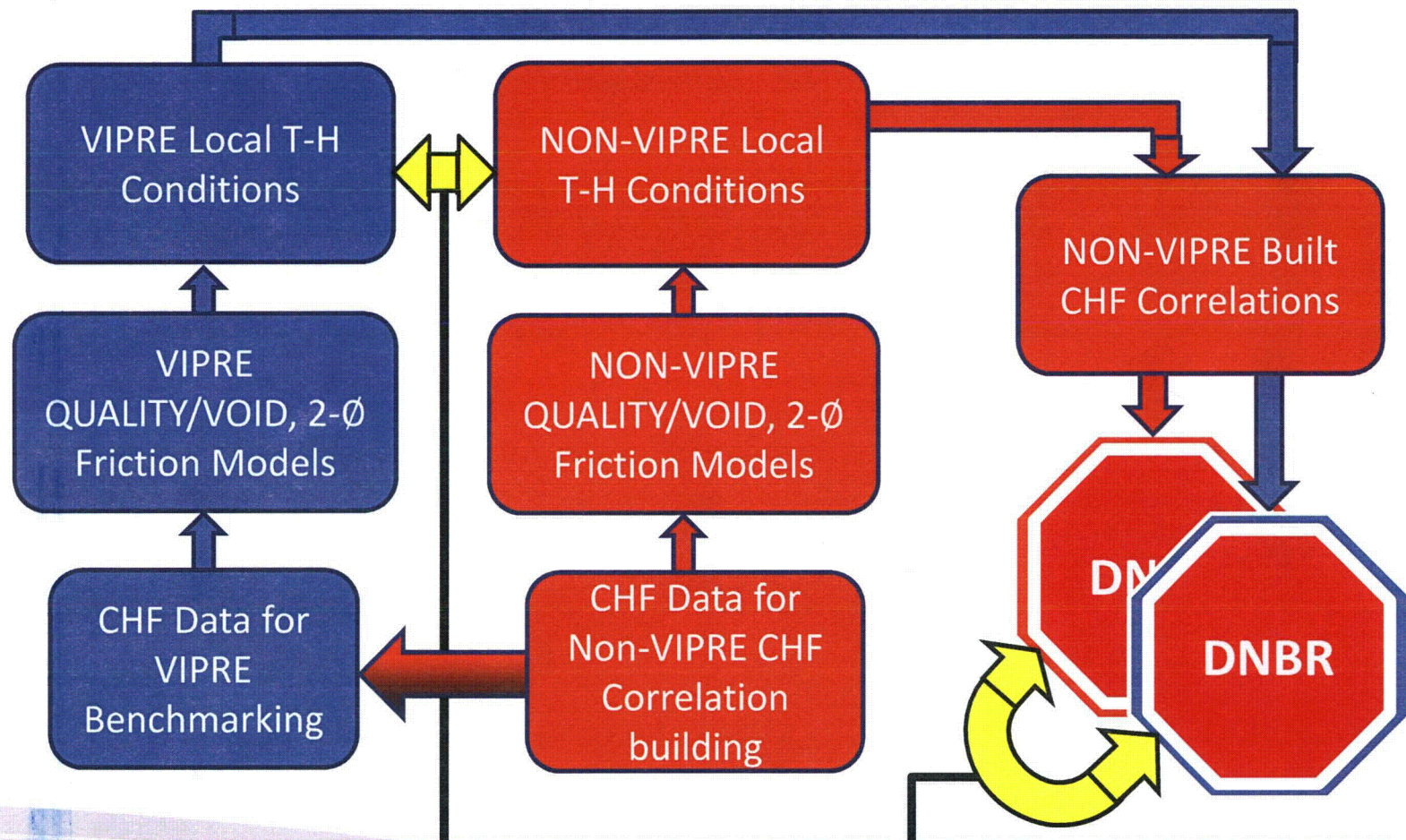
# Compliance with VIPRE-01 SER



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

# CHF Correlation Applicability

Westinghouse and Dominion Benchmarked VIPRE to other T-H Codes

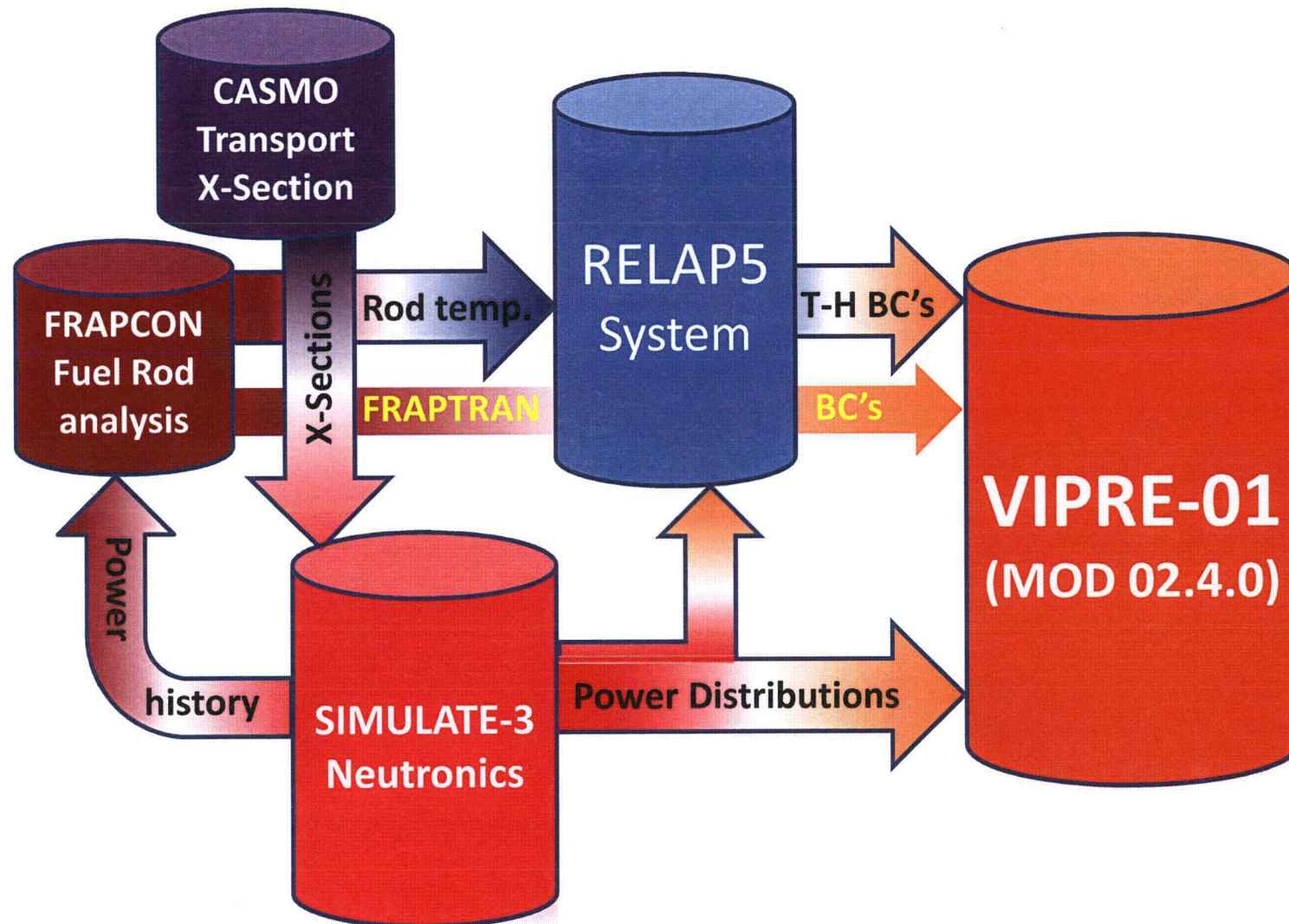


- NON-VIPRE built CHF Correlations are valid for use with VIPRE
- Validates the chosen combination of Quality-Void- 2-Ø friction correlations





# Boundary Conditions





# Method Overview Discussion

## Turbulent Momentum Factor - FTM

[

]

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



[

]

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



[

]

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

generation  
**mPower**

[





[

]

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

# Applications

- VIPRE-01 SER permits the use of steady-state CHF correlations for transient analyses, and only up to CHF
- A B&W mPower CHF correlation Topical Report to be submitted for NRC review
- VIPRE-01 will be used for the analysis of:

[

]

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



[

# VIPRE-01 Fuel Rod Model

]

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

## *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)]
  - [

]

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



# B&W mPower CHF Test Bundle

[

Test  
Bundle  
(showing  
top end  
grid)



[Redacted text]

]

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



# B&W mPower CHF Test Section

[

Flow  
Channel

Pressure  
Boundary

]

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

# Example of Test Results

[

]



# 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:  
[

]

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



# Local Conditions for Completed Tests

[

]

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

# Preliminary Correlation

Surface fit based on local conditions:

[

]

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

# Preliminary Correlation Results

[

]

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



# Preliminary Correlation Ranges

[

]

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

# Preliminary Correlation Statistics

[

]

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

generation

# **mPower** Upcoming Critical Heat Flux Testing

- Additional testing is currently scheduled for November 2012
- [

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

# CHF Topical Report

- To be based on the tests described here:
  - [ ] test series
  - [ ] 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 [ ]
- On-time submission of a CHF topical report is anticipated

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



# generation *mPower*

## *Steam Generator Riser Design Basis (Redacted Version)*

*July 26, 2012*

© 2012 Babcock & Wilcox mPower, Inc. All Rights Reserved. This document is the property of Babcock & Wilcox mPower, Inc. (B&W mPower)

This is a pre-application document and includes preliminary B&W mPower Reactor design or design supporting information and is subject to further internal review, revision, or verification.

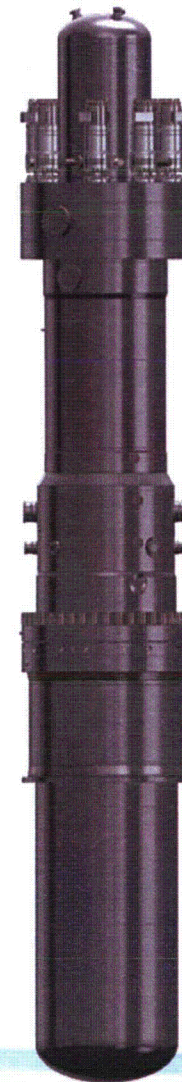
## Objectives

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



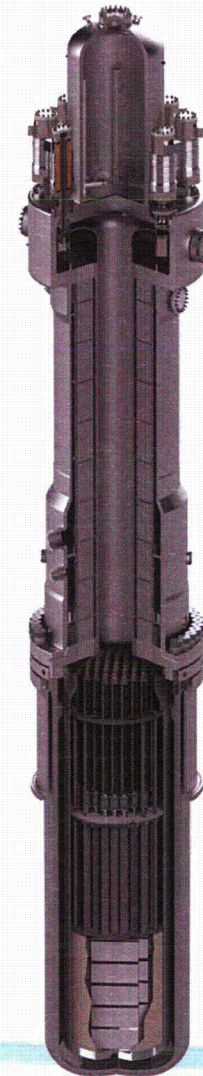
## B&W mPower Reactor

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



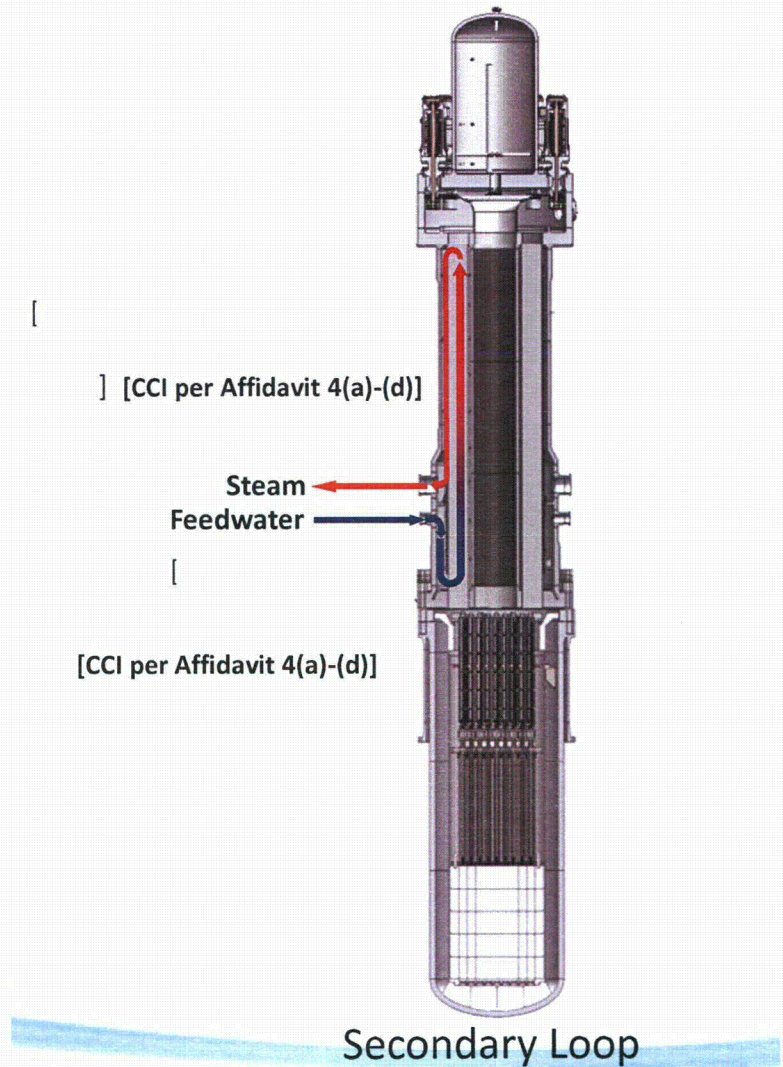
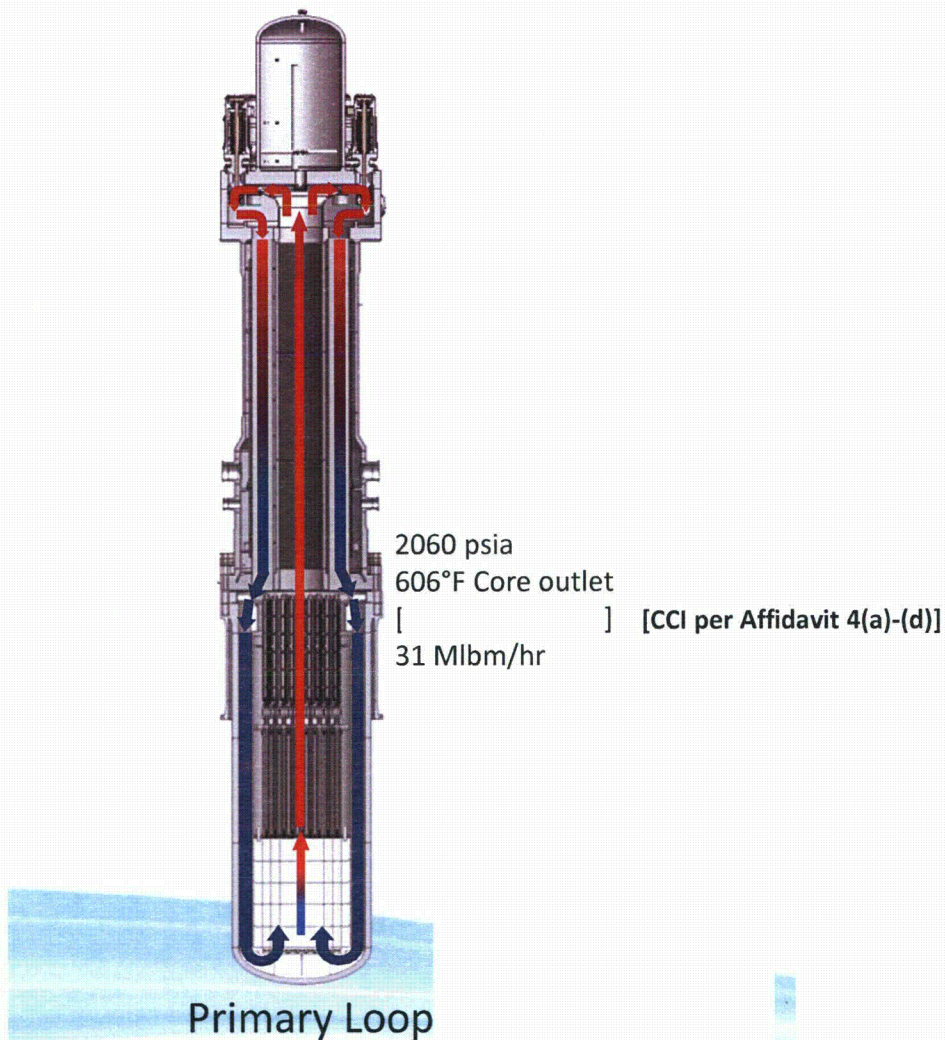


Design Characteristics	
Integral Vessel	No large primary piping
Internal CRDMs	No rod ejection
Passively Safe	Natural circulation for decay heat removal
CRDM Quantity	[ ] [CCI per Affidavit 4(a)-(d)]
Fuel Assembly Quantity	69
Fuel Assembly	17 x 17 fuel pin array
Design Pressure	2300 psi
Design Temperature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



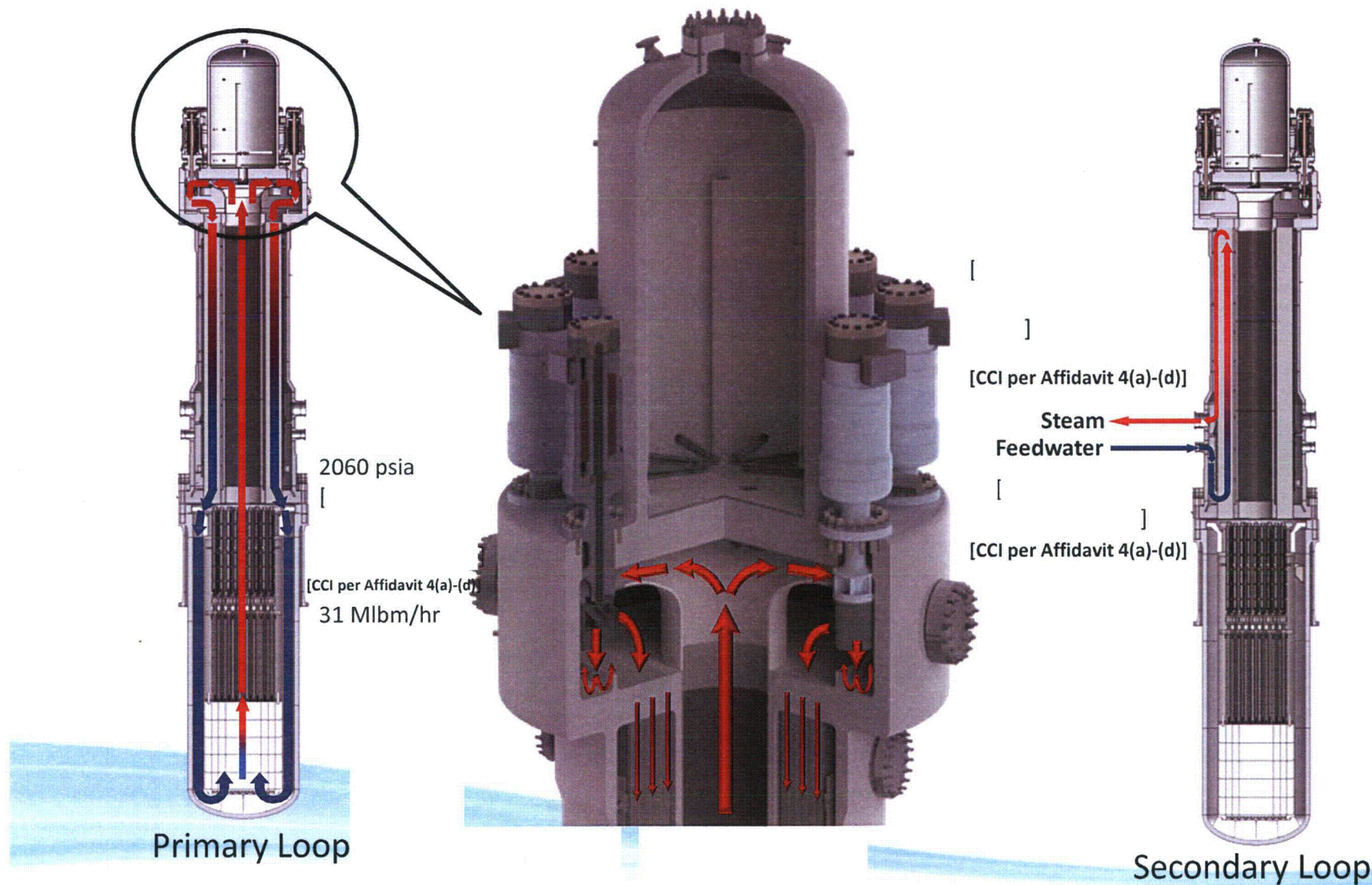


# B&W mPower Reactor

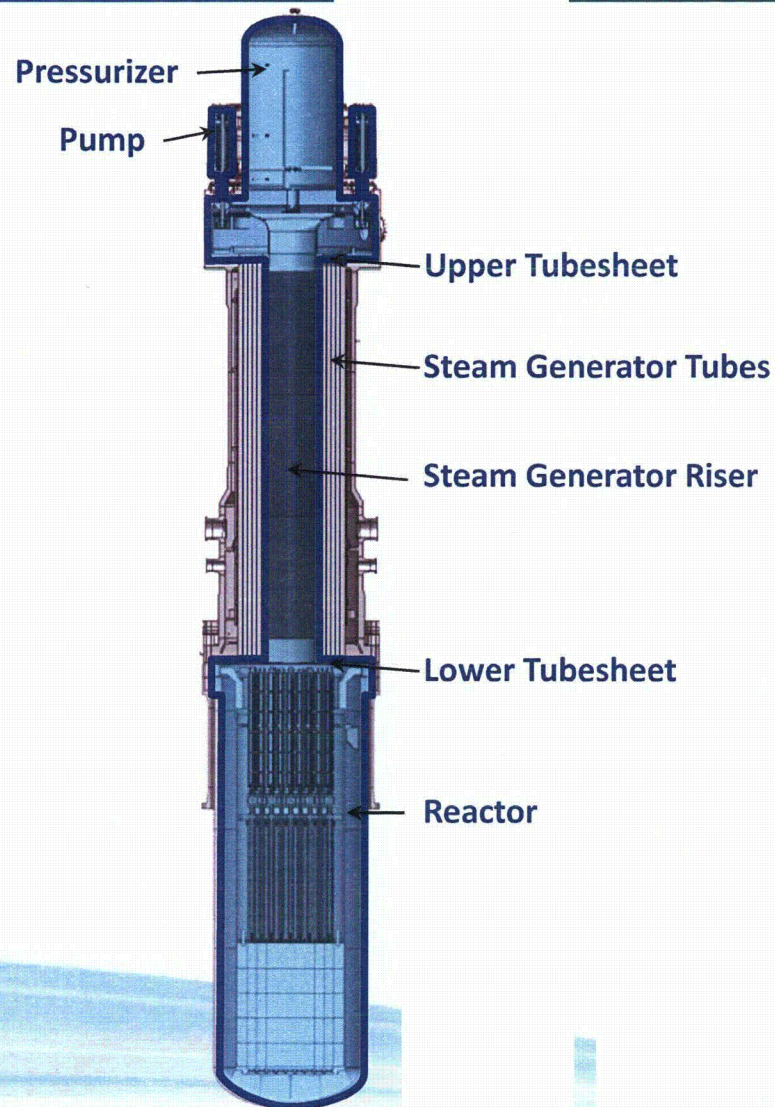




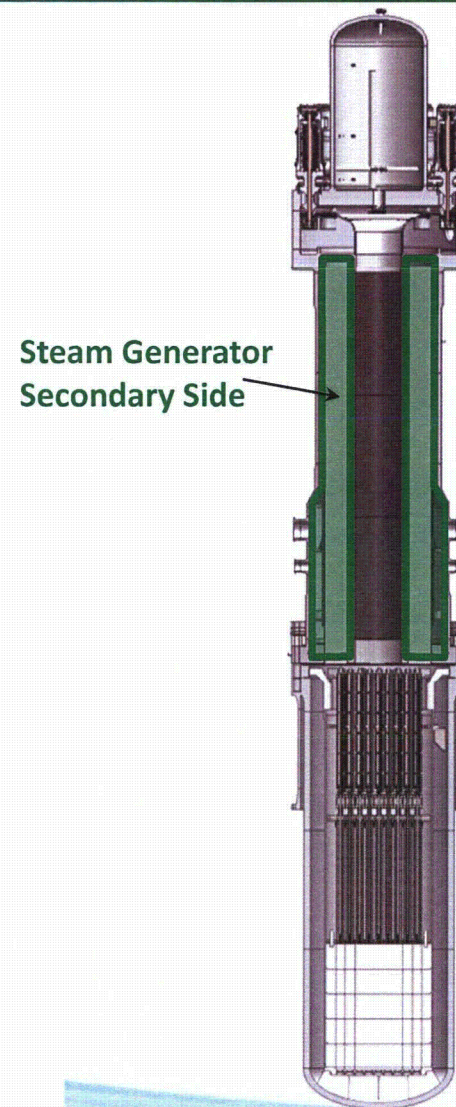
# B&W mPower Reactor



## Pressure Boundary



**Primary**

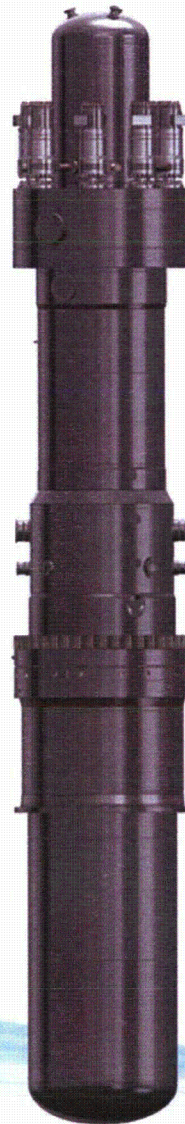


**Secondary**



## Reactor Breakdown

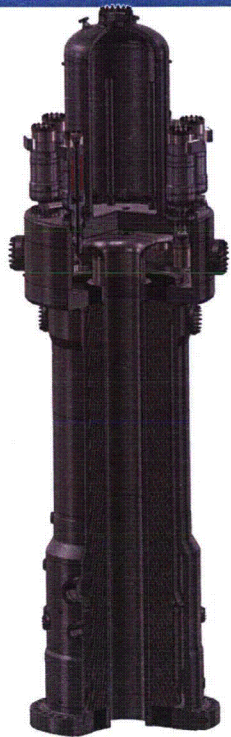
---



## Reactor Breakdown



## Reactor Breakdown



Upper Vessel



Core Support  
Structure

Lower Vessel



Fuel Assembly



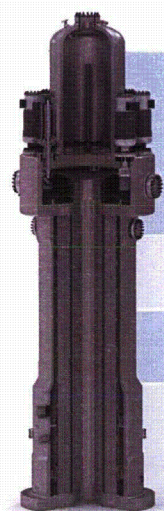
Upper Internals



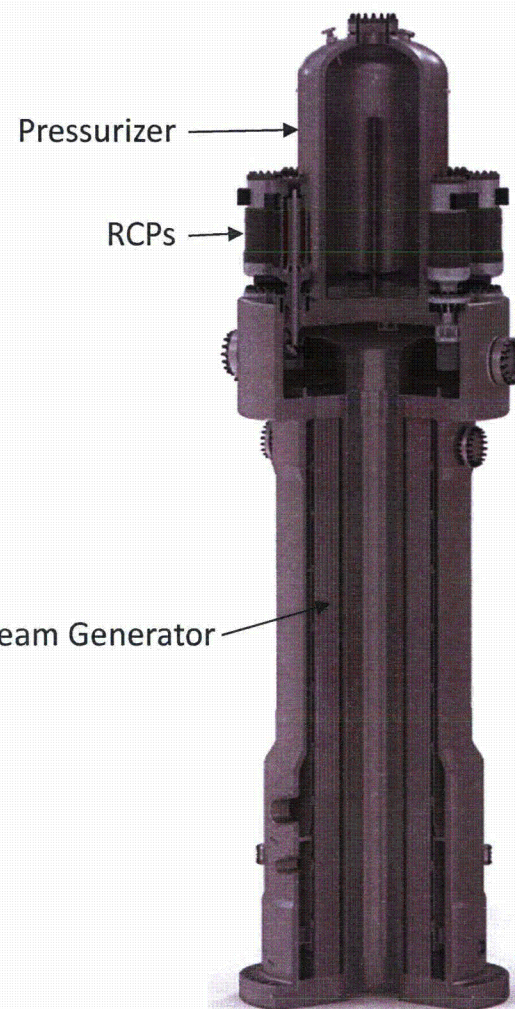
Riser Cone



# Upper Vessel Configuration

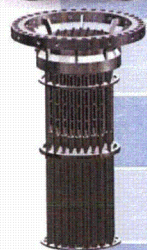
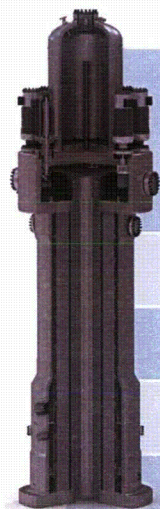


Configuration	Integral Pressurizer & Steam Generator (8) External motor RCPs
Vessel Diameter	13'
Height	[ ]
Weight	[ ] [CCI per Affidavit 4(a)-(d)]



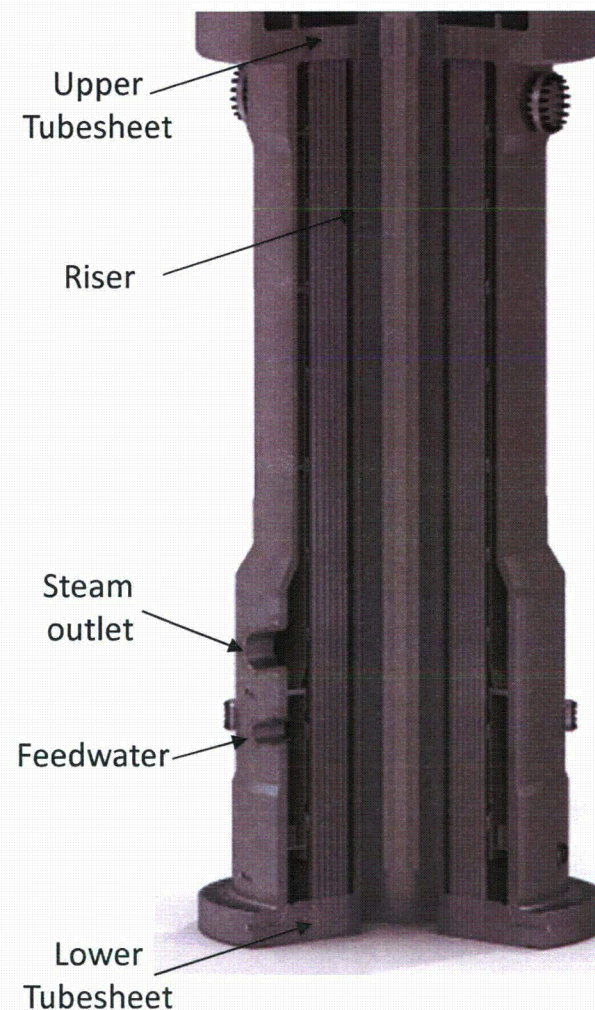


## Steam Generator



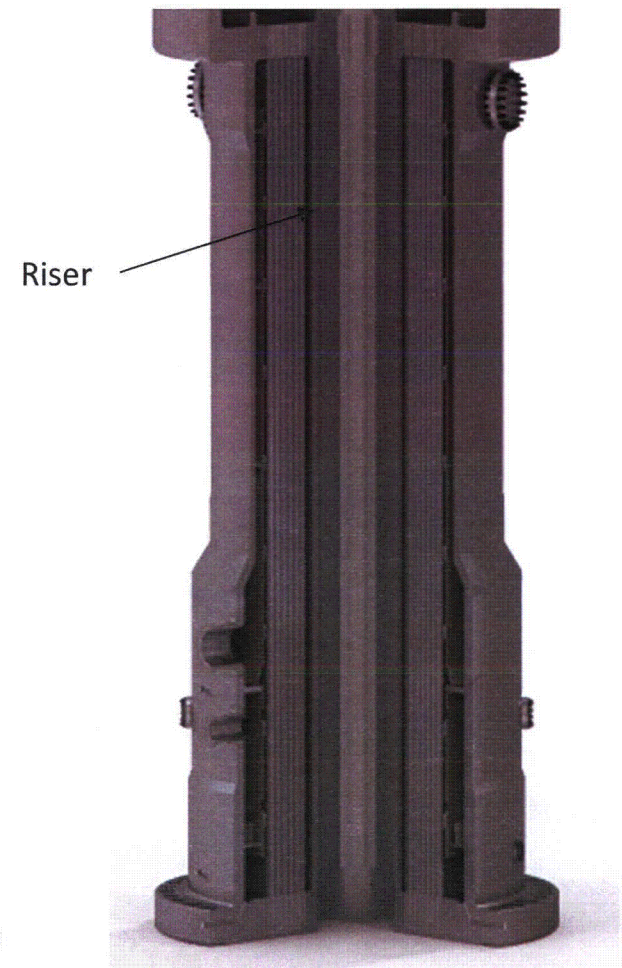
Configuration	Integral Economizer Once Through Steam Generator (IEOTSG)
Vessel OD	13'
Riser ID	[ <input type="text"/> ]
Number of tubes	<input type="text"/>
Active tube length	<input type="text"/>
Steam outlet nozzle	<input type="text"/>
Feedwater nozzle	<input type="text"/>
Shells	<input type="text"/>
Tubes	<input type="text"/>
Tube Supports	<input type="text"/> ]

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

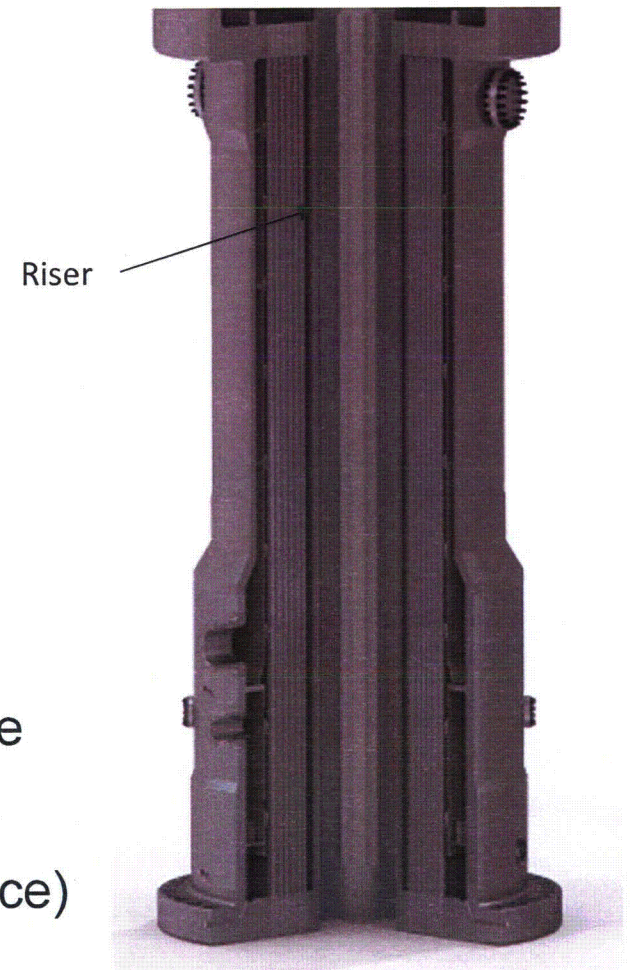




- Classification
  - ASME Section III, Div 1, Class 1 Vessel
    - SG is a multi-chambered vessel
- Design & Construction
  - NB-3300, vessel design
  - N-1 data report
  - N-Stamp
- Material
  - [
  - ] [CCI per Affidavit 4(a)-(d)]
- Inspection
  - ASME Section XI, subsection IWB
    - SG vessel welds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



- 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)



# Fabrication Concept

[

]

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

]

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



## Upper Vessel Assembly

---

[

]

]

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

## Summary and Closing Discussions

---

- mPower SG Riser is designed as vessel
- Materials and fabrication are typical and non-unique
- Code applicability is typical for the SSC
- Discussions and feedback regarding riser design and NRC review guidance