Materials Selection

High Temperature Metallic Materials

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Meeting Approach

- **Issue definition and outcome objectives as described at 1st planning meeting**
- **Materials selection considerations**
  - High temperature materials - metallics
- **Exelon RAIs approach**
- **Next steps**

Philosophy

- **PBMR structures, systems and component material selection shall (in order of preference):**
  - use materials within the limits of a code or standard that the NRC has accepted, or
  - use materials within the limits of a code or standard that has been accepted by a standards body but the NRC has not yet accepted, or
  - use materials that are not incorporated in a code at this time and design from first principles with appropriate supporting qualification programs.

Issue Definition

- **Background**
  - PBMR makes extensive use of materials that conform with codes and standards found acceptable by the NRC in prior applications.
  - PBMR utilizes several materials that, while known to the NRC, are used outside limits previously accepted.
  - In select cases, PBMR uses materials that the NRC has not reviewed.
- **Issue**
  - Demonstrate adequacy of materials selection program by confirming:
    - *Materials selection and operating environment process*
    - *Materials qualification process*
  - Demonstrate adequate understanding of helium chemistry and the impact on component lifetimes and reliability

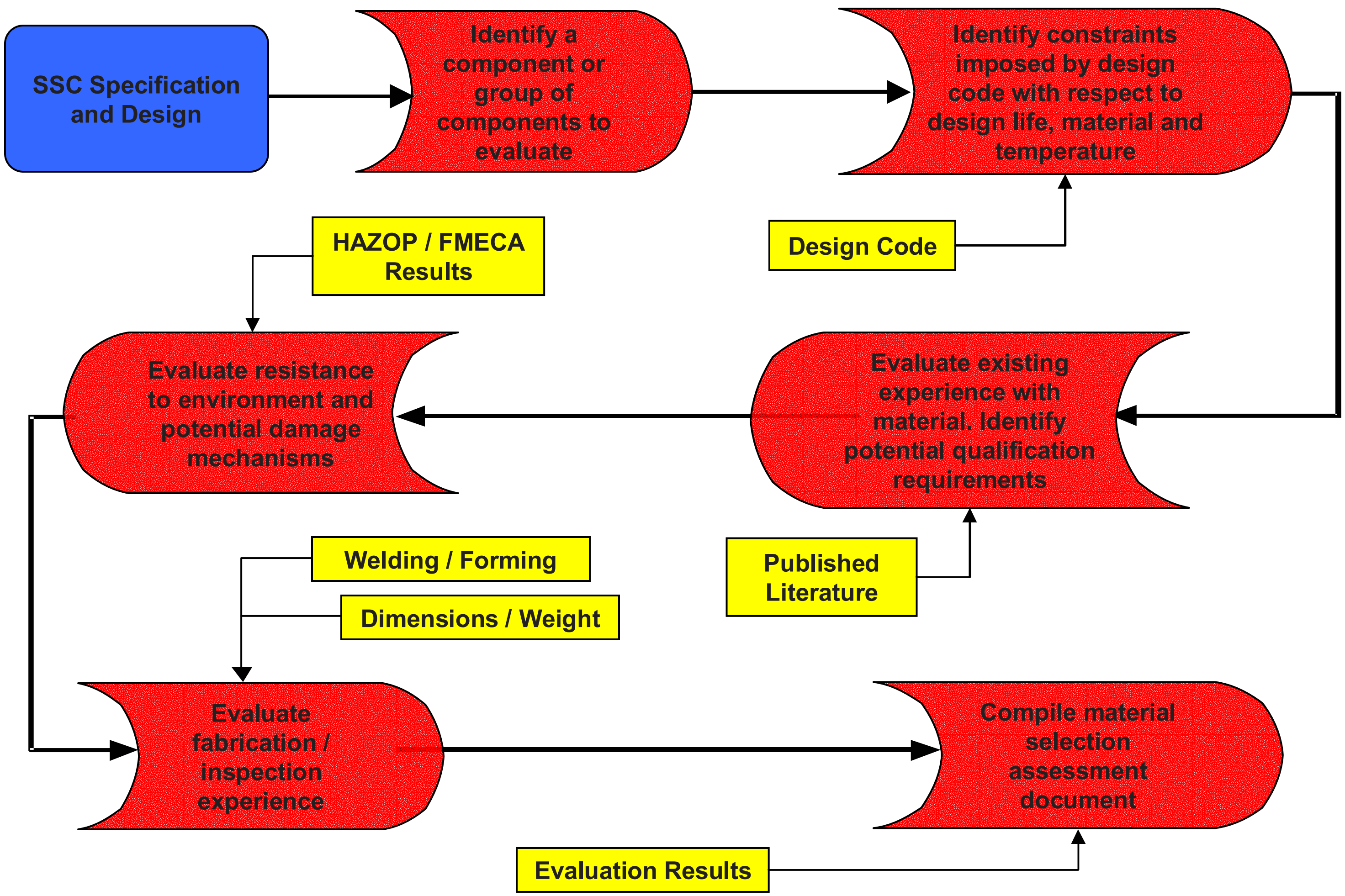
Issue Focus

- **Agreement is required on a suitable process for material selection and qualification.**
- **This issue can be subdivided as follows:**
  - Metallic materials
  - Carbon-based and ceramic materials
- **Processes to be addressed:**
  - Process for material selection, including consideration of operating environment and its effect on the performance of the material, and
  - Process to determine material qualification requirements.
    - *Focus on materials with required performance that falls outside existing codes and standards*
    - *Particular emphasis on confirming adequacy of performance of materials designed to first principles.*

Outcome Objectives

- Agreement on the PBMR approach to materials selection and qualification
- Understanding of acceptance criteria for material qualification programs
- Understanding of the extent of documentation required to describe the effects of helium chemistry impurities during normal and upset conditions which affect material performance lifetimes and reliability
- Tied closely to the Outcome Objectives for the Codes and Standards focus topic

Material Selection Process



Key Material Selection for High Temperature Components

Material Selection	Application	Application within the ASME qualified envelope	Application outside the current ASME qualified envelope	Material Testing Required
SA508 Grade 3 Class 1 / SA533 Type B Class 1	Reactor Pressure Vessel	Yes		No
SA508 Grade 3 Class 2 / SA533 Type B Class 2	Power Conversion Unit Pressure Boundary (Vessels and Pipes)	Yes		No
SA240 Type 316H	Core Barrel Assembly	Yes		No
SB 407 Alloy 800H	Reactivity Control Rods		Yes	No*
SB 409 Alloy 800H	Core Outlet Pipe Liner		Yes	No*

Note: "ASME Envelope" refers to allowable limits with respect to temperature, loading and design life.

* Design data is available in non-ASME international standards.

Reactor Pressure Vessel Operating Conditions

Normal Operating Temperature: 260-300°C

Short Term, Abnormal Temperature: 400-500°C

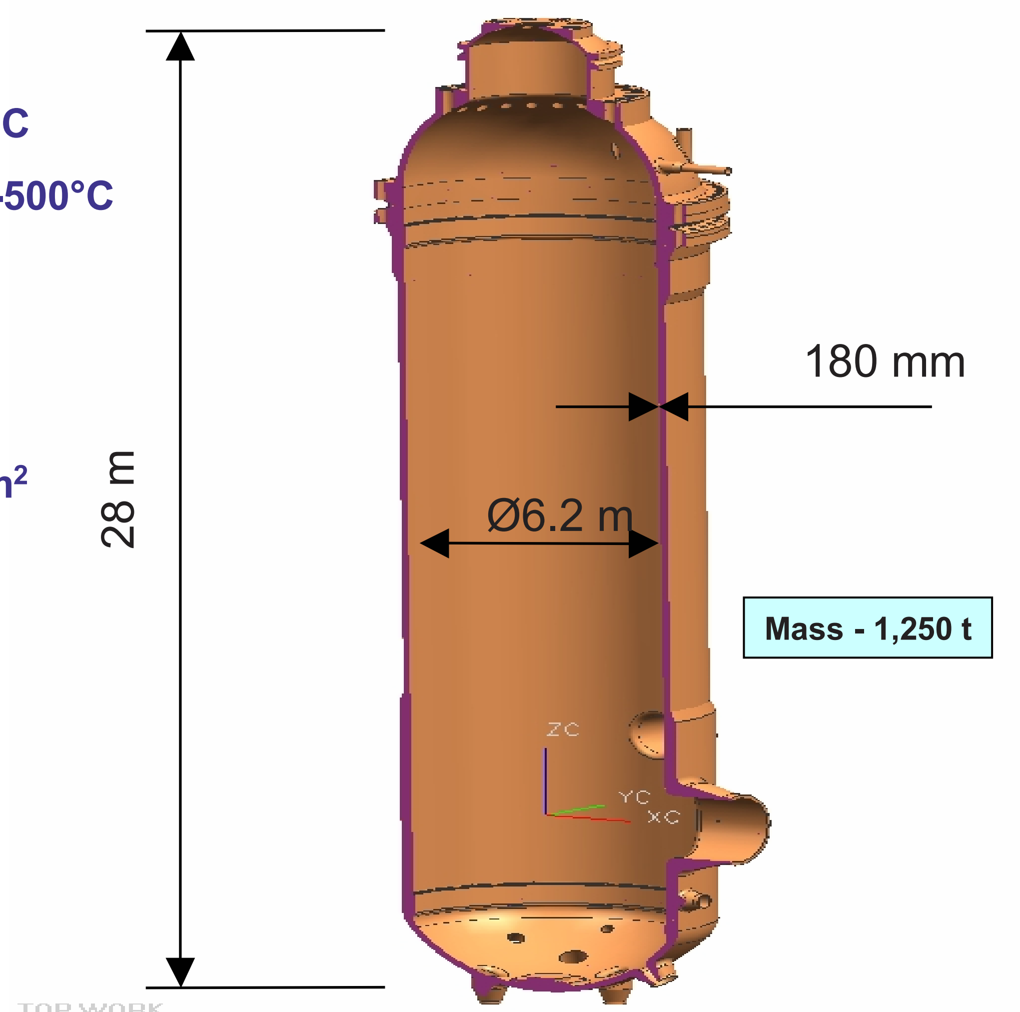
Design Temperature: 350°C

Normal Operating Pressure: 9MPa

Design Pressure: 9.7MPa

Max End-of-Life Fast Fluence: 2×10^{18}n/cm^2 (E>0.1MeV)

Environment:
- **Internal – Helium Coolant**
- **External – Dry Air (~200°C)**



Power Conversion Unit
Pressure Boundary Operating Conditions

Normal Operating Temperature: 110°C

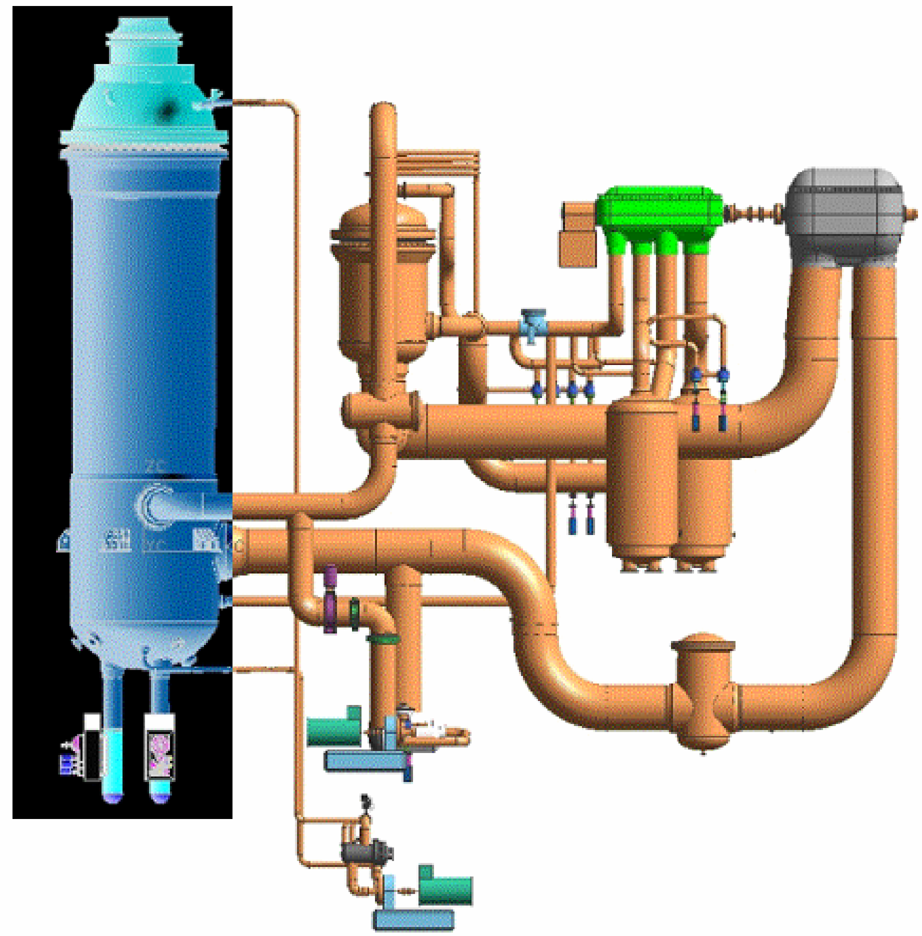
Design Temperature: 150°C

Normal Operating Pressure: 9MPa

Design Pressure: 9.7MPa

Max End-of-Life Fast Fluence: None

Environment:
- **Internal – Helium Coolant**
- **External – Dry Air (~100°C), insulated**



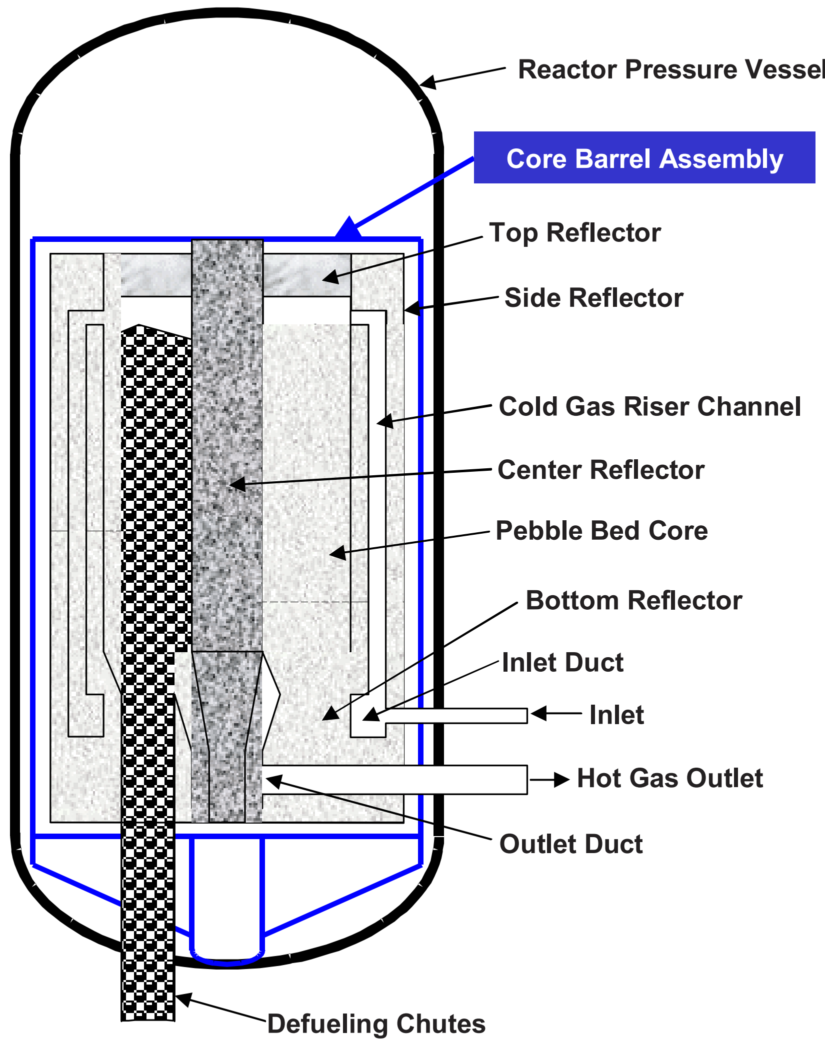
Core Barrel Assembly Operating Conditions

Normal Operating Temperature: 400°C

Short Term, Abnormal Temperature:
~600°C

Max End-of-Life Fast Fluence:
$5x10^{18}n/cm^2$ (E>0.1MeV)

Environment:
- **Internal – Helium Coolant**
- **External – Helium Coolant**

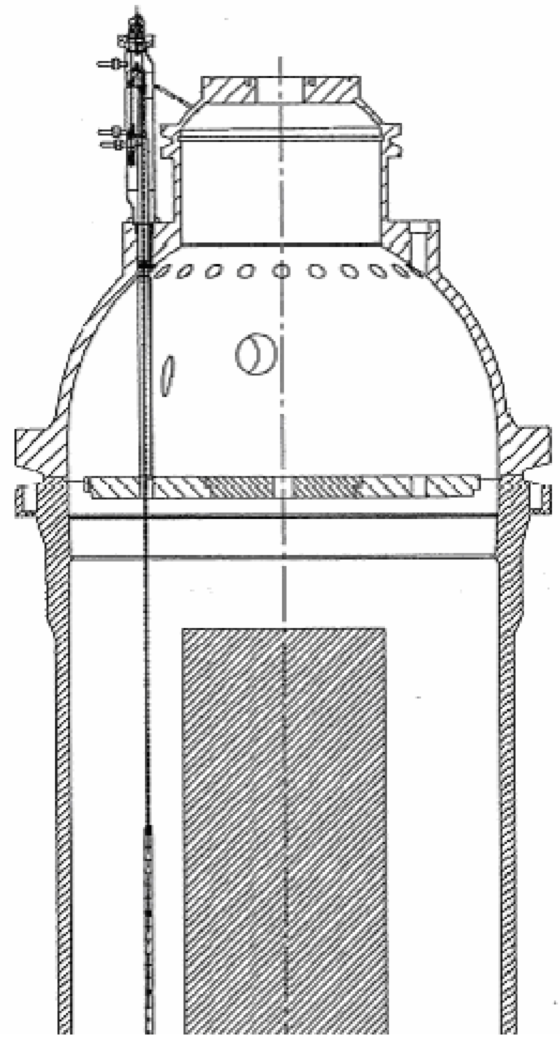


Reactivity Control System Operating Conditions

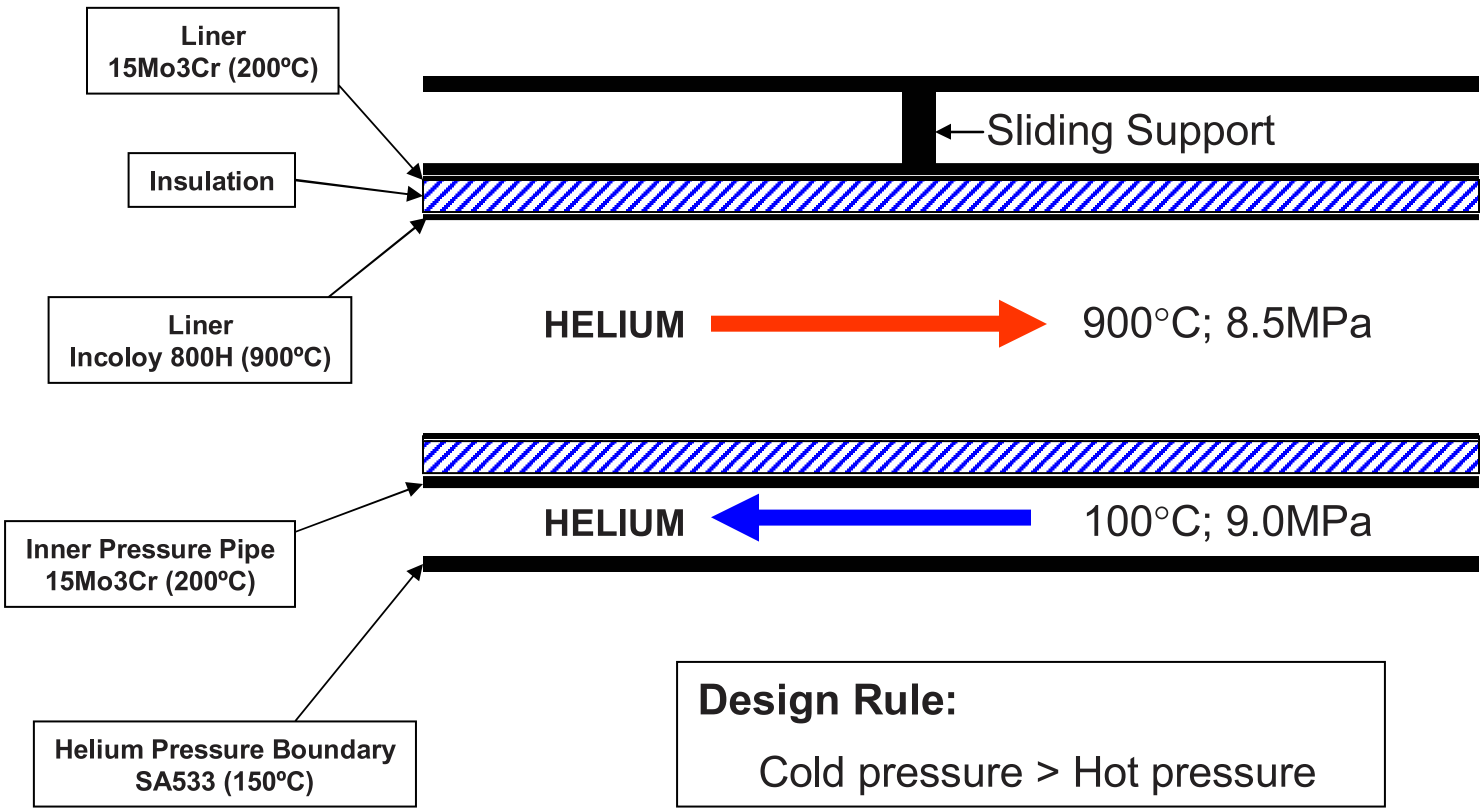
Normal Operating Temperature: ~700°C

Max End of Life Fast Fluence:
$2x10^{22} n/cm^2$ (E>0.1MeV)

Environment:
- **Internal – Helium Coolant**
- **External – Helium Coolant**



Core Outlet Pipe Liner Operating Conditions



Design Rule:

Cold pressure > Hot pressure

Helium Chemistry Impurities

- **The expected levels of impurities in the helium coolant are calculated with a chemical mass-balance, mathematical model that accounts for the effects of:**
  - Impurities remaining after initial system drying/cleaning
  - Impurity addition due to release from fresh fuel spheres
  - Impurity addition due to maintenance practices
  - Impurity release due to helium leakage from the pressure boundary
  - Impurity removal by the purification system
  - Chemical reaction of the impurities with the graphite and metallic components

Steady State Helium Composition

With respect to the effect on the mechanical properties of the metallic materials, the following impurities have been shown to be of significance: H_2, H_2O, CO, CO_2 and CH_4

(Composition of experimental atmospheres, partial pressures in Pa)

	H_2	H_2O	CO	CO_2	CH_4
PBMR	20	0.2	20	0.5	4-110
HTR	50	0.1	5	--	2
PNP	50	0.2	2	0.1	2

HTR – High Temperature Reactor

PNP – Prototype Nuclear Process

PBMR

Gas/Metal Reactions

The test data reported in the following publications are being used as a design basis, to evaluate the effect of helium impurities on the mechanical properties.

Reference	Title
NUREG/CR-6824	Materials Behavior in HTGR Environments
Nuclear Technology, Vol. 66, No. 2 (1984), pages 383-478.	Status of Metallic Materials Development for Application in Advanced High-Temperature Gas-Cooled Reactors (Various papers on Gas/Metal Reaction)

Exelon RAIs

Area of Review	Timing	Pre-application Work Item(s)
High Temperature Materials - Metallics		
Design of Piping and Pressure Vessels		
RAI 4.1.2	2	
RAI 4.1.3	N/A	This RAI is no longer relevant as the PB connecting piping between the vessels are now being designed to piping codes.
Material Properties of Metallic Materials of Construction at High Temperatures		
RAIs 4.2.1, 4.2.2, 4.2.3	2	
Design of Reactor Vessel, Metallic Core Barrel, and Reactor Internal and Support Structures		
RAIs 4.2.5, 4.2.7, 4.2.8	2	

Exelon RAIs

Area of Review	Timing	Pre-application Work Item(s)
Control of Chemical Attack		
II. Metals		
RAI 2.2.22	**2**	

Proposed Work Items

- **The following are proposed work items :**
  - Develop White Papers on the high temperature metallics selection; the qualification envelope of the materials for the PBMR applications; the effects of helium impurities on metallic performance
  - Workshop to discuss white papers and outcomes; propose DCA specification on this topic
  - NRC review and provide RAI's
  - Workshop to preview/discuss RAI responses
  - Revise white papers and resubmit for NRC final consideration
  - NRC complete topic analysis to reach closure on Outcome Objectives