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ASME NUCLEAR CODES AND STANDARDS
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Codes and Standards Needs for PBMR

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What is the PBMR?

The ‘Pebble Bed Modular Reactor’ is:

- A graphite-moderated, helium-cooled reactor in which the gas is heated by the nuclear fission process, with a direct cycle power conversion unit in which the heat is converted into electrical energy by means of a closed cycle turbine-driven generator.
- The Main Power System (MPS) utilizes a recuperative Brayton thermodynamic cycle.
- The core consists of spherical fuel elements that are replenished on-line.

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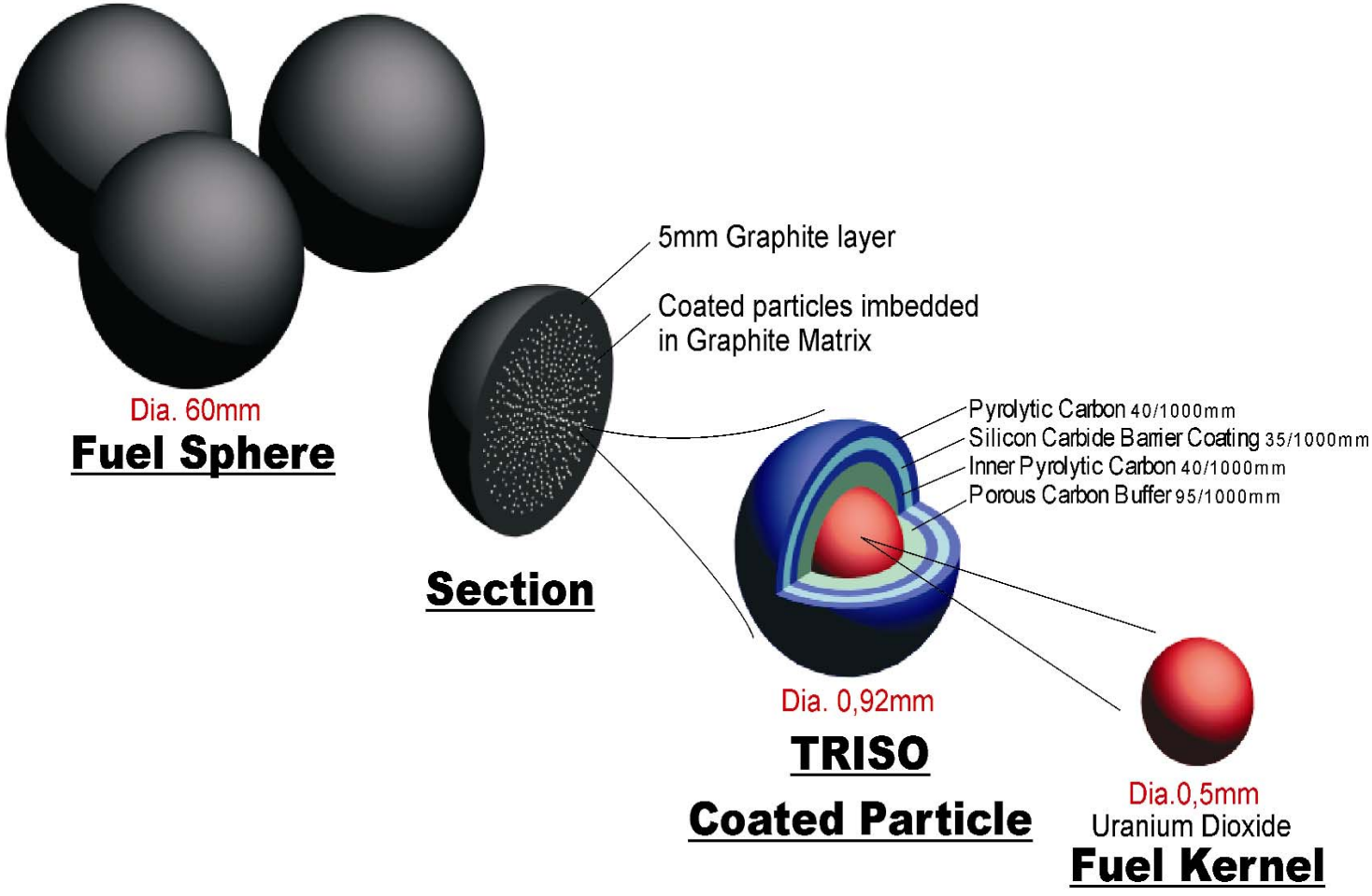
Fuel Sphere



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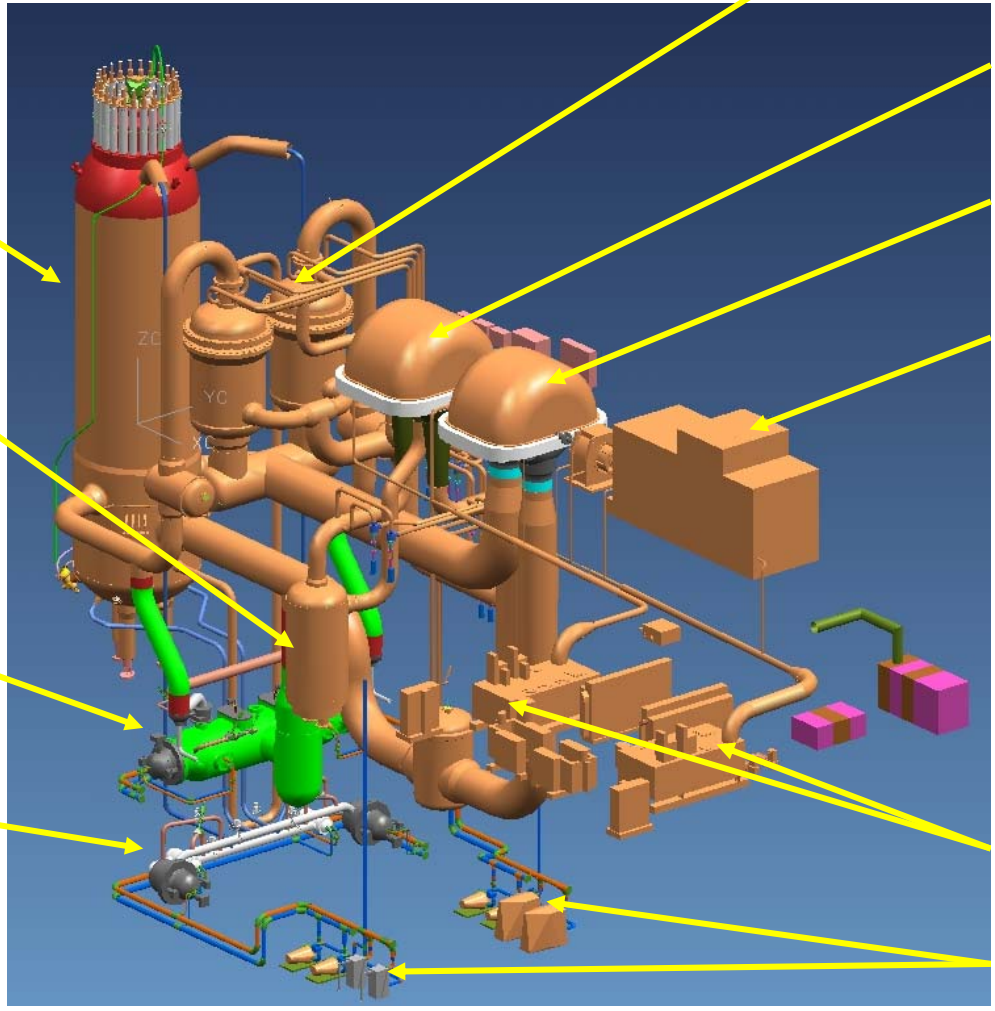
Main Power System



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PBMR Development and Testing Philosophy

- Base the PBMR on the technology demonstrated on the AVR, THTR, and other early gas reactors where sufficient successful experience exists
- Utilize materials, components and processes that have a proven nuclear industry track record or proven industrial record to the maximum extent
- Conduct development and testing to address technology applications new to the PBMR nuclear applications or where PBMR conditions go beyond existing industry experience data
- Develop test facilities that are capable of additional confirmatory benchmarking of PBMR Pty analytical codes for the PBMR design conditions
- Utilize the Demonstration Plant for final integrated plant performance and testing and providing the final confirmation of the plant performance and safety

Challenges

- Existing Codes are predominantly LWR based
- ASME Section III Material temperature limits based on LWR operating conditions
- Majority of Material experience is from LWR therefore at LWR operating temperatures
- PBMR maximum gas temperature 900 ^{o}C (1650 ^{o}F)

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Why do we have Code Needs?

NCA-2110 SCOPE

(a) **Division 1 specifies rules for:**

(1) **nuclear power system metal components, parts, and appurtenances**

(2) **metal containment vessels**

(3) **supports**

(b) **Division 2 specifies rules for:**

(1) **concrete reactor vessels**

(2) **concrete containments**

(c) **While providing for several classes of construction (NCA-2120, NCA-2130), this Section does not provide guidance in the selection of a specific classification to fit a component in a given system. Such guidance is derived from systems safety criteria for specific types of nuclear power systems, such as pressurized water reactors, boiling water reactors, or high temperature gas cooled reactors, and may be found in engineering standards or in the requirements of regulatory and enforcement authorities having jurisdiction at the nuclear**

power plant site.

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History

- Why are the general requirements in Subsection NCA?
- General Requirements for Division 1 were in NA.
- General Requirements for Division 2 were in CA.
- Combined to give NCA.
- Division 2 had rules for concrete reactor vessels.
- Two HTGRs with concrete reactor vessels and a steam cycle were built and operated in the US.
- Appears that both Division 1 and Division 2 are applicable to HTGRs.

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- PBMR operating conditions totally different to the HTGR with a concrete vessel and using a steam cycle.
- Need requirements for:
  - Steel Vessels
  - Piping
  - Heat exchangers
  - Rotating Equipment
  - Metallic Core Barrel
  - Graphite Core Structure

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Design Criterion

- From ASME Sec XI div 2- ISI for HTGR 1992“Unlike water-cooled nuclear power plants, the integrity of the primary pressure boundary is not the primary concern of inspection rules.”
- For a LWR it is imperative that the Reactor Coolant Pressure Boundary maintains its integrity (leak tightness) to ensure that the fuel remains covered by coolant (water) at all times, to prevent significant fuel damage and release of radioactivity.
- For a PBMR loss of helium does not have the same consequences and therefore the continuing leak tightness of the Pressure Boundary does not have the same importance as in a LWR.
- PBMR is a new configuration which does not fall into the LWR profile – different safety functions and safety classifications

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Possible Solutions - PB

1) Develop HTGR specific Design Code with appropriate materials for use at high temperatures.
2) Allow Pressure Boundary to exceed 371 ^{o}C (700 ^{o}F) (ASME Section III Subsection NH)
3) Keep Pressure Boundary at temperature below 371 ^{o}C (700 ^{o}F) (ASME Section III Subsection NB/NC)

Option 1

Develop HTGR specific Design Code with appropriate materials for use at high temperatures.

In the time frame set by PBMR for the design and construction of a "Demonstration" unit, the anticipated period to develop such a Code and have it accepted by a Regulator was seen to be prohibitive, but was seen to be a logical long-term goal.

Materials suitable for use for extended periods (300000 or 450000 hrs) at elevated temperatures (in creep range) to be identified and allowable stress values developed.

Develop a design methodology based on current knowledge and not necessarily an extension of existing rules.

Have such a code accepted by all stakeholders

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Option 2

Allow Pressure Boundary to exceed 371 °C (700 °F) (ASME Section III Subsection NH)

During the early concept design phase of PBMR the materials available in Subsection NH were very limited, the only candidate low alloy material was 2¼ Cr-1Mo. Whilst having Design Stress Intensity values for temperatures up to 648 °C (1200 °F), these values are low, giving required RPV shell thicknesses in excess of 350 mm (15”) based on S_{mt} 300000 hrs and 450 °C.

Extend the list of materials for Subsection NH to include high strength materials to permit economic vessels to be designed and manufactured.

Option 3

Keep Pressure Boundary at temperature below 371 °C (700 °F) (ASME Section III Subsection NB/NC) Ferritic Materials

Require additional gas circulating/cooling systems to stay within current temperature limitations, the normal operating temperature requirement is satisfied, if the vessel is insulated or cooled by helium returning from the turbine.

During Upset conditions (Loss of Forced Cooling) the RPV wall temperature can rise to 450 °C for short periods of time. This situation was identified during the development of the MHTGR during the 1980's and led to ASME Nuclear Code Case 499 being developed for SA-533 Grade B, Class 1 plates, SA-508 Class 3 forgings and their weldments to be used at elevated temperatures for limited periods of time.

Selection of these materials and applying ASME Section III Subsection NB with Code Case N-499 gives a required RPV shell thickness of 170 mm (6.75")

PBMR Design Basis – Option 3

- Use Existing Design Codes
- Use Existing Materials
- Design Parameters to be within existing Code and Material limits

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Pressure Boundary & In-Vessel Metallics

- The PBMR approach to design methodology should be seen as a compromise, using materials and a design Code developed for water cooled reactors, to design a reactor with completely different operating parameters and design needs.

Operating Conditions

RPV:

Normal Operation:

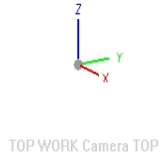
Pressure up to 9.00 MPa
Temperature 260 to 300 ^{o}C

Upset conditions:

Pressure up to 7.00 MPa
Temperature up to 450 ^{o}C

Design Code: ASME Section III NB with Code Case N-499

Material: SA 508 Gr.3 Cl. 1 and SA 533 Type B Cl. 1



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RPV

- Using Code Case N-499 provides rules to cater for the temperature excursions.
- Permits only one type of material.
- Developed for a project that was not built
- Not approved for use by NRC, no licensee requires this case

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Core Barrel Assembly

Differential Pressure: 0.31 MPa
Temperature: 427 oC to 520 oC

Material : Type 316 Austenitic Stainless Steel
Design Code: ASME Section III NG with Code Case N-201

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Core Barrel Assembly

- Using Code Case N-201 provides rules to cater for the temperature excursions.
- Permits only a limited number of materials.
- Not approved for use by NRC, no licensee requires this case

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PBMR Requirements for Codes & Standards (Metallic Components)

- Develop HTGR specific Design Code with appropriate materials for use at high temperatures.
- Identify suitable high strength material for pressure vessels to enable economic (weight and cost) component manufacture

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PBMR Requirements for Codes & Standards (Non-Metallic Components)

- Develop HTGR specific Design Code.
- Develop a design methodology for carbon and ceramic based materials.
- Identify and / or develop suitable materials.
- Specify material properties required for use with the design methodology.

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ASME Code for HTGRs

- ASME Section III has voted to develop a Division 5 specifically for High Temperature Gas-Cooled Reactors.
- Identified that whilst there is much of existing Section III that is applicable to HTGR's, there are sufficient HTGR specific requirements to justify set of rules specifically for HTGR's.
- Work is underway to identify material requirements and the required material properties.
- The development of a Code for Graphite Core Components is in an advanced stage.
- The development of this HTGR specific Division has support from South Africa, Japan and USA.

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ASME Code for HTGRs

- ASME Standards Technology LLC is coordinating activities in areas related to:
  - Materials
  - Design methodology
  - Code development

  In support of Division 5

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Inservice Inspection

- PBMR is required to specify an Inservice Inspection Programme.
- Section XI Division 1 is for Light Water Reactors
- The existing Section XI Division 2 specifically excludes Pebble Bed Reactors
- Section XI Division 3 is for Liquid Metal Cooled Reactors

- Need rules for Pebble Bed type HTGRs.

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Involvement

- Use the “Inquiry” process to:
- get clarification of Code or
- initiate a Code Case or
- change the Code or
- change a Code Case

to meet your requirements

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Thank You For Your Time

Any Questions?

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