HTGR Technology Course for the Nuclear Regulatory Commission

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Module 10a

Vessel System

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Outline

- Vessel System functions and requirements
- Key design options
- Vessel System design concepts
- Vessel System design issues
- Experience

Key Vessel System Functions

- **Support components of the reactor system**
  - Reactor core
  - Reactor internals
  - Refueling interface
- **Maintain the relative position of the core and the control rods**
- **Maintain coolable (reactor) geometry**
- **Part of residual heat removal path during conduction cooldown (thermal radiation, conduction, and convection)**
- **Support the primary heat transport equipment**
  - SG tube bundle and/or IHX modules
  - Primary coolant circulators
  - Associated piping
- **Maintain primary pressure boundary integrity**
  - Containment primary coolant
  - Retain radionuclides
  - Limit air ingress
- **Provide/enclose primary heat transport path from reactor to SG/IHX and shutdown cooling system**
- **Provide vessel overpressure protection**

Key Vessel System Design Requirements

- The Vessel System (VS) shall be design, fabricated, and operated in accordance with ASME B&PV Code Section III
- In normal operation, creep effects on the reactor vessel shall be negligible
- No significant leakage shall result from AOOs
- All major parts of the VS shall be designed for an operating lifetime of 60 years
- The VS shall be designed for design basis duty cycle events
- For AOOs and DBEs, the vessel system shall not prevent restarting of the plant
- Vessel supports shall support lateral and vertical loads, accounting for thermal expansion, circulator vibration, and seismic events
- The reactor/SG/IHX vessels shall have a drain mechanism in case of water buildup in the vessel
- During normal operation, the reactor vessel operating temperature shall be maintained through a thermal balance between the core heat flux, core inlet helium flow, and the reactor cavity cooling system
- The pressure relief system shall be designed to eliminate overpressure in the primary system
- Provisions shall be made for ISI and material surveillance

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Key Design Options

- Single vessel
- Multiple interconnected vessels
- Multiple vessels connected with pipes
- Reactor vessel uninsulated (for residual heat removal)
- Heat exchanger vessels insulated (to minimize parasitic heat loss)

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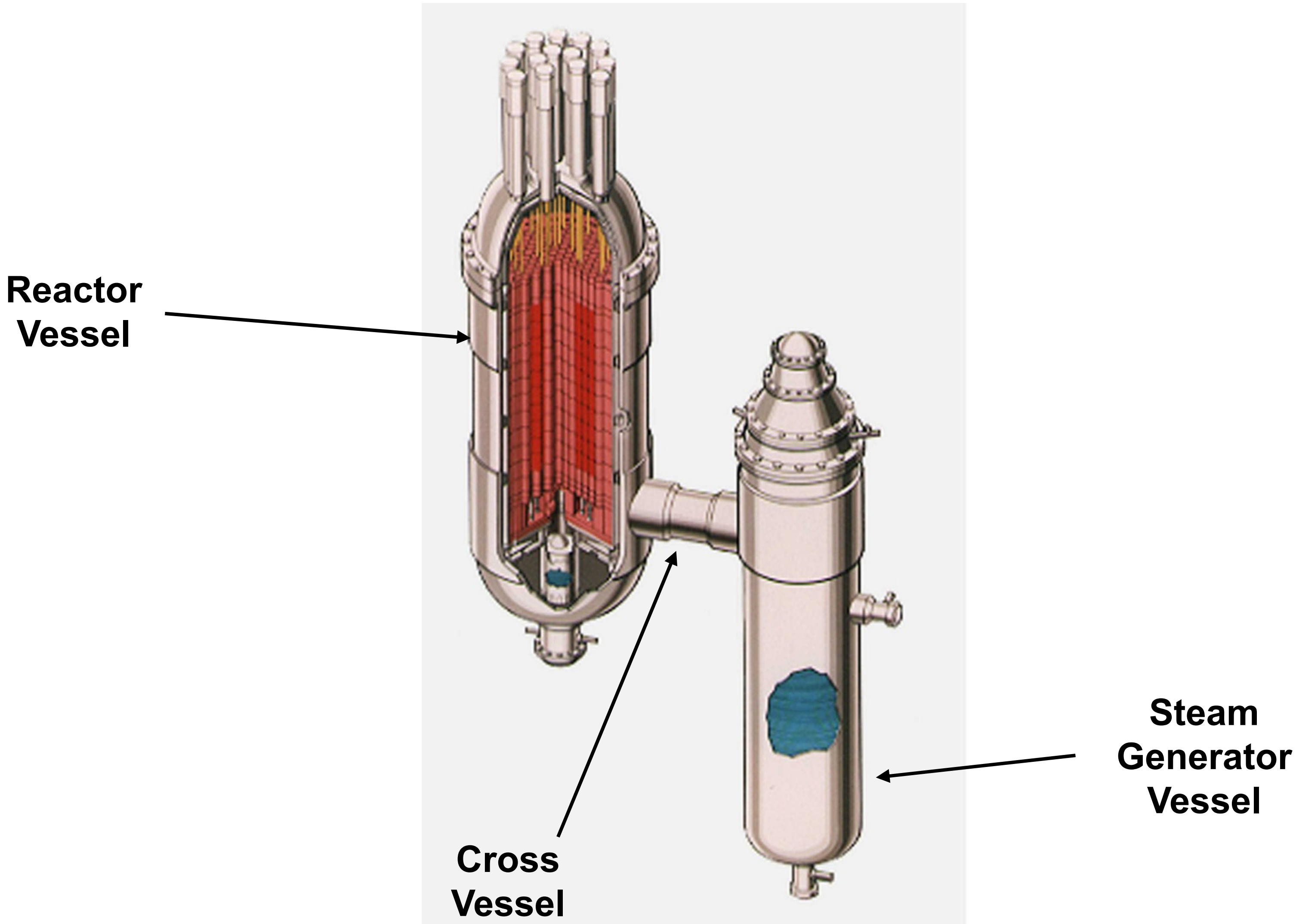
MHTGR Vessel Concept



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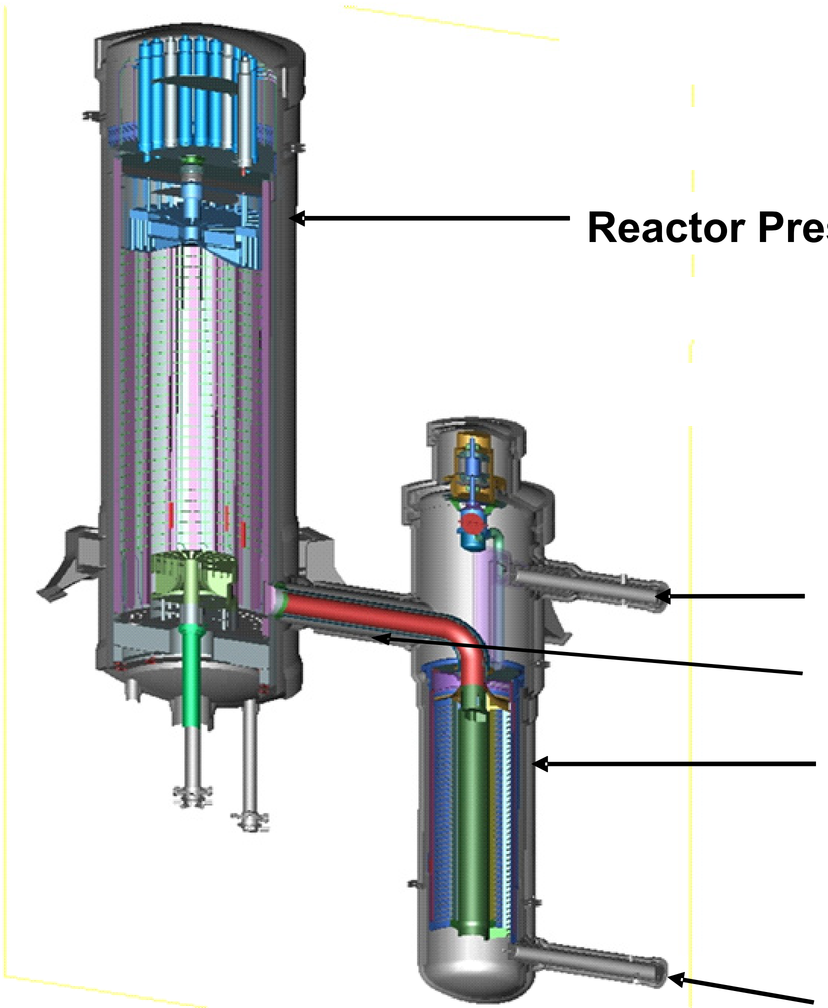
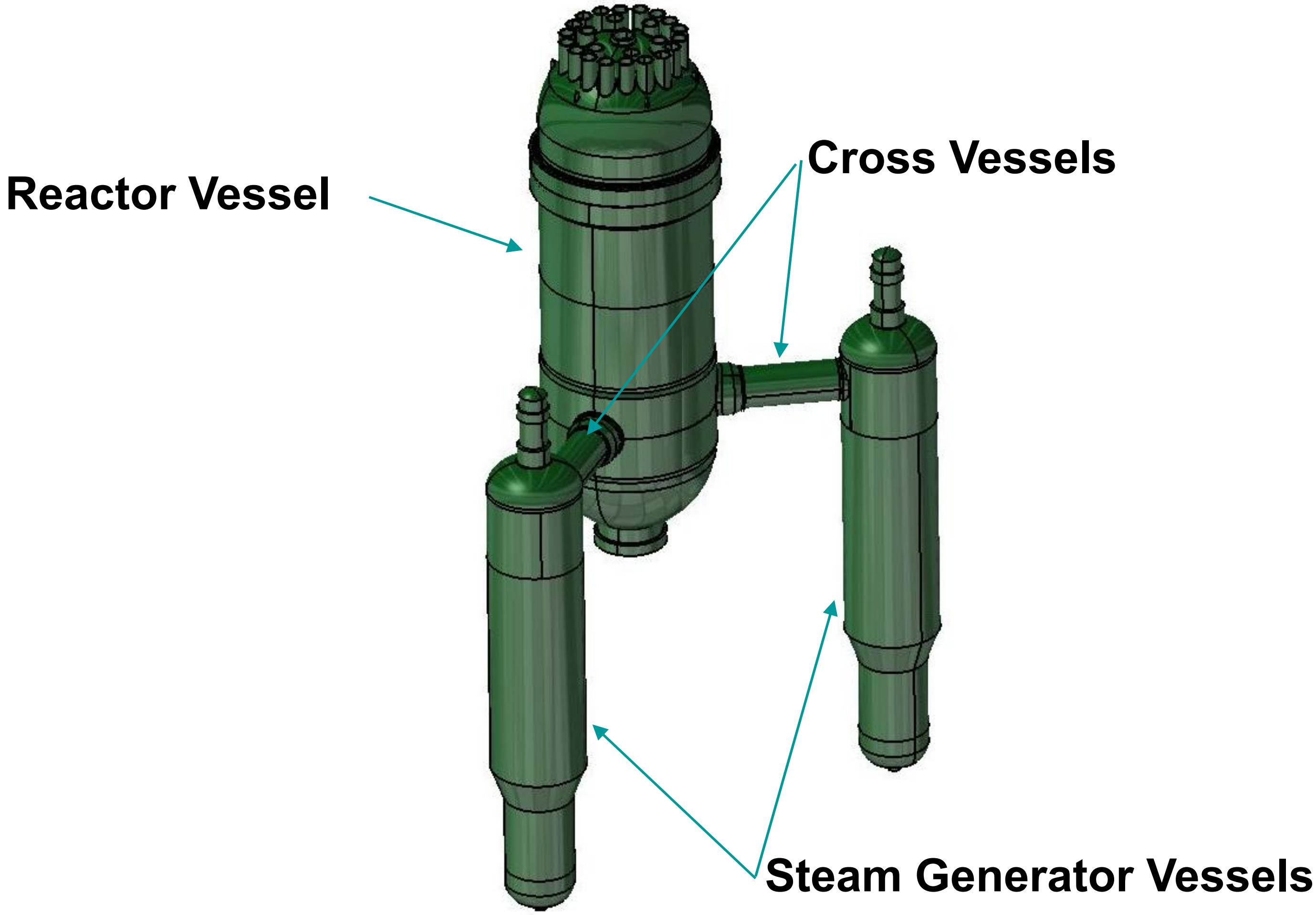
PBMR-CG Vessel Concept

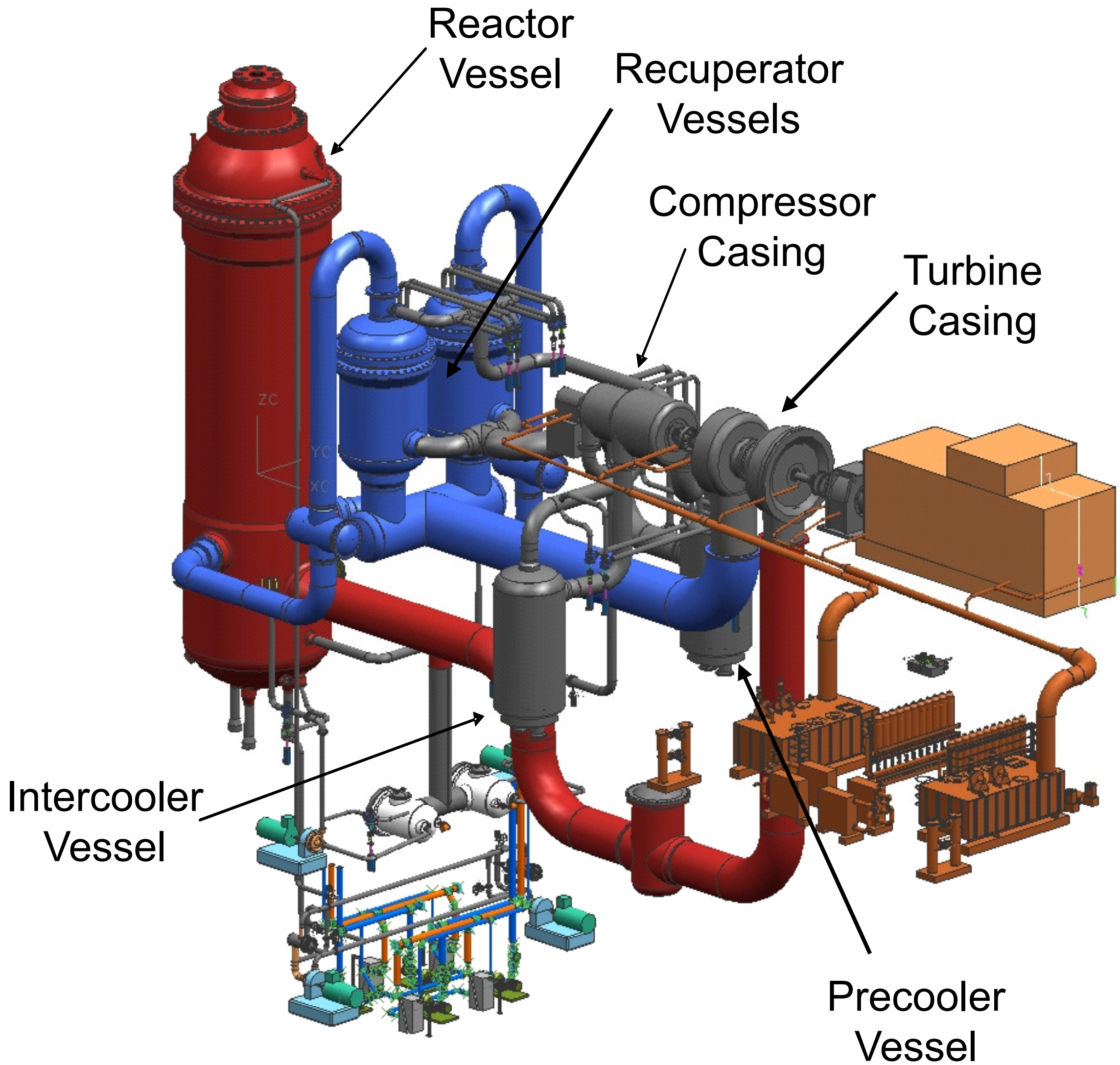


AREVA Large Steam Cycle Vessel Concept



PBMR-DPP Vessel Concept

- **Brayton power cycle**
- **Distributed components in individual vessels**
- **Double-walled connectors**
- **High-temperature outer pressure boundary cooled with buffer helium**



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Vessel Design Issues

- **Key design issues include:**
  - Temperature
  - Helium coolant
  - Size
  - Irradiation spectrum
- **These issues are main drivers for the choice of vessel material**
- **In most cases, the reactor vessel will drive the material choices for the Vessel System**

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Vessel Design Issues - Temperature

- **Two temperatures drive reactor vessel design**
- **Normal operation wall temperature**
  - Vessel temperature during normal operation is primarily driven by the choice of plant core inlet temperature
  - Interior coolant flow design keeps hotter gasses away from the vessels
- **Accident wall temperature**
  - Reactor vessel wall is a key part of the passive heat removal path during accidents
  - Several factors control accident wall temperature
    - Reactor geometry (core, reflectors, core barrel)
    - Residual heat
    - Reactor inlet and outlet temperatures
- **Other vessels also affected by normal operation**
  - Other vessels typically insulated

Vessel Thermal Design Options

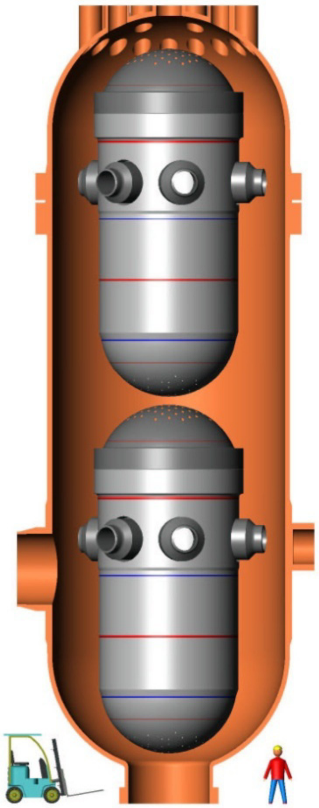
- **RPV and other vessels treated separately**
  - RPV exposed to cavity
  - Other vessels insulated
- **For reactor inlet temperature less than about 350°C**
  - LWR material a good option
- **For higher temperatures**
  - Use higher temperature material
  - Provide internal thermal protection
    - Move inlet flow path in RPV
    - Balance internal and external insulation in other vessels
  - Vessel temperature conditioning system(s)

Vessel Design Issues – Helium Coolant

- **Helium coolant presents different material performance considerations than water**
  - Oxidation
  - Carburization
  - Decarburization
- **In general these considerations are minor at 350°C**
- **Corrosion issues of LWR systems are minimized (e.g., boric acid)**
- **More detailed evaluation will be required taking into account different vessel system functions and requirements, etc.**

Vessel Design Issues – Vessel Size

- **Per unit power output, HTGR vessels are much larger than LWR vessels**
- **Increased size may impact:**
  - Fabricability
  - Transportation to the plant site
  - Availability of key components
- **Potential required solutions may include:**
  - Partial fabrication of vessels on site
  - Use of welded plate construction



600 MWt HTGR RPV vs PWR RPV

Vessel Design Issues – Irradiation Spectrum

- **Due to moderator differences, HTGR neutron spectrum is "harder" than typical LWR spectrum**
  - Higher average neutron energy
- **Has impacts on vessel embrittlement (NDTT) and expected lifetime**
- **Likely more than balanced by lower overall neutron dose**
- **Extrapolation of LWR vessel experience complicated by combined effect of**
  - Spectrum (e.g., harder)
  - Irradiation temperature (e.g., lower or higher)
  - Fluence (e.g., lower)
- **Need for confirmation testing must be evaluated**

Vessel Material Options

- **SA 508 Grade 3**
  - Standard LWR material
  - Acceptable for service to T_{in} ≈ 350°C (long-term limit 371°C)
  - Cooling or insulation needed for higher temperatures
- **2.25Cr-1Mo Annealed**
  - Acceptable for service to T_{in} ≈ 420°C
  - Lower stress allowables limit practicality
- **Modified 9Cr-1Mo**
  - Preferred option for very high temperature service
- **Last two options require development and adoption of appropriate Code Cases as well as resolution of fabricability issues for large structures**

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Relevant Vessel Experience

- **LWR database**
  - Lower inlet temperatures now being considered bring the reactor vessel wall temperatures into the same range as LWRs
  - Use of LWR-type vessel material will benefit from this experience
- **HTGR steel vessels**
  - Dragon
  - Peach Bottom 1
  - AVR
  - HTTR
  - HTR-10

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Summary

- **HTGR Vessel System based largely on proven technology**
- **Vessel temperature main driver for material choice**
- **LWR vessel material (SA508/533) requires least development effort**
  - Prime VS candidate for current designs
- **Some confirmatory testing of vessel system materials may be needed for HTGR operating conditions**

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