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

Reactant Vessel

Cross Vessel

Steam Generator Vessel
AREVA Large Steam Cycle Vessel Concept

- Reactor Vessel
- Cross Vessels
- Steam Generator Vessels
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**
• 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
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 $T_{in} \approx 350^\circ C$ (long-term limit $371^\circ C$)
  - Cooling or insulation needed for higher temperatures

- **2.25Cr-1Mo Annealed**
  - Acceptable for service to $T_{in} \approx 420^\circ C$
  - 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
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