HTGR Technology Course for the Nuclear Regulatory Commission

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Module 6d
Pebble Bed HTGR Refueling Design

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• Principal functions and features of Pebble Bed Fuel Handling System (FHS)
• Fuel Handling System operation
• Fuel Handling System experience and lessons learned
Principal Functions of Pebble Bed Fuel Handling System

- Charge fresh fuel from storage
- Circulate used fuel
- Discharge spent fuel to storage
- Allow core to be unloaded and reloaded
- Limit planned shutdowns to be compatible with most process heat users
On-line Refueling System Features

• Flexibility to introduce fuel for a different fuel cycle on-line
• Core design uncertainty is reduced by measuring each fuel sphere for burnup instead of calculating
• Excess reactivity can be adjusted on-line by changing the refueling parameters
• No reload analyses are required and approach to criticality is only required on initial core load or when the core is reloaded from the used fuel tank
• Automated and closed fuel handling system allows for accounting of all fuel at any time
• The safeguards approach for the pebble-bed uses integrated inventory control rather than the traditional item control. This approach has been successfully used by the IAEA on AVR and THTR
Outline

- Principal functions and features of Pebble Bed Fuel Handling System (FHS)
- Fuel Handling System operation
- Fuel Handling System experience and lessons learned
Fuel Charging Operation

• Fresh fuel is normally stored in drums on site
• Fresh fuel is charged from the drums into the circulating circuit to replace spent fuel
• Sufficient drums are stored for ~180 days of operation without resupply
Fuel Circulation Operation

- Extract spheres from the bottom of the core by means of gravity, this allows spheres to move down through the core
- Separate out broken/damaged spheres
- Measure each sphere for burnup
- When a sphere has reached its burnup limit, discharge as spent fuel, otherwise lift the sphere to the top of the reactor by pneumatic means
- Distribute spheres to inner and outer core depending on burnup and reactor requirements (AVR & THTR)
- Spheres pass a number of times through the core (1-15) before reaching burnup limit. Number of passes influences the power profile and the amount of spheres circulated per day
Fuel Discharge Operation

- Fuel determined to have reached their burnup limit are discharged to spent fuel storage
- Spent fuel storage can be in casks (HTR-Modul), drums (THTR) or tanks (PBMR)
- Storage geometry ensures subcriticality
- Decay heat can be removed by air or water cooling
• Online maintenance is possible for a majority of the components – The plant can operate without running the fuel circulation, loading and unloading for about 15~20 days
  – Most actuators (except Isolation valves), burnup measurement system, gas blowers, filter, and broken sphere containers

• Reactor must be depressurized for maintenance of
  – Core unloading device (CUD), isolation valves
Outline

- Principal functions and features of Pebble Bed Fuel Handling System (FHS)
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AVR Experience

- Circulated 2,400,000 Pebbles
- Charged/Discharged: ~ 300,000 Pebbles
- Overall Impact on Plant Unavailability <3% (higher initial period, later lower)

Note: Low AVR Broken Sphere Rate: ~10^{-4} (and even better the latter part of life: ~2 \times 10^{-5}) had significant positive impact on the reliability
Lessons Learned from AVR

- **Simplify sphere removal from core:**
  - 2 (redundant) Core Unloading Devices (CUD) that take over the function of the reducer, singularizer, and the broken sphere separator

- **Improve actuation method for various moving components**
  - Electro-pneumatic actuators for valves and indexers, diverters and collectors, mounted in functional blocks for easier maintenance, instead of the dosing wheel and elevator

- **Maintenance on AVR components can be done readily after some decontamination (dust is not a major issue)**
THTR Experience

- Circulated: ~1,400,000 pebbles
- Charged/discharged: ~235,000 pebbles
- Overall impact on plant unavailability ~15% (higher initial, lower later)
- THTR completed the core unloading in 10 months, without major interruptions, demonstrating that the modifications to the FHS performed as designed

Note: high broken sphere rate: initially ~1.5% to later ~0.6% caused jamming in the FHS near the discharge of the CUD. Also required frequent exchange of the damaged sphere container. Broken spheres were caused by the in-core rod design that pushed into the bed.
Lessons Learned from THTR

• Early troubles can be resolved – but more testing prior to plant installation reduces the downtime

• Dust is there, but has not been a maintenance/health-physics issue at either AVR or THTR

• Do not use in-core rods which causes high failure rate of spheres resulting in frequent exchange of broken sphere can and jamming in the sphere circulation system

• Excess reactivity in the core allows online maintenance of most of the system (15 to 20 day reactivity reserve)

• Many of the maintenance activities could be carried out when the plant was at power – Exceptions are isolation valves, CUD and broken sphere container
Pebble Bed FHS Design Philosophy

- Follow THTR’s example to the extent practicable
  - Functional blocks mounted in the floor
  - Components installed in functional blocks
  - All components monitored for leaks
- Improve those components with known deficiencies
  - Pebble counter
  - Core unloading device and lead-in plenum
Typical Functional Block

- Drive
- Penetration Seal
- Functional unit such as indexer
- Leak Monitoring
- Steel block filled with iron shot concrete
- Actuator Penetrations
- Pebble Lines
- Building Floor
- Actuator Inserts
- Electro-Pneumatic Drives
- Pebble Pathway
FHS Tests at the PBMR Helium Test Facility

• **System Tests**
  – Sphere circulation
  – System cleaning
  – System maintenance

• **Component Tests**
  – Core unloading device
  – Tank unloading device
  – Sphere valve and valve block
  – Sphere counters
  – Gas valves and valve blocks
  – Mechanical and pneumatic sphere brakes
  – Indexer and double-seat isolation valves

• **Burnup Measurement System testing done in Russia**

*Note: These tests have been ongoing since 2006 and will continue up to qualifications tests when a reactor construction project is ordered*
Refueling is accomplished on-line during power operation in a pebble bed reactor and provides core design flexibility.

Most maintenance activities on the FHS is accomplished on-line during power operation.

Good experience on the AVR and THTR of FHS operation and maintenance.

Lessons learned from AVR & THTR are incorporated in modern pebble bed FHS designs.

Full scale FHS circulation loop and components are under test at the PBMR HTF in South Africa.
Suggested Reading