Joint IAEA–GIF Technical Meeting on the Safety of High Temperature Gas Cooled Reactors

GIF VHTR Activities and future plans on VHTR SDC and SDG

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Outline

1 GIF VHTR activities
2 VHTR SSC position for SDC
3 Activities in member countries
1 GIF VHTR activities

- VHTR SSC overview
- VHTR PMBs
Active projects:

1. Materials
2. Fuel and Fuel Cycle
3. Hydrogen Production
4. Computational Methods, Validation & Benchmarking (under signature)
5. System Integration and Assessment (under discussion)


+ CDN in H₂ Production project
Materials PMB
Highly productive:

- All high-level deliverables (HLDs) are on track for completion
  - Most HLDs due at the end of the most recent PP (December 2015) have been completed. Others have been rescheduled for extension into the revised PP for 2018-2022, since they address continuing activities
  - Detailed plans for completion of all HLDs have been developed and include both compilations of low-level deliverables (LLDs) and interpretive reports. These have been incorporated in the revised PP
  - 420 supporting LLDs will have been uploaded into the Gen IV Materials Handbook for use by all Signatories by October, 2019, and have provided very valuable technical information exchange

- Extensive experimental data are also being shared
  - Well over 10,000 materials data records have been uploaded into Gen IV Materials Handbook
  - Contribution of materials data records is still unbalanced among Signatories but improving, and unbalance is being addressed both by Signatory commitments and Handbook technical issue resolution
Ion Irradiated - PCIB Graphite

=> C ion irradiation: 35MeV, $4.50 \times 10^{17}$ ion/cm², RT

FIB-ed Sample
Improved DB Process for Alloy 617

- Process improvement to have interface free from secondary precipitates
  - Poor high temperature properties of diffusion weldment above 700 °C
  - An array of Al-rich oxides at the interface
  - FIB/TEM micrographs tell us that oxides at the interface are almost removed
  - Domestic patent in progress

DB-617D (1150 °C/15.0 MPa)  DB-617E (1150 °C/15.0 MPa)
Excellent cooperation between PMB signatories towards establishing full fuel qualification capability in view of licensing.

PMB cooperation has helped establish additional bilateral contracts between signatories and with private companies covering proprietary topics.

5th Workshop on High Temperature Gas-Cooled Reactor SiC Material Properties on 21-22 May at ORNL

JAEA proposes Benchmarking computational models for the release of fission products (iodine and fission gases) during normal operating conditions
Adaptation and coupling to high T heat source (nuclear, solar) and into HES

**Sulfur-iodine cycle (830°C):** KR, JA, CN
- Enhancement of individual processes and cycle stability
- Technology development towards better durability (corrosion, cyclic loads) and higher throughputs

**High-Temperature Steam Electrolysis (650-850°C):** FR, US, EU, CN, CDN
- Stack manufacturing and qualification, life-cycle optimization

**Hybrid copper-chlorine cycle (530°C):** CDN
- Lab-scale demonstration
Tools for licensing, elimination of unnecessary design conservatisms, improved cost estimates
Builds on work from earlier international efforts

- **Reactor performance assessment tools**
  - Phenomena identification and ranking table
  - Computational fluid dynamics
  - Reactor core physics and nuclear data
  - Chemistry and transport
  - Reactor and plant dynamics

- **Code validation**
  - Benchmark tests
  - Code-to-code comparison
  - Basic phenomena to integrated experiments
  - Supported by HTR-10 and HTR-PM tests or by historical reactor data (AVR, THTR and Ft. Saint Vrain)
## CMVB Work Packages

*PA will be signed soon*

<table>
<thead>
<tr>
<th>WP No</th>
<th>WP Title</th>
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<tbody>
<tr>
<td>1</td>
<td>Phenomena identification and ranking table (PIRT) methodology</td>
<td>DOE (USA)</td>
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<tr>
<td>2</td>
<td>Computational fluid dynamics (CFD)</td>
<td>INET (CHINA)</td>
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<tr>
<td>3</td>
<td>Reactor core physics and nuclear data</td>
<td>DOE (USA)</td>
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<tr>
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<td>Chemistry and transport</td>
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<td>5</td>
<td>Reactor and plant dynamics</td>
<td>INET (CHINA)</td>
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</table>
Mostly guided by licensing-relevance:

- **Materials** (metals, graphite, ceramics): Development and qualification, Codes & Standards, Component tests

- **Fuel and Fuel Cycle**: Qualification technique incl. fabrication, QA, irradiation, safety tests, PIE

- **H₂ Production**: 3 processes (IS, Cu-Cl, HTS), from lab-scale tests to pilot/demo scale, components, coupling, economics, compatibility with other GIF concepts

- **Computational Methods, Validation & Benchmarks**: test facilities, V&V of multi-physics codes
Targeted towards medium-term demonstration, market adaptation and long-term performance / flexibility optimization

- Materials (advanced), Components and Supply Chain
- Fuel, (advanced) Fuel Cycle, and Waste Minimization
- Design, System Integration
- Cost Reduction Approaches
- Safety Demonstration and Licensing
- Coupling to Cogeneration Applications
- Energy System Integration (Advanced Energy Use and Storage Methods, Hybrid Energy Systems)
2 VHTR SSC position for SDC

- Unlike GIF SFR, GIF VHTR has no specific project to develop safety design criteria

- The main reason is that IAEA has CRP on this topic, many members were involved
  - Many members such as China, Germany, Japan, USA has domestic project and licensing experience
  - The document from CRP can be shared with GIF
2 VHTR SSC position for SDC

- VHTR SSC did not have the chance to discuss the actual plan for VHTR SDC/SDG yet, we plan to discuss this topic in next VHTR SSC meeting in next May, based on the TECDOC and NE report from the CRP

- Also request / recommendation / guide from IAEA, GIF PG, EG, RSWG are welcomed
3 Activities in member countries

- Japan developed their own version of SDC
- China also developed own HTR version of SSR 2/1
  - Important result are merged into CRP document
  - Original version of SSR also adopted by NNSA for LWR
  - More detailed guides for HTR were also under development
    - Draft is finished, review by external experts is under way
    - LWR version guides also under development
- China has own version design criteria/guides
  - 40 chapters
  - Developed during 2004-2007 before HTR-PM project
  - Revision is expected based on HTR-PM feedback
# Chinese HTR version of requirements/guides

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<tr>
<th>No</th>
<th>Title</th>
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<tr>
<td>1</td>
<td>Safety requirement for design of HTGR power plant</td>
<td>Based on IAEA SSR 2/1 rev.1</td>
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<td>2</td>
<td>Safety requirement for operation of HTGR power plant</td>
<td>Top level requirement for operation</td>
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<td>3</td>
<td>Format and content of the safety analysis report for HTGR power plant</td>
<td>Guide, based on IAEA guide, NRC SRP, and HTR-PM experience</td>
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<td>4</td>
<td>Safety design of the core for HTGR power plant</td>
<td>Guide</td>
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<td>5</td>
<td>Design and fabrication of fuel element for HTGR power plant</td>
<td>Guide</td>
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<td>6</td>
<td>Beyond design basis accident management programme for HTGR power plant</td>
<td>Guide</td>
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<td>7</td>
<td>Safety evaluation and verification for HTGR power plant</td>
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<td>8</td>
<td>Design of vented low pressure containment for HTGR power plant</td>
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<td>9</td>
<td>Instrumentation and control system important to safety for HTGR power plant</td>
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<td>10</td>
<td>Fuel handling and storage system for HTGR power plant</td>
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<td>11</td>
<td>Radiation protection design for for HTGR power plant</td>
<td>Guide</td>
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<td>12</td>
<td>Core and fuel management for HTGR power plant</td>
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<td>13</td>
<td>Safety function and component classification for HTGR power plant</td>
<td>Guide, based on IAEA SSG 30</td>
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<td>14</td>
<td>Reactor coolant system and related system for HTGR power plant</td>
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<td>15</td>
<td>Operation limit and condition and operation procedure for HTGR power plant</td>
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<td>16</td>
<td>Commissioning test for HTGR power plant</td>
<td>Guide</td>
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<td>17</td>
<td>Maintenance, supervision and in-service inspection for HTGR power plant</td>
<td>Guide</td>
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<tr>
<td>18</td>
<td>Decommissioning preparedness for HTGR power plant</td>
<td>Guide</td>
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</table>
3 Activities in member countries

HTR-PM Design criteria (40 chapters)

- 1 Operation and accident conditions
- 2 Safety class of structures, systems and components
- 3 Accept criteria for accident analysis
- 4 Accident analysis method related to environment
- 5 Design principles and requirement for radiation protection
- 6 Design criteria for radioactive solid waste treatment system
- 7 Design criteria for air purification system of nuclear grade
- 8 Design criteria for radioactive liquid waste treatment system
- 9 Neutronics design criteria
- 10 Thermo-hydraulics design criteria
3 Activities in member countries

**HTR-PM design criteria (40 chapters)**

- 11 General design criteria for reactor structure
- 12 Design criteria for ceramics core internals
- 13 Design criteria for metal core internals
- 14 Design criteria for pressure vessels
- 15 Design criteria for hot gas duct
- 16 Design criteria for the supporting of main components in reactor coolant system
- 17 Design criteria for steam generator
- 18 Design criteria for nuclear fuel
- 19 Design criteria for fuel handling system
- 20 Design criteria for fuel storage and transportation system
3 Activities in member countries

- HTR-PM design criteria (40 chapters)
  - 21 Design criteria for helium coolant system
  - 22 Design criteria for helium purification and supporting system
  - 23 Design criteria for decay heat removal system
  - 24 Design criteria for confinement
  - 25 Design criteria for main helium circulator
  - 26 Design criteria for control rod system
  - 27 Design criteria for small absorber ball system
  - 28 protection criteria for the hypothetic pipe break accident
  - 29 Design criteria for the pressure control and relief system for primary circuit
  - 30 Design criteria for the reactor protection system
3 Activities in member countries

HTR-PM design criteria (40 chapters)

- 31 Design criteria for the instrumentation and control system
- 32 Design criteria for the process instrumentation
- 33 Design criteria for the control room
- 34 Design criteria for backup shutdown point
- 35 Design criteria for the emergency electricity supply system
- 36 Design criteria for the cable layout and isolation
- 37 Design criteria for layout of nuclear steam supply system
- 38 Design criteria for the installation, commissioning, operation and maintenance requirement
- 39 Design criteria for the decommissioning
- 40 Design criteria for radiation shielding
Conclusion remarks

- GIF VHTR has several fundamental research projects (PMBs)
- No specific project to develop VHTR SDC/SDG yet, because of existing IAEA CRP activities
- Member countries of IAEA / GIF VHTR SSC have domestic projects to develop VHTR SDC/SDG
- VHTR SSC will review the outcome of IAEA CRP
- Following action will be discussed in next SSC meeting, based on feedback
  - Design of HTR-PM comply with current HTR version of SSR
  - Optimization on economic feature must be considered and practiced, especially for SDG
Thanks for listening
&
Thanks for comments!