HTTR Licensing Experience and Commercial Modular HTGR Safety Design Requirements including Coupling of Process Heat Applications

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1. Road map for HTGR safety standards
2. Safety demonstration test using HTTR
3. Modular HTGR safety design requirements
4. HTTR licensing experience
5. Future test using HTTR
6. Summary
Roadmap for HTGR safety standards

HTTR safety standards
- LWR safety standards
  - Basic research
  - Seismic evaluation methods
  - Safety analysis data
- HTTR safety standards, safety evaluation methods

HTTR safety demonstration test
Data acquisition of HTGR inherent safety features
  - Reactivity insertion
  - Loss of forced cooling (at 30%)
  - Fuel performance

HTTR safety review
(Nov. 2014 ~ 3 Jun. 2020)

HTTR tests
(1) HTTR safety demonstration test (at full power)
(2) HTTR hydrogen production test

Issue of safety standards by regulatory authority

Commercial HTGR
(Electricity) (heat application)

Development of safety requirements
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### Main design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>30 MWt</td>
</tr>
<tr>
<td>Fuel</td>
<td>SiC TRISO UO$_2$ coated particle fuel, pin in block</td>
</tr>
<tr>
<td>Design type</td>
<td>Prismatic core</td>
</tr>
<tr>
<td>Coolant</td>
<td>Helium</td>
</tr>
<tr>
<td>Temperature</td>
<td>850~950 °C</td>
</tr>
<tr>
<td>Pressure</td>
<td>4 MPa</td>
</tr>
</tbody>
</table>

### Reactor building Interior

- **Dry cooling tower**
- **Control room**
- **Refuel machine**
- **Intermediate heat Exchanger (IHX)**
- **Reactor pressure vessel**
- **Reactor core**

Safety demonstration test

- 30% power (9MW) **Loss of forced cooling test** (All HGCs tripped) • • • Finished (2010)

- 100% power **Loss of forced cooling test** (All HGCs tripped) • • • Planned

- 30% power **Loss of core cooling test** (All HGCs + VCS tripped) • • • Planned

**Test condition**
- Initial power 30% (9MW)
- Reducing core flow rate to zero
- Keeping VCS operation
- No scram operation (No CR insertion)

**Test result**

Reaction is naturally shut down as soon as the core cooling flow rate to zero. Reactor is kept stable long after the loss of core cooling.
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Safety design approach

- No significant fuel (core) degradation
- Fission product is confined by the combination of coated fuel particle and other barriers
- Passive engineered safety features and Inherent safety design features

Defence in depth

Level 1: Prevention of abnormal operation
Level 2: Control of abnormal operation
Level 3: Control of accident to limit radiological releases
Level 4: DEC without significant fuel (core) degradation
Level 5: Mitigation of radiological consequences

Fundamental safety functions

- Control of reactivity
  - Control rod system
  - Temperature coefficient
- Core heat removal
  - Vessel cooling system
  - Heat conduction to the reactor surrounding structure
- Confinement of radioactive material
  - Coated fuel particle (CFP) and other barriers
# Safety requirements

<table>
<thead>
<tr>
<th>Safety requirements</th>
<th>Modular HTGRs</th>
<th>LWRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design extension condition (DEC)</td>
<td><strong>DEC without significant fuel degradation</strong></td>
<td>DEC without significant fuel degradation</td>
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<tr>
<td></td>
<td></td>
<td>DEC with core melting</td>
</tr>
<tr>
<td>Reactor shutdown</td>
<td>At least two diverse and independent means (Inherent design features is</td>
<td>At least two diverse and independent systems</td>
</tr>
<tr>
<td></td>
<td>regarded as one of means)</td>
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<tr>
<td>Heat removal from core</td>
<td><strong>Passive cooling</strong> from the outside surface of reactor vessel</td>
<td>In shutdown states: Residual heat removal (Forced cooling)</td>
</tr>
<tr>
<td></td>
<td>(Passive cooling)</td>
<td>In accident condition: Emergency core cooling (Forced cooling)</td>
</tr>
<tr>
<td>Confinement of radioactive materials</td>
<td>In operational states and <strong>in accident conditions</strong></td>
<td>In operational states (normal operation and AOO)</td>
</tr>
<tr>
<td>Fuel integrity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Containment system</td>
<td><strong>Confinement</strong> (i.e., vented low-pressure containment)</td>
<td>Containment Vessel</td>
</tr>
<tr>
<td>Additional specific considerations</td>
<td><strong>Mitigation of air and water ingress</strong> into core during accidents</td>
<td>-</td>
</tr>
</tbody>
</table>
Safety design approach for coupling of process heat applications

- **Assurance of nuclear facility safety**
  - Ensure safety of nuclear facility against postulated event initiated in heat applications

- **Construction of process heat application facility as non-nuclear**
  - Design, construct and operate the process heat application facilities under conventional industrial regulation in order to facilitate the entry of conventional industries into the HTGR market

Postulated safety-related phenomena for coupling of process heat applications

I. Temperature and pressure transients due to heat application facility abnormal events

II. Tritium migration from nuclear facility to heat application facility and product such as H2

III. Transportation of chemical substances from heat application facility to nuclear facility

Certification requirements for construction of process heat application facilities as non-nuclear

In order to construct process heat application facility as non-nuclear facility, safety of nuclear facility should be assured even the reliability of process heat application facility is same as conventional industrial plant.

In nuclear facility, safety-related structures, systems and components (SSCs) execute functions either prevention of accidents or mitigation of their consequences.

Process heat application facility should be exempted from safety-related SSCs

If there are no countermeasures, process heat application facility may be classified into the following safety functions:

- Cooling of secondary circuit during normal operation
- Maintain reactor coolant pressure boundary between primary & secondary circuits
- Storage of radioactive material

**Requirement:**
Maintain normal operation of nuclear facility against temperature and pressure transients

**Requirement:**
Mitigate tritium concentration in process heat application facility to allowable level

Safety requirements for coupling of process heat applications

In a condition that process heat application facility is classified as non-nuclear facility, leakages of combustible gas and hazardous chemicals should be classified as external human-induced events.

Safety requirements against external human-induced events are already included in the existing safety requirements for nuclear facility.

**IAEA SSR-2/1 (Rev.1) “Safety of Nuclear Power Plants: Design”**

Requirement 17: Internal and external hazards

All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated.

5.19. Features shall be provided to minimize any interactions between buildings containing items important to safety (including power cabling and control cabling) and any other plant structure as a result of external events considered in the design.

Requirement 65: Control room

6.39. Appropriate measures shall be taken, including the provision of barriers between the control room at the nuclear power plant and the external environment, and adequate information shall be provided for the protection of occupants of the control room, for a protracted period of time, against hazards such as high radiation levels resulting from accident conditions, releases of radioactive material, fire, or explosive or toxic gases.

**Requirement:**

Ensuring the capability of SSCs functions, prevention and mitigation of accident consequences, and maintaining habitability of control room

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Towards the restart of HTTR

- Following the nuclear accident at the Fukushima Daiichi nuclear power station on March 11, 2011, revised regulatory requirements were issued by the Nuclear Regulation Authority (NRA) in July 2013.
- **JAEA had submitted the application** including evaluation results satisfying the New Regulatory Requirements to the Nuclear Regulation Authority (NRA) on **Nov. 26th, 2014**.
- Through many discussions with the NRA, **on June 3rd, 2020, JAEA obtained the permission** by the NRA for changes to Reactor Installation of the HTTR.
- It is targeted to restart HTTR in July 2021.

### Calendar year

<table>
<thead>
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<tbody>
<tr>
<td>Pre-service inspection</td>
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<td>3, June</td>
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<tr>
<td>Operational Safety Programs</td>
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<td>Approval of the Design and Construction Method</td>
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<td>Inspection</td>
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<td>Pre-service inspection</td>
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<td>Restart</td>
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<td>Restart</td>
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<th>Regulatory review results</th>
<th>Additional countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquake Design seismic ground motion</td>
<td>Raised from 350gal to 973gal</td>
<td>No large-scale reinforcement due to the degradation of the SSCs.</td>
<td>Not required</td>
</tr>
<tr>
<td>Re-evaluation of seismic design classification</td>
<td>Some of structures, systems and components (SSCs) were downgraded taken into account the results of safety demonstration tests.  ➢ Core heat removal: S class to B class  ➢ Reactor internal structure: S class to B class.</td>
<td></td>
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</tr>
<tr>
<td>Tsunami evaluation</td>
<td>Assumption of tsunami height for evaluation : 17.8m from sea level</td>
<td>Tsunami does not reach the site because siting location is 36.5 meters high from the sea level.</td>
<td>Not required</td>
</tr>
<tr>
<td>Evaluation of integrity of SSCs against natural phenomena such as tornado, volcano, etc.</td>
<td>Design basis tornado wind speed: 100 m/s  Thickness of descent pyroclastic material by volcano: 50 cm</td>
<td>All SSCs needed to be protected are installed inside the reactor building  Fire proof belt necessary around reactor building.</td>
<td>Fire proof belt was required.</td>
</tr>
</tbody>
</table>
### HTTR safety review results by Nuclear Regulation Authority (2/2)

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<th>Additional countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire</strong></td>
<td>Burnable materials in and around the reactor building was additionally evaluated.</td>
<td>● Amount of burnable materials in the reactor building is limited.</td>
<td>Cable protection against fire was required.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Cables necessary to be protected against fire</td>
<td></td>
</tr>
<tr>
<td><strong>Reliability of power supply</strong></td>
<td>Emergency power supply failure was evaluated.</td>
<td>Decay heat is removable from the core without electricity.</td>
<td><strong>Only portable power generator for monitoring during accident is required.</strong></td>
</tr>
<tr>
<td><strong>Beyond design basis accident (BDBA)</strong></td>
<td>Postulated BDBAs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>➢ DBA + failure of reactor scram</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>➢ DBA + failure of heat removal from the core</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>➢ DBA + failure of containment vessel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>● No core melt occurs in all BDBAs.</td>
<td></td>
</tr>
</tbody>
</table>

**HTTR will restart without significant additional reinforcements due to its inherent safety features.**

GIF Webinar: 22 April 2021  
Series 52: Experience of HTTR licensing for Japan’s New Nuclear Regulation  
https://www.gen-4.org/gif/jcms/c_82831/webinars
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Demonstration of nuclear hydrogen production using HTTR

- **Objectives**
  - To demonstrate the performance of nuclear hydrogen and power generation systems
  - To license hydrogen production facility coupling to HTTR as non-nuclear facility

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JAEA has been carried out R&D on safety standards to contribute to the establishment of commercial modular HTGR safety standards by regulatory authority.

JAEA has been demonstrating the inherent safety features of HTGR and accumulating the data using HTTR.

Based on the inherent safety features demonstrated by HTTR, JAEA developed the safety requirements for the design of commercial modular HTGR and proposed it to the related activities in IAEA.

JAEA got the official approval of the HTTR restart from Nuclear Regulation Authority (NRA) on 3rd June 2020. The inherent safety features demonstrated by HTTR were taken into account for the safety review, and NRA confirmed that there are no major reinforcements due to its inherent safety features.

JAEA is planning to conduct the safety demonstration test after the restart of HTTR. After that, the HTTR heat application test will be planned to contribute to the development of safety standards for the coupling of process heat applications.