R&D Activities in JAEA for HTGR Developments

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Japan Atomic Energy Agency
Plan for global warming countermeasures (Cabinet decision on May 13, 2016)
• Mid-term target: 26.0% reduction by FY2030 compared to FY2013
• Long-term goal: 80% reduction by 2050

GHG emission in Japan (Final report of FY2018)

- Use of HTGR is a key to achieve the GHG reduction goal.
  • HTGR producing hydrogen for nuclear steel making and fuel cell vehicle
  • HTGR producing steam for conventional industries
  • HTGR for absorbing renewable power variation

Use of HTGR is a key to achieve the GHG reduction goal.
Nuclear steel making using hydrogen as reducing agent produced by HTGR
Reduction of 100% of CO₂ emitted from steel making factory
First step: hydrogen by steam reforming, Future step: hydrogen by IS process

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost reduction(USC/Nm³)</th>
<th>H₂ production cost(USC/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ production only</td>
<td>-</td>
<td>24.2</td>
</tr>
<tr>
<td>Cogeneration: H₂ and electricity</td>
<td>12.4*</td>
<td>11.8</td>
</tr>
<tr>
<td>Waste heat utilization: District heating**</td>
<td>11.7</td>
<td>0.1</td>
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</tbody>
</table>

* Changing the share of depreciation cost of HTGR construction (by H₂ production and power generation) and selling cogenerated electricity at 8.0 JPY/kWh, whereas the original power generation cost is 5.8 JPY/kWh., ** Market production cost: 0.65 JPY/MJ

HTGR hydrogen system has economical competitiveness due to its high heat utilization rate.
HTTR (High Temperature Engineering Test Reactor) Graphite-moderated and helium-cooled VHTR

**Major specification**

- **Thermal power**: 30 MW
- **Fuel**: Coated fuel particle / Prismatic block type
- **Core material**: Graphite
- **Coolant**: Helium
- **Inlet temp.**: 395°C
- **Outlet temp.**: 950°C
- **Pressure**: 4 MPa

**First criticality**: 1998
**Full power operation**: 2001
**50 days continuous 950°C operation**: 2010
**Loss of forced cooling test at 9MW**: 2010
<table>
<thead>
<tr>
<th>Major discussion item</th>
<th>Regulatory review condition</th>
<th>Regulatory review results</th>
<th>Additional countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquake</td>
<td>Design seismic ground motion Raised from 350gal to 973gal</td>
<td>No large-scale reinforcement due to the degradation of the SSCs.</td>
<td>Not required</td>
</tr>
</tbody>
</table>
| Re-evaluation of seismic design classification| Some of safety systems, structures and components (SSCs) were classified from S to B based on results of safety demonstration tests.  
- Core heat removal: S class to B class  
- Reactor internal structure: S class to B class. |                                                                                           |                                   |
| Tsunami evaluation                            | Assumption of tsunami height for evaluation: 17.8m from sea level                            | Tsunami does not reach the site because siting location is 36.5 meters high from the sea level | Not required                      |
| Evaluation of integrity of SSCs against natural phenomena such as tornado, volcano, etc. | - Design basis tornado wind speed: 100 m/s  
- Thickness of descent pyroclastic material by volcano: 50 cm | - All SSCs needed to be protected are installed inside the reactor building  
- Fire proof belt necessary around reactor building. | Fire proof belt was required.       |
| Fire                                          | Burnable materials in and around the reactor building was additionally evaluated.            | - Amount of burnable materials in the reactor building is limited.  
- Cables necessary to be protected against fire | Cable protection against fire was required.                                               |
| Reliability of power supply                   | Emergency power supply failure was evaluated.                                               | Decay heat is removable from the core without electricity.                                | Only portable power generator for monitoring during accident is required. |
| Beyond design basis accident (BDBA)           | Postulated BDBAs  
- DBA + failure of reactor scram  
- DBA + failure of heat removal from the core  
- DBA + failure of containment vessel  
- Intentional aircraft crash | - No core melt occurs in all BDBAs.  
- Intentional aircraft crash does not damage SSCs in the reactor building. |                                   |

Obtained permission for changes to Reactor Installation of the HTTR by NRA on June 3rd, 2020. HTTR will restart without significant additional reinforcements due to its inherent safety features.

JAEA has many experiences on safety licensing and lots of data needed for HTGR safety licensing.
Test program using HTTR

Safety demonstration test under OECD/NEA project

- 30% power (9MW) Loss of forced cooling test (All HGC tripped) Finished (2010)
- 100% power Loss of forced cooling test (All HGC tripped) Planned
- 30% power Loss of core cooling test (All HGC + VCS tripped) Planned

Test Result

The reactor is naturally shut down as soon as the core cooling flow rate to zero. The reactor is kept stable long after the loss of core cooling

Future tests

- Core physics: Xenon stability, decay heat measurement, burnup characteristic, etc.
- Fuel: Iodine plateout, integrity after long time operation, tritium behavior, etc.
- Components: IHX performance, etc.
- HTTR-GT/H₂ test

JAEA has a plan to conduct many tests to confirm safety, core physics & thermal-fluid characteristics, fuel & high temperature component performances, etc. for commercial systems after the restart. We have room to accept your request on HTGR development.
**Project goal**

1. Licensing
   - License acquisition of world’s first nuclear GT/H₂ cogeneration plant
2. Operability
   - Confirm safe & reliable operation
3. Complete system technology

**Project plan**

- Design, construction & operation for HTTR-GT/H₂ plant
- Establish new licensing framework for coupling GT/chemical plant to nuclear reactor
- Demonstration of key technologies

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HTTR-GT/H₂ test layout


HTTR has the capability to conduct various tests for heat applications.
**Thermo-chemical water splitting Iodine-Sulfur (IS) Process**

- **H₂ Production Test Facility**
  - **Process**
    - Electric heating
  - **Component materials**
    - Liquid phase
      - Fluoroplastic lining
      - Glass lining
      - Silicon carbide (SiC)
      - Graphite (impervious)
    - Gaseous phase
      - Hastelloy C-276
      - JIS SUS316
  - **Control panels**
  - **Bunsen reaction**
  - Production of hydrogen iodide and sulfuric acid
  - Decomposition of hydrogen iodide (HI)
  - Decomposition of sulfuric acid

- **Test result**
  - The 150-hour and 30 L/h continuous H₂ production was performed with integration of 3 sections in January 2019.

- **Future tests**
  - 100 L/h operation, longer operation.
  - Development of automatic control system, high performance membrane, etc.
  - Data acquisition on reliability, durability, etc.

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**So far, JAEA had developed engineering materials components and confirmed controllability of the system. Experiments using H₂ test facility and design study on commercial system are on going.**
Use of HTTR for development of HTGR

2020

- Design of demonstration reactor (GT, SR)
- Demonstration tests for component (GT, SR)

2030

- Construction of demonstration reactor (GT, SR)
- Design of demonstration reactor (GT, IS)
- Demonstration tests for component (IS)
- Technology of Steam generator, Steam system connecting technology
- High burnup fuel, High performance core
- System with inherent safety
- Establishment of safety standard for steam connecting technology

2040

- Construction of commercial reactor (GT, SR)
- Construction of demonstration reactor (GT, IS)

2050

- HTTR-GT/H₂ test
- Establishment of safety standard through licensing
- Demonstration of H₂ plant coupling technologies
- Demonstration of system technologies
- Training of operators

JAEA

- HTTR test, HTTR-GT/H₂ (SR) test
  - Confirmation of fuel/material performance under commercial reactor condition
  - Support of establishing design/ material standard
  - Development of basic technologies for IS process

- HTTR-GT/H₂ (IS) test
  - Confirmation of fuel/material performance under commercial reactor condition

※GT : Gas Turbine, SR : Steam Reforming, IS : IS process, ** : JAEA’s draft plan
Summary

• HTGR hydrogen cogeneration system is superior in economy due to its high efficiency and expected to be a promising system to reduce Green House Gas emission from the fields of steel making, transportation as well as electricity generation.

• JAEA got official approval of the restart from Nuclear Regulation Authority (NRA) on June 3rd this year. NRA confirmed HTTR resumes without major reinforcements due to its inherent safety features. HTTR is the only reactor to provide 950°C heat to heat applications worldwide.

• JAEA completed the development of engineering materials, control scheme and so on for IS system.

• JAEA’s test facilities can be served as test beds under a bilateral cooperation with US for mutual benefit.

We hope you will participate in our programs to obtain technical data on HTGR and hydrogen production system. We are willing to provide our data, experiences and so forth under the conditions to be determined.
Appendix
(1) Reactor technology: HTTR

- 30 MWt and 950 °C prismatic core advanced test reactor (Operation started in 1998)
- Technology of fuel, graphite, superalloy and experience of operation and maintenance.
- Safety evaluation by NRA has been completed.

(2) Gas turbine and H₂ technology

- R&D of gas turbine technologies such as high-efficiency helium compressor, shaft seal, and maintenance technology
- In January 2019, 150 hours of hydrogen production with the rate of 0.03 m³/h was achieved.

(3) Innovative HTGR design

- GTHTR300 for electricity generation, cogeneration and nuclear/renewable energy hybrid system
- HTGR with thorium fuel
- Clean Burn HTGR for plutonium burning
- Establishment of safety design philosophy

(4) HTTR-GT/H₂ test

- Connection of a helium gas turbine and hydrogen production system with the HTTR.
- Basic design for the HTTR-GT/H₂ test has been completed.
Various types of SMR systems based on HTGR

**Hydrogen production system**
- Hydrogen
- **GTHTR300C**
- Thermo-chemical water splitting process (IS process)
- Steam methane reforming process for hydrogen production

**High temperature steam for industry**
- **HTR50S**
- Process heat: Supplied to chemical plant, petroleum refining plant, etc.
- Power: Produced by steam turbine

**Hybrid system with renewable energy**
- **GTHTR300C**
- Renewable power variation: Absorbed by HTGR power and additional hydrogen cogeneration

**Multipurpose cogeneration**
- **GTHTR300C**
- Hydrogen, Desalination
- Electricity
- Hydrogen town

**HTGR**, owing to high temperature capability, can yield high efficiency (up to 50% in power generation, and 80% for heat utilization rate), resulting in competitive economics. It may be sited near demand areas due to its excellent safety.
# HTGR Systems

## HTGR Gas Turbine (GT) System
- Reactor: ~ 600 MWe, 850°C
- Helium gas turbine
- High economy
- Deployment in 2030s

## HTGR Hydrogen Production System
- Reactor: ~ 600 MWe, 950°C
- Hydrogen production: ~ 50,000 Nm³/h
- Deployment in 2040s

## HTGR Cogeneration System (hydrogen production & power generation by GT)
- Reactor: ~ 600 MWe, 950°C
- Cogeneration of hydrogen and electricity
- Hydrogen production: ~ 50,000 Nm³/h
- Heat utilization rate is about 80%
- Deployment in 2040s
HTTR’s systems

- **HTTR’s design, construction and operational experiments**
  (MHI, Toshiba/IHI, Hitachi, Fuji Electric, KHI and etc.)
  Design optimization based on extensive technical database

- **Primary coolant system (MHI)**
  Construction of efficient transport and cooling system for very high temperature heat (950°C)

- **He/He intermediate heat exchanger (IHX) (Toshiba/IHI)**
  Developed new heat (950°C) resistance material to enable extraction of heat and making of derivative equipment based on such material

- **Reactor pressure vessel**
  (Hitachi)
  Developed new material having high resistance to very high temperature and pressure and construct new pressure vessel using such material

- **Fuel (Nuclear Fuel Industries)**
  Advanced technology to coat uranium fuel using ceramics with high radioactivity retaining performance

- **Reactor internals (Fuji Electric)**

- **Graphite material IG-110**
  (Toyo Tanso)
  High strength
  High heat conduction
  Irradiation-resistance
Technologies of design, construction, operation, maintenance, etc. have been established by HTTR.

Advanced Technologies

High burn-up fuel
Technologies to be established by future HTTR tests

Establishment of fundamental technologies

In progress

Owner of technologies:
- JAEA
- MITSUBISHI
- TOSHIBA
- HITACHI, etc.

- JAEA
- NFI
- TOYO TANSO, etc.

Commercial HTGR System

High burn-up fuel

Code validation and upgrading

Operation, test and maintenance of HTTR

Design and construction of HTTR

Core design

Fuel

Graphite

Metallic material

Instrumental equipment

Thermal hydraulics design, high-temperature demonstration test

Safety analysis

Earthquake-proof and component reliability test

Hydrogen production by IS process
He gas turbine
Heat utilization system connection technologies
High Temperature Reactor Simulation Methods and Models Development

- HTTR loss-of forced cooling test under pressurized conditions: JAEA
- Depressurized loss-of forced cooling test using US facility: INL
- Simulation methods and model development: INL/JAEA

Results from report INL/EXT-18-51317

HTTR-GT/H$_2$ Test Plan Development

- Design of HTTR heat-driven gas turbine system: JAEA
- Develop a system analysis model for HTTR-GT/H$_2$ plant: INL
- Simulation of steady-state and transient operational modes (startup, shutdown, loss-of-load, load following, hybrid use with renewable energy): INL
- Development of test plans for HTTR-GT/H$_2$ plant: JAEA/INL
Improvement of cooling performance of fuel elements is required to increase power density of a commercial HTGR. However, the gap between the graphite sleeve and fuel compacts in conventional fuel element of the pin-in-block HTGR deteriorates the cooling performance.

Applying **sleeveless fuel element and dual side directly cooling structures** have a possibility of improving cooling performance, but **the oxidation damage of graphite-matrix fuel compact** would be problem in case of the air ingress accident.

The oxidation resistance of fuel compact can be improved by replacing the matrix material with **SiC (Silicon carbide)** from graphite.

Fabrication of SiC matrix and mechanical peripeties measurement are on-going.

Irradiation test is planned in Kazakhstan in 2021.