R&D Activities in JAEA for HTGR Developments

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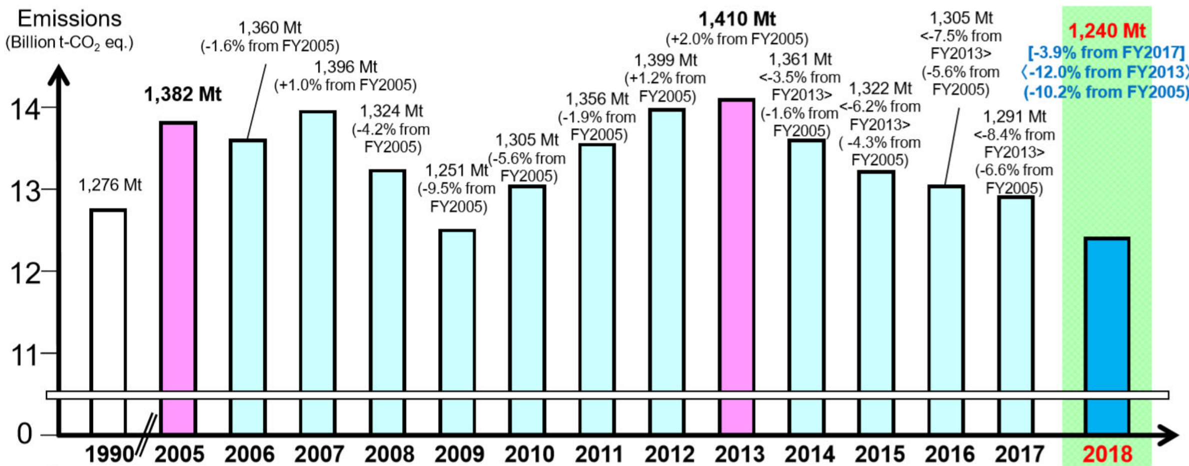
Role of HTGR in Japan
-Greenhouse gas emissions & reduction goals-

Plan for global warming countermeasures (Cabinet decision on May 13, 2016)

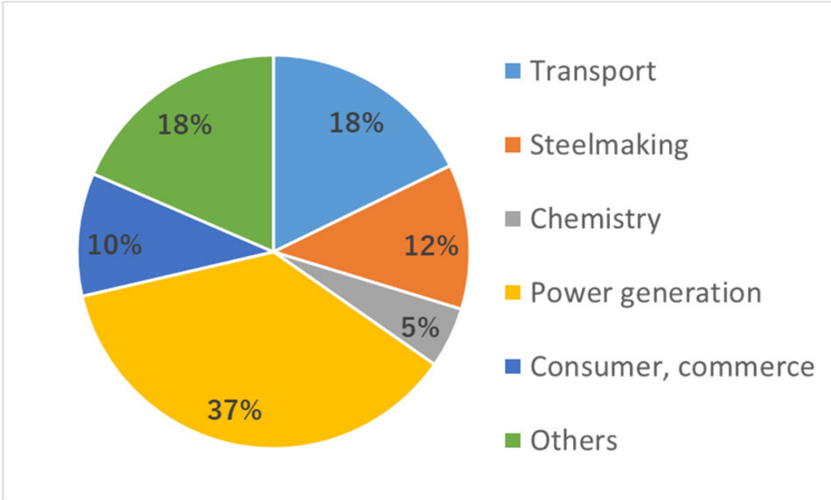
- Mid-term target: 26.0% reduction by FY2030 compared to FY2013
- Long-term goal: 80% reduction by 2050

GHG emission in Japan (Final report of FY2018)



Ref. : Website of Ministry of Environment, Japan

Breakdown of GHG emission (2018)



- The emission reduction in FY2018 : 12.0% compared to FY2013
- To achieve the goal,
  - ✓Reduction by additional 14% by 2030
  - ✓Reduction by additional 68% by 2050

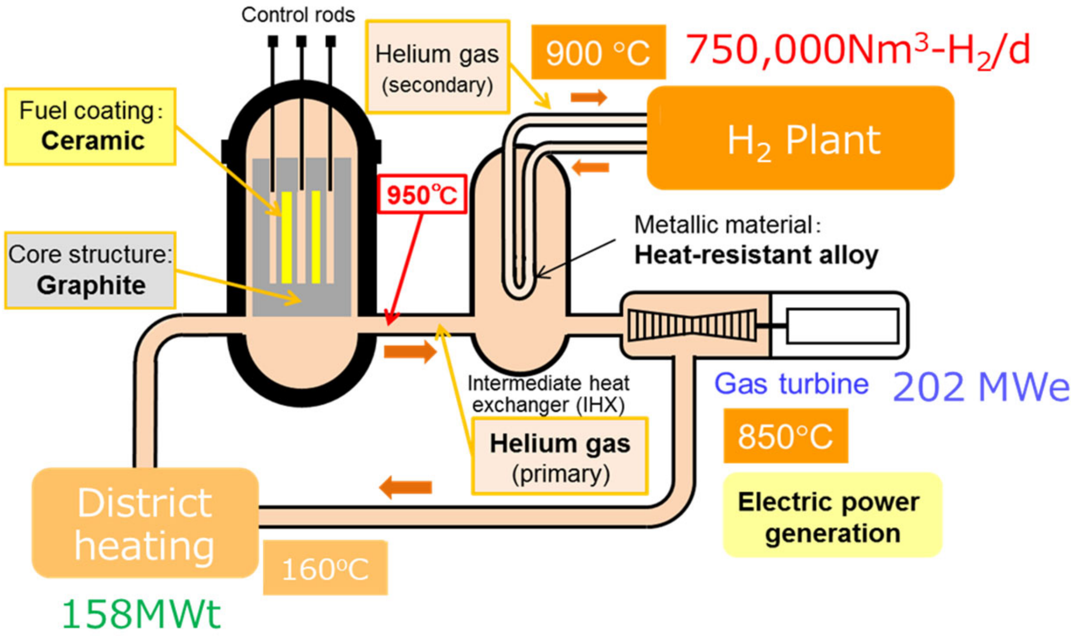
Role of HTGR

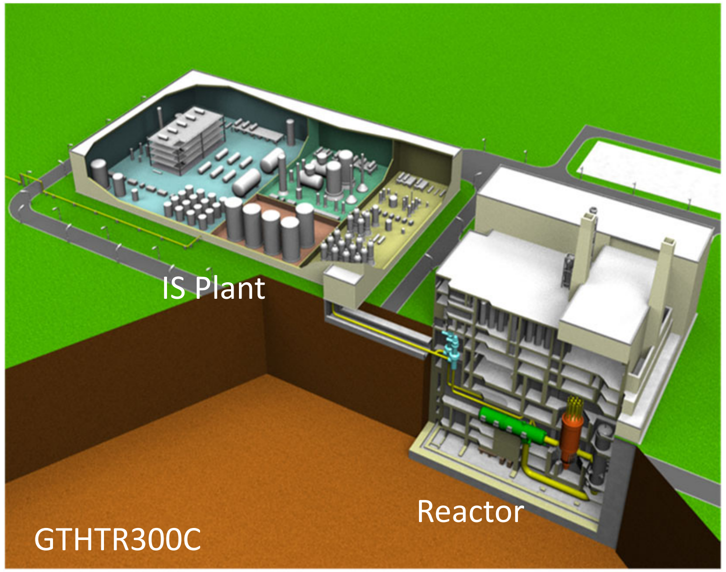
- HTGR producing hydrogen for nuclear steel making and fuel cell vehicle
- HTGR producing steam for conventional industries
- HTGR for absorbing renewable power variation

Use of HTGR is a key to achieve the GHG reduction goal.

HTGR Hydrogen Cogeneration System –Nuclear Steel Making-

- Nuclear steel making using hydrogen as reducing agent produced by HTGR
- Reduction of 100% of CO_2 emitted from steel making factory
- First step : hydrogen by steam reforming, Future step: hydrogen by IS process





H_2 cost reduction by multi-purpose heat utilization systems.

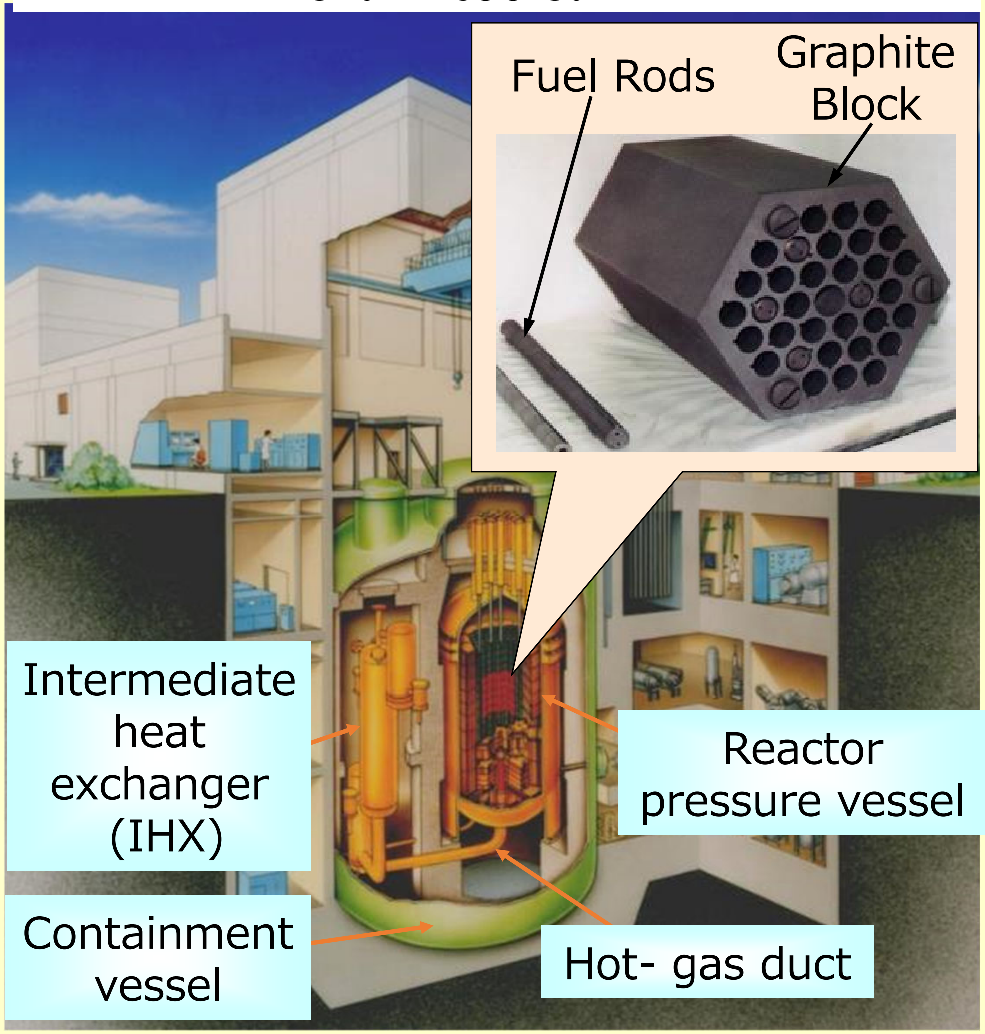
Item	Cost reduction(USC/Nm³)	H_2 production cost(USC/Nm³)
H_2 production only	-	24.2
Cogeneration: H_2 and electricity	12.4*	11.8
Waste heat utilization: District heating**	11.7	0.1

* Changing the share of depreciation cost of HTGR construction (by H_2 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.

HTGR development in JAEA : HTTR

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

Results of safety review by Nuclear Regulation Authority

Major discussion item		Regulatory review condition	Regulatory review results	Additional countermeasures
Earthquake	Design seismic ground motion	Raised from 350gal to 973gal	No large-scale reinforcement due to the degradation of the SSCs.	**Not required**
	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.	

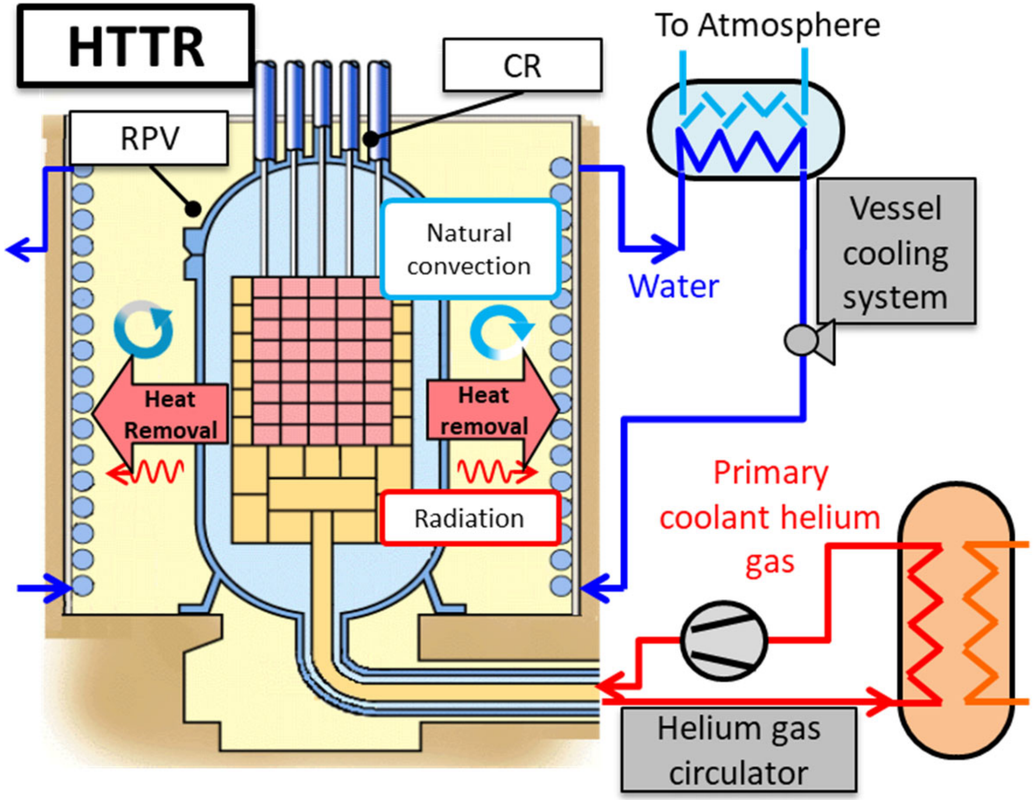
Obtained permission for changes to Reactor Installation of the HTTR by NRA on June 3rd, 2020
HTTR will restart without significant additional reinforcements due to its inherent safety features.

JAEA has many experiences on safety licensing and lots of data needed for HTGR safety licensing.

Test program using HTTR

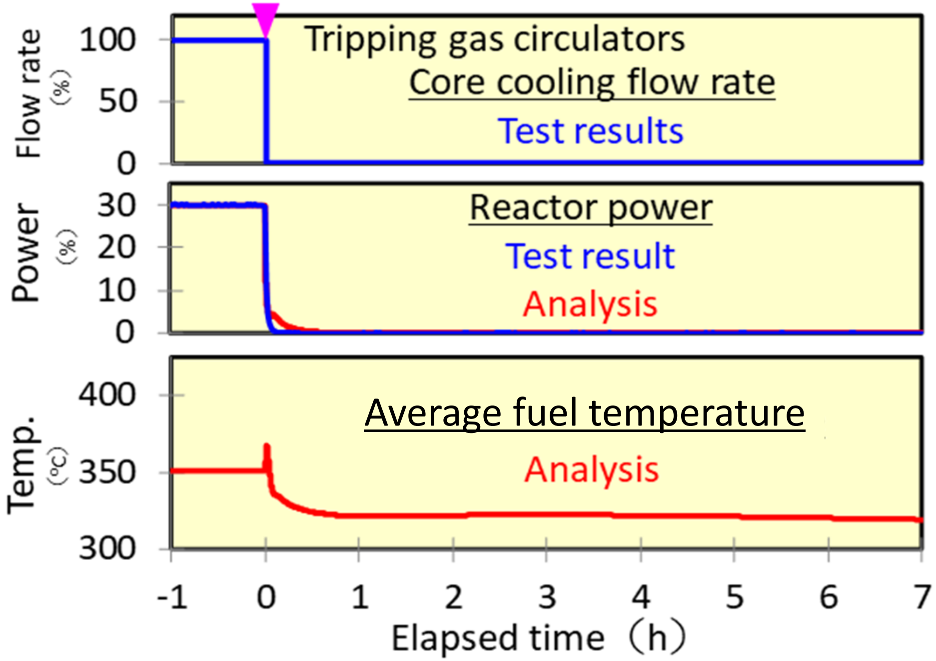
Safety demonstration test under OECD/NEA project

- ■ 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/H_2 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.

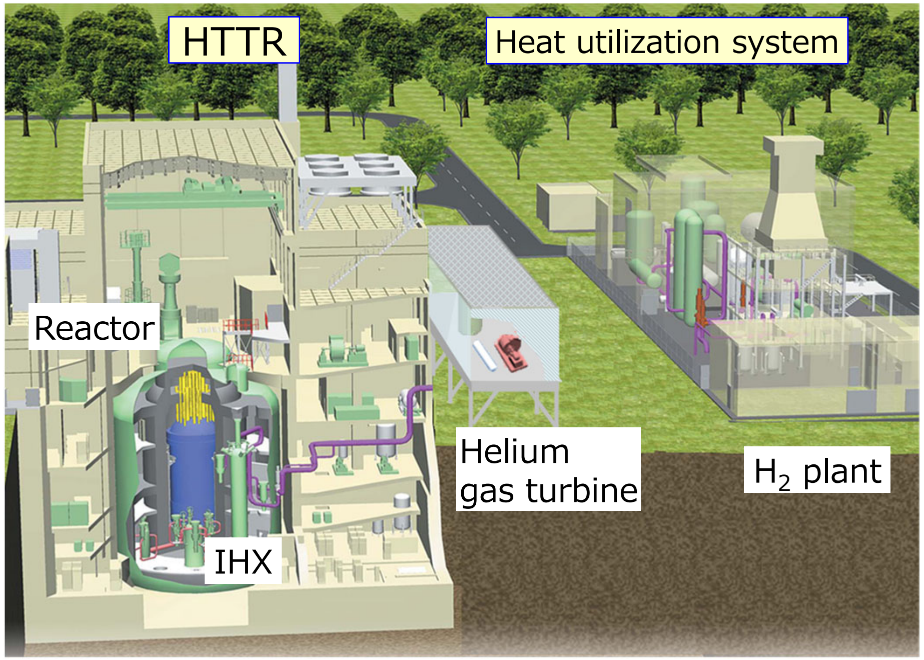
HTTR-GT/H_2 test

■ Project goal

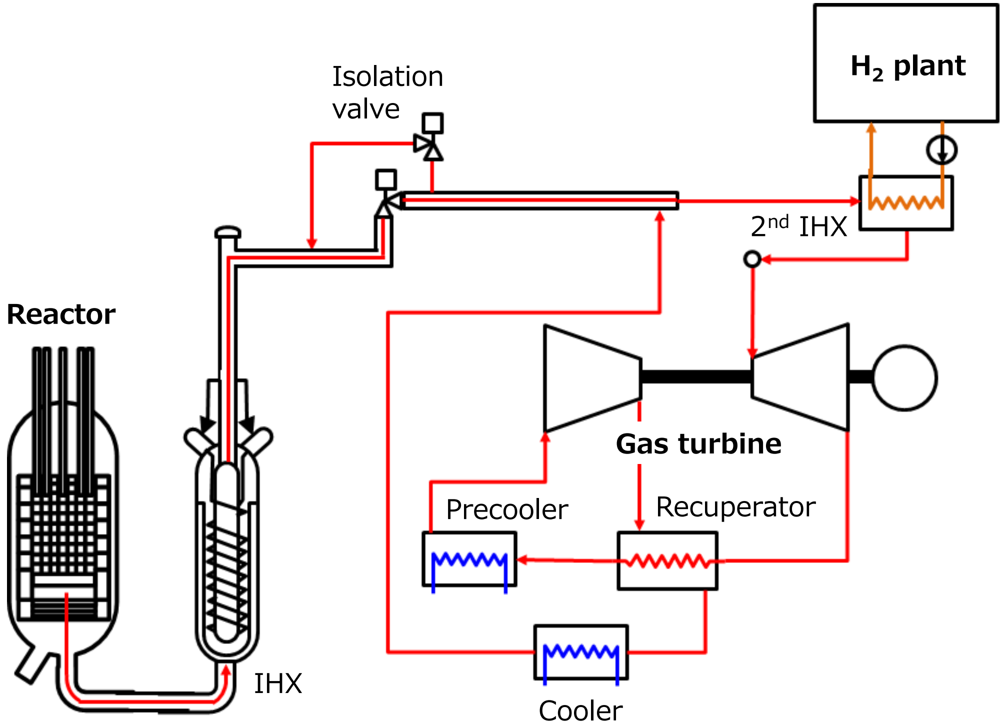
1. Licensing
   License acquisition of world's first nuclear GT/H_2 cogeneration plant
2. Operability
   Confirm safe & reliable operation
3. Complete system technology

■ Project plan

- Design, construction & operation for HTTR-GT/H_2 plant
- Establish new licensing framework for coupling GT/chemical plant to nuclear reactor
- Demonstration of key technologies



HTTR GT/H_2 test layout



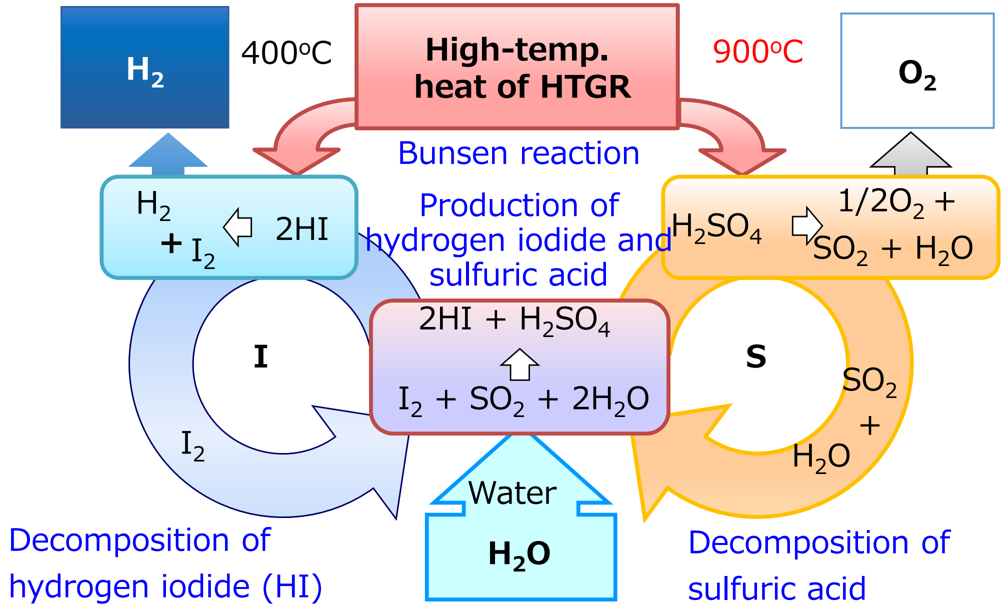
HTTR GT/H_2 test system configuration

X. Yan, et al., Nuclear Engineering and Design, 329, 223-233 (2018).

HTTR has the capability to conduct various tests for heat applications.

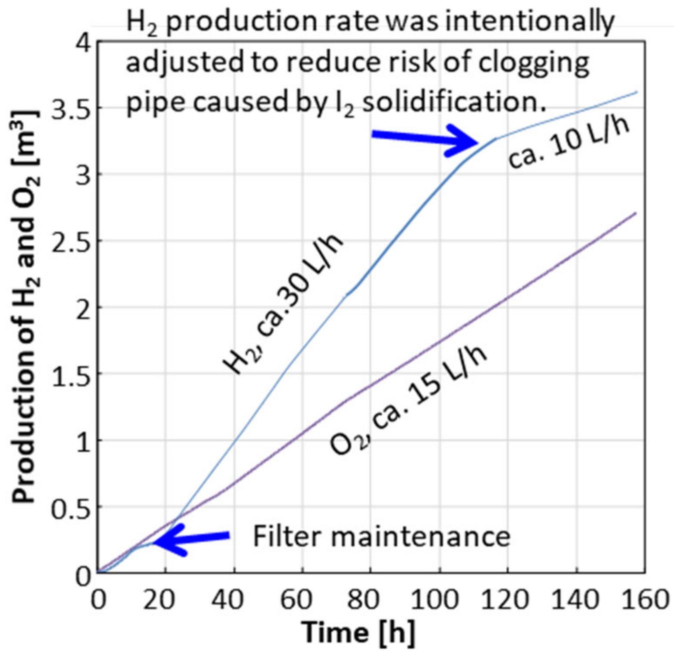
HTGR development in JAEA -H_2 production technology-

Thermo-chemical water splitting Iodine-Sulfur (IS) Process

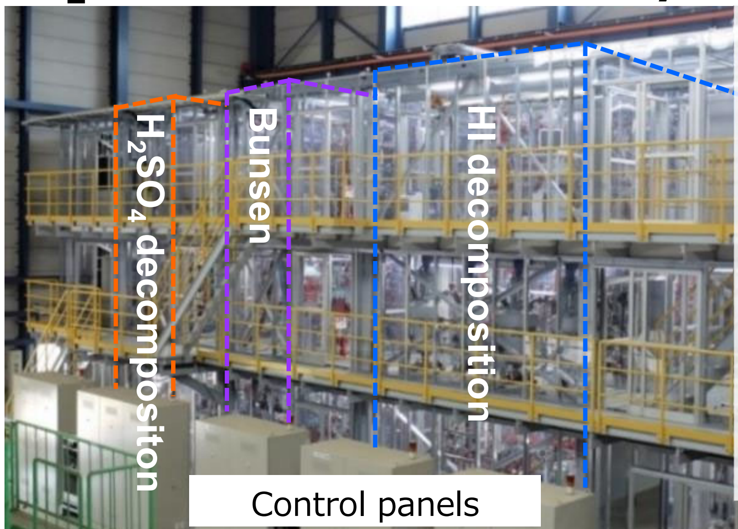


Test result

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



H_2 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

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

So far, JAEA had developed engineering materials components and confirmed controllability of the system. Experiments using H_2 test facility and design study on commercial system are on going.

Use of HTTR for development of HTGR

2020 | 2030 | 2040 | 2050

Target schedule (Private sector)**

- 2020–2030:
  - Design of demonstration reactor (GT, SR)
  - Demonstration tests for component (GT, SR)
- 2030–2040:
  - Construction of demonstration reactor (GT, SR)
  - Design of demonstration reactor (GT, IS)
  - Demonstration tests for component (IS)
- 2040–2050:
  - Construction of commercial reactor (GT, SR)
  - Construction of demonstration reactor (GT, IS)

International collaboration

- Research reactor
- Demonstration reactor

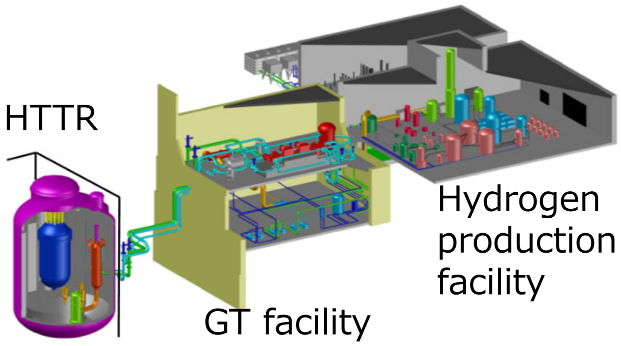
- Technology of Steam generator, Steam system connecting technology
- High burnup fuel, High performance core
- System with inherent safety
- Establishment of safety standard for steam connecting technology

JAEA

- HTTR test, HTTR-GT/H_2 (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/H_2 (IS) test
  - Confirmation of fuel/material performance under commercial reactor condition

HTTR-GT/H_2 test

- Establishment of safety standard through licensing
- Demonstration of H_2 plant coupling technologies
- Demonstration of system technologies
- Training of operators



※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℃ 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

HTTR & Recent Developments on HTGR technology

(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 H_2 technology

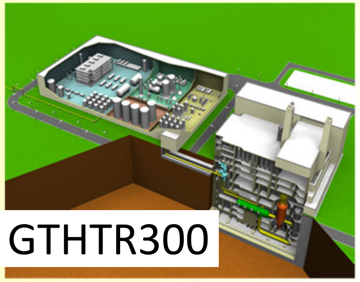

He compressor

- R&D of gas turbine technologies such as high-efficiency helium compressor, shaft seal, and maintenance technology


Hydrogen facility

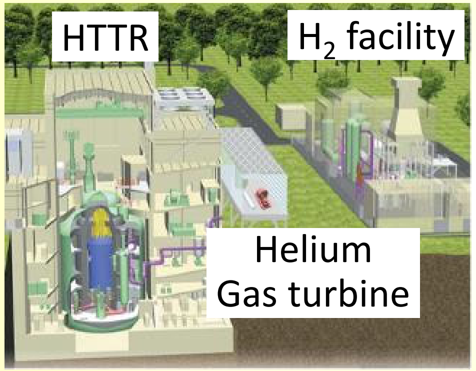
- In January 2019, 150 hours of hydrogen production with the rate of 0.03 m^3/h was achieved.

(3) Innovative HTGR design


GTHTR300

- 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

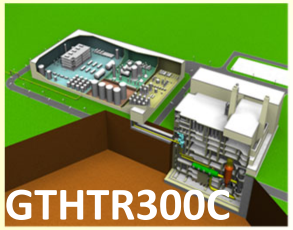
(4) HTTR-GT/H2 test



- Connection of a helium gas turbine and hydrogen production system with the HTTR.
- Basic design for the HTTR-GT/H_2 test has been completed.

Various types of SMR systems based on HTGR

Hydrogen production system



Hydrogen

Fuel cell vehicles

Iron making

- Thermo-chemical water splitting process (IS process)
- Steam methane reforming process for hydrogen production

High temperature steam for industry

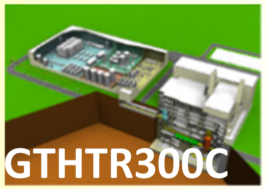
Process heat

Electricity

Chemical plant

- Process heat : Supplied to chemical plant, petroleum refining plant, etc.
- Power : Produced by steam turbine

Hybrid system with renewable energy



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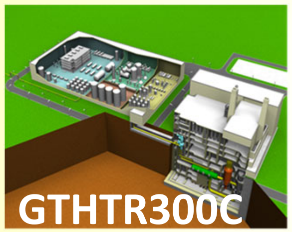
Constant power to grid

Hydrogen production

- Renewable power variation : Absorbed by HTGR power and additional hydrogen cogeneration

Multipurpose cogeneration



Hydrogen, Desalination

Electricity

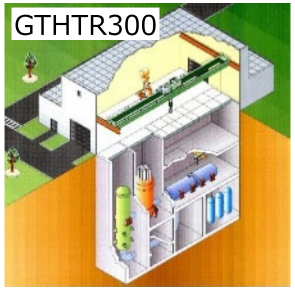
Hydrogen town

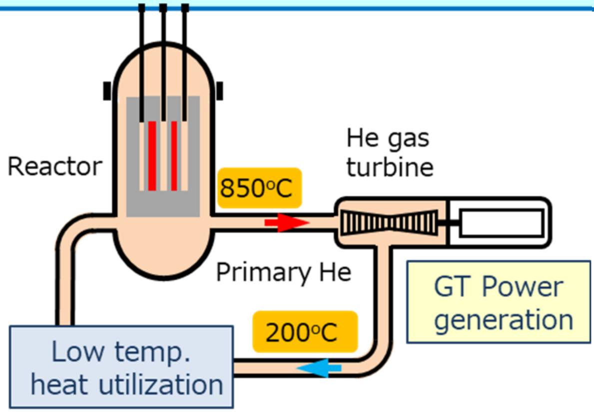
- Cogeneration : Achieve 80% of heat utilization rate

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

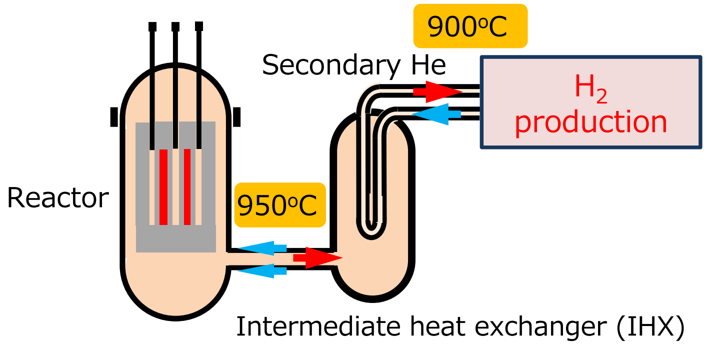
HTGR Gas Turbine (GT) System





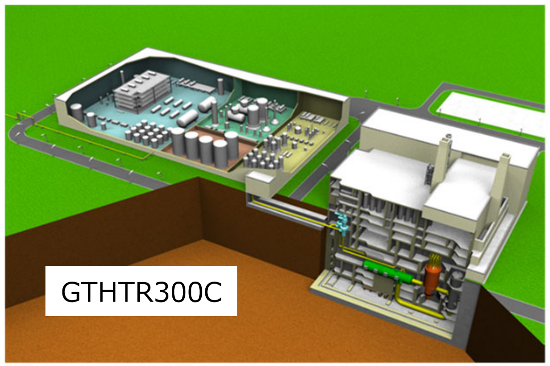
- Reactor: ～ 600 MWt, 850°C
- Helium gas turbine
- High economy
- Deployment in 2030s

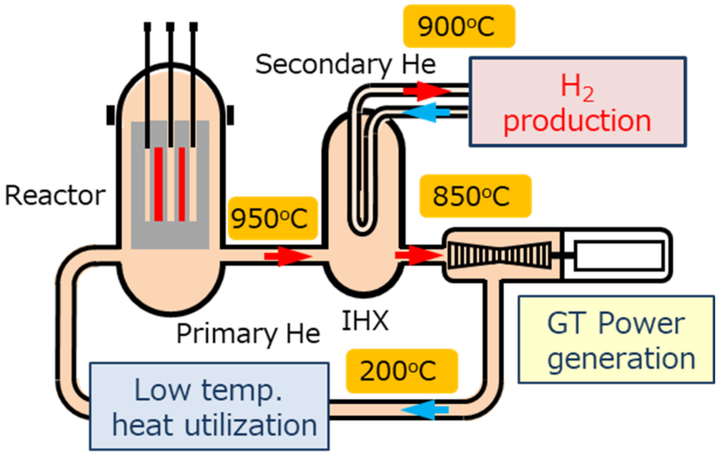
HTGR Hydrogen Production System



- Reactor: ～ 600 MWt, 950°C
- Hydrogen production ～ 85,000 Nm^3/h
- Deployment in 2040s

HTGR Cogeneration System (hydrogen production & power generation by GT)





- Reactor : ～ 600 MWt, 950°C
- Cogeneration of hydrogen and electricity
- Hydrogen production ～ 50,000 Nm^3/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)

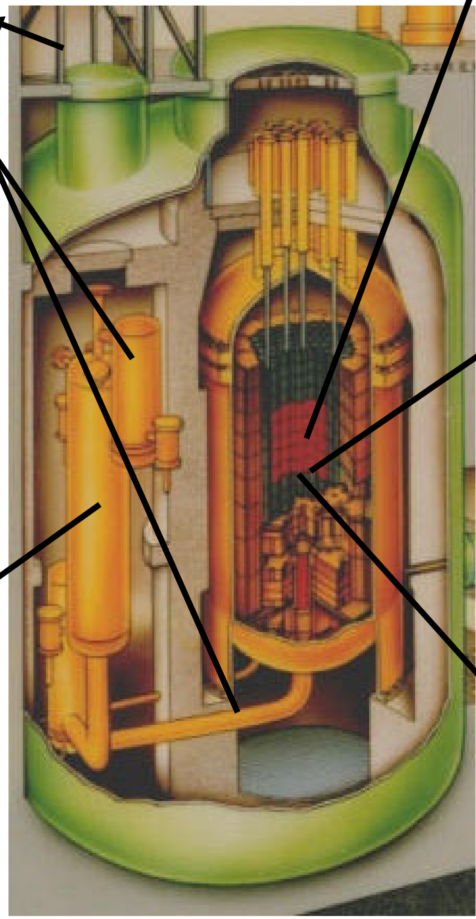
Concentric hot gas duct

Primary pressurized water cooler

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

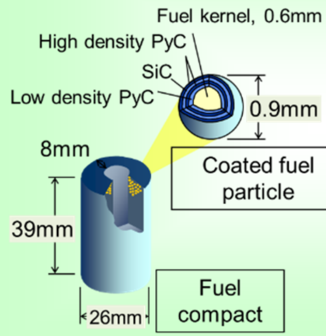
HTTR



Reactor pressure vessel
(Hitachi)

Developed new material having high resistance to very high temperature and pressure and construct new pressure vessel using such material

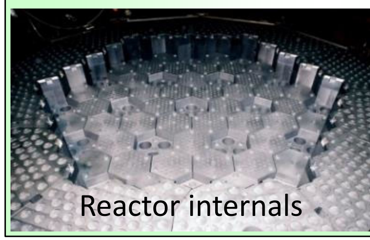
Fuel (Nuclear Fuel Industries)



Advanced technology to coat uranium fuel using ceramics with high radioactivity retaining performance

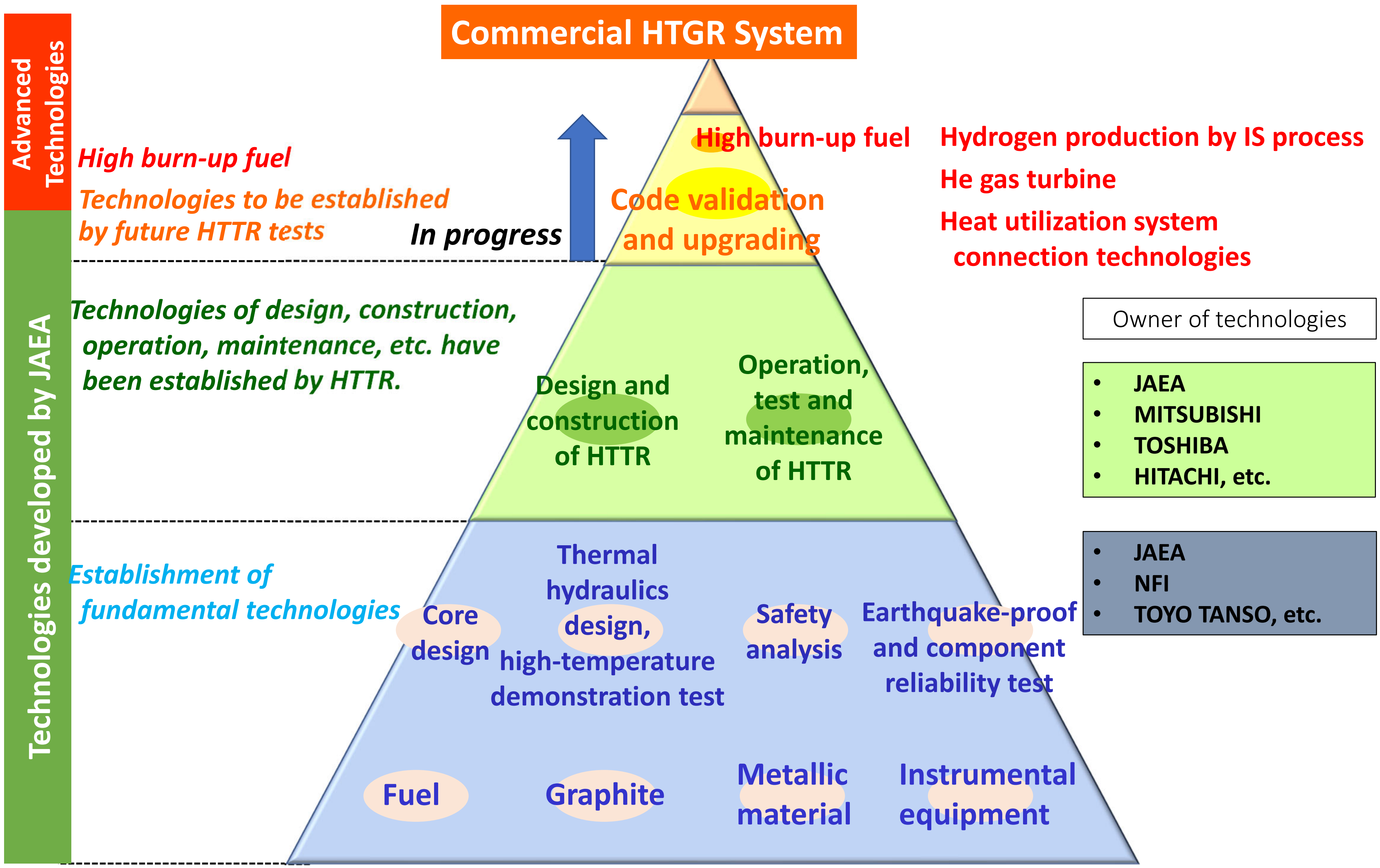
Reactor internals
(Fuji Electric)

Graphite material IG-110
(Toyo Tanso)



High strength
High heat conduction
Irradiation-resistance

Overall of R&D for Japanese HTGR

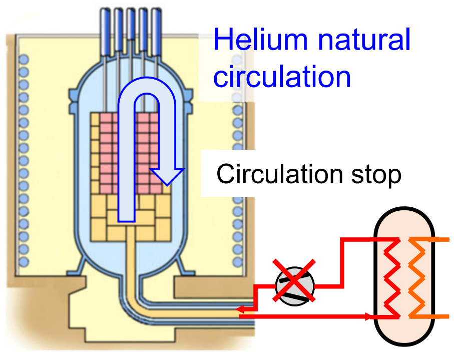


CNWG Collaboration: High Temperature Reactor

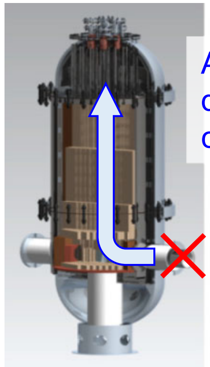
Civile Nuclear Energy Research and Development Working Group: CNWG

High Temperature Reactor Simulation Methods and Models Development

HTTR loss-of forced cooling test under pressurized conditions: JAEA

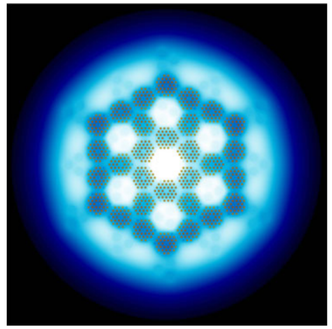


Depressurized loss-of forced cooling test using US facility: INL



Test data

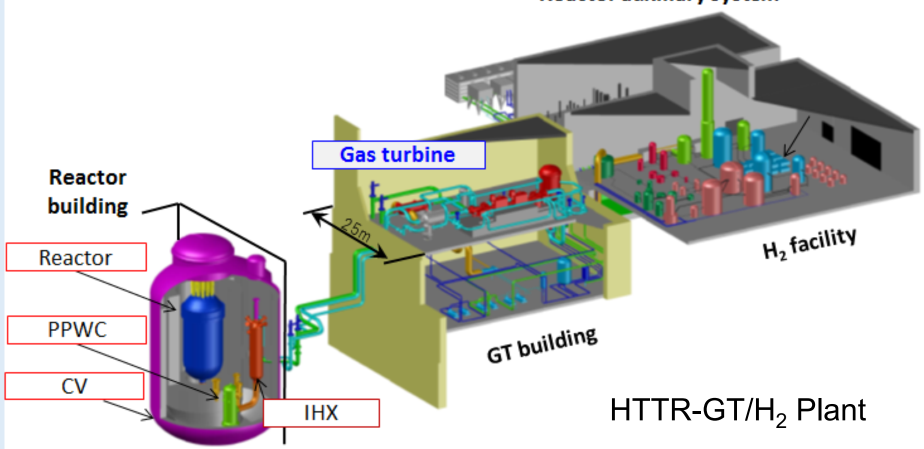
Simulation methods and model development: INL/JAEA



Results from report INL/EXT-18-51317

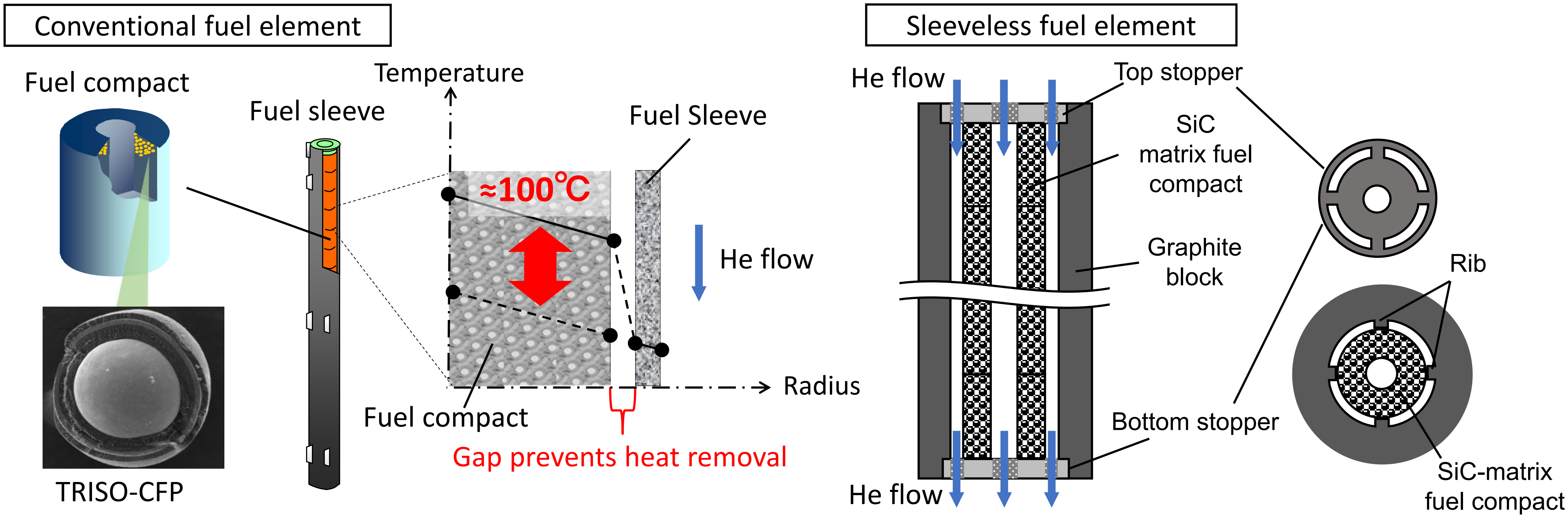
HTTR-GT/H_2 Test Plan Development

- 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



HTTR-GT/H_2 Plant

Study of SiC-matrix fuel element for HTGR



- 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.