HTGR development in Japan

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Self Introduction of Speaker

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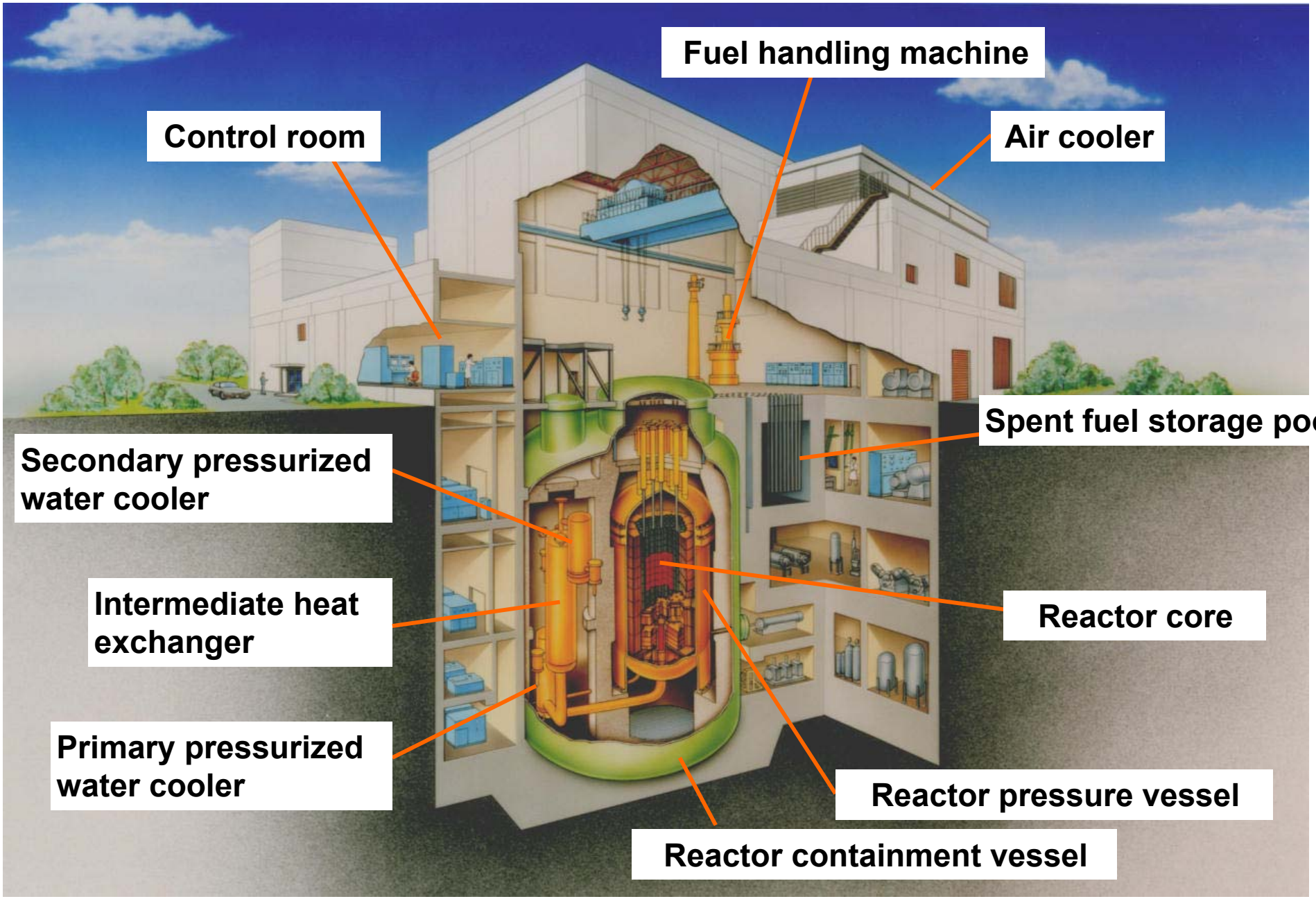
Contents

Bird's-eye View of HTTR Reactor Building



Major Specifications of HTTR

Thermal power	30MW
Average power density	2.5MW/m^3
Outlet coolant temperature	850°C/950°C
Inlet coolant temperature	395°C
Primary coolant pressure	4MPa
Direction of coolant flow (core)	Downward
Moderator / Reflector	Graphite
Core height	2.9m
Core diameter	2.3m
Fuel	Low enriched UO_2
Uranium enrichment	3 ~ 10% (Ave. 6%)
Fuel element type	Prismatic block
Pressure vessel	2 1/4Cr-1Mo steel
	13m(H) × 6m(ID)
Containment vessel	Steel containment
	30m(H) × 18.5m(ID)

S. Saito et al., JAERI-1332 (1994).

Japan's High Temperature Engineering Test Reactor "HTTR"

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)

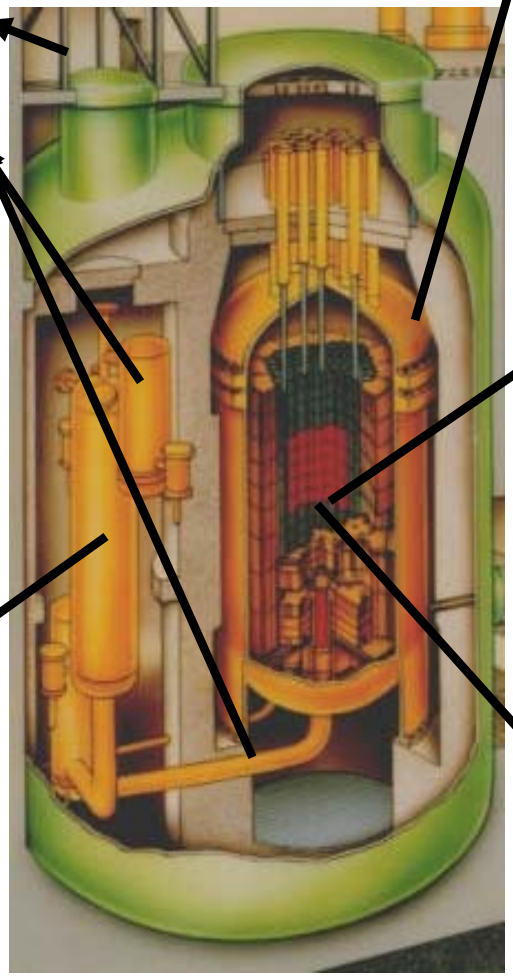
Concentric hot gas duct

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

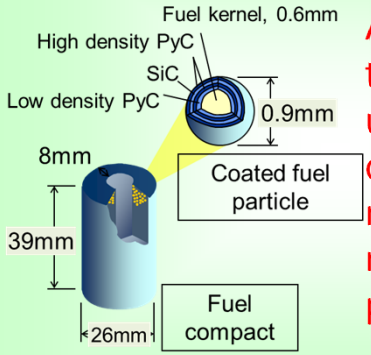
HTTR



Reactor pressure vessel (Hitachi)

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

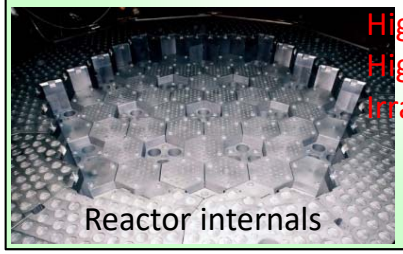
Fuel (Nuclear Fuel Industries)



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

History of HTTR

High temperature engineering test reactor (HTTR)

The first HTGR built in Japan
Thermal power: 30MWth
Reactor outlet coolant temperature: 950 °C

Establishment of fundamental technology

Proposal of a prototype of commercial HTGR's system

2010	Start of Loss of Forced cooling test **950℃/50 days operation**
2007	850℃/30 days operation
2004	Reactor outlet coolant temperature 950℃
2002	Safety demonstration test (Control rods withdrawal test)
2001	Reactor thermal power (30MW), Reactor outlet coolant temperature 850℃
1998	First criticality
1997	Construction
⟆	Application and permission of construction
1985	Detail design
	HTTR
1984	Basic design
⟆	System integrity design
1969	Conceptual design
	Experimental very high-temperature gas-cooled reactor for multipurpose

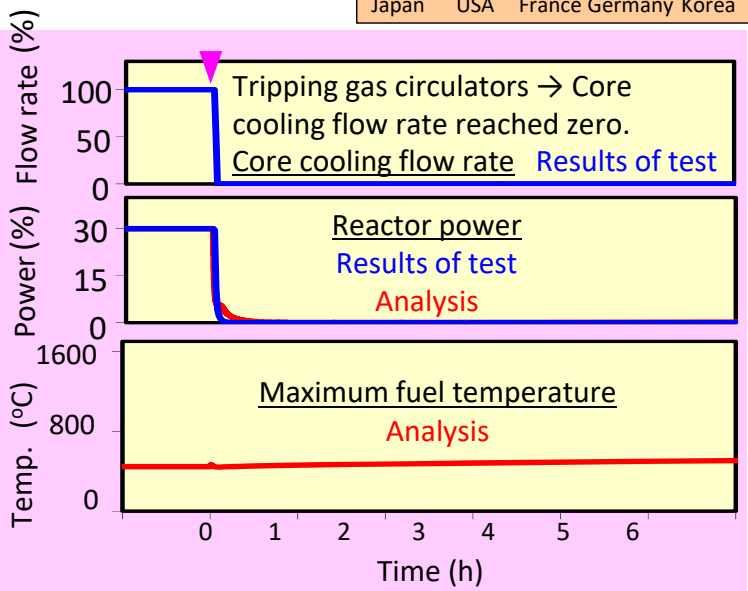
Construction of Reactor

Research and development
Conceptual design

Safety demonstration tests

OECD/NEA project

Japan USA France Germany Korea Czech Hungary



No CR reactivity control. No core cooling. Reactor is kept stable naturally with only physical phenomena.

Research and development

Fuel and Material

Oarai gas loop-1 (OGL-1)

Reactor physics

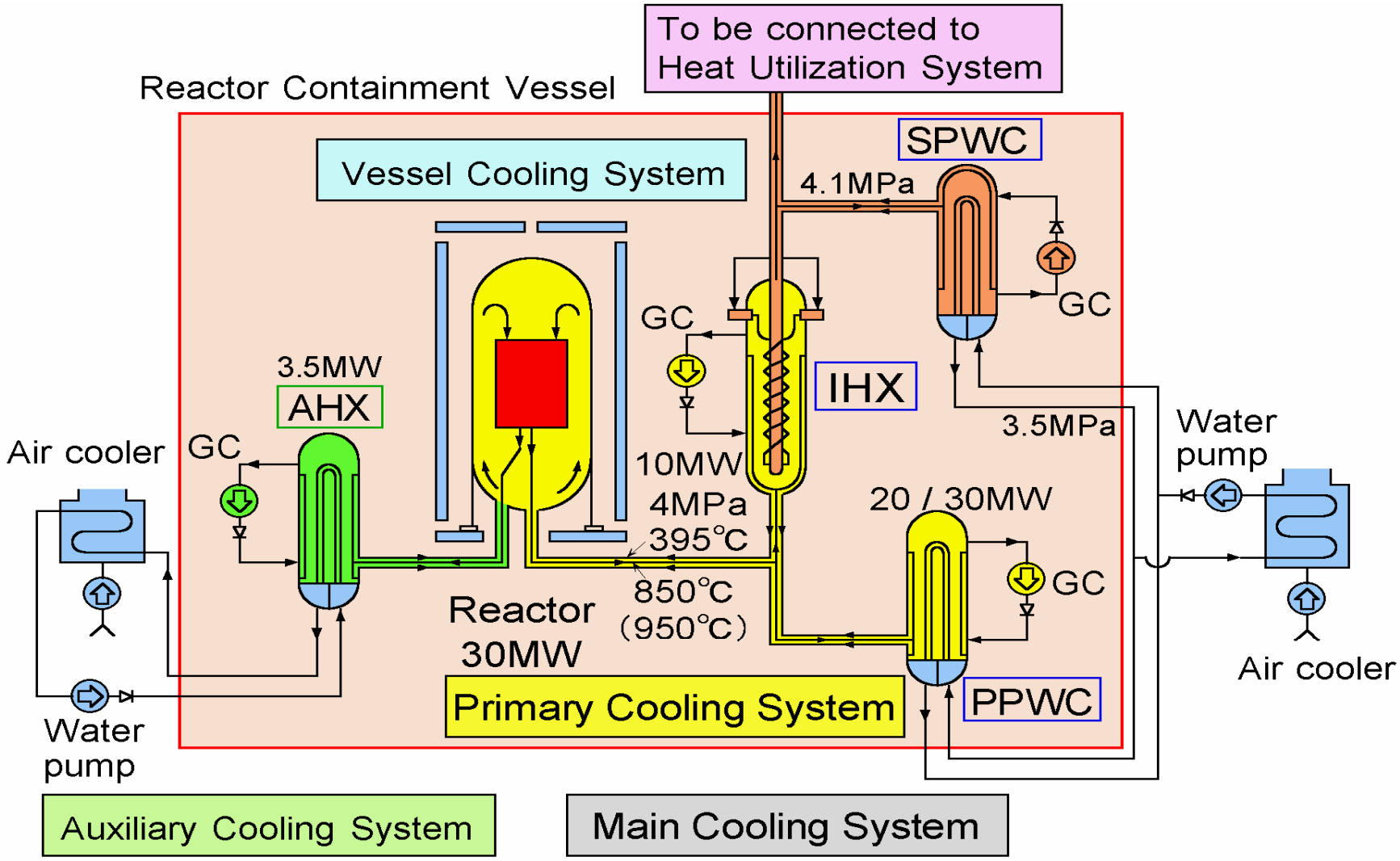
Very high temperature reactor critical assembly (VHTRC)

Thermal-Hydraulics

A helium engineering demonstration loop (HENDEL)

Contents

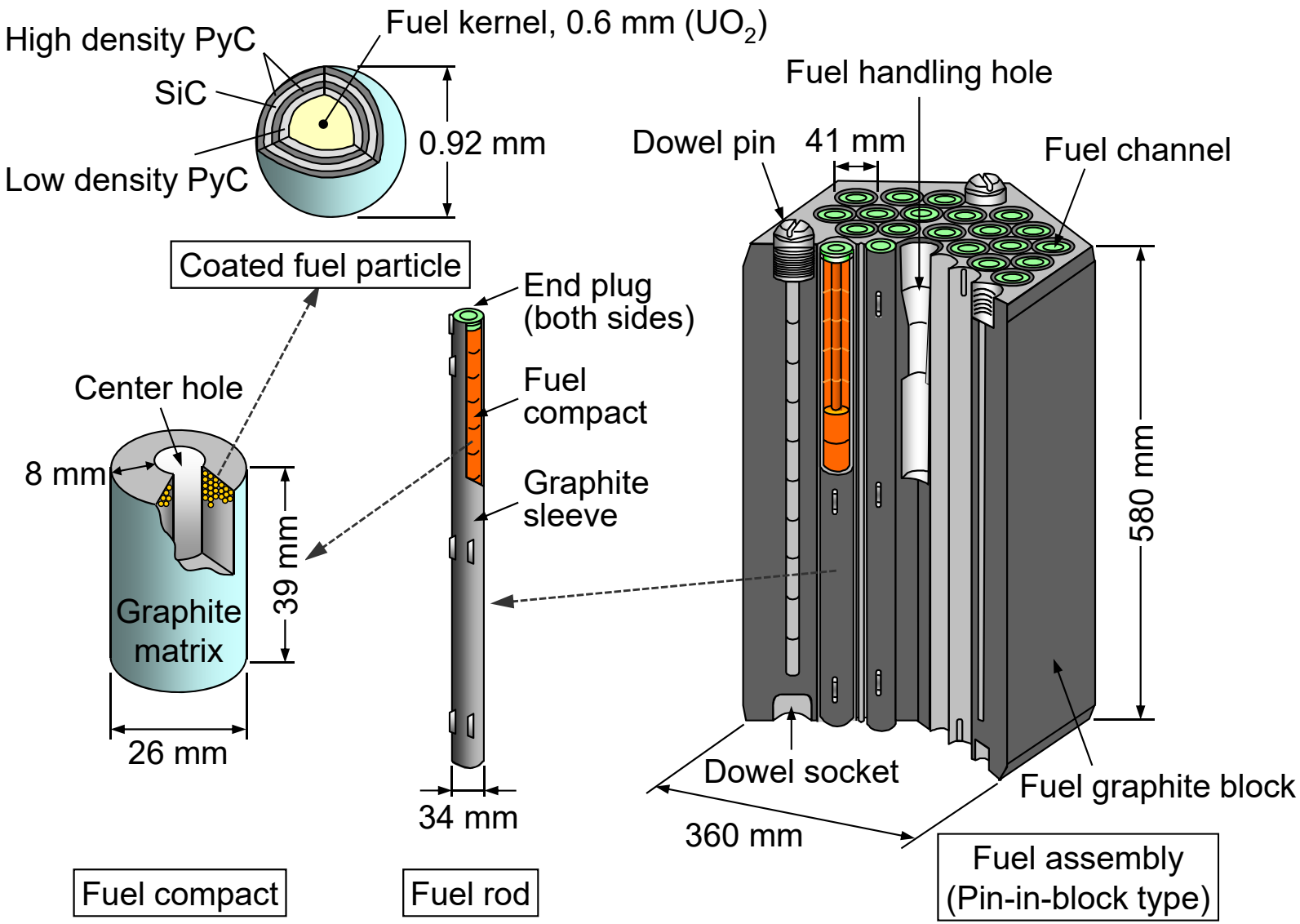
System Configuration



IHX : Intermediate heat exchanger
PPWC: Primary pressurized water cooler
SPWC: Secondary pressurized water cooler
AHX : Auxiliary heat exchanger

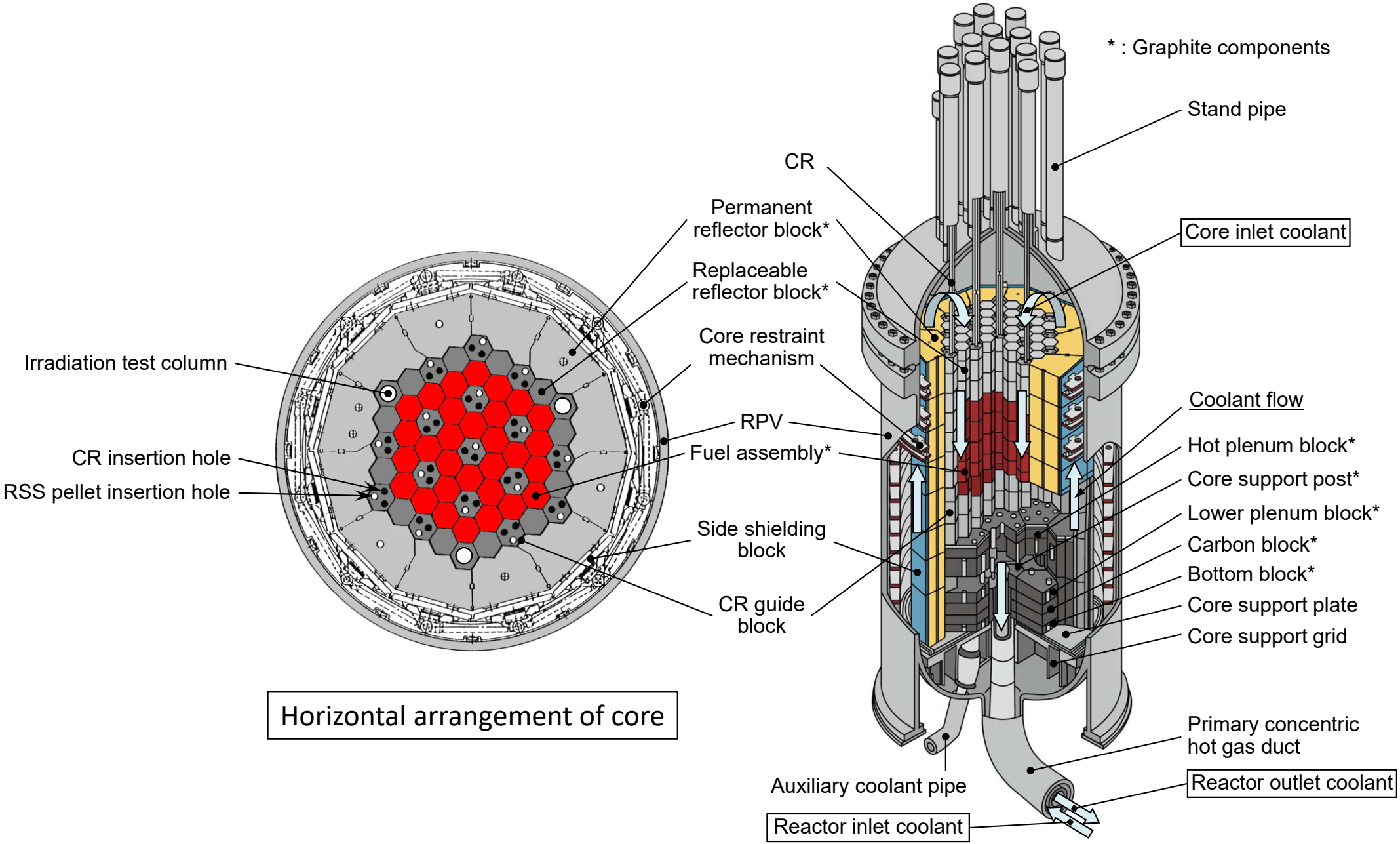
S. Saito et al., JAERI-1332 (1994).

Fuel Assembly



S. Saito et al., JAERI-1332 (1994).

Structure of HTTR Core



S. Saito et al., JAERI-1332 (1994).

Graphite in HTTR

	IG-110	PGX	ASR-0RB
Bulk density (Mg/m^3)	1.78	1.73	1.65
Mean tensile strength (MPa)*	25.3	8.1	6.8
Mean compressive strength (MPa)*	76.8	30.6	50.4
Young's modulus (GPa) ($\pm 1/3S_u$)**	7.9	6.5	8.7
Mean thermal expansion coefficient ($10^{-6}K$) (293～673K)	4.06	2.34	4.40
Thermal conductivity (W/m･K) (673K)	80	75	10
Ash (ppm)	Max. 100	Max. 7000	Max. 5000
Grain size (μm)	Mean 20	Max. 800	Max. 2000

* : at room temperature

** : Determined from the cord joining two points (one point is the one-third of the specified minimum tensile strength and the other is the one-third of the specified minimum compressive strength) on the stress-strain curve.

Contents

High Temperature Continuous Operation

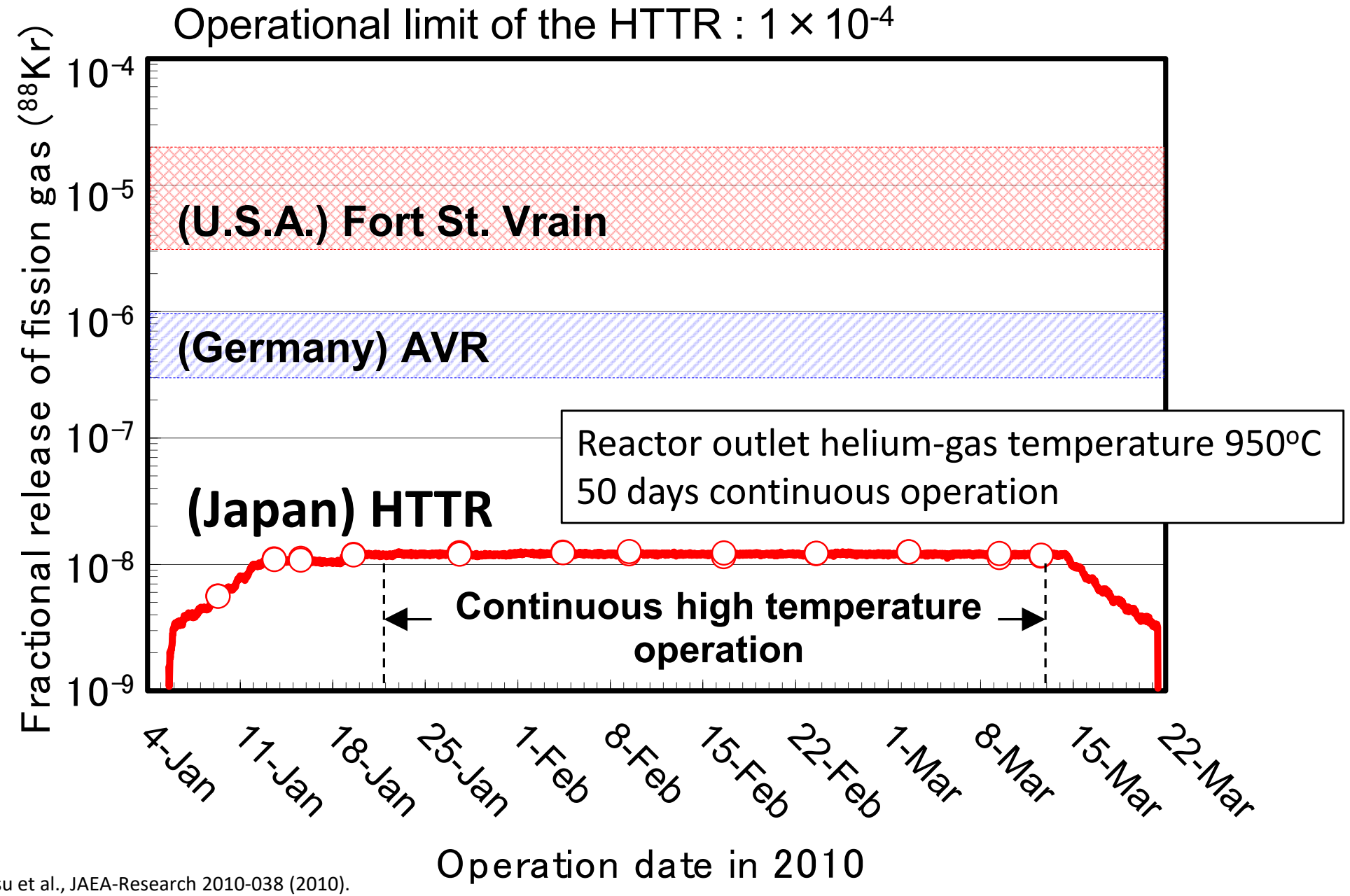
2010: Reactor outlet helium-gas temperature 950°C
50 days continuous operation

Purpose

- To establish fundamental technologies of HTGR
- To demonstrate stable heat supply to a future heat application system

- ✓ Evaluation of fuel performance (FP retention)
- ✓ Evaluation of core physics
- ✓ Evaluation of impurity control technology in helium coolant
- ✓ Evaluation of IHX performance
- ✓ Evaluation of structural integrity of components
- ✓ Accumulation of operation and maintenance technologies

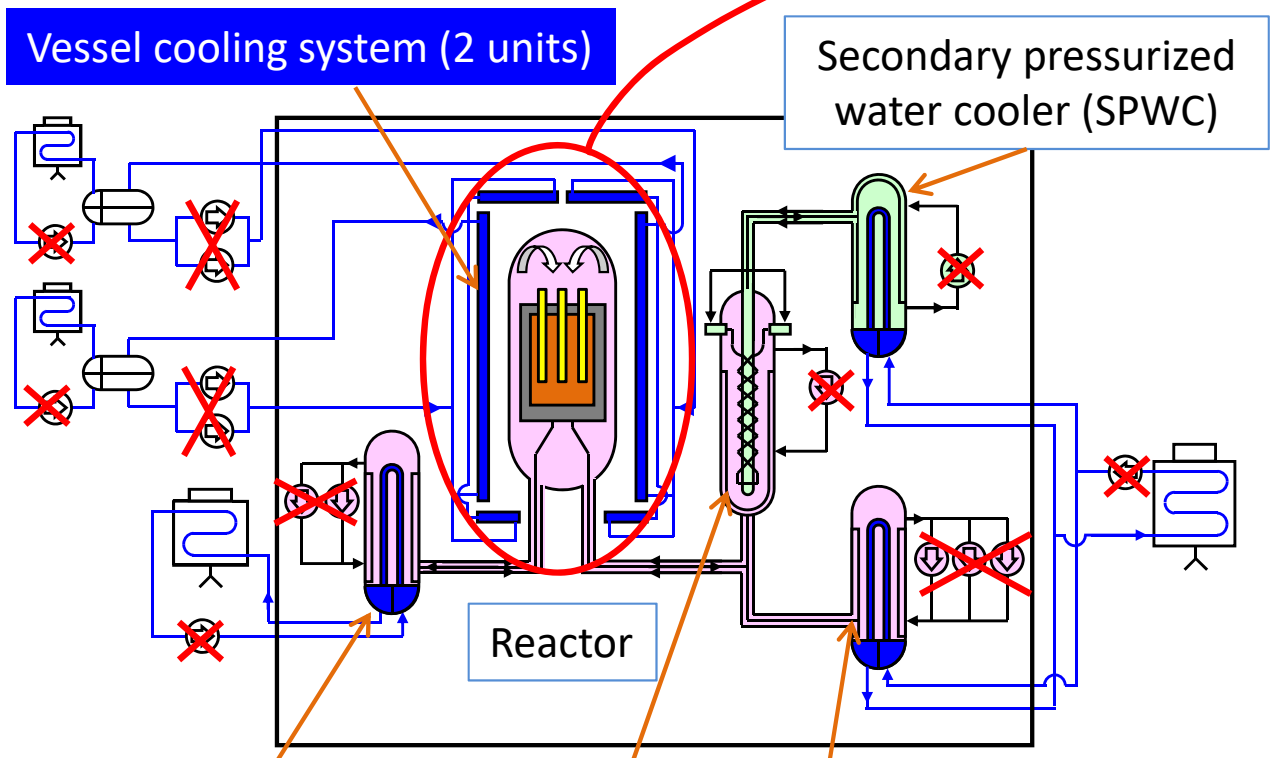
Fuel Performance in HTTR



K. Takamatsu et al., JAEA-Research 2010-038 (2010).

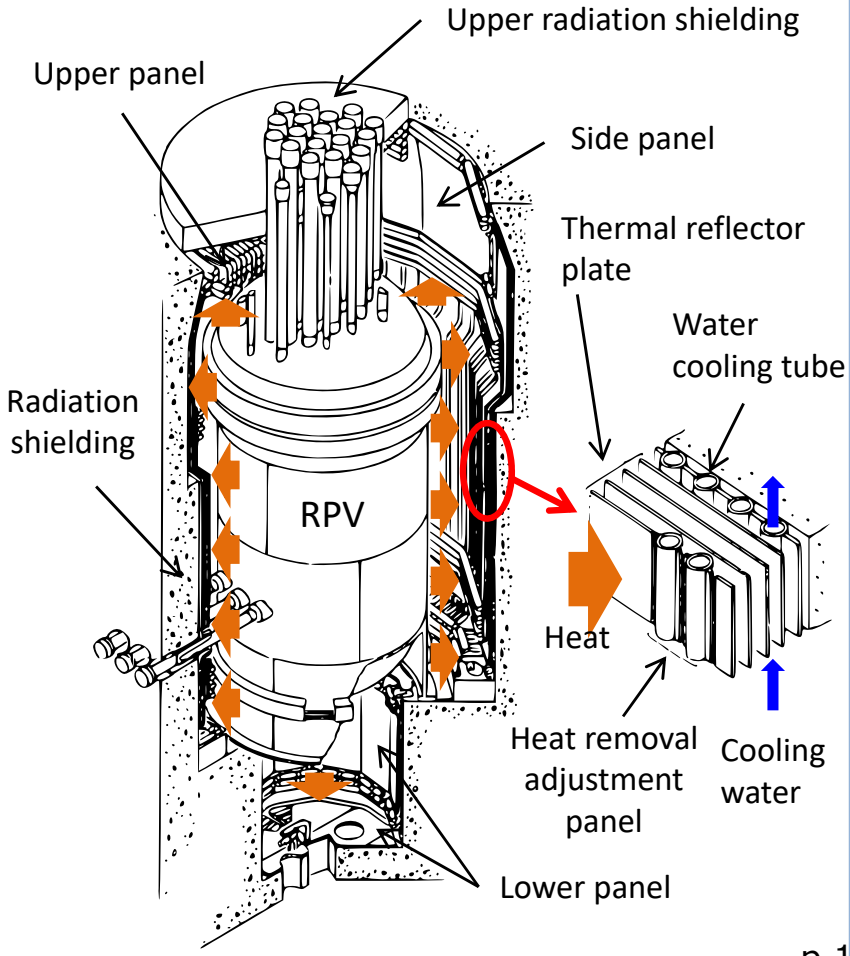
Loss of Forced Cooling Test

Loss of forced cooling (LOFC) & Loss of vessel cooling (LOVC) ➡ simulation of station blackout



Vessel cooling system (VCS)

Core is cooled from the outside by radiation and natural convection.



Loss of Forced Cooling Test

Loss of forced cooling test (LOCF test) : Stop of all circulators in primary circuit

Stop of all primary circulators
flow rate of primary coolant : 100% → 0%）

↓

Increase of reactor core temperature

↓

Decrease of reactor power due to negative reactivity feedback
（ resonance absorption of neutron in U^{238}）

↓

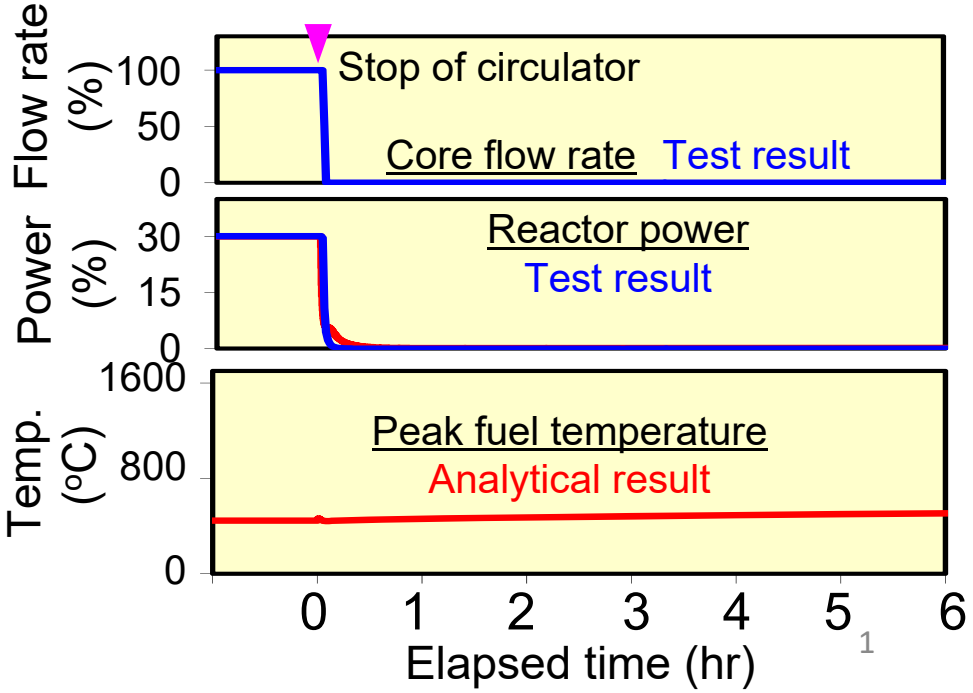
Reactor power and fuel temperature remain in stable condition

Test Date Dec.21, 2010

Test Condition

- Initial reactor power 30% (9MW)
- Without scram (no movement of CR)

Test Results



Ref) Leaflet of HTTR, JAEA.

Contents

Policies of HTGR Development in Japan

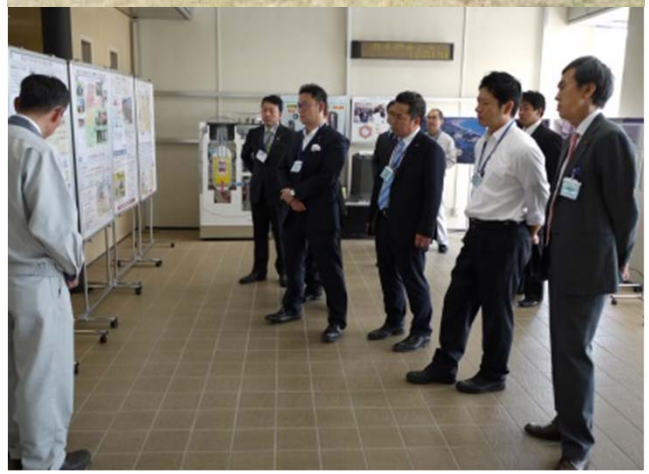
- **Technical development of HTGR is stated in the following policies approved by the Cabinet.**
  - "**Strategic Energy Plan**" approved by the Cabinet on **April 11, 2014**
    - ✓ Under international cooperation, government of Japan facilitates R&D of nuclear technologies that serve the safety improvement of nuclear use, such as high-temperature gas-cooled reactors which are expected to be utilized in various industries including hydrogen production and which has inherent safety."
  - **"Growth Strategy 2017"** approved by the Cabinet on **June 9, 2017.**
    - ✓ calls for future R&D concerning the HTGR development to be promoted using JAEA's HTGR test reactor and through international cooperation.
  - **"Strategic Roadmap of hydrogen and fuel cell"** issued by the committee in the METI on **June 23, 2014.**

METI : Ministry of Economy, Trade and Industry

Recent Topics of HTTR Project

- Following VIPs visited the HTTR.
  - **The Minister of the MEXT**, Hakubun Shimomura, on July 4, 2014.
  - The Parliamentary Vice-Minister of the MEXT, Tsutomu Tomioka, on August 6, 2014.
  - **The Minister Environment**, Nobuteru Ishihara and five members of the House of Representatives, Takeshi Noda et.al., on April 7, 2014.
  - A member of the House of Representatives, Taku Yamamoto, on April 25

They are all supportive of deployment and development of HTGR.



- **HTGR development supporting group** consisting of more than **40 LDP members** was made on July 19, 2014(*)
  - **The third meeting was held on June 14th, 2017.**
  - Thirteen LDP members of the HTGR development supporting group visited the HTTR site on October 13th, 2015.

LDP: Liberal Democratic Party of Japan
(*) currently about 50 members

Ongoing Activities under MEXT (1/2)

- **MEXT established a committee including MEXT, METI, JAEA, industries and universities to discuss roadmap and conceptual design for the first demonstration plant.**
  - A board member in industry participate in this forum.
  - Preparatory meeting was held on February 26, 2015, to discuss the vision of future commercial HTGR.
  - The first meeting was held on April 28, 2015.
    - Specification of commercial HTGR, R&D plan, introduction scenario will be discussed.
  - Total five meetings were held: 2015/4/28, 9/29, 2016/4/26, 6/23 and 2017/6/12.

Industry

Vendors
- Toshiba Corporation
- Hitachi, Ltd.
- Fuji Electric Co., Ltd.
- Mitsubishi Heavy Industries, Ltd.

Fuel/Graphite manufactures
- Nuclear Fuel Industries, Ltd.
- Toyo Tanso Co., Ltd.

Trading company/Think tank
- Marubeni Utility Services, Ltd.
- Canon Institute for Global Studies

Users (Electricity/Hydrogen/Heat Utilization)
- Nippon Steel & Sumitomo Metal Corporation
- Iwatani Corporation
- Chiyoda Corporation
- Toyo Engineering Corporation
- JGC Corporation
- Hitachi Zosen Corporation

- Toyota Motor Corporation
- Nissan Motor Co., Ltd.
- Honda R&D Co.,Ltd.

Academy
- University of Tokyo
- Tokyo Institute of Technology
- Tokyo City University
- Toyo University of Agriculture and Technology
- Kyushu University

Government
- Ministry of Education, Culture, Sports, Science and Technology (MEXT)
- Japan Atomic Energy Agency (JAEA)

Observer: Japan Electrical Manufacturers Association, Japan Atomic Power Company, Institute of Applied Energy, Ministry of Economy, Trade and Industry (METI)

Ongoing Activities under MEXT (2/2)

- **The committee established a working group including MEXT, JAEA, industries and universities to discuss overseas deployment strategy for domestic HTGR technologies.**
  - ➢ Major industrial companies participated in the HTTR construction joined in this WG.
  - ➢ The first meeting was held on August 9, 2017.
    - ➢ Organizational structure and strategy for exporting domestic products and technologies to foreign countries were discussed.
  - ➢ Total two meetings were held: 2017/8/9 and 8/31.

Industry

Vendors

Toshiba Corporation
Hitachi, Ltd.
Fuji Electric Co., Ltd.
Mitsubishi Heavy Industries, Ltd.
IHI Corporation

Fuel/Graphite manufactures

Nuclear Fuel Industries, Ltd.
Toyo Tanso Co., Ltd.

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Iwatani Corporation
Chiyoda Corporation
Toyo Engineering Corporation
JGC Corporation
Hitachi Zosen Corporation

Toyota Motor Corporation

Academy

University of Tokyo
Tokyo Institute of Technology
Toyo University of Agriculture and Technology

Government

Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Institute of Applied Energy
Japan Electrical Manufacturers Association
Japan Atomic Energy Agency (JAEA)

Overview of HTGR and Heat Application Technologies

(1) Reactor technology

- Reactor outlet coolant temperature 950°C at 30 MWt (April 2004)
- 950°C / 50 days operation (March 2010)

- Advanced fuel development
- HTTR tests for HTGR safety enhancement
- Safety review by NRA is underway

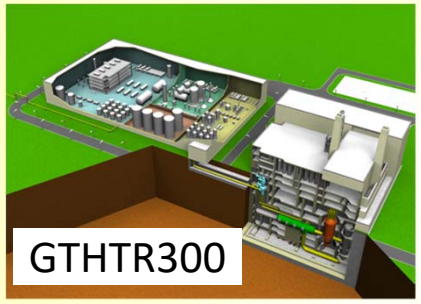
(2) Heat application technologies

He compressor

Hydrogen facility

- Completion of basic technologies related to hydrogen production facility and gas turbine power generation
- Establishment of operation control technology and facility reliability for IS process
- 31 hrs. hydrogen production with 0.02m^3/h (October 2016)

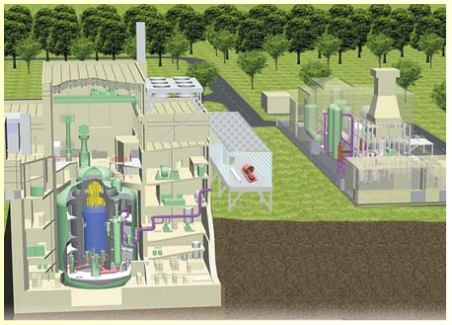
(3) Commercial HTGR design



- Design study of commercial HTGR systems
- Core design of plutonium burning HTGR

- Establishment of safety design philosophy and international standardization for commercial HTGRs

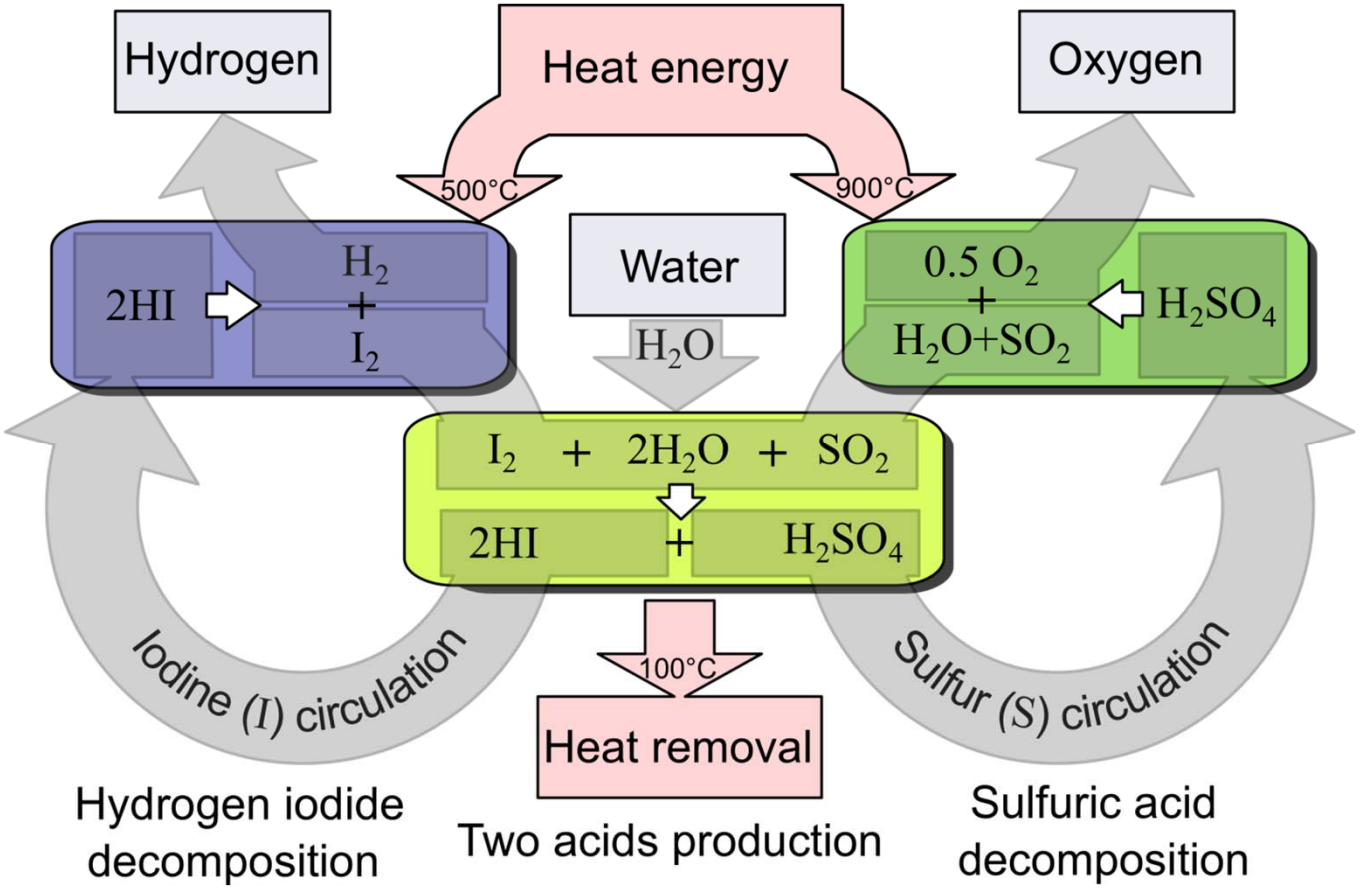
(4) HTTR-GT/H_2 test



- Coupling to HTTR
- Licensing demonstration
- Plant performance test

- Integrated demonstration of HTGR heat application system technologies

Iodine-sulfur (Sulfur-iodine) process

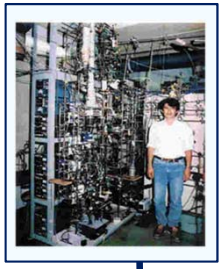


- ✓ Widely investigated in the world
  (Japan, USA, France, Korea, China….)
- ✓ Lab-scale integrated cycle was demonstrated

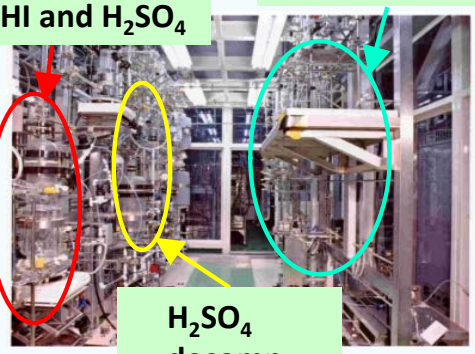
- ✓ Number of reaction: 3
- ✓ Number of element: 4
- ✓ Maximum temperature: 900°C
- ✓ Full liquid/gas phase operation
- ✓ Not including electrochemical reaction (May use electricity in concentration of HI)

H_2 Production Technology Development

Lab-scale test
validation of closed cycle theory (1997)



Bench-scale test (199-2004)



Demonstration of one-week continuous hydrogen production by glass apparatus (0.03 m^3/h-H_2)

Elemental technologies (2005-2009)

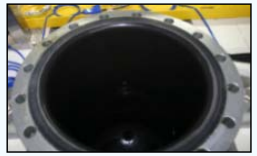
2000

Present

Industrial material component test (2010-)

H_2SO_4 reactor (~900°C)

HI reactor (~500°C)



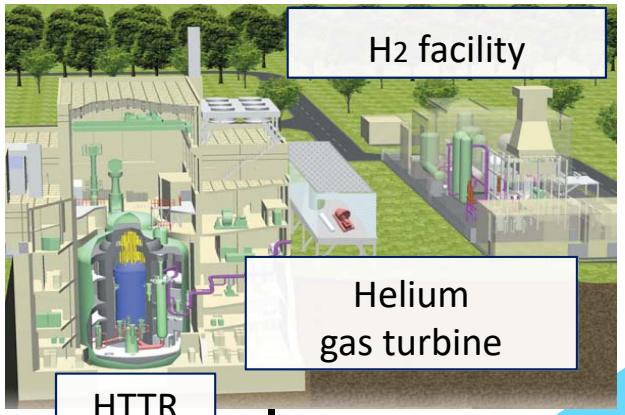
Bunsen reactor (~100°C)

Integrity of key components in the IS process environment (corrosion resistance, heat resistance)

H_2 production test facility (0.1 m^3/h-H_2)

- Verification of reliability and long-term stability
- Development of HI concentration technology and strength evaluation methodology for ceramic components

HTTR-GT/H_2 test



Establishment of basic technologies

Technology transfer to private company

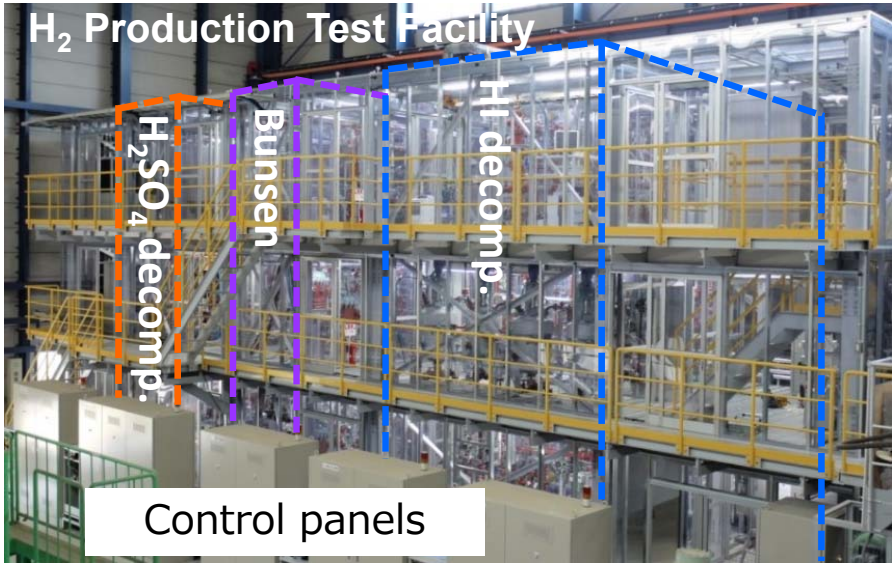
Commercial use

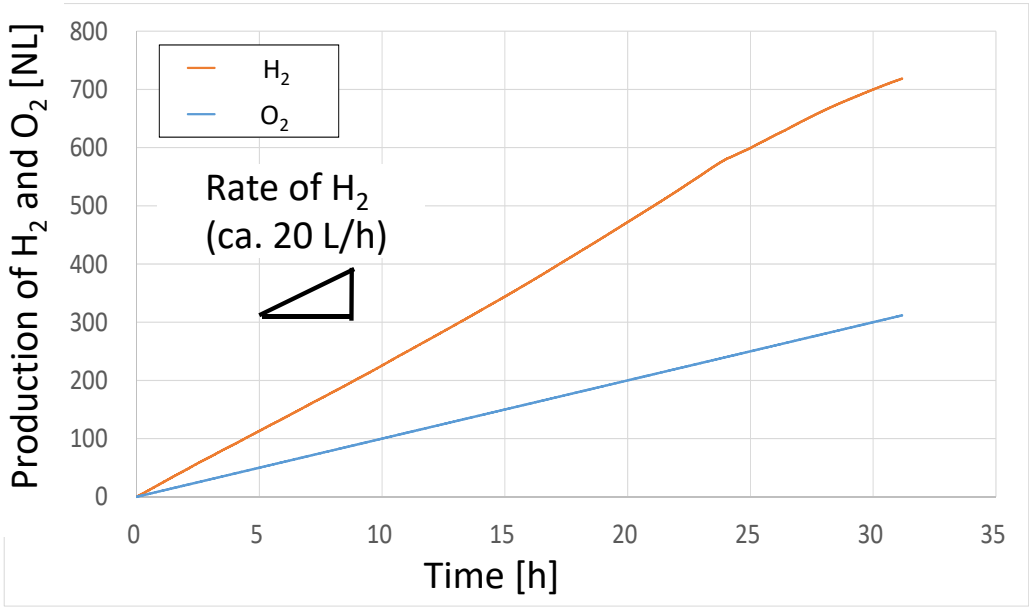
Recent Achievement in H_2 Production Technology

- Integrated 3 sections of IS process
  - ✓ HI decomposition section
  - ✓ H_2SO_4 decomposition section
  - ✓ Bunsen reaction

- First operation : Feb. 16-17 (2016)
  - ✓ Hydrogen production rate of ca. 10 L/h for 8 hours

- Second operation : Oct.24-26 (2016)
  - ✓ Hydrogen production rate of ca. 20 L/h for 31 hours.





Helium Gas Turbine Technology Development

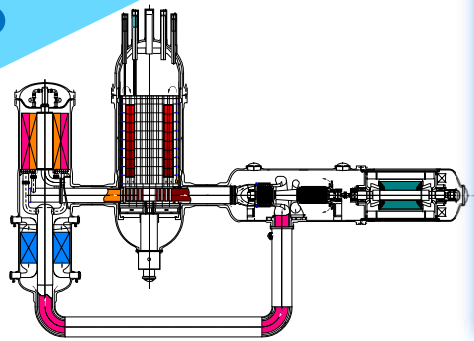
GTHTR300 basic design and component development (2001-)

Collaborative work with MHI

- Plant basic design, safety design and cost estimation according to users' request
- Development of high-efficiency helium compressor, compact heat exchanger and turbine blade alloy

World's first successfully operated high-efficient axial helium compressor and validated helium compressor design method

Conceptual design of GTHTR300 power generation system (1998-2001)



Present

GTHTR300 commercial lead plant by private companies

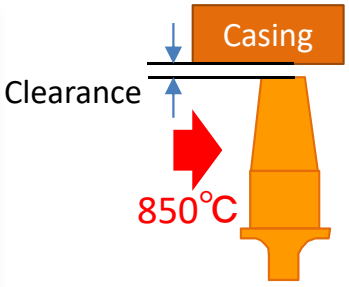
- 850°C reactor outlet temp.
- 125 MWe electric power
- Enable electric power improvement to 300 MWe without design change

Improvement of power

HTTR-GT power generation system

Hot function test of full-size turbine disc at high temperature

- Confirmation of clearance between turbine disc and casing

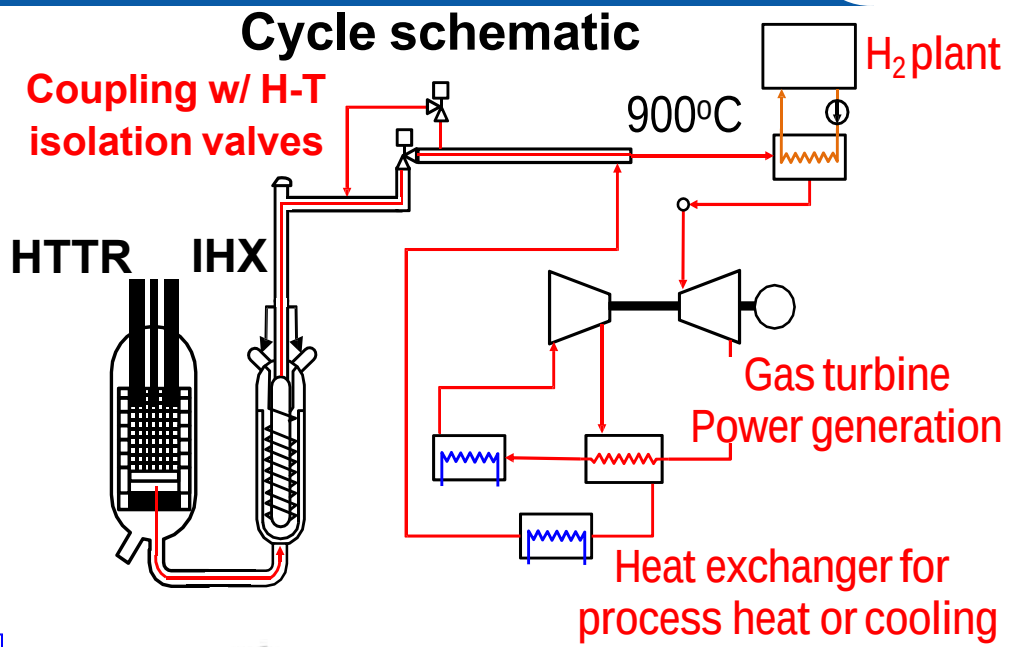


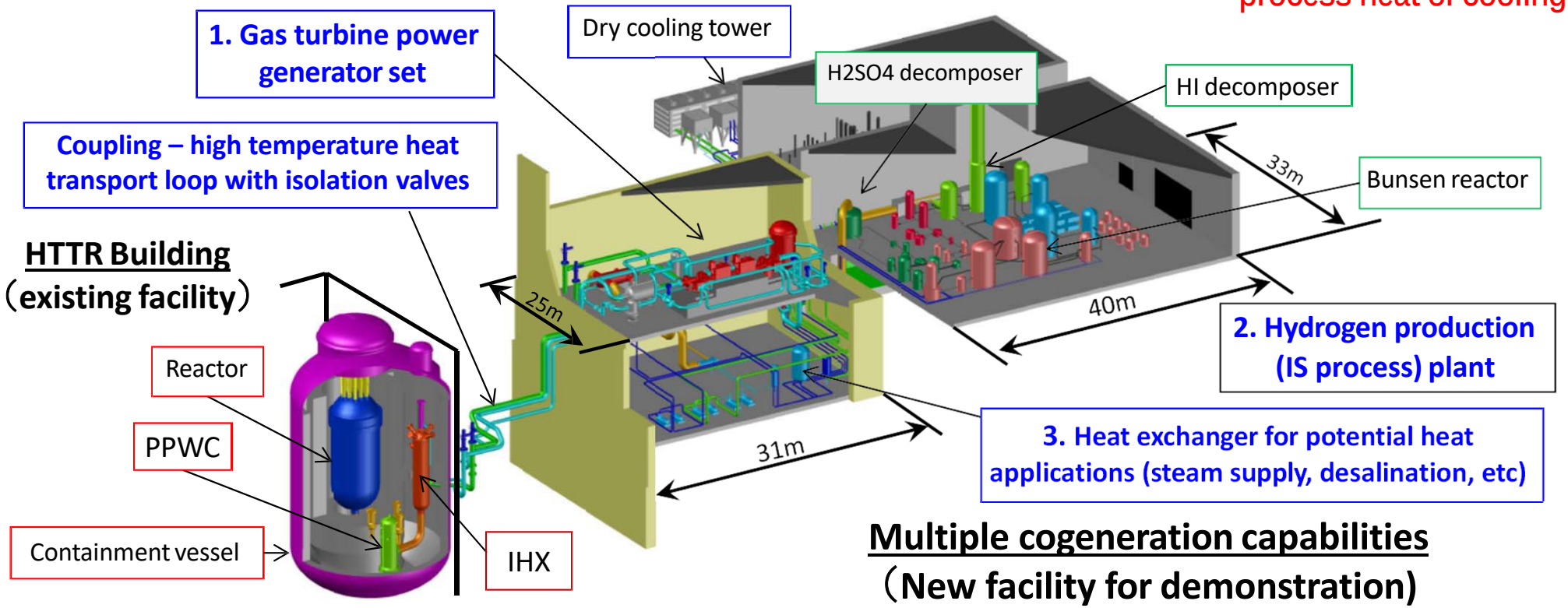
Single turbine disc

Flexible cogeneration test plan on HTTR (@ 950°C)

Plant design completed in 2017

HTTR reactor power/temperature	30 MWt/950°C
IHX thermal power/temperature	10 MWt/900°C
IHX heat supply temperature	900 °C
Gas turbine power generation	1 MWe
Hydrogen production	30 Nm³/h
Heat (steam, desalination, etc)	3 MWt





Multiple cogeneration capabilities
(New facility for demonstration)

Tank you for your attention.