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Core Characteristic and Thermal Hydraulic aspect of Prismatic

2026/5/20

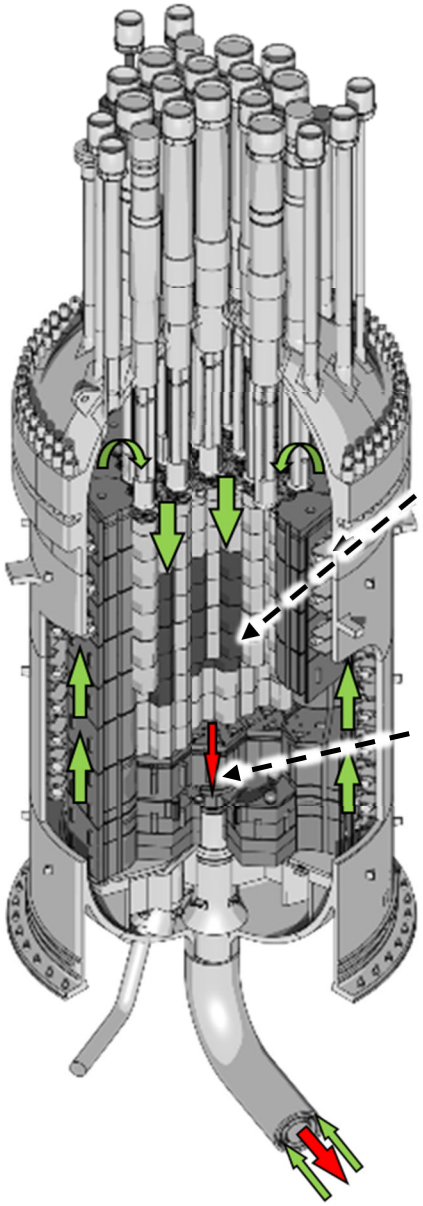
Department of HTTR

Oarai Nuclear Engineering Institute

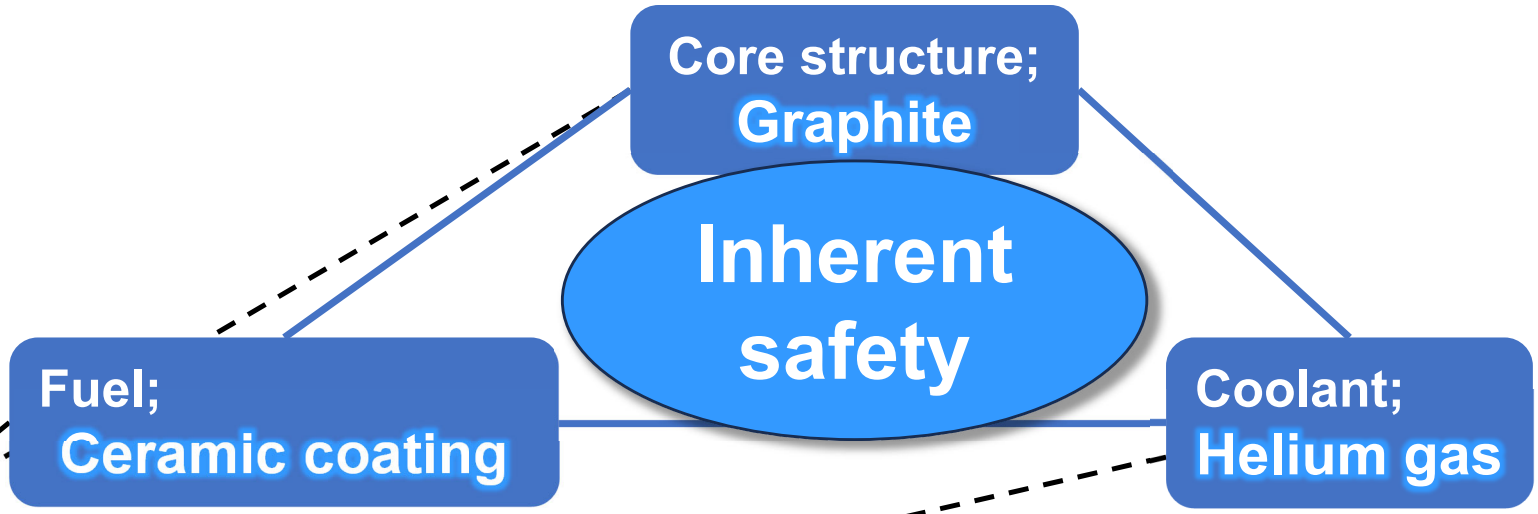
Japan Atomic Energy Agency

What is HTGR?

➢ HTGR; **H**igh **T**emperature **G**as-cooled **R**eactor



Prismatic type HTGR

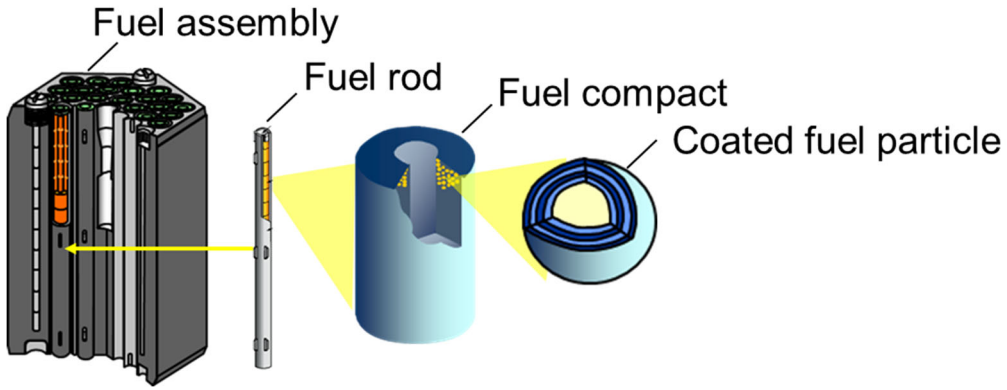


	HTGR	LWR
Electric power (Thermal power)	~300 MW (~600 MW)	1000 MW (3000 MW)
coolant temperature	850ºC~950 ºC	About 300 ºC
Coolant	Helium gas	Light water
Moderator	Graphite	Light water
Fuel	Ceramic coated fuel particle	Zircalloy fuel cladding
Applications	Heat utilization and Electric power generation	Electric power generation
Turbine	Helium gas turbine	Steam turbine

Prismatic and Pebble-bed

➢ **Prismatic type HTGR ⟵ Focusing on in this lecture**

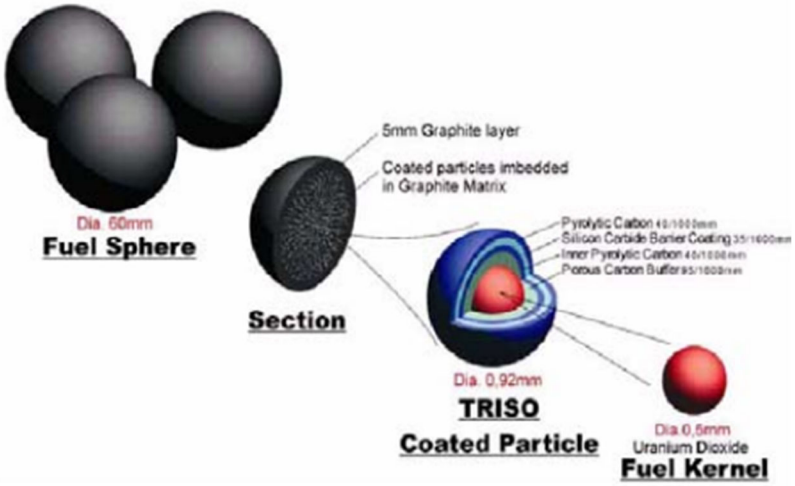
- TRISO coated fuel particle.
- Fuel blocks are assembled in the reactor core.
- Reactor outlet coolant temperature of 950 ℃.
- HTTR (test reactor) is under operation in Japan.



Fuel components of prismatic type

➢ **Pebble-bed type HTGR**

- TRISO coated fuel particle.
- Fuel sphere (pebble) can be loaded into the core during the operation.
- Demonstration reactor is under operation in China*. (HTR-PM, Power output: 210 MWe)
- HTR-PM600S is under development in China*. (one turbine rated at 650 MWe driven by six reactor modules)



Fuel components of pebble-bed type

*Reference: https://www.world-nuclear-news.org (2026/5/11)

"High Temperature Gas Cooled Reactor Fuels and Materials", IAEA-TECDOC-1645.

Characteristics of HTGR (1/2)

Superior inherent safety features

- After the Tokyo Electric Power Company Fukushima-Daiichi Nuclear Power Station accident in 2011, higher safety of nuclear plant is required.
- HTGR can be designed to prevent core meltdown.

Ceramic fuel coating

Retain radioactive material at 1600 ºC

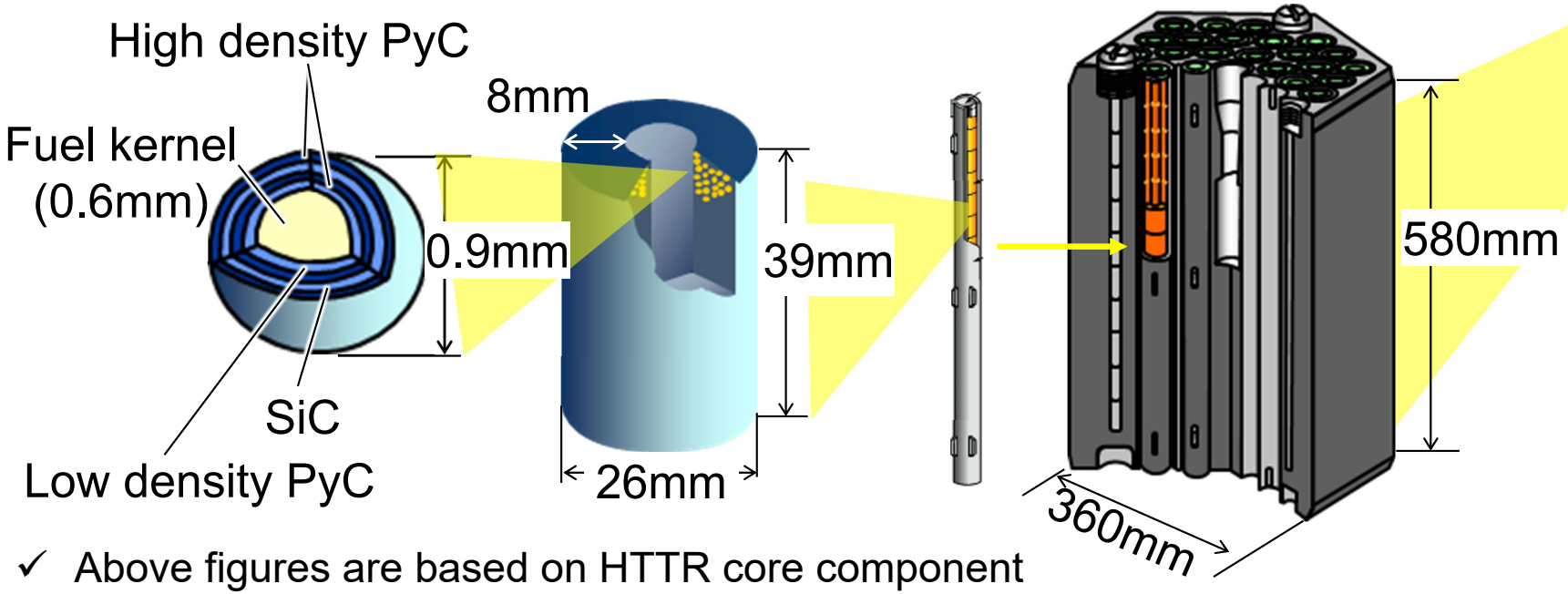
Helium coolant

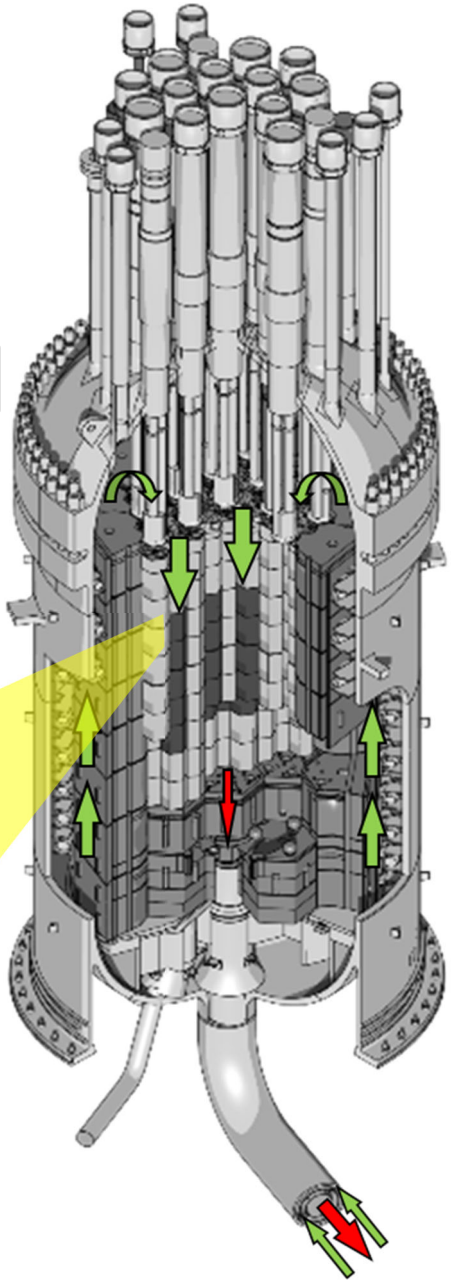
Stable at high temperature

Graphite core structure

Temperature limit: 2500 ºC

Coated fuel particle | **Fuel compact** | **Fuel rod** | **Fuel assembly**





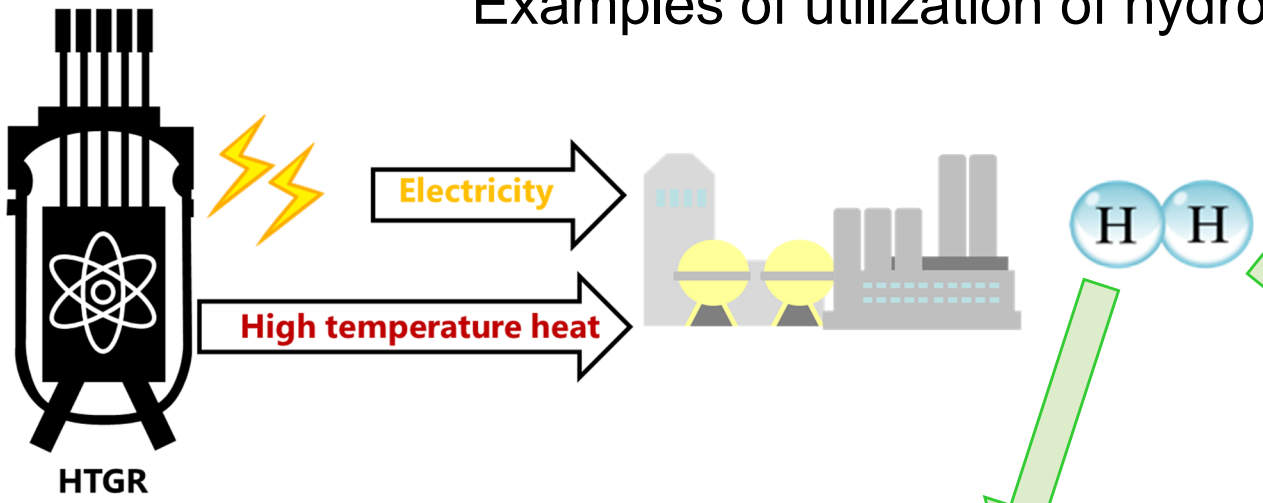
✓ Above figures are based on HTTR core component

Characteristics of HTGR (2/2)

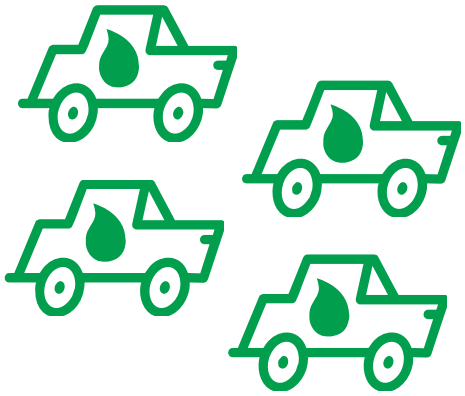
Great versatilities in applications

HTGR can supply high temperature heat above 900 ℃ and provide for great versatility in the applications including H_2 production, power generation, desalination, etc.

Examples of utilization of hydrogen from HTGR

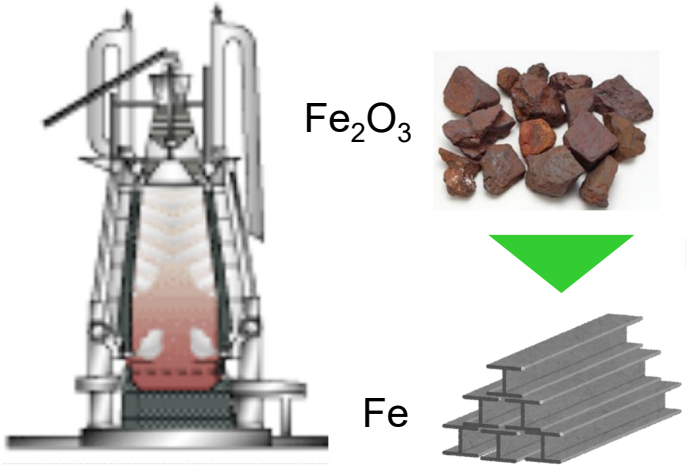


✓ Fuel Cell Vehicle



Fuel milage: 152 km/kg-H_2
Annual travel distance: 10,000km
Annual H_2 consumption：Approx. 730m^3/unit
One unit of HTGR* （250MW$_{th}$） can provide H_2 for 300,000 FCVs
(*H_2 production efficiency 50%, plant availability 80%)

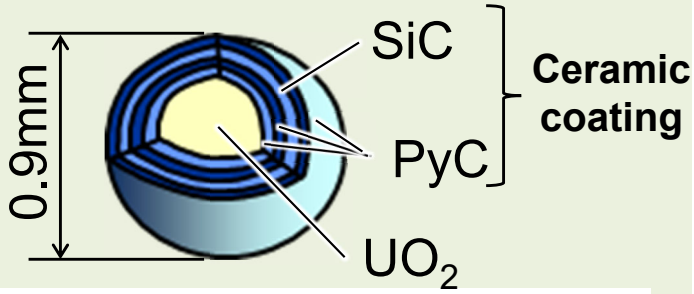
✓ H_2 reduction steel production

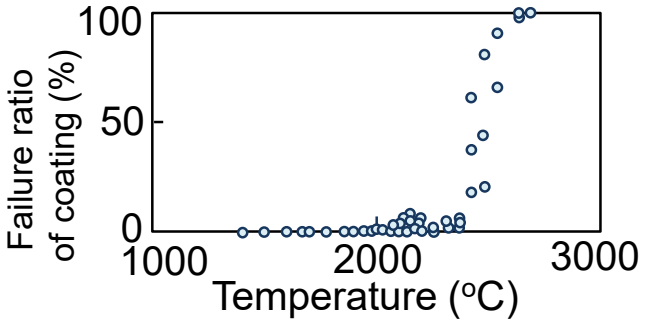


Inherent safety features of HTGR

Ceramic coated fuel particle

- High heat-resistance

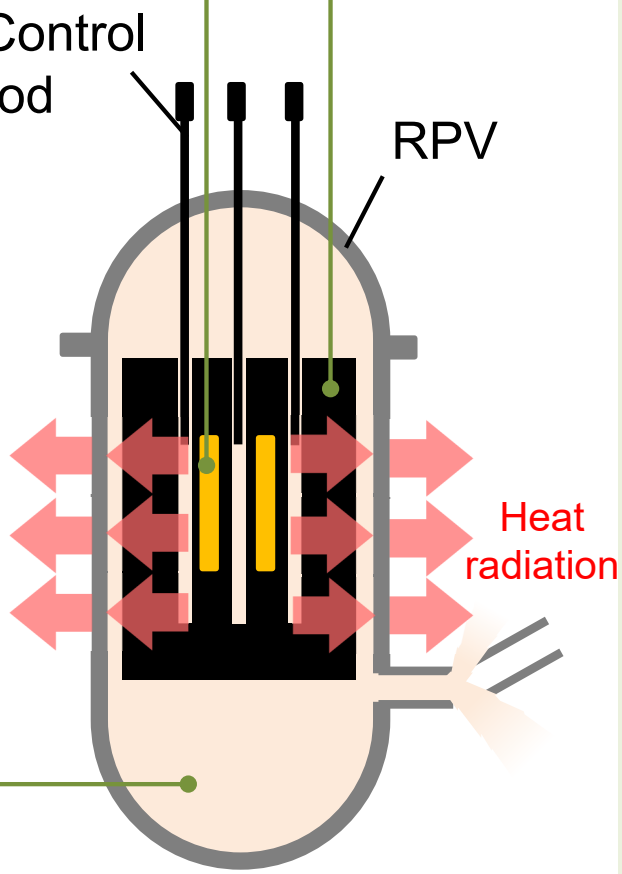




Experimental result for heated fuel particle

Helium coolant

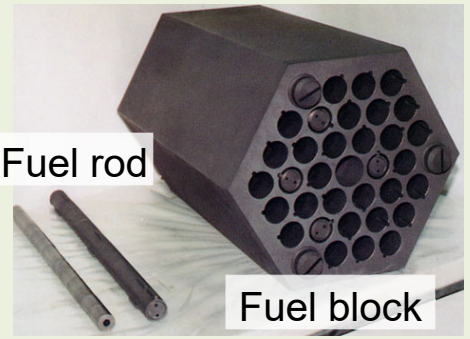
- No explosions of H_2 and vapor due to chemical inertness and phase change inability

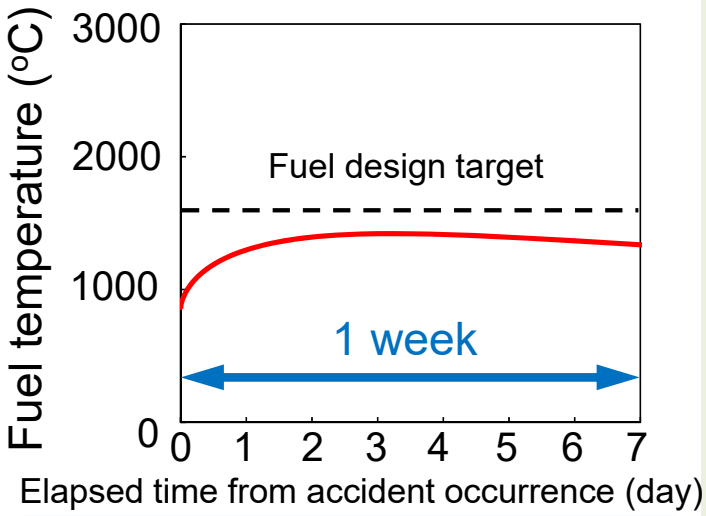


Reactor is safely shutdown and cooled by passive design features without reliance on any equipment or operator actions in the event of loss of coolant.

Graphite moderator

- Capable to remove heat passively from RPV outside due to high heat capacity and large thermal conductivity

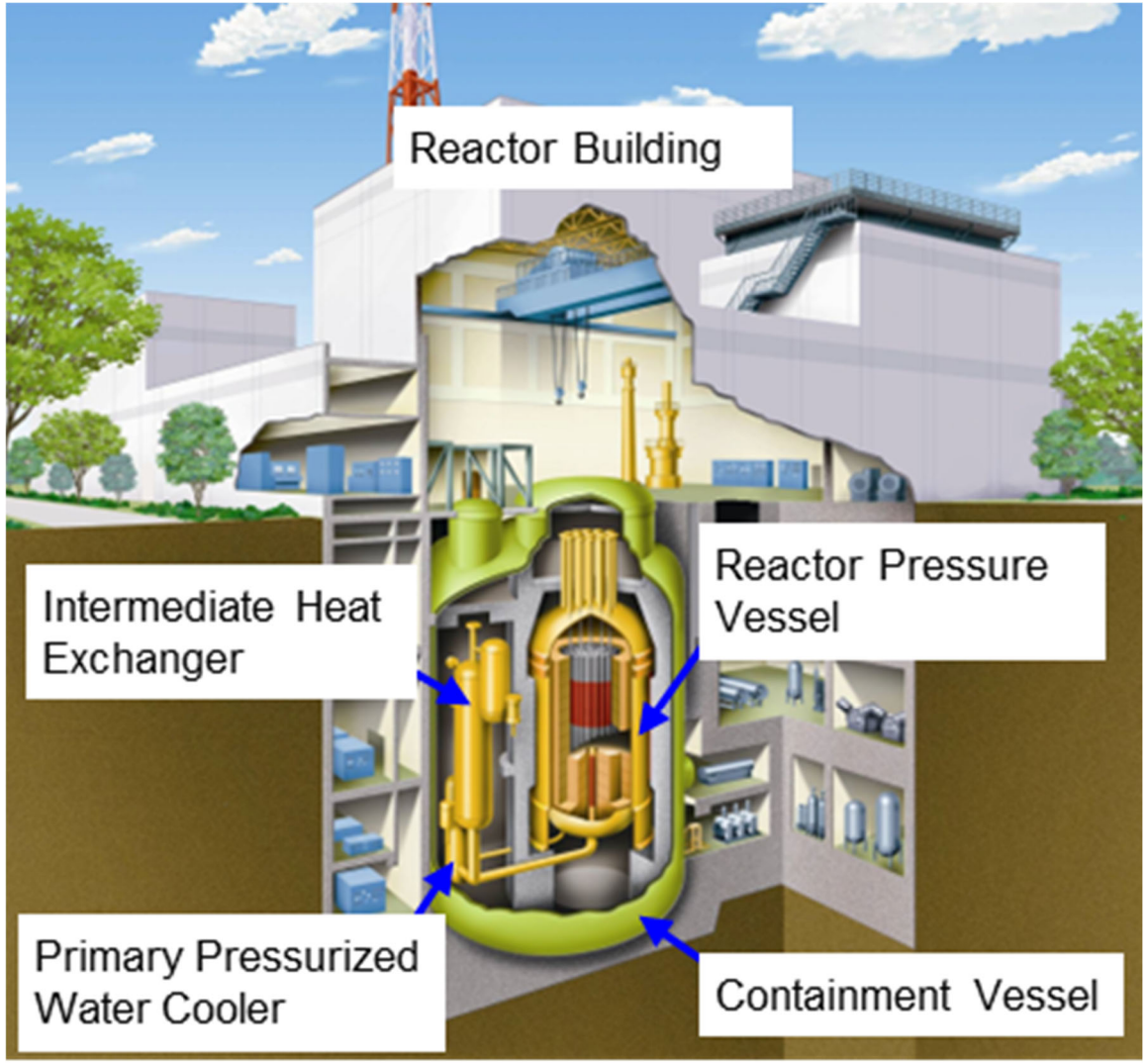




Fuel temperature during loss-of-coolant accident (Simulation result)

HTTR (High Temperature engineering Test Reactor)

- HTTR is the first and only one HTGR in Japan



- Type ····· Prismatic
- Reactor thermal power ··· 30 MW
- Coolant ····· Helium gas
- Inlet / Outlet coolant temperature ····· 395 / 850, 950ºC
- Core material ····· Graphite
- Fuel ····· UO_2
- Uranium enrichment ···· 3 - 10% (average 6%)

Japanese domestic technology developed through the HTTR design, construction and operation

- Experiences of HTTR design, construction, operation
  (MHI, Toshiba/IHI, Hitachi, Fuji Electric, KHI, etc.)

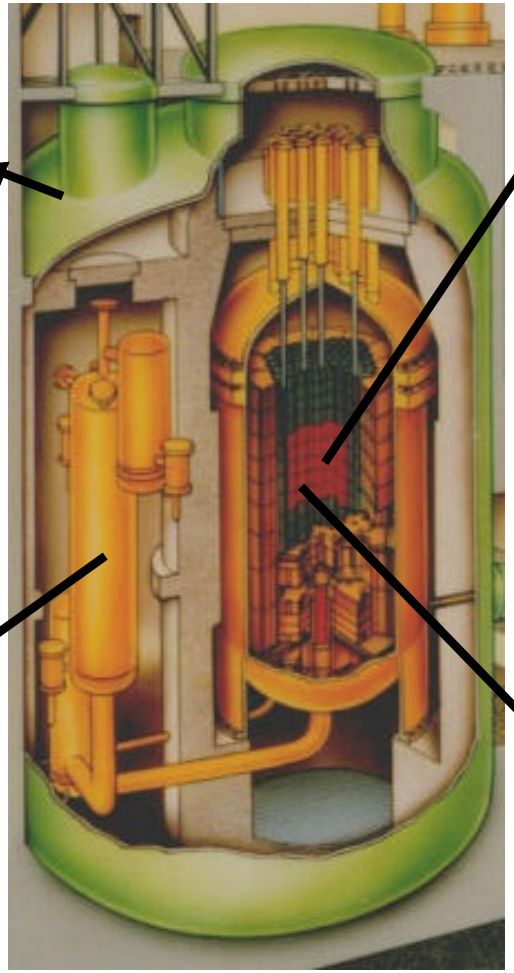
A lot of technical data of HTTR was accumulated.
Optimum design of commercial HTGR can be conducted by only Japanese technology.

- High temperature resistant metal, Hastelloy XR
  (Mitsubishi material)

Intermediate Heat Exchanger (IHX)

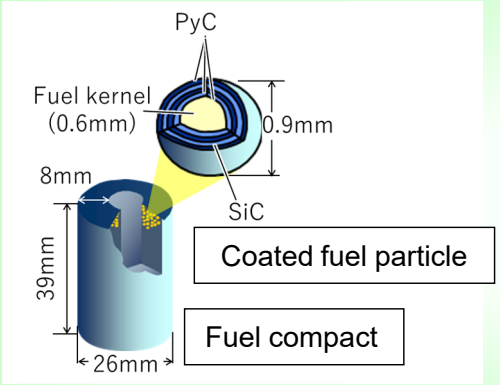
Hastelloy XR is applicable at 950°C as the nuclear structural material .

IHX can deliver hot helium gas at 950°C to outside the reactor pressure vessel.



Constructed by domestic technology

- Fuel (Nuclear Fuel Industry)

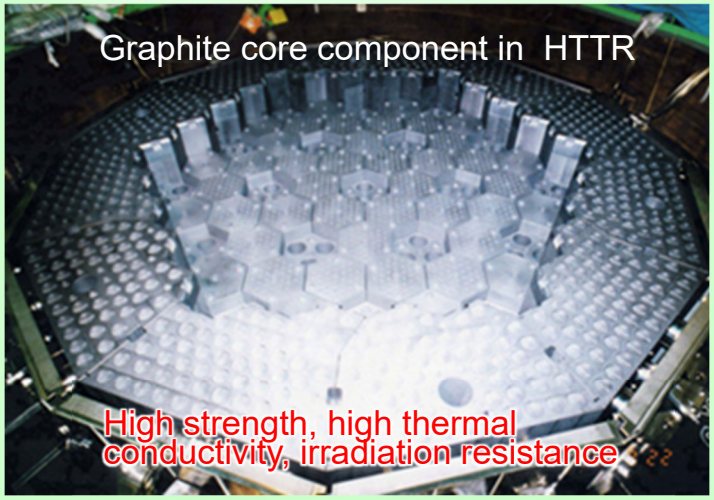


Ceramics coating layer retains fission products inside the coated fuel particle at extreme low leak level.

Ceramics coating is stable for long-term.
(3 times higher burnup than LWR)

- Graphite, IG-110 (Toyo tanso)

World highest quality graphite
(isotropic, high density)



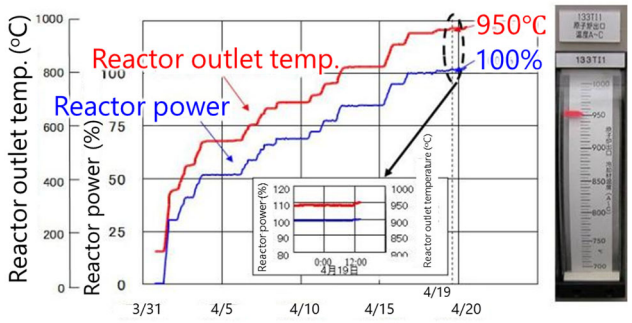
History of HTTR

High temperature engineering test reactor
HTTR

Purpose

- ☐ Establishment of HTGR technology
- ☐ Establishment of Heat utilisation technology

First in the world



HTTR heat application test and HTGR demonstration reactor

Establishment of fundamental technology

2024	**Thermal load fluctuation test**
	Safety demonstration test (Loss of core flow test at full power)
2022	Safety demonstration test (Loss of core cooling test at 9 MWt)
2021	**Restart of HTTR**
2020	Permission of changes to reactor installation in conformity to new Regulatory Requirements
2014	Start of conformity review on new Regulatory Requirements
2010	Safety demonstration test (Loss of core flow test at 9 MWt)
	950°C/ 50 days operation
2007	850°C/ 30 days operation
2004	Reactor outlet coolant temperature 950°C
2002	Safety demonstration test (Control Rod drawing test)
2001	Reactor outlet coolant temperature 850°C (30MWt)
1998	First criticality
1997 ~ 1991	Construction
1990 ~ 1989	Application and permission of construction
1988 ~ 1985	Detail design
	H T T R
1984 ~ 1981	Basic design
1980 ~ 1974	System integrity design
1973 ~ 1969	Conceptual design
	Experimental Multi-Purpose Very High-Temperature Reactor

Construction of Reactor

Research development and design

HTTR restarted in July 2021 and completed conformity to the new regulatory requirements in September 2021.

HTTR has no possibility of the severe accident

- ➢ Core melt is precluded.
- ➢ The evacuation of inhabitants is not necessary at the accidents. *

※ Except for the case of natural phenomenon to be far beyond the safety design and the terrorism to destroy the confinement function of radioactive materials.

Specification of HTTR

- Reactor thermal power ··· 30 MW
- Reactor coolant ····· Helium gas
- Reactor inlet/outlet coolant temperature ····· 395/850, 950°C
- Reactor material ····· Graphite
- Fuel ····· UO_2
- Uranium enrichment ····· 3 - 10% (average 6%)

Research and Development

Fuels・Materials

In-pile Helium loop (OGL-1)

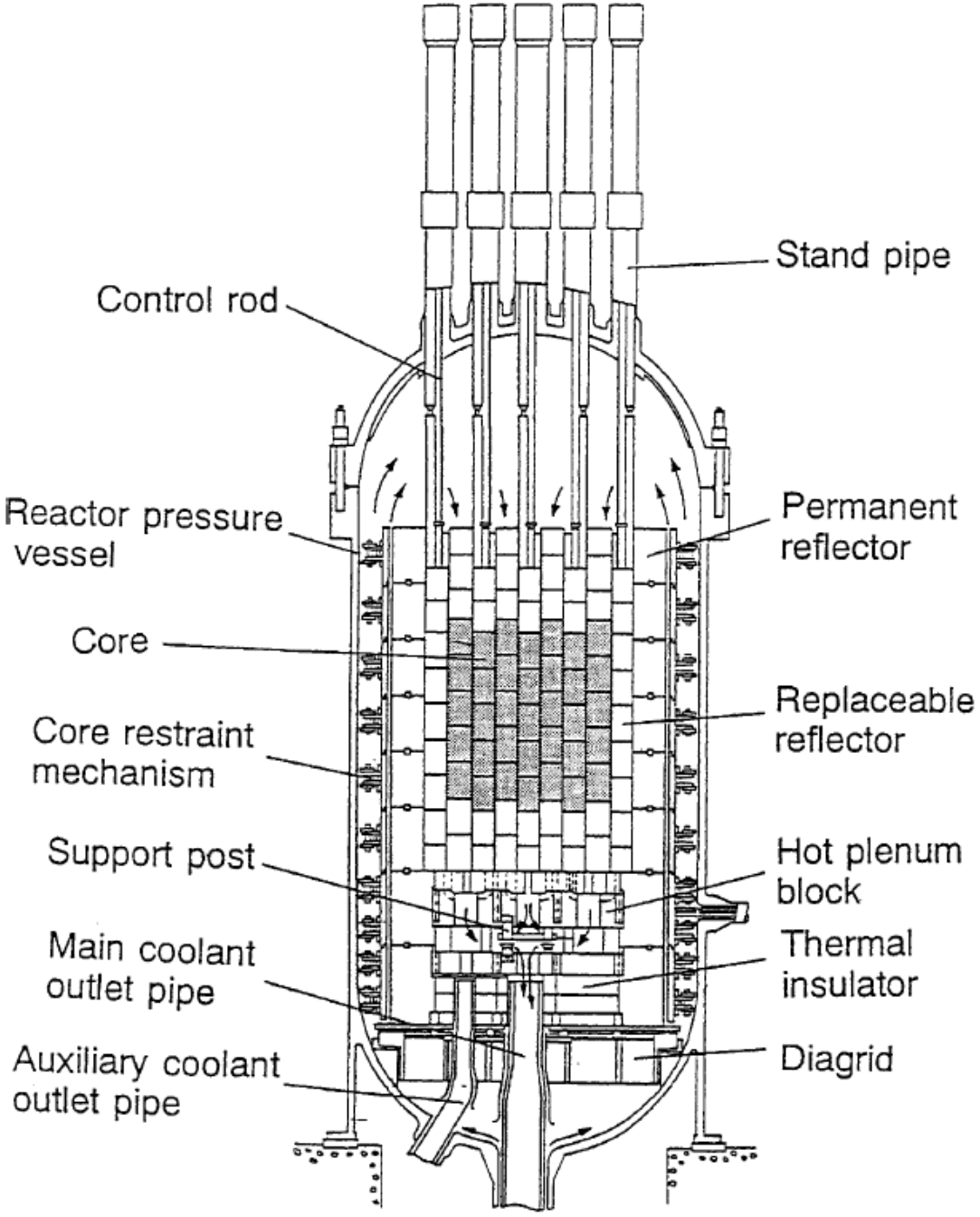
Reactor Physics

Very High Temperature Reactor Critical Assembly (VHTRC)

Thermal Hydraulics

Helium Engineering Demonstration Loop (HENDEL)

Vertical view of the HTTR core



➢ <u>He coolant flow</u>

- Enters from the bottom of the core and flows at outer part toward the top.
- Changes the direction at the top, flows through the core with removing the heat, and exits from the bottom.

➢ <u>Core structure</u>

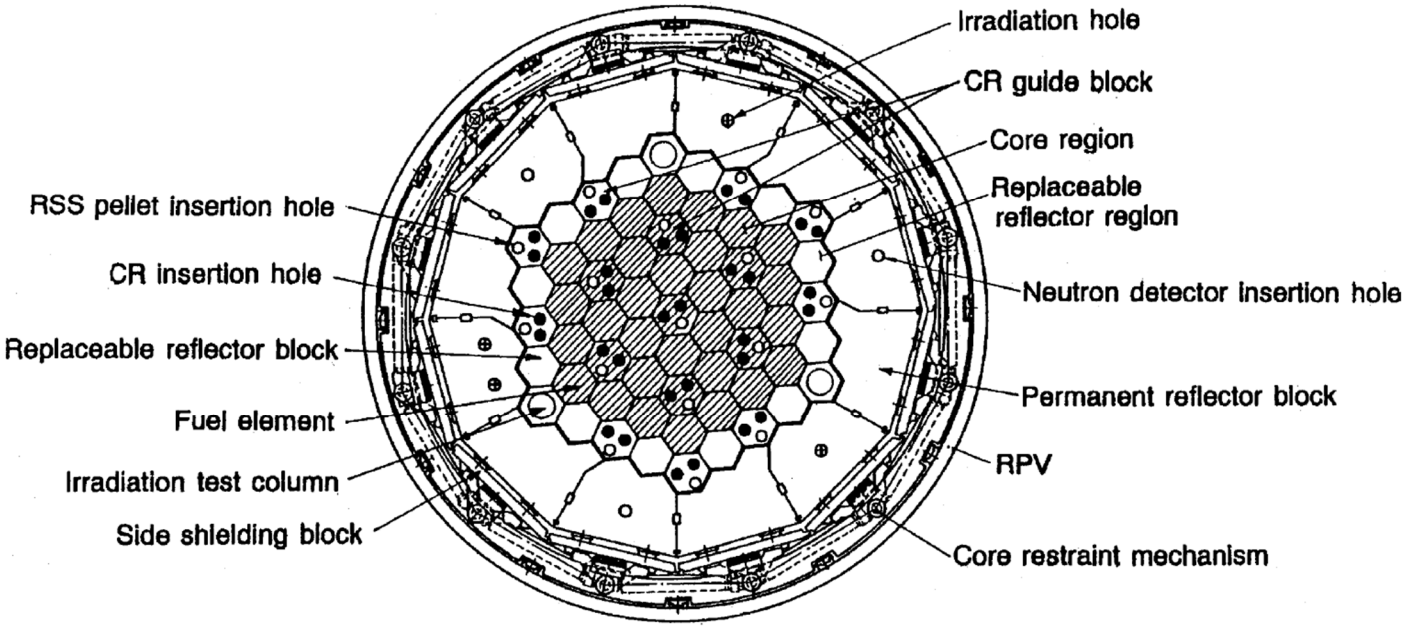
- 5 fuel blocks per each fuel column. (5 fuel blocks × 30 columns = 150 fuel blocks)
- Fuel blocks are surrounded by reflectors.

➢ <u>Control Rod</u>

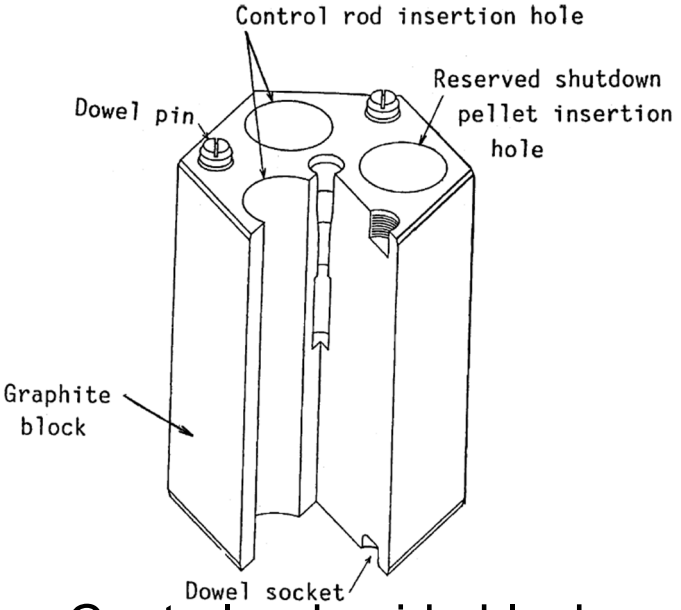
- Number: 32 (16 pairs)
- Inserted from the top.

T. Iyoku, *et al*., Nucl. Eng. Des., 233, 71-79 (2004).

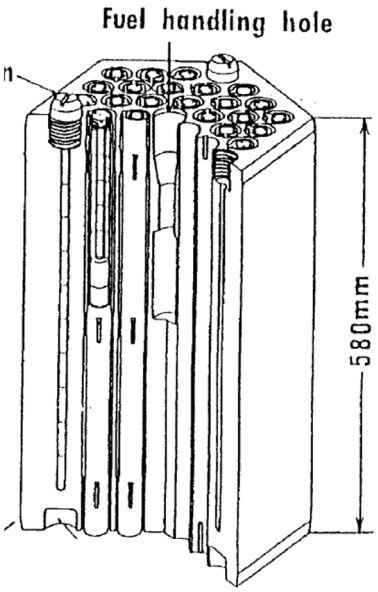
Horizontal arrangement of the HTTR core



- Specification of columns
- 30 fuel columns
- 16 control rod guide columns
- 12 replaceable reflector columns
- 3 irradiation test columns



Control rod guide block



Fuel block

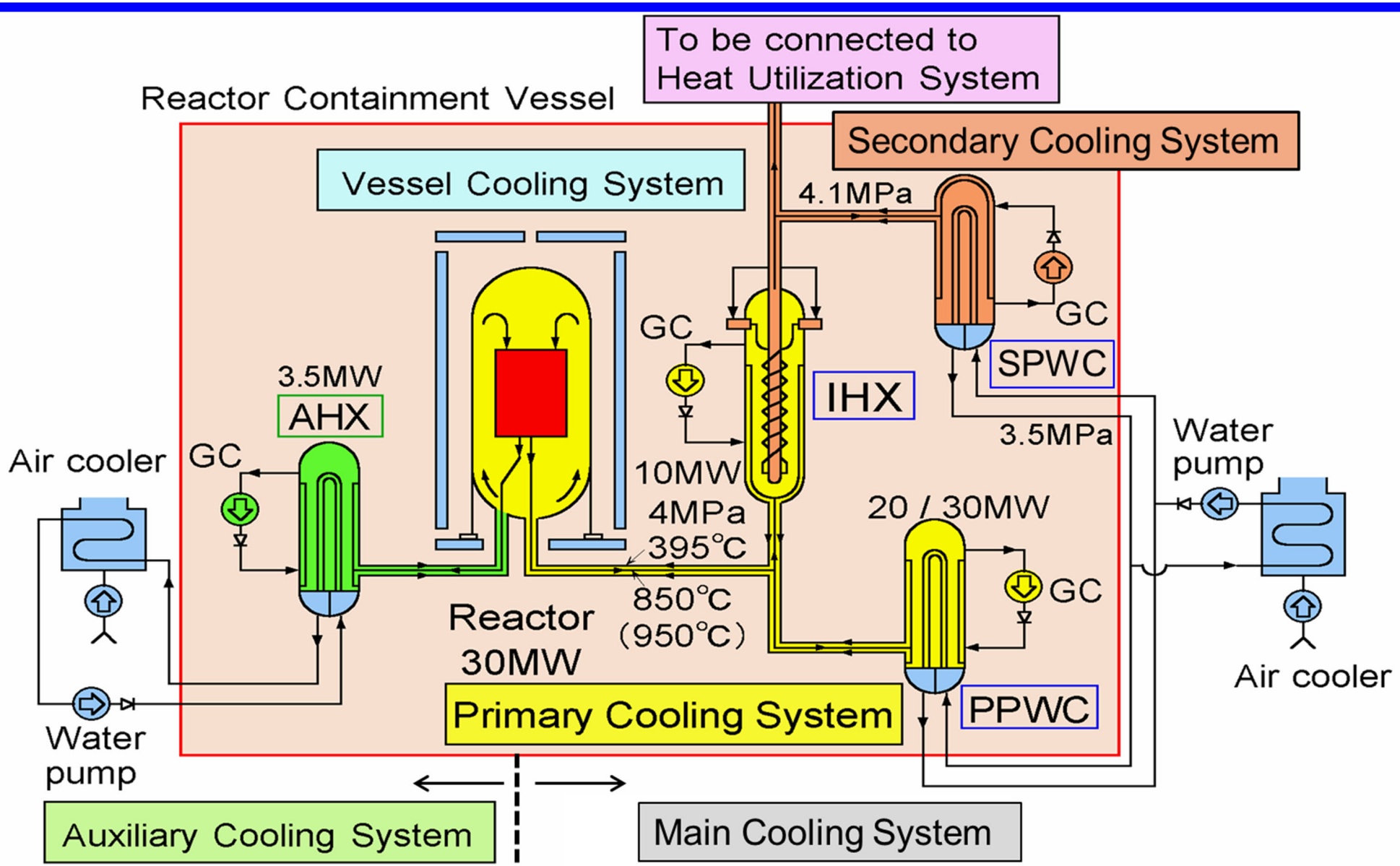
- Control rod guide block
- 2 holes for CR insertion and 1 for Reserved Shutdown System.

- Fuel block
- 31 or 33 holes for Fuel rod.

Both blocks have the hole for handling them at the center.

T. Iyoku, *et al.*, Nucl. Eng. Des., 233, 71-79 (2004).

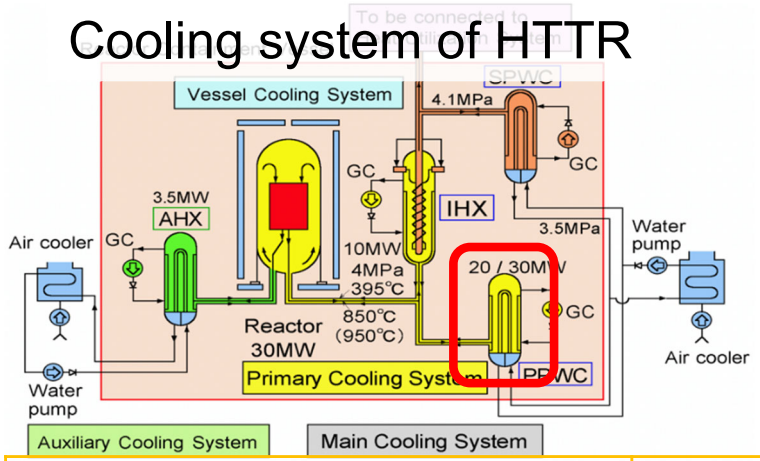
Cooling system of HTTR



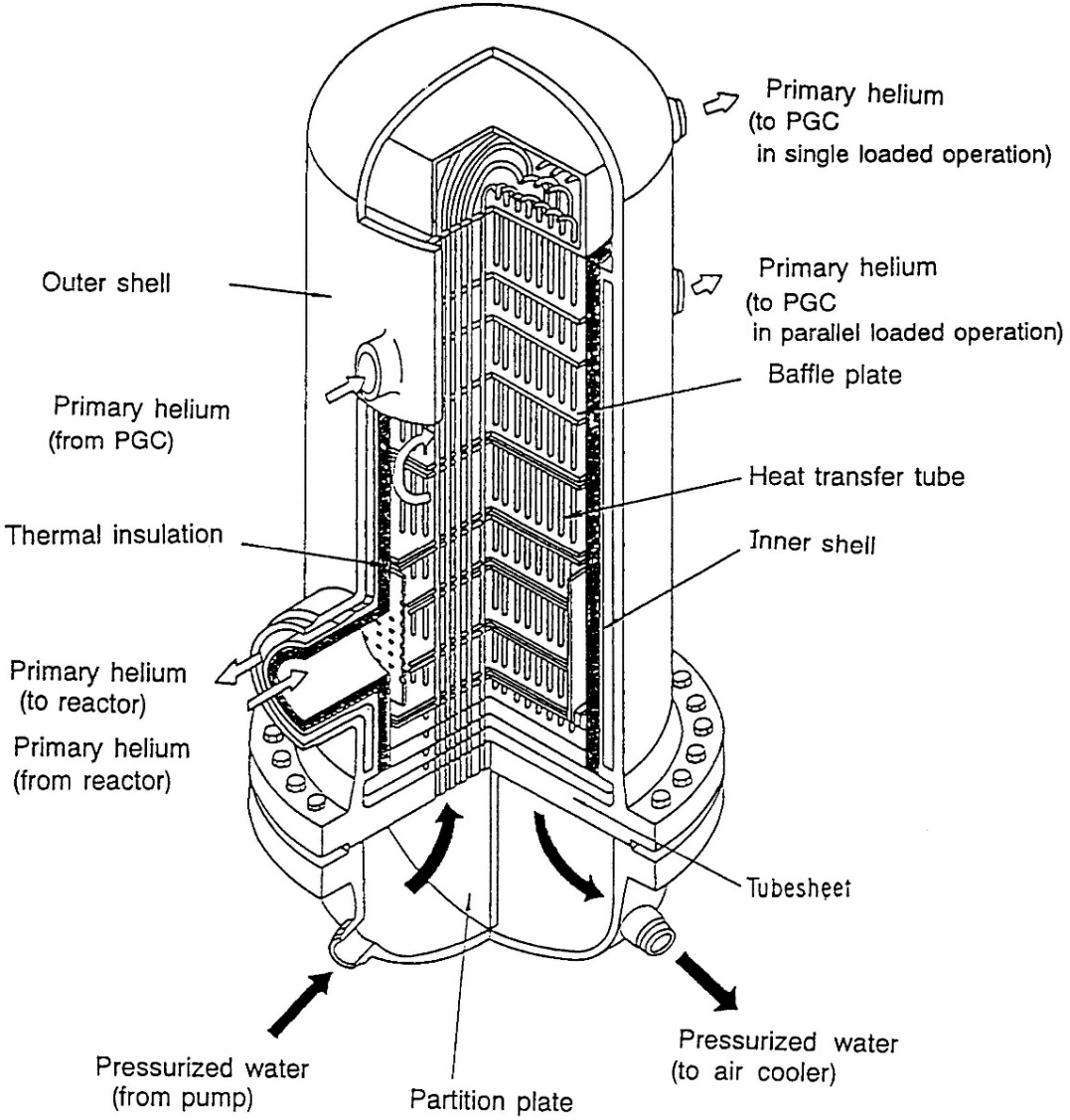
IHX : Intermediate Heat Exchanger
PPWC: Primary Pressurized Water Cooler
GC : Gas Circulator
AHX: Auxiliary Heat Exchanger
SPWC : Secondary Pressurized Water Cooler

Primary Pressurized Water Cooler (PPWC)

Cooling system of HTTR



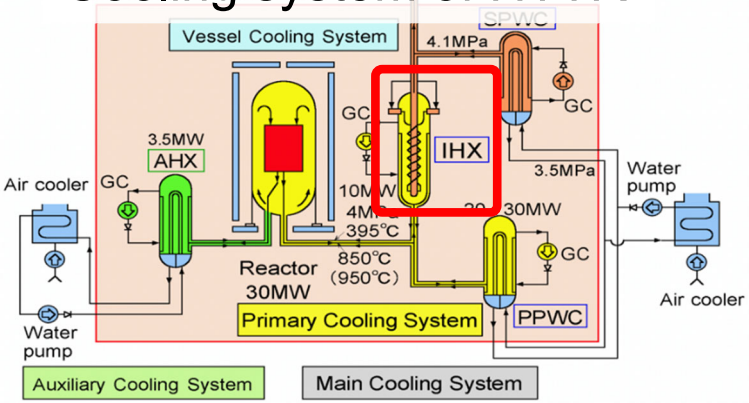
Type		Vertical U-tube
Heat capacity		Max. 30 MW
Design pressure		4.8 MPa (Shell/Tube)
Design temperature		430 °C (Shell) / 380 °C (Tube)
Flow rate (Max.)	Primary He coolant	45 t/h
	Cooling water	625 t/h
Temperature (Max.)	Primary He coolant	950 °C (Inlet) / 395 °C (Outlet)
	Pressurized water	150 °C (Inlet) / 190 °C (Outlet)
Heat transfer tube	Number	136
	Outer diameter	25.4 mm
	Thickness	2.6 mm
Shell	Outer diameter	2.1 m
	Overall height	7.5 m



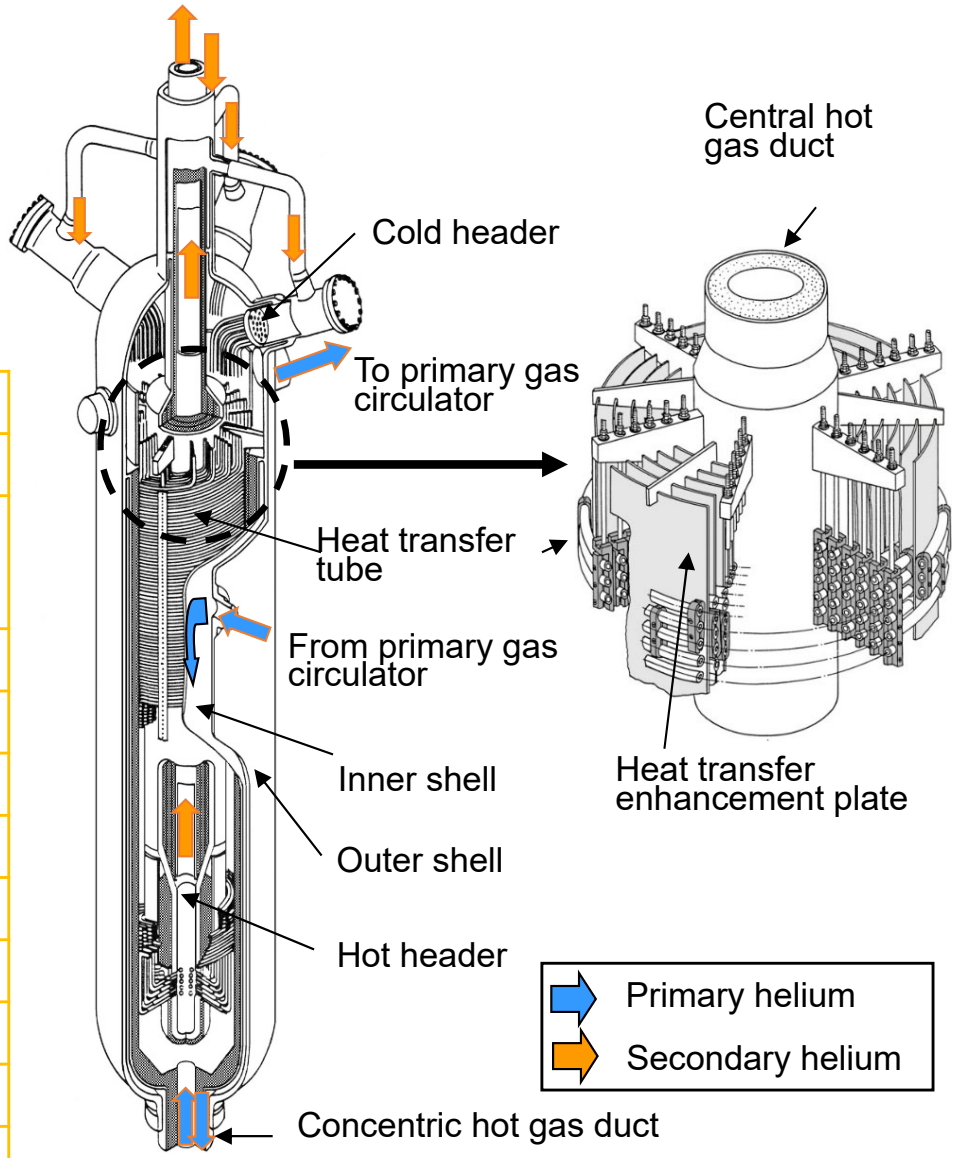
T. Furusawa *et al.*, Nucl. Eng. Des., 233,113-124 (2004).

Intermediate Heat Exchanger (IHX)

Cooling system of HTTR



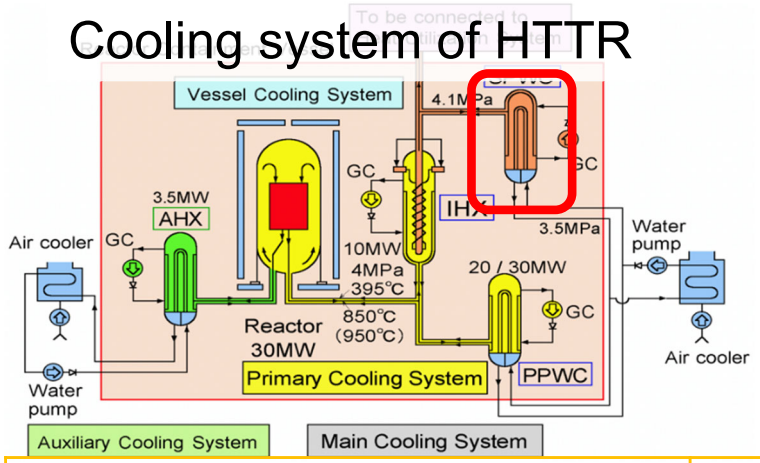
Type		Vertical helically-coiled counter-flow
Heat capacity		10 MW
Design pressure		4.7 MPa (shell) / 0.3 MPa (Tube; Differential pressure)
Design temperature		430 °C (Shell) / 955 °C (Tube)
Flow rate (Max.)	Primary He coolant	15 t/h
	Secondary He coolant	14 t/h
Temperature (Max.)	Primary He coolant	950 °C (Inlet) / 390 °C (Outlet)
	Secondary He coolant	300 °C (Inlet) / 860 °C (Outlet)
Heat transfer tube	Number	96
	Outer diameter	31.8 mm
	Thickness	3.5 mm
Shell	Outer diameter	2.0 m
	Overall height	11 m



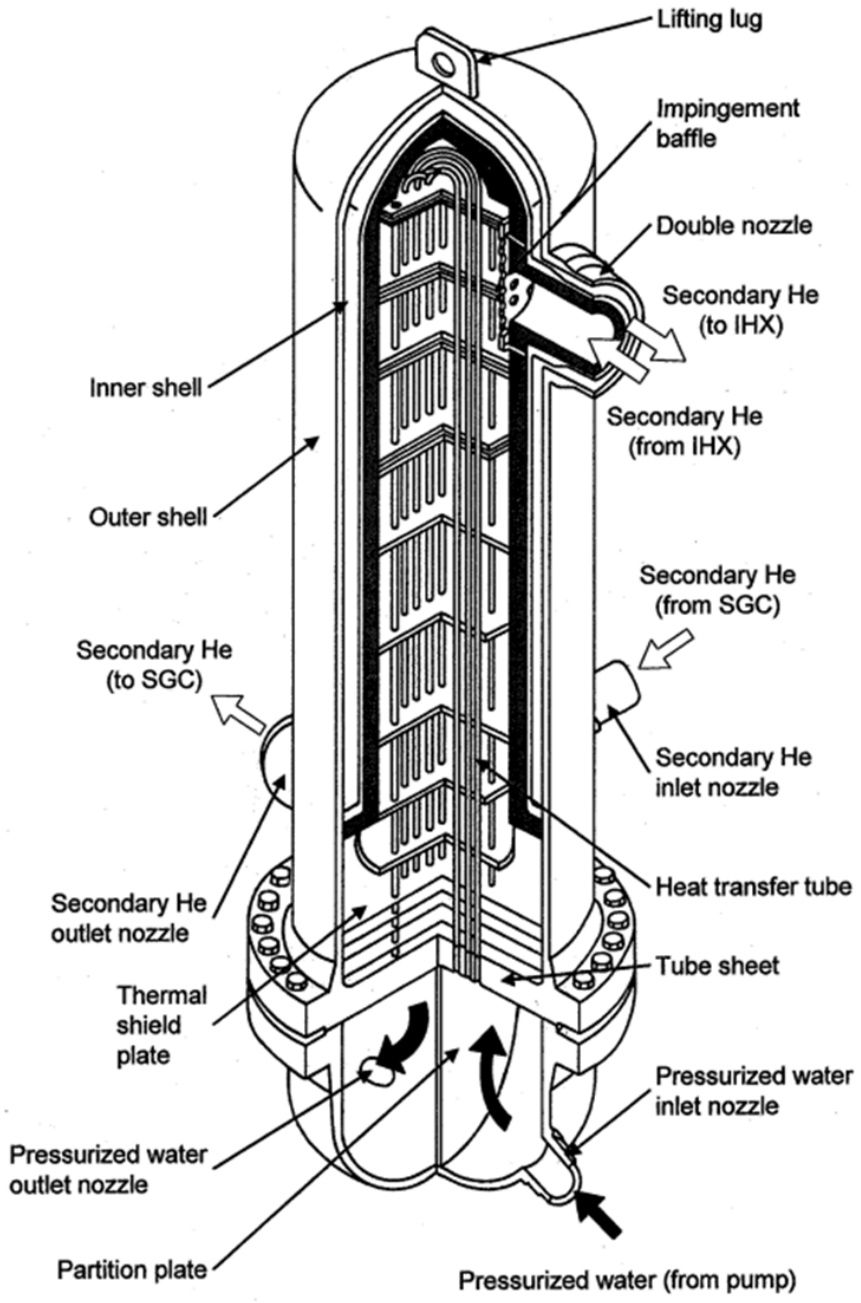
T. Furusawa *et al.*, Nucl. Eng. Des., 233, 113-124 (2004).

Secondary Pressurized Water Cooler (SPWC)

Cooling system of HTTR

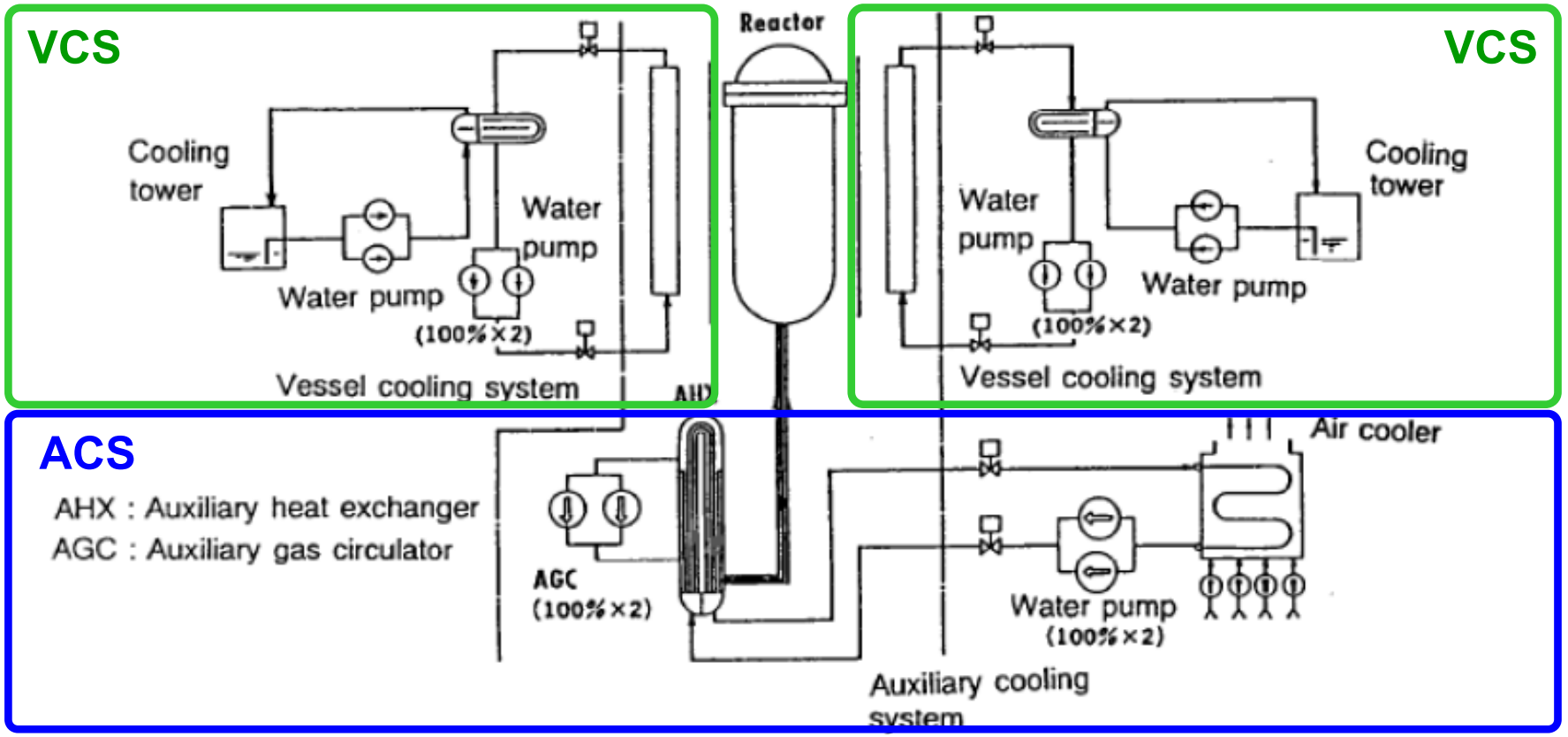


Type		Vertical U-tube
Heat capacity		Max. 10 MW
Design pressure		5.1 MPa (Shell) / 4.8 MPa (Tube)
Design temperature		350 °C (Shell) / 380 °C (Tube)
Flow rate (Max.)	Secondary He coolant	15 t/h
	Cooling water	220 t/h
Temperature (Max.)	Secondary He coolant	860 °C (Inlet) / 300 °C (Outlet)
	Pressurized water	Inlet 150 °C / outlet 190 °C
Heat transfer tube	Number	104
	Outer diameter	25.4 mm
	Thickness	2.6 mm
Shell	Outer diameter	1.4 m
	Overall height	5.4 m



D. Tochio *et al.*, JAEA-Technology 2006-005 (2006).

Vessel Cooling System/Auxiliary Cooling System



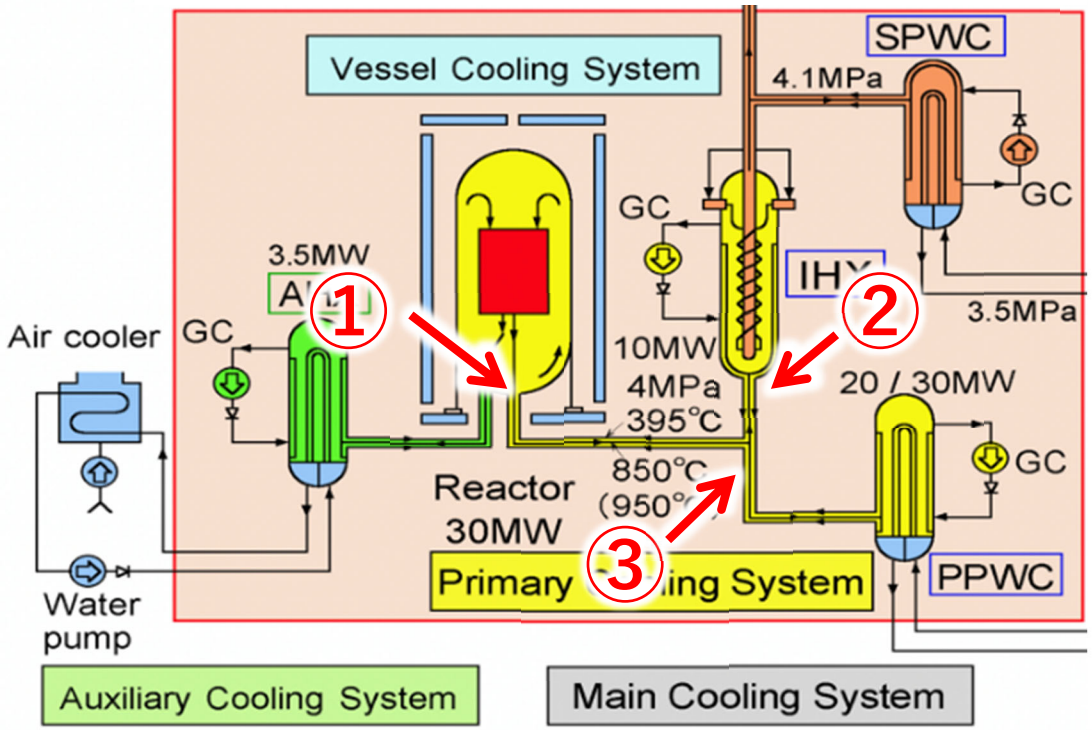
Cooling system of HTTR

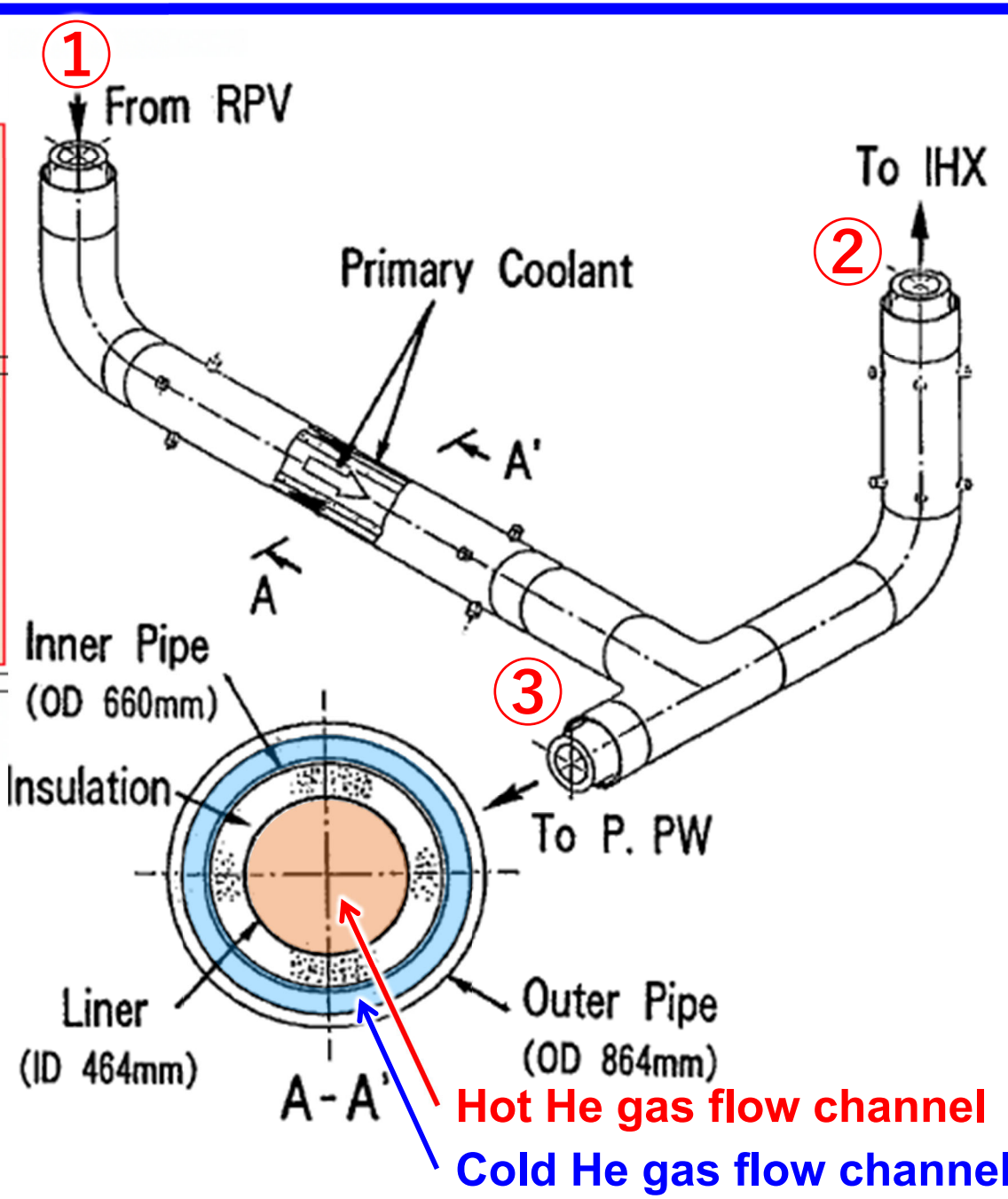
- Vessel Cooling System (VCS);
  - cools the biological concrete shield surrounding the RPV at normal operation.
  - removes heat of the core by natural convection and radiation outside of the RPV under accidents of loss of forced-cooling condition such as rupture of the primary concentric hot gas duct.
- Auxiliary Cooling System (ACS);
  - is standby during normal operation and starts up to remove residual heat after a reactor scram.

Y. Tachibana *et al.*, JAEA-Technology 2009-063 (2009).

Coaxial double piping

Cooling system of HTTR



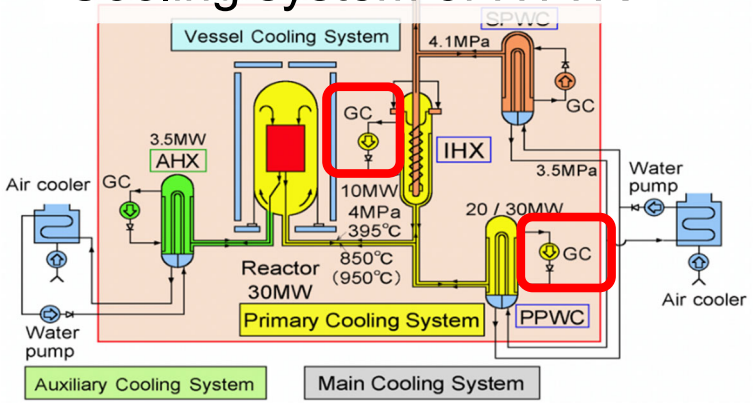


- Hot He gas flows in the inner pipe.
- Cold He gas flows in the gap between the inner and outer pipe.
- Inner pipe has the layer of insulation and liner (Hastelloy XR) on its inner surface.

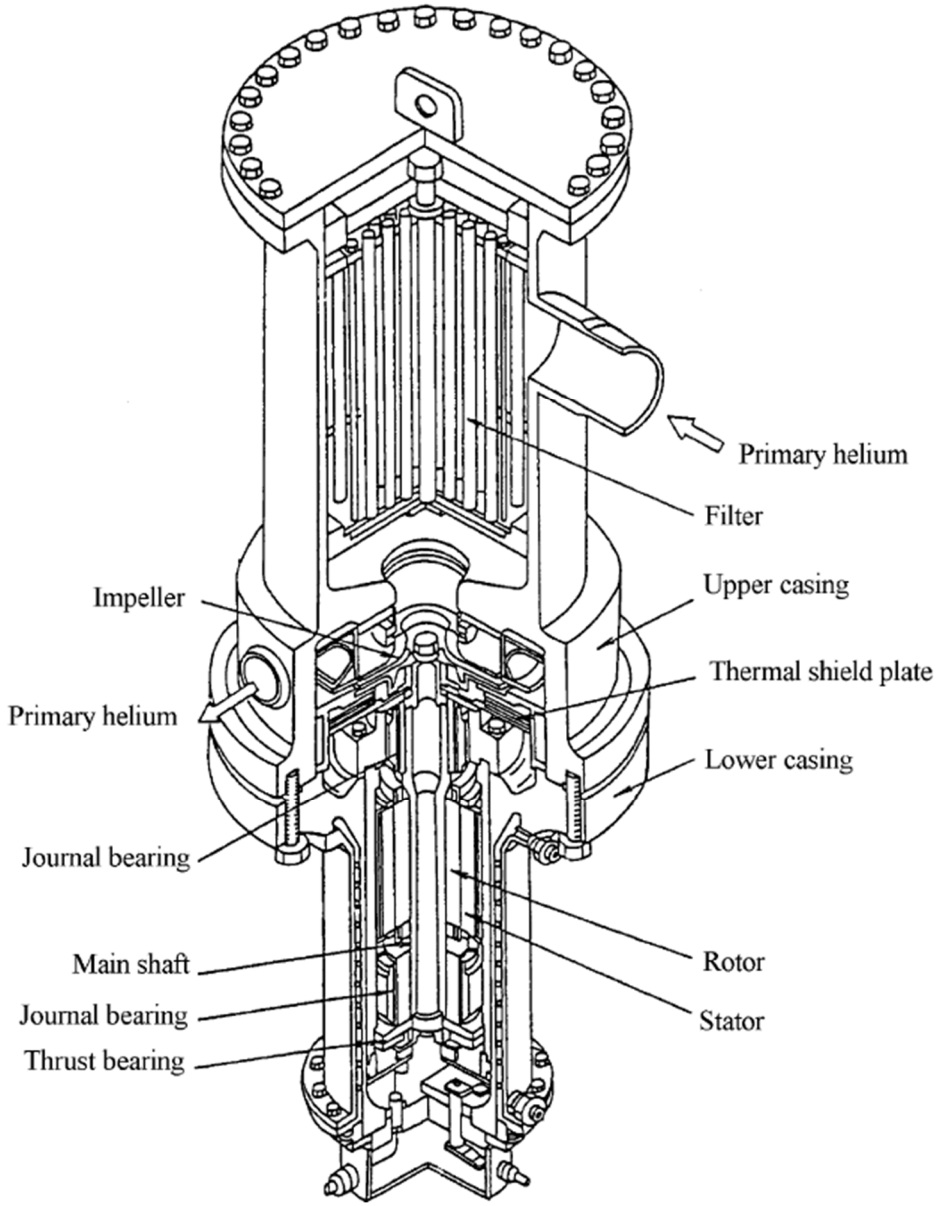
I. Minatsuki *et al.*, Nucl. Eng. Des., 233, 377-390 (2004).

Gas Circulator (GC)

Cooling system of HTTR



Name	IHX HGC	PPWC HGC
Type	Centrifugal gas bearing	
Number	1	3
Flow rate (max.)	15 t/h (per each GC)	
Head (max.)	79.4 kPa	107.9 kPa
Design pressure	4.7 MPa	
Design temperature	430 °C	



T. Furusawa *et al.*, Nucl. Eng. Des., 233, 113-124 (2004).

Summary

- HTGRs use Helium gas coolant, graphite for the core structure and its fuel has the structure of ceramic coating.
- HTGRs have the inherent safety features, and it can generate high temperature heat of 950 ℃. The high temperature heat can be used for versatile applications.
- HTTR is the first and only one prismatic HTGR in Japan.
- In Japan, HTGR technology has been developed through designing, constructing and operating of HTTR.
- HTTR achieved reactor outlet coolant temperature of 950 ℃ in 2004.
  → The first achievement in the world
- Through the design and construction of HTTR, Japanese commercial companies have accumulated the HTGR technology such as Hastelloy XR, Graphite IG-110 and coated fuel particles.