Status Report - GTHTR300 (Japan)

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1. Overview

- ☐ **In Operation**
- ☐ **Under Construction**
- ☐ **Described in**

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	2040

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	300
Gross Power Output (MWe)	--

1.1 Introduction

The 300 MW(e) Gas Turbine High Temperature Reactor (GTHTR300) is a multi-purpose, inherently safe and site-flexible small modular reactor (SMR) being developed by Japan Atomic Energy Agency (JAEA) for commercialization in 2030s. As a Generation-IV technology, the GTHTR300 offers important advances over current light water reactors. The coolant temperature is significantly higher in the range of 850-950oC. Such high temperature capability as proven in the JAEA's HTTR test reactor operation enables a wide range of applications. The design employs a direct-cycle helium gas turbine to simplify the plant by eliminating water and steam systems while generating power with enhanced efficiency of 45-50%.

Figure 1. Schematic of GTHTR300

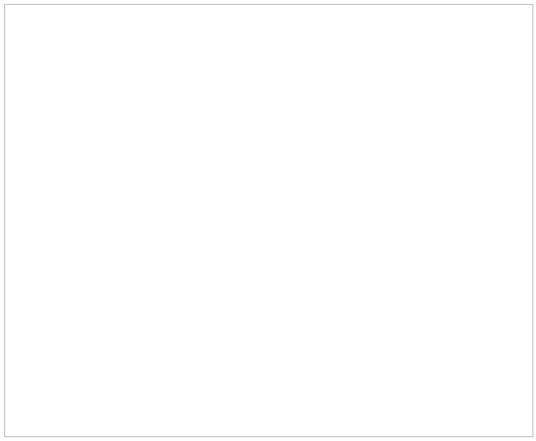


Figure 2. Fuel block, fuel rod, fuel compact and fuel particle

Target Applications

Typical applications include electric power generation, thermochemical hydrogen production, desalination cogeneration using waste heat, and steel production. The reactor thermal power may be rated up to 600 MW(t). The maximum hydrogen production per reactor is 120 t/d, enough to fuel about one million cars, 280-300 MW(e) electricity generation with additional seawater desalination cogeneration of 55 000 m3/d potable water for about a quarter million of population, and annual production of 0.65 million tons of steel. All these are produced without CO2 emission.

1.2 Development Milestones

2003	Basic design of GTHTR300 completed
2005	Design for cogeneration plant GTHTR300C
2015	Basic design for HTTR-connected gas turbine and H2 plant (HTTR-GT/H2) for system demonstration
2020s	HTTR-H2 (hydrogen) test plant construction and operation (planned)

2040s	Operation of demonstration plant (TBD)

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

Design Philosophy

The overall goal of the GTHTR300 design and development is to provide a family of system options capable of producing competitive electricity, hydrogen, desalination, other products, and yet deployable in the near term. The development of the multiple systems simultaneously does not necessarily suggest having investment and risk multiplied. Rather, the development requirement is minimized by pursuing system simplicity, economic competitiveness and originality, namely the SECO design philosophy.

1.6 Licensing Application Support Documents

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Demonstration	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Non-electric (H2 production and others)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Multiple Units	e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	He	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)

Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	GCR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	Graphite	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Integral	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Brayton	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid		e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Prismatic	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Hexagonal	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Basic Design	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources		# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design		n Units/Modules
Capacity to Electric Grid		MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	~ 250 x 250 (4 reactor plants)	m2 (rectangular building envelope)
Site Footprint		m2 (fenced area)
Emergency Planning Zone		km (radius)
Releases during Normal Operation		TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed		x – 100%, % per minute
Seismic Design (SSE)	>0.18	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	7	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	7	MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)		kg

Nominal Coolant Flow Rate (primary)		kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	587	ºC
Core Outlet Coolant Temperature	850	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	23000	mm
- NSSS Largest Component Diameter	8000	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	1000	tonne
Reactor Vessel Material		e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design		e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory		kg
Pressurizer Design		e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume		m3 / m3 (total / liquid)
Containment Type		Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3
Spent Fuel Pool Capacity and Total Volume		Years of full-power operation / m3
Non Electric Application		-
Core Delta Temperature	263	ºC
Fuel/Core		
Single Core Thermal Power	600	MW(th)

Refuelling Cycle	48	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	14/--	%
Average Neutron Energy		eV
Fuel Cladding Material	TRISO	e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	90 Fuel Assemblies	Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit		kg
Total Fissile Loading (initial)		kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation		Applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge		%
Core Discharge Burnup	120	MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)		MWd/kgHM
Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing		e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber		e.g. Gd2O3
Core Volume (active)		m3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary		n/(cm²*s)
Max. Fast Neutron Flux		n/(cm²*s)
Core Control Rod Absorber		-
Core Soluble Neutron Absorber		-
Safety Systems		

Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Active/Passive	- / - / -
- core injection	Active/Passive	- / - / -
- decay heat removal	Active/Passive	- /- / -
- containment isolation and cooling	Active/Passive	- / - / -
- emergency AC supply (e.g. diesels)	Active/Passive	- / - / -
DC Power Capacity (e.g. batteries)		Hours
Events in which Immediate Operator Action is required		e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time		Hours (that are assumed when following EOPs)
Severe Accident Core Provisions		e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)		x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions		e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)		x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)		Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort		Person-years (PY) [DP&P]
Construction and Commissioning Effort		PY [C&C]
Material and Equipment Overnight Capital Cost		Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete		

- Nuclear Island (NSSS)		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Conventional Island (Turbine and Cooling)		
- Balance of Plant (BOP)		
- Commissioning and First Fuel Loading		
Factory / On-Site split in [C&C] effort		%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate		kg/s
System Steam Pressure		MPa
System Steam Temperature		ºC
System Feedwater Flow Rate		kg/s
System Feedwater Temperature		ºC
Reactor Core		
Active Core Height		m
Equivalent Core Diameter		m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density		MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The reactor building is a below-grade, steel concrete structure housing 4 units of reactor systems consists of subsystems including reactor module, gas turbine module and heat exchanger modules.

4.1 Site Requirements during Construction
4.2 Site Considerations during Operation
4.3 Grid Integration

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

Power Conversion

The reactor system combines a high temperature gas-cooled reactor with direct-cycle gas turbine to generate power while circulating the reactor coolant. The system consists of three functionally-oriented pressure vessel units, housing the reactor core, the gas turbine, and the heat exchangers respectively. The multi-vessel system facilitates modular construction and independent maintenance access to the functional vessel units. The reactor system is placed below grade in the reactor building. The pre-application basic design of the system was completed in 2003 by JAEA and domestic industrial partners Mitsubishi Heavy Industries, Fuji Electric, Nuclear Fuel Industries and others. The reactor system design added cogeneration capabilities by adding an IHX between the reactor and gas turbine that can accept the various roles of cogeneration while sharing equipment designs with GTHTR300.

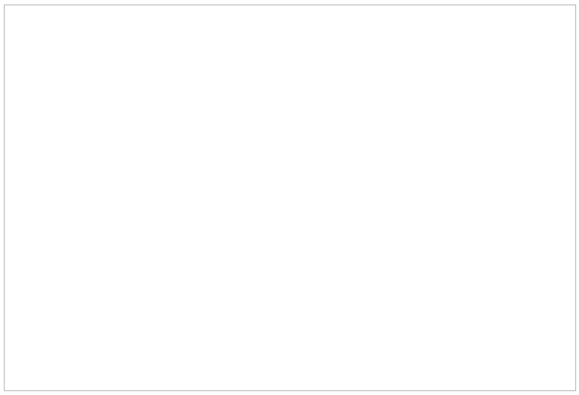


Figure 3. Reactor primary system of GTHTR300

Reactor Core

The reactor core consists of 90 fuel columns arranged in an annular ring, 73 and 48 inner and outer removable reflector columns, and 18 outer fixed reactor sectors. The effective annular core is about 3.6-5.5m in inner to outer diameter and 8m in height. The fuel column is a hexagonal graphite block similar to the HTTR fuel but improved from it by an integral or sleeveless fuel rod for increased heat flux and by and enlarged coated particle buffer for improved fission product retention integrity under high burnup.

Fuel Characteristics

The fuel design is coated fuel particle of less than 1 mm in diameter. Each particle consists of a UO2 kernel coated by four layers of low and high density pyro-carbon and silicon carbide. The all ceramic particle fuel is heat resistant up to 1600oC. Approximately 10 000 particles are packaged into a compact of the size of a thumb. The compacts are then assembled into graphite-clad fuel rods. The fuel rods are inserted into the bore holes of a hexagonal graphite fuel block of about 1 m long and 41 cm across, where the annulus formed between the fuel rod and the bore hole provides coolant flow channels. The fuel blocks are loaded into the reactor core. The more fuel blocks are placed in the

core, the higher the power output of the reactor.

Fuel Handling System

The fuel handling system consists of fuel loading machines, door valves, a control rod exchange machine, and a transport carriage. The fuel loading machine is used to remove fuel blocks from core and load fuel blocks to core and spent fuel storage facility. The door valves are devised at the interface between fuel loading machine and spent fuel storage facility to maintain airtightness and radiation shielding. The control rod exchange machine is installed for removal of control rods from reactor and loading of used control rods to maintenance pit. The transport carriage is used for the transportation of the fuel loading and control rod exchange machines.

Reactivity Control

Reactivity control system consists of control rods, control rod drive mechanisms and reserve shut down systems. The system is used to adjust control rod position for reactivity control as well as shut down reactor in case of reactor scram. GTHTR300 has 30 pairs of control rod and reserve shut down systems. The control rods and reserve shut down system channels are located in reflector blocks on inner and outer rings of fuel region.

Reactor Pressure Vessel and Internals

The reactor core consists of graphite hexagonal blocks, one-third of which are fuel blocks arranged in an annular region while the other two-thirds are reflector blocks arranged inside and outside of the fuel region. Each fuel block has 57 coolant holes with fuel rods forming annular-shaped coolant channels. A permanent reflector which surrounds side replaceable reflectors contains coolant channels. The helium coolant from the reactor inlet is introduced to the channel. A core barrel is installed between reactor internals and reactor pressure vessel to support internal structure laterally.

Reactor Coolant System

Helium is heated in the reactor core to the cycle top temperature at high pressure. It then enters the turbine for expansion to convert thermal energy into shaft power needed by the turbine to drive the compressor and electric generator on single shaft. The turbine exhaust helium enters the recuperator, wherein its residual heat is recovered in high effectiveness to preheat coolant to the reactor.

Instrumentation and Control System

The instrumentation and control system consists of reactor and process instrumentations, control systems, safety protection system, and engineered safety features actuating systems. The six (6) fundamental controls are for turbine bypass, inventory, reactor outlet temperature, turbine inlet temperature, process heat supply rate and IHX differential pressure controls. They are combined in the basic plant control to provide controllability for a variety of transients including loss-of-load and electric load following as shown above.

5.1 Primary Circuit
5.2 Reactor Core and Fuel
5.3 Fuel Handling
5.4 Reactor Protection
5.5 Secondary Side

5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface
5.8 Unique Technical Design Features (if any)

6. Technology Readiness

SUMMARY FOR BOOKLET

Testing Conducted for Design Verification and Validation

The test results using the HTTR will be utilized for the development of GTHTR300. The test items cover fuel performance and radionuclide transport, core physics, reactor thermal hydraulics and plant dynamics, and reactor operations, maintenance, control, etc. The results of the system performance analysis showed that the reactor could be continuously operated with the above variable load conditions. However, an actual demonstration test is warranted for performance confirmation.

Design and Licensing Status

The design is developed at pre-licensing basic design stage. The design and development are planned to be concluded to prepare for the demonstration plant operation in 2040s.

6.1 Deployed Reactors
6.2 Reactors under Licensing Review
6.3 Reactors in the Design Stage

7. Safety Concepts

SUMMARY FOR BOOKLET

The reactor delivers fully inherent safety due to three enabling design features:

- Ceramic coated particle fuel maintains containment integrity under a temperature limit of 1600oC.
- Reactor helium coolant is chemically inert and thus absent of explosive gas generation or phase change.
- Graphite-moderated reactor core provides negative reactivity coefficient, low-power density, and high thermal conductivity.

As a result of these features, the decay heat of the reactor core can be removed by natural draft air cooling from outside of the reactor vessel for a period of days or months without reliance on any equipment or operator action even in such severe accident cases as loss of coolant or station blackout, while the fuel temperature will remain below the fuel design limit.

Engineered Safety System Approach and Configuration

An engineered safety system in the GTHTR300 consists of a reactor cavity cooling system and confinement. GTHTR300 safety design is based on philosophy of maintaining safety functions relying on inherent and passive safety features. Accordingly, the system is designed not to rely on active components or operator actions in principle.

Decay Heat Removal System / Reactor Cooling Philosophy

GTHTR300 design removes the core decay and residual heat from the outside surface of the reactor vessel by the natural convection and radiation, and to transfer it to an ultimate heat sink in the operational states and in the accident conditions so that the design limits for fuel, the reactor coolant pressure boundary and structures important to safety are not exceeded.

Spent Fuel Cooling Safety Approach / System

The fuel cycle is of once-through-then-out design allowing for 1460 days (4 years) of in-core fuel residence with 120 GWd/ton average burnup. The spent fuel is stored in dry cooling facility with expenses included in fuel cycle cost estimate. Fuel reprocessing is technically feasible and preliminary evaluation for this option is being conducted.

Containment System

GTHTR300 employs a vented confinement rather than a conventional high-pressure, airtight containment used in LWRs. The confinement is designed to meet requirements designated in safety design. The confinement is designed to release helium coolant blown out from primary system in case of depressurized loss-of-forced cooling accidents. Dampers are devised and recloses when the pressure between outside and inside of confinement equalizes. The design leak rate is set to 20%/day to limit the amount of air ingress to reactor core.

Chemical Control

The helium purification systems are installed in the primary and secondary cooling systems in order to reduce the quantity of chemical impurities such as hydrogen, carbon monoxide, water vapor, carbon dioxide, methane, oxygen, and nitrogen. The primary helium purification system is mainly composed of a pre-charcoal trap, an inlet heater, two copper oxide fixed beds, coolers, two molecular sieve traps, two cold charcoal traps and helium compressors.

Plant Safety and Operational Performance

The ability to follow variable power and heat loads is simulated as shown in the following figure. The simulation shows the plant response to an electric demand increase of 5%/min with corresponding reduction in heat rate, which is the maximum required for ramp load follow. The reactor remains at 100% power at all times. Starting from a base cogeneration ratio of 203 MW(e) electricity and 170 MW(t) net heat, the turbine power generation is increased to follow the increasing electric demand by increasing primary coolant inventory with opening of inventory valve IV1. The IHX heat rate is lowered by lowering secondary loop flow of the IHX. The power sent out to external grid increases to 276 MW(e) in as little as a few minutes. The pressure in the reactor increases to 7 MPa from 5 MPa.

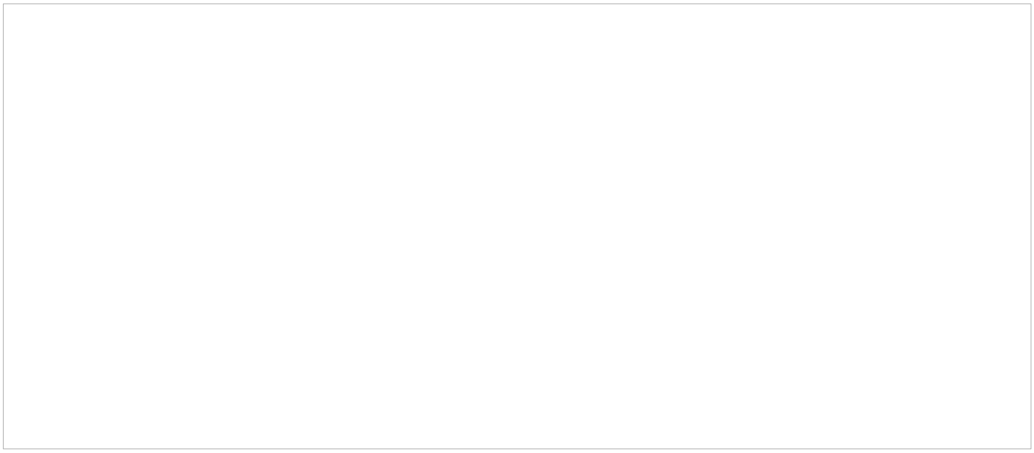


Figure 4. Plant parameters

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

The design is applicable to fuel cycle options including UO2, MOX, and Pu-burning.

Waste Management and Disposal Plan

The design is applicable to options of direct disposal or reprocessing for spent fuel.

8.1 Fuel Cycle Options
8.2 Resource Use Optimization
8.3 Unique Fuel/Fuel Cycle Design Features

9. Safeguard & Physical Security

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9.1 Safeguards
9.2 Security
9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

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10.1 Project Preparation and Negotiation
10.2 Construction and Commissioning
10.3 Operation and Maintenance