Status Report - HTR-10 (China)

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1. Overview

- [x] **In Operation**
- [ ] **Under Construction**
- [ ] **Described in**

Link to PRIS	--

- [ ] **New Concept**

Number of Units	--
Year	--

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	2.5
Gross Power Output (MWe)	--

1.1 Introduction

In 1992, the China Central Government approved the construction of the 10 MW(t) pebble bed high temperature gas cooled test reactor (HTR-10) in Tsinghua University's Institute of Nuclear and New Energy Technology (INET). In 2003, the HTR-10 reached its full power operation. Afterwards, INET conducted many experiments using the HTR-10 to verify crucial inherent safety features of modular HTRs, including (i) loss of off-site power without scram; (ii) main helium blower shutdown without scram; (iii) withdrawal of control rod without scram; and (iv) Helium blower trip without closing outlet cut-off valve. The second step of HTR development in China began in 2001 when the high-temperature gas-cooled reactor pebble-bed module (HTR-PM) project was launched.

The HTR-10 is a major project on the energy sector within the Chinese National High Technology Programme, serving as the first major step of the development of modular HTGR in China. Its main objectives are to: (1) explore the technology in the design, construction and operation of HTGRs; (2) establish an irradiation and experimental facility; (3) demonstrate the inherent safety features of modular HTGR; (4) test electricity and heat co-generation and closed cycle gas turbine technology; and (5) perform research and development work on nuclear process heat application. The aims of this project are to demonstrate the inherent safety features of the HTGR modular design and test the

technologies of electricity generation, district heating as well as process heat application with modular HTGR.

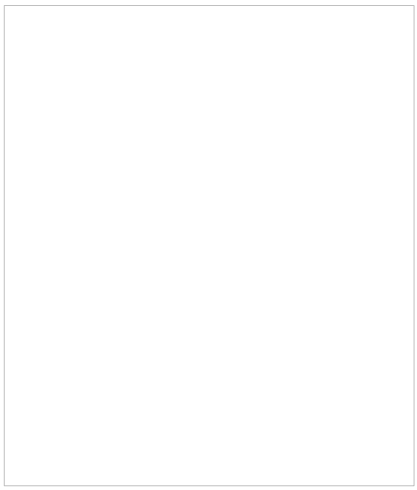


Figure 1. HTR-10 Concept design

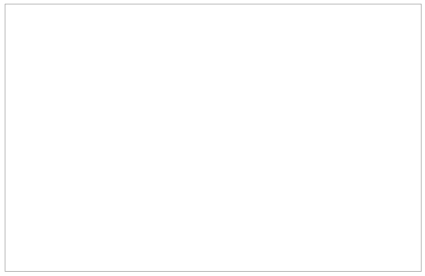


Figure 2. HTR-10 site

1.2 Development Milestones

1992	Project approved
1995	Construction began
2000	First criticality
2001	HTR-PM Project is launched
2003	Commission date and full power operation
2018	Restart after upgrade of systems; Melt-wire tests to measure temperatures distribution conducted.

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The primary pressure boundary consists of reactor pressure vessel, steam generator pressure vessel and hot gas duct pressure vessel which connects the above two vessels. This arrangement can make the

maintenance and inspection of the components easier and mitigate the accident result of water ingress into reactor core if the steam generator heat transfer tubes might fail.

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 (Cogeneration)	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)		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		e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type

Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle		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	Coated Sphere	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Other	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	Operational	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	20	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	2.5	MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	13000	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)	3.3 m/s2	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	3	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	4	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	250	ºC
Core Outlet Coolant Temperature	700	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	Reactor vessel	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	11100	mm
- NSSS Largest Component Diameter	4200	mm

- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	167	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	cogeneration	-
Core Delta Temperature	450	ºC
Fuel/Core		
Single Core Thermal Power	10	MW(th)
Refuelling Cycle	continuous	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	17	%
Average Neutron Energy		eV
Fuel Cladding Material		e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”		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	80-90	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 and negative temperature feedback	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		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Nuclear Island (NSSS)		
- 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 HTR-10 plant includes the reactor building, a turbine/generator building, two cooling towers and a ventilation center and stack. These buildings are arranged and constructed on an area of 100 x 130 m2. The HTR-10 plant does not contain a leak-tight pressure containing system. The concrete compartments that house the reactor and the steam generator as well as other parts of the primary pressure boundary are preferably regarded as confinement.

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

Reactor Core

The reactor core volume is 5m3, 1.8 m in diameter and the mean height is 1.97 m. About 27 000 spherical fuel elements with 60 mm in diameter will be filled up in the reactor core, the enrichment of fuel is 17% and the mean discharge burn up is designed to be 80 000 MWd/tU. The reactor core is entirely constructed by graphite materials, no metallic components are used in the region of the core. At the funnel bottom of the reactor core, there is a fuel-element discharging tube with a diameter of 500 mm and a length of 3.3 m. At the tube end the special fuel discharge facility singularise the fuel to be unloaded through a 65 mm diameter pipe that penetrates the reactor pressure vessel.

Figure 3. Reactor

Reactor Pressure Vessel and Internals

The pressure vessel unit consists of the reactor pressure vessel, the steam pressure vessel and the hot gas duct pressure vessel. The upper part of the reactor pressure vessel is a cover which is connected via eighty bolts, and its lower part is a cylindrical shelf with a lower closure head. A metallic O-ring and an Ω-ring are used for sealing between the upper and lower parts. The tube nozzle for irradiation channels and the control rods driving system are mounted on the cover.

Reactor Coolant System

Cold helium channels are designed within the side reflector for the helium primary coolant to flow upward after entering the reactor pressure vessel from the annular space between the connecting vessel and the hot gas duct. Helium flow reverses at the top of reactor core to enter the pebble bed, so that a downward flow pattern takes place. After being heated in the pebble bed, helium then enters into a hot gas mixing chamber in the bottom reflector, and from there it flows through the hot gas duct and then on to the heat exchanging components.

Steam Generator

The steam generator (SG) is a once through, modular helical tube type. Hot helium from the hot gas duct flows through its central tube to the top part of the SG and then is fed in above the SG heat transfer tubes. While flowing around the tubes, the helium releases its heat to the water/steam side, thereby cooling down from 700°C to 250°C. The cold helium flow is then deflected to the inlet of the helium blower and returns to the reactor along the wall of the pressure vessel. The water flows through the helical tubes from the bottom to the top. The feed water temperature is 104°C and the steam temperature at the turbine inlet is 435°C. The SG mainly consists of the pressure vessel, the steam generator tube bundle modules and the internals.

Helium Circulator

The helium circulator is a key component for high temperature helium cooled reactors and therefore an important component to develop and test in the HTR-10. The helium circulator assures the thermal energy transfer from the reactor core to the steam generator and operates at 3.0 MPa and at 250°C. The circulator is integrated into the steam generator vessel and installed on top of the SG. The helium circulator was designed and manufactured by INET at Tsinghua University and the Shanghai Blower Works Co., Ltd.

Fuel Characteristics

The fuel elements are the spherical type fuel elements, 6 cm in diameter with coated particles. The reactor equilibrium core contains about 27 000 fuel elements forming a pebble bed that is 180 cm in diameter and 197 cm in average height. The spherical fuel elements move through the reactor core in a multi-pass pattern.

Fuel Handling System

The HTR-10 is designed to use spherical fuel elements. Its Fuel Handling System (FHS) is different from the refuelling machines of reactors using rod shaped or block shaped fuel elements. The main feature of the FHS is to charge, circulate and discharge fuel elements in the course of the reactor operation, or in other words on-line. For the initial core loading, dummy balls (graphite balls without nuclear fuel) were firstly placed into the discharge tube and the bottom cone region of the reactor core. Then, a mixture of fuel balls and dummy balls were loaded gradually to approach first criticality. The percentages of fuel balls and dummy balls were 57% and 43% respectively. After the first criticality was reached, mixed balls of the same ratio were further loaded to fill the core in order to make the reactor capable of being operated at full power. The full core (including the cone region) is estimated to have a volume of 5 m3.

Reactivity Control

There are two reactor shutdown systems, one control rod system and one small absorber ball system. They are all designed in the side reflector. Both systems are able to bring the reactor to cold shutdown conditions. Since the reactor has strong negative temperature coefficients and decay heat removal does not require any circulation of the helium coolant, the turn-off of the helium circulator can also shut down the reactor from power operating conditions. There are ten control rods placed in the side reflector. Boron carbide (B4C) is used as the neutron absorber. Each control rod contains five B4C ring segments which are housed in the area between an inner and an outer sleeve of stainless steel. These are then connected together by metallic joints. The inner and outer diameter of the B4C ring is 60 mm and 105 mm respectively, while the length of each ring segment is 487 mm. There are 7 holes in the side reflector of the HTR-10 for small absorber ball system.

Instrumentation and Control Systems

The control system makes use of the distribution control system (DCS). Full digitalized control room and reactor protection system are used in HTR-10.

Figure 4. HTR-10 control room

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

Design and Licensing Status

HTR-10 is operational. The extension of operation license is undergoing.

Research and Development Plan

From 1986 to 1990, eight (8) research topics for key technologies were defined: (i) a conceptual design and the supporting reactor physics and thermal fluid design and safety software codes; (ii) manufacturing process of the fuel spheres; (iii) reprocessing technologies for the thorium-uranium cycle; (iv) core internal graphite structure design and supporting analysis; (v) helium technology establishment, (vi) pressure vessel designs, (vii) the fuel handling design; (viii) development of special materials.

Before the commissioning, the following engineering experiments were conducted: (i) a hot gas duct performance test; (ii) measurements to establish the mixing efficiency at the core bottom (limit stratification and heat streaks); (iii) two-phase flow stability tests on the once-through steam generator; (iv) fuel handling performance test; (v) control rods drive mechanism performance; (vi) V&V of the digital reactor protection systems; (vii) measurements to confirm the neutron absorption cross-section

of the reflector graphite and (viii) a performance test for the helium circulator.

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

7. Safety Concepts

SUMMARY FOR BOOKLET

HTR-10 has inherent safety features common to the new generation of advanced reactors, i.e. the reactor automatically shuts down because of the negative temperature reactivity coefficients and the decay heat is passively removed from the reactor to the environment. HTR-10 is a new generation reactor whose design is based on the ideas of module reactors.

Reactivity control

The on-line refuelling leads to a small excess of reactivity, the overall temperature coefficient of reactivity is negative, and two independent shutdown systems are available.

Decay Heat Removal System

After shutdown, the decay heat will be dispersed from the core to outside of reactor pressure vessel via conduction, convection and radiation, even in the case of depressurized accident condition. Then the decay heat can be carried out by two independent trains of passive decay heat removal systems to environment. Two independent reactor cavity coolers are located at the surface of the reactor cavity. During an accident, the decay heat is removed to the environment by the passive heat transfer mechanisms, i.e. heat conduction, natural convection and thermal radiation.

Containment Function

There are three barriers to the release of fission products to the environment, i.e. the coating layers of the TRISO coated fuel particles, the pressure boundary of the primary loop and the confinement. In any accidents the maximum temperature of the fuel elements could not exceed the temperature limit and a significant radioactivity release can be excluded. In addition, the low free uranium content of fuel elements, the retention of radioactivity by graphite matrix of fuel elements, and the negligible activated corrosion products in the primary coolant system will maintain the radioactivity of the primary coolant system at a very low level. In the depressurization accidents of the primary coolant, the impact of radioactivity release on the environment will be insignificant. Therefore, it is not necessary to provide containment for the HTR-10. Therefore, a confinement without requirement of pressure-tightness is adopted.

Plant Safety and Operational Performances

There are two operational phases for the HTR-10. In the first phase, the plant is operated at a core outlet temperature of 700°C and inlet of 250°C. The secondary circuit include a steam turbine cycle for

electricity generation with the capability for district heating. The steam generator produce steam at temperature of 440°C and pressure of 4 MPa to feed a standard turbine-generator unit. In the second phase (not implemented yet), the HTR-10 will be operated with a core outlet temperature of 900°C and an inlet of 300°C. A gas turbine (GT) and steam turbine (ST) combined cycle for electricity generation is in preliminary design. The intermediate heat exchanger (IHX), with a thermal power of 5 MW, provides high temperature nitrogen gas of 850°C for the GT cycle. There are other options under consideration to operate HTR-10 in higher temperature mode.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

For the test reactor a once through fuel cycle is initially implemented.

Waste Management and Disposal Plan

To be included in the national plan of test facilities.

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

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

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

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

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