Status Report - HAPPY200 (China)

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1. Overview

- ☐ **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)	--
Gross Power Output (MWe)	--

1.1 Introduction

The Heating-reactor of Advanced low-Pressurized and Passive SafetY system – 200 MW(t) (HAPPY200) is a so called pool-loop combined type reactor, which has both features of swimming pool reactor and PWR to some extent. The HAPPY200 operates under low temperature and at low pressure in the closed primary circuit boundary with forced circulation mode. All engineered safety systems operate in a passive mode, and can cope at least for 1 month after accident without any active operator intervention, taking advantage of external cold air as the ultimate heat sink. A large pool of water inventory is incorporated to enhance its safety and reliability under postulated accident conditions. The key design objectives of HAPPY200 include: inherent safety; good economy; proven technology; and easy decommissioning. Aiming for high reliability with inherent safety features, HAPPY200 can be deployed in the vicinity of the targeted heating supply district or community with high population density.

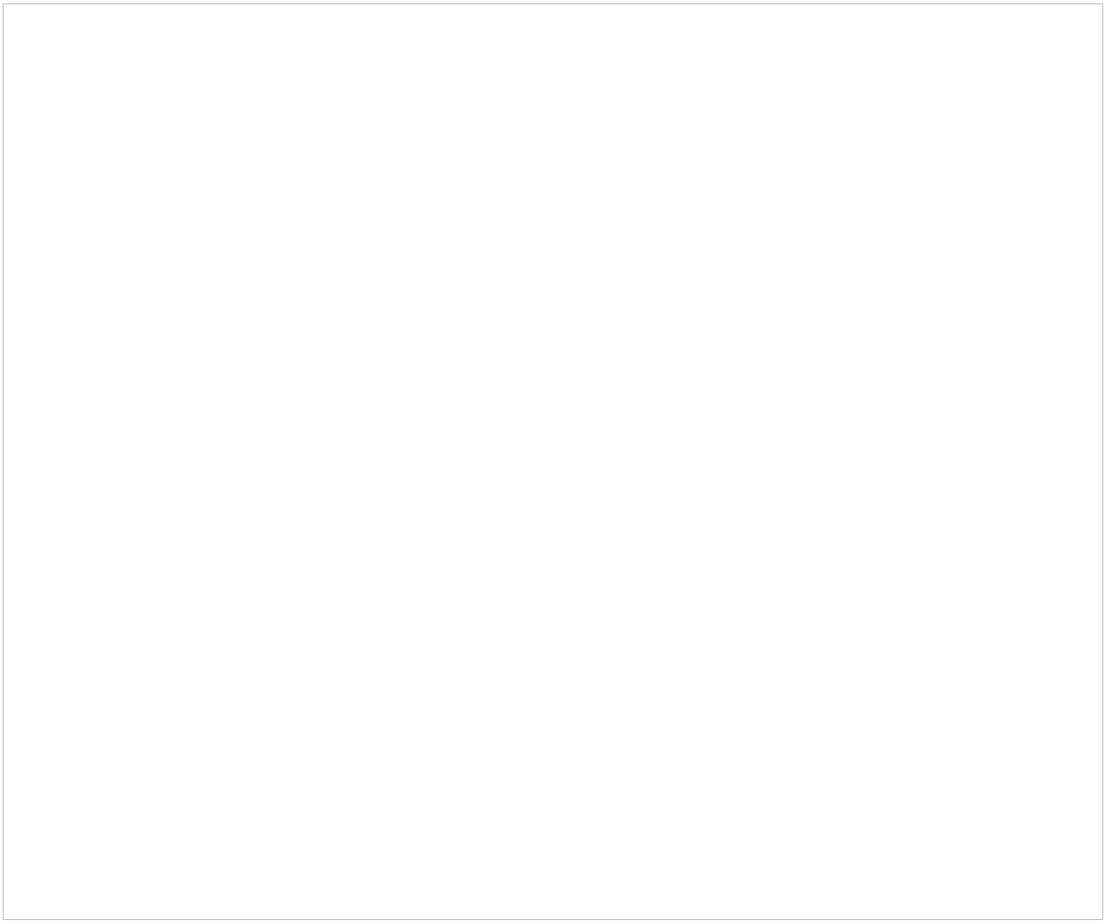


Figure 1. HAPPY 200 Reactor

Target Application

The HAPPY200 is designed for heat generating power source, dedicated to provide northern cities in China with a clean heating solution, and can be operated for 4 – 8 months each year during the winter. Its non-electric applications include sea water desalination, house cooling in summer, energy storage etc. without any need of substantial design change.

1.2 Development Milestones

2015	Start market investigation and concept design (changes)
2016	Conceptual design
2019	Start pre-project work in north of China
2024	Project suspended for the time being

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

Design Philosophy

The HAPPY200 draws on the mature operating experience of light water-cooled reactors, pool reactors and passive nuclear safety technology. Both RCS and ESF system are operated under low pressure and low temperature spectrum, and the design parameters can be fine-tuned to adapt to local civil heating requirement. HAPPY200 adopts proven technology and equipment, such as truncated fuel assembly, plate-type heat exchanger, etc. These equipments have full operational record, high reliability and high maintainability. The plant is to be built half-underground, with reactor core vessel totally submerged in a large underground pool, to elimination of external-event challenge. And 5 FP shielding and barriers are deployed to ensuring radioactivity isolation from terminal users, as well as the surrounding public. The primary safety objective of HAPPY200 design is practical elimination of core melting and technical cancellation of off-site emergency, so that the reactor can meet basic evaluation principle for heating reactor formulated by the Chinese National Nuclear Safety Administration.

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	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Non-electric (District Heating)	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	H2O	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	PWR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	H2O	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Loop-type	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced (2 pumps)	e.g. Forced (# pumps), Natural
Thermodynamic Cycle		e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H2O	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Square	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	264	e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Detailed 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	120 days/year (refuelling, plant maint., training)	# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources	60/2 units	# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design	2	n Units/Modules
Capacity to Electric Grid	0	MWe (net to grid)
Non-electric Capacity	200	e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	1150	m2 (rectangular building envelope)
Site Footprint	40000-60000	m2 (fenced area)
Emergency Planning Zone	3 for demonstration plant	km (radius)
Releases during Normal Operation	62 / 1.62 / 3.01E-5	TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed		x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	0.6	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	0.8	MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)	20000	kg
Nominal Coolant Flow Rate (primary)	1293	kg/s

Nominal Coolant Flow Rate (secondary)	1078	kg/s
Core Inlet Coolant Temperature	80	ºC
Core Outlet Coolant Temperature	120	ºC
Available Tempeature as Process Heat Source	160	ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	6000	mm
- NSSS Largest Component Diameter	2250	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	26	tonne
Reactor Vessel Material	SS316	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	11800	kg
Pressurizer Design		e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume	2.6 / 1.3	m3 / m3 (total / liquid)
Containment Type	Dry/wet pool	Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3
Spent Fuel Pool Capacity and Total Volume	30/15	Years of full-power operation / m3
Non Electric Application	District Heating	-
Core Delta Temperature	40	ºC
Fuel/Core		
Single Core Thermal Power	200	MW(th)
Refuelling Cycle	18	months or “continuous”

Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	2.76/4.45	%
Average Neutron Energy		eV
Fuel Cladding Material	Zr-4	e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	37 Fuel assemblies	Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit	400	kg
Total Fissile Loading (initial)	247	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	33	%
Core Discharge Burnup	40	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	Rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber	Gd2O3	e.g. Gd2O3
Core Volume (active)	3.5	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	Passive	- / 100 / -
- core injection	Passive	- / 100 / -
- decay heat removal	Passive	- /100 / -
- containment isolation and cooling	Passive	- / 50 / -
- emergency AC supply (e.g. diesels)	N/A	- / - / -
DC Power Capacity (e.g. batteries)	72	Hours
Events in which Immediate Operator Action is required	None	e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time	1 hours after EOP	Hours (that are assumed when following EOPs)
Severe Accident Core Provisions	No core melt	e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)	<1E-7	x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions	PARs	e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)	<1E-8	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)	18	Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort	200 PY	Person-years (PY) [DP&P]
Construction and Commissioning Effort	1500 PY	PY [C&C]
Material and Equipment Overnight Capital Cost	150	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)
- Nuclear Island (NSSS)		

- Conventional Island (Turbine and Cooling)		(20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- 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	1.92	m
Equivalent Core Diameter	1.52	m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density	57.14	MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

HAPPY200 is designed to be sited in inland areas near the targeted heating supply area centre. No special requirements to adapt with the local air temperature, humidity and other conditions. The principal structures are the reactor building, electrical building, fuel building and auxiliary building. HAPPY200 unit itself does not generate electricity. In normal operation, external power supply is required to ensure the operation of each device and system. In accident conditions, the unit can be returned to the shutdown state and take away the decay heat without relying on the external power supply by the inherent safety features and passive safety system. HAPPY200 does not discharge waste heat or require a large amount of cooling water, because the plant design adopts closed cycle. By using closed cycle, the amount of water replenished in normal operation is small and all of the heat

is supplied to the heat consumer. HAPPY200 with smaller or zero emergency planning zones (EPZ) up to only 3 km in radius is expected to be approved by the regulators.

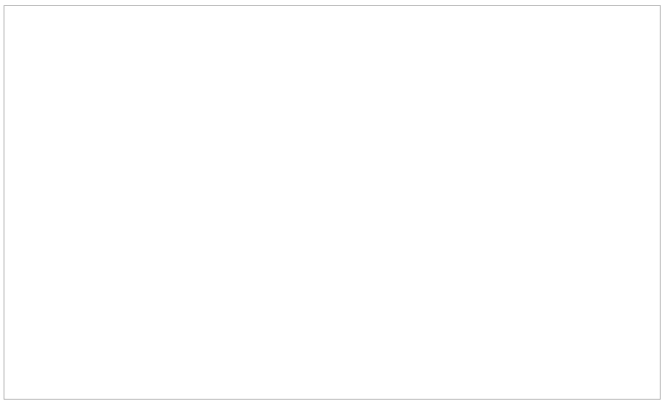


Figure 2. HAPPY200 layout

Engineered Safety System Approach and Configuration

The reactor building is used to prevent the radioactive materials escaping to the environment at the condition of LOCA accident. At normal conditions and accident conditions, it provides radiation protection and protects the internal systems from external disasters. The reactor building is mainly used to arrange reactors and other primary loop equipment, such as main pump, primary/secondary heat exchanger, pressurizer, shielding pool, timeless air-cooling system, chemical and volume control system, equipment cooling water system, NI ventilation and air conditioning system, etc.

Electrical building

The electrical building is mainly used to arrange power distribution equipment, instrumentation and control equipment, main control room, battery, ventilation system, fire protection system, and so forth.

Fuel building

The fuel building is mainly used for equipment layout and operation of fuel handling, transportation and storage systems. It is also used to arrange pool cooling and purification system, ventilation and air conditioning system, chemical and volume control system, etc.

Auxiliary building

The liquid waste treatment system is performed at the auxiliary building. The system includes the radioactive liquid waste recovery system, nuclear sampling system, exhaust gas treatment system, and nuclear auxiliary building ventilation system.

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

Primary Circuit

During normal operation, the 80ºC inlet water enters into the core from the bottom, and the water is then heated to a temperature of 120ºC. The outlet water enters the 2 hot legs and then enters four separate primary heat exchangers. Inside the primary heat exchanger, the primary water is cooled to 80ºC by the secondary side water. The water flowing through the primary exchangers enters 2 cold legs separately. The water then flows down to the bottom and enters the core again. No boiling will occur during normal operations.

Figure 3. Primary circuit

Reactor Core and Fuel

The core of the HAPPY200 consists of 37 fuel assemblies. Each fuel assembly is 2.1 m long and its design is modified from a standard 17×17 PWR fuel assembly with 264 fuel rods. The fuel is UO2 with Gd as a burnable absorber. The 235U enrichment is below 5%. The reactor operates 180 days per year (typical 6-month winter period in northern China) and a three-batch refuelling is conducted off power on an 18-month refuelling cycle.

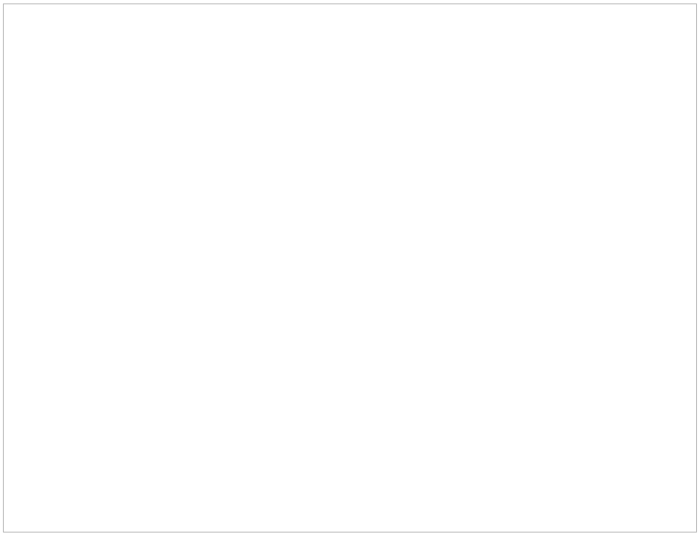


Figure 4. Reactor core

Secondary Side

The secondary coolant system is an isolated sealed intermediate loop that separates the primary loop and the third loop while transfer heat from the primary to the third. The pressure of the secondary loop is designed to be higher than that of the primary loop, so there is no chance that the radioactive primary side water could contaminate the third loop.

Reactivity Control

HAPPY200 uses 21 control rod clusters to provide enough reactivity compensating capacity, with magnetic force type and hydraulic force type control rod driving mechanism (CRDM). No chemical shim (e.g. Boron) is used for reactivity control. HAPPY200 blends a lot of gadolinium oxide in fuel rods. Because there is non-soluble boron in the core, the reactor is operated by shifting control rods to maintain criticality.

Reactor Pressure Vessel and Internals

The reactor pressure vessel is submerged inside the large water pool, isolated from the pool during normal operation and other conditions, RCS is connected to pool only if the RCS is depressurized and need injection of cooling water from the pool.

Instrumentation and Control Systems

The instrumentation and control (I&C) system provides the capability to monitor, control and operate plant systems. The I&C system is implemented using mature technology based on high economy.

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 HAPPY200 reactor system is in general designed based on proven technology and method. The spectrum of reactor core and coolant temperature and pressure is decreased consequently both under the normal operation and accident conditions, which resulted in larger thermal margin compared to conventional LWR design criteria, as well as possible cooling and flooding of reactor core accessible to low pressure system, as part of ESF features. To date, 3 important test facilities, one for secondary reactor shutdown system validation testing and one for engineering design validation of PFB and PHR system, and in addition, a large steel containment for validation of PAC system has been built and ready for performing of validation test. Besides, a test for critical heat flux of truncated fuel assembly is also planed for near-term construction.

Design and Licensing Status

HAPPY200 has completed conceptual design. Preliminary design is underway. The commercial demonstration project is carrying out preliminary work of the project, and the site selection and preliminary feasibility analysis have been completed. HAPPY200 meets regulatory requirements for design and licensing in most countries. The first project has completed the site selection and preliminary feasibility analysis report review. The next step will submit site safety assessment report and site stage environmental impact assessment report to the Chinese regulatory authorities.

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

7. Safety Concepts

SUMMARY FOR BOOKLET

The primary safety objective of HAPPY200 design is practical elimination of core melting and technical cancellation of off-site emergency. To achieve this safety objective, the safety concept of HAPPY200

is based on inherent safety features, the defence in depth principle, the use of passive systems to prevent accidents and mitigate their consequences, and multi-barriers to the release of radioactive materials into the environment.

Engineered Safety System Approach and Configuration

HAPPY200 has many characteristics including low temperature, low pressure parameters, high thermal safety margin, negative power reactivity, simplified engineered safety features (ESF), etc. And the system uses passive cooling system and anti-seismic system. The safety systems of HAPPY200 consist of: redundant shutdown system, passive feed-bleed system (PFB), passive residual heat removal system (PHR), passive pool air cooling system (PAC), etc. These systems could maintain core integrity through the plant lifetime.

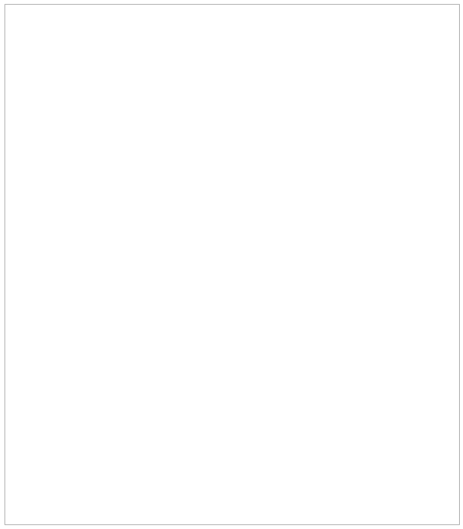


Figure 5. Engineered Sasafety features.

Decay Heat Removal System

The passive residual heat removal system is designed to remove the residual heat from the reactor core during unexpected operational occurrences and events, especially for the non-LOCA events. It consists of two series vertical tube heat exchangers connected with the hot legs and cold legs of each loop. The passive residual heat removal mode is provided by the natural circulation of the coolant in primary circuit through the heat exchangers, which use the large capacity pool water as the heat sink. The heat sink capacity is adequate to passively cool down the reactor and prevent hazardous superheating of the core.

Emergency Core Cooling System

Pool water heat sink is used for emergency core coolant injection and residual heat removal.

Containment System

The containment of HAPPY200 is a steel shell type, acting as the last barrier of fission product. It also partially functioned as heat removal sink to environment during normal operation and accident condition.it is partially deployed underground. A total of 5 safety barriers: fuel pellet, fuel cladding, primary circuit system, large volume shielding pool and steel containment.

Plant Safety and Operational Performances

HAPPY200 unit itself does not consider generating electricity. In normal operation, external power supply is required to ensure the operation of each device and system. In accident conditions, the unit can be returned to the shutdown state and take away the decay heat without relying on the external power supply by the inherent safety features and passive safety system.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

Because in the north of China, heating system is required to work about six months in a year, the HAPPY200 reactor should be operated about 18 months in the 3-year cycle, the reactor should be shutdown for six months every year. However, there is no need for refuelling in one cycle for 3 years. The enrichment of uranium used by HAPPY200 is less than 5%, and the average discharge burnup of fuel assemblies is about 40 GWd/tU.

Waste Management and Disposal Plan

After spent fuel discharge from the reactor, it is stored on plant site and then cooled and decrease in radioactivity for some years. Once-through fuel cycle option is considered after plant site decommissioning. Spent fuel leave at safety level and transfer to specific disposal site.

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