Status Report – HAPPY200 (SPIC)
People's Republic of China **2019/10/1**

Advanced low-Pressurized and Passive SafetY system – 200 MWt
This reactor design is a new concept with a projected earliest deployment (start of construction) time of 2021.

The reactor has a net power output of 200 MWth.

INTRODUCTION

Indicate which booklet(s): [ ] Large WCR [√] SMR [ ] FR

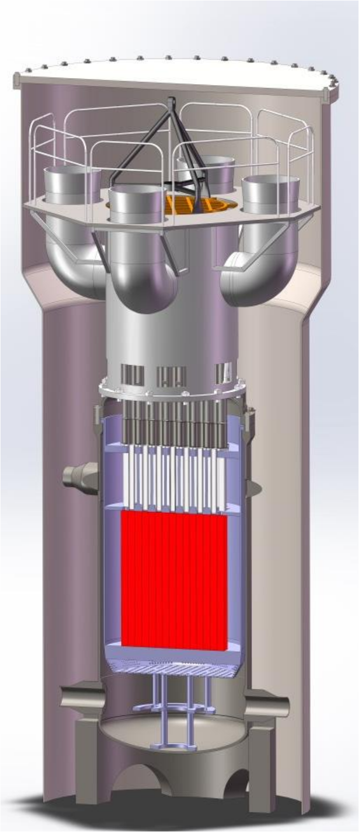
The Heating-reactor of Advanced low-Pressurized and Passive SafetY system – 200 MWt(HAPPY200) is a so called pool-loop combined type reactor, which has both features of swimming pool reactor and PWR to some extent. The HAPPY200 operates under low temperature and low pressure in in the closed primary circuit boundary with forced circulation mode. All engineering safety systems operate in a passive mode and can last at least for 1 month after accident without any active intervention, by take advantage of external cold air as the ultimate heat sink Large inventory water pool is incorporated to enhance its safety and reliability under postulated accident conditions. Significant design features include: Inherent safety; good economy; proven technology; easy decommission. Due to the high reliability and inherent safety features, HAPPY200 can be deployed in the vicinity of the targeted heating supply district or community with high population density.
The HAPPY200 is dedicated to provide northern China city with a clean heating solution, and can be operated for 4-8 month each year in the winter, its application can also be extended to sea water desalination, house cooling in summer, energy storage etc. without consequent design change.

Development Milestones

2015	Start of market investigation and concept design (changes)
2016	Concept design completed
2019	Start of pre-project work in CHINA
2022	expected to Start construction of a first proto-type NPP in CHINA
2024	expected commissioning and Commercial operation

Design organization or vendor company (**e-mail contact**): chenyaodong@spic.com.cn

Links (www.spic.com.cn) to designer/vendor homepage:



Abbreviations

HAPPY200	Advanced low-Pressurized and Passive SafetY system – 200 MWt
NPP	Nuclear Power Plant
SMR	Small Modular Reactor
PWR	Pressurized Water Reactor
RPV	Reactor Pressure Vessel
CDF	Core Damage Frequency
LRF	Large Release Frequency
BOP	Balance of Plant
CRDM	Control Rod Driving Mechanism
PFB	Passive Feed-Bleed System
PHR	Passive Residual Heat Removal System
PAC	Passive Pool Air Cooling System
HE	Hydrogen Elimination System
RCS	Reactor Coolant System
LOCA	Loss of Coolant Accident
SBO	Station Black Out
SAMG	Severe Accident Management Guidelines
BP	Burnable Poison
HEX	Hot Excess Reactivity
I&cC	Instrumentation and Control
FCD	First Concrete Date

Table 1: ARIS Category Fields (see also Spreadsheet "Categories") for Booklet

ARIS Category	Input	Select from
Current/Intended Purpose	Commercial – Non-electric, Demonstration	Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Civil heat-supply	Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Dual Unit	Single Unit, Dual Unit, Multiple Unit (# units)
Reactor Core Size (1 core)	Small	Small (<1000 MWth), Medium (1000-3000 MWth), Large (>3000 MWth)
Reactor Type	PWR	PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Core Coolant	H_2O	H_2O, D_2O, He, CO_2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Neutron Moderator	H_2O	H_2O, D_2O, Graphite, None, (Other-specify)
NSSS Layout	Loop-type	Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced (2 pumps)	Forced (# pumps), Natural
Thermodynamic Cycle	n/a	Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H_2O	H_2O, He, CO_2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly	Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Square	Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	264	#, n/a
Fuel Material Type	Oxide	Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Detailed	Conceptual, Detailed, Final (with secure suppliers)
Licensing Status	DCR	DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In

Table 2: ARIS Parameter Fields (see also Spreadsheet "Data") for Booklet

ARIS Parameter	Value	Units or 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	n/a	MWe (net to grid)
Non-electric Capacity	200 MWth	e.g. MWth heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption	2 MWe	MWe
Plant Footprint	1150	m^2 (rectangular building envelope)
Site Footprint	40000-60000	m^2 (fenced area)
Emergency Planning Zone	3 for demonstration plant	km (radius)
Releases during Normal Operation	62 / 1.62 / 3.01E10-5	TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed	40- 110	x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary/secondary)	0.6 MPa /0.8 MPa	MPa(abs), i.e. MPa(g)+0.1, at core/secondary outlets
Primary Coolant Inventory (incl. pressurizer)	20000	kg
Nominal Coolant Flow Rate (primary/secondary)	1293/1078	kg/s
Core Inlet / Outlet Coolant Temperature	80/120	ºC / ºC

ARIS Parameter	Value	Units or Examples
Available Temperature as Process Heat Source	160	ºC， by employing technology of thermal pump
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- dimensions	4.5 / 2.4 / 26000	m (length) / m (diameter) / kg (transport weight)
Reactor Vessel Material	SS316	e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design	n/a	e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory	11800	kg
Pressurizer Design	separate vessel, steam pressurized	e.g. separate vessel, integral, steam or gas pressurized, etc.
Pressurizer Volume	2.6 / 1.3	m^3 / m^3 (total / liquid)
Containment Type and Total Volume	Dry/wet pool	Dry (single/double), Dry/Wet Well, Inerted, etc. / m^3
Spent Fuel Pool Capacity and Total Volume	30/15	years of full-power operation / m^3
Fuel/Core		
Single Core Thermal Power	200	MWth
Refuelling Cycle	18	months or “continuous”
Fuel Material	UO_2	e.g. UO_2, MOX, UF_4, 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 FAs	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	n/a	applicable to online refuelling and molten salt reactors

ARIS Parameter	**Value**	**Units or Examples**
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 Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing	None	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	Gd_2O_3	e.g. Gd_2O_3,
Core Volume (active)	3.5	m^3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary		N/m^2s
Max. Fast Neutron Flux		N/m^2-s
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	2/100 passive	/
- core injection	2/100 passive	/
- decay heat removal	2/100 passive	/
- containment isolation and cooling	2/50	/
- emergency AC supply (e.g. diesels)	0	/
DC Power Capacity (e.g. batteries)	72	hours
Events in which ***Immediate Operator Action*** is required	no	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)

ARIS Parameter	**Value**	**Units or Examples**
Severe Accident Core Provisions	No core melt	e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)	$<10^{-7}$	x / reactor-year (based on reference site and location)
Severe Accident Containment Provisions	PARs	e.g. H_2 ignitors, PARs, filtered venting, etc.
Large Release Frequency (LRF)	$<10^{-8}$	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) (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)

1. *Plant Layout, Site Environment and Grid Integration*

SUMMARY FOR BOOKLET

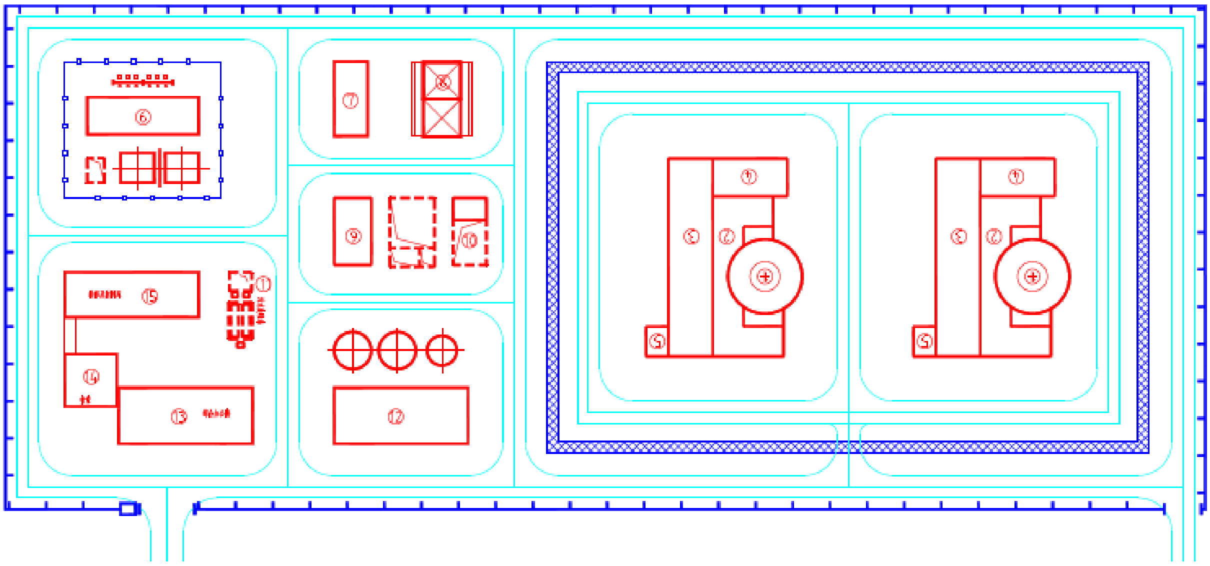
HAPPY200 has been designed to be located in inland area, near the targeted heating supply area centre. No special requirements for air temperature, humidity and other conditions. The principle structures are the reactor building, electrical building, fuel building and auxiliary building. HAPPY200 unit 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. HAPPY200 doesn't discharge waste heat, and doesn't require a large amount of cooling water, because the HAPPY200 adopts closed cycle, the amount of water replenished in normal operation is small, and all of the heat is supplied to the heat consumer. HAPPY200 near the targeted heating supply area with smaller or zero EPZ (emergency planning zones， up to 3 km in radius) is expected to be approved by regulators.

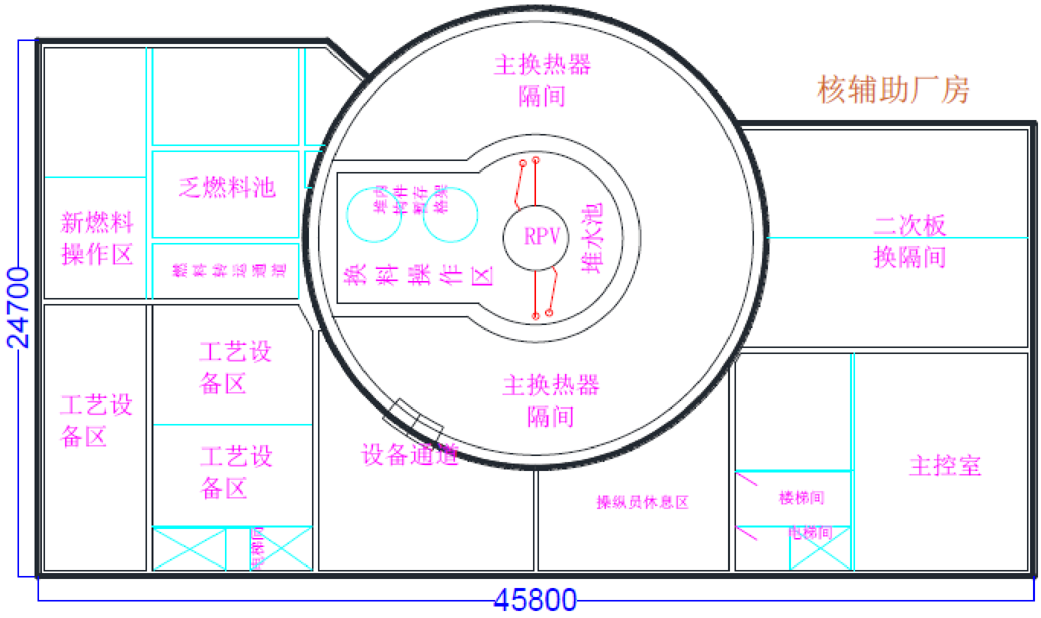
1.1. Site Requirements during Construction

HAPPY200 has been designed to be located in inland area, near the targeted heating supply area centre.

The design is available for both medium and rock site soil conditions.

The layout of the HAPPY200 is illustrated below. The principle structures are the reactor building, electrical building, fuel building and auxiliary building.





a. reactor building

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.

b. electrical building

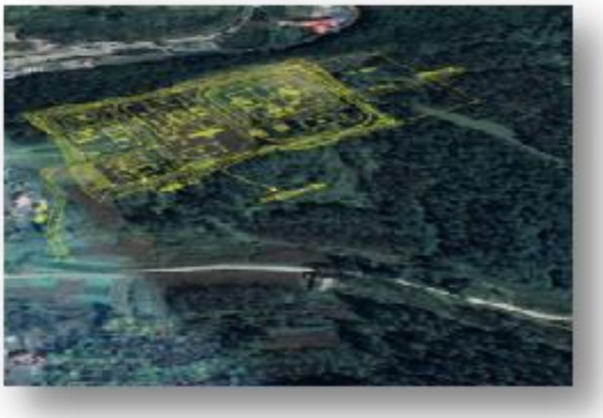
The electrical building is mainly used to arrange power distribution equipment, instrumentation and control equipment, main control room, battery, ventilation system, fire fighting system, etc.

c. 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.

d. auxiliary building

The auxiliary building is used to arrange waste liquid treatment system, radioactive waste water recovery system, nuclear sampling system, exhaust gas treatment system, nuclear auxiliary building ventilation system, etc.



1.2. Site Considerations during Operation

The HAPPY200 doesn’t discharge waste heat, and doesn’t require a large amount of cooling water, because the HAPPY200 adopts closed cycle, the amount of water replenished in normal operation is small, and all of the heat is supplied to the heat consumer.

No special requirements for air temperature, humidity and other conditions.

The operating staff needs 80 people.

No online repair required, because there are about half a year to carry out refueling inspection and maintenance at pure heating scene.

Based on analysis, the radiation emission limits are satisfied for all conditions.

HAPPY200 near the targeted heating supply area with smaller or zero EPZ (emergency planning zones) is expected to be approved by regulators.

1.3. Grid Integration

The total thermal power of HAPPY200 is 200 MWt, all heat is supplied to the heat consumer, no thermoelectric conversion unit, no external transmission. It need two power input to ensure the normal operation of the unit. The power input system uses two power levels: high voltage and low voltage, according to the location of the site, the condition of the electrical equipment and the economy.

HAPPY200 is capable of load following at different phase of whole heating period.

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.

Heat capacity per unit is 3,000,000 GJ. Heating area per unit is 5,000,000~7,000,000 m2. Heat network inlet/outlet temperature is 110/50 °C.

2. *Technical NSSS/Power Conversion System Design*

SUMMARY FOR BOOKLET

- Primary Circuit

During normal operations, the 80°C inlet water enters the core from the bottom, and the water is then heated to a temperature of 120°C. 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 80°C 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.

- 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 percent. 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.

- Fuel Handling

The fuel handling system of HAPPY200 is modified from traditional PWR and with familiar handling procedures.

- Reactor Protection

Core reactivity is controlled by control rods under operating and load following conditions. The soluble boron tanks are used only under necessary accident conditions. The burnable absorber Gd is used for suppressing the excess reactivity. And there is no conventional boron system and the dilution operation.

- 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 will contaminate the third loop.

- Containment/Confinement

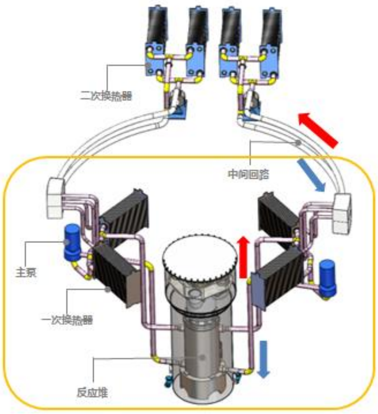
The containment of HAPPY200 is a steel type with cylinder body and 2 hemi-spheric bottom head. And the steel containment can be cooled by air circulation at certain conditions. But the water pool located in the containment lower part, is the main heat sink at the early stage of accident conditions. The inventory in the water pool can maintained at subcooled state for at least 3 days, and fulfill core cooling and flooding capability for at least30 days after an accident without active or manual intervention.

- Electrical, I&C and Human Interface

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 and economical technology.

2.1. Primary Circuit

During normal operations, the 80℃ inlet water enters the core from the bottom, and the water is then heated to a temperature of 120℃. 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 80℃ 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.

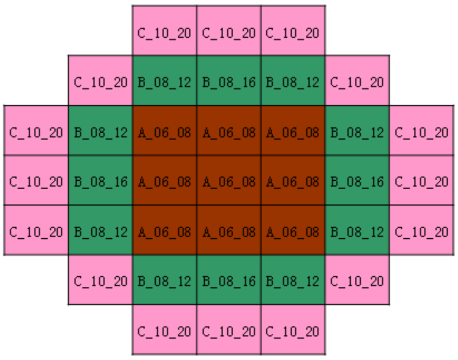


2.2. Reactor Core and Fuel

The HAPPY200 reactor core consists of 37 fuel assemblies, loaded in a 21.5 cm square pitch octant mirror-symmetric configuration and designed to meet the energy requirements of three years of heat generation in a fuel cycle. Each fuel assembly consists of 264 fuel rods with a 192 cm core active zone and 1.26 cm fuel pitch.

Core thermal power is rated at 200 MW. The HAPPY200 reactor should be operated about 18 months in one cycle, if the reactor should be shutdown for six months every year, there is no need for refueling 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.

Fuel assembly of HAPPY200 is similar to fuel assembly used by conventional nuclear power plant, the biggest difference is active length of fuel assembly used by HAPPY200 is shorter, so it is not a big challenge to supply. There are severial fuel suppliers have the ability to supply fuel for HAPPY200.



		C_10_20	C_10_20	C_10_20		
	C_10_20	B_08_12	B_08_16	B_08_12	C_10_20	
C_10_20	B_08_12	A_06_08	A_06_08	A_06_08	B_08_12	C_10_20
C_10_20	B_08_16	A_06_08	A_06_08	A_06_08	B_08_16	C_10_20
C_10_20	B_08_12	A_06_08	A_06_08	A_06_08	B_08_12	C_10_20
	C_10_20	B_08_12	B_08_16	B_08_12	C_10_20	
		C_10_20	C_10_20	C_10_20		

2.3. Fuel Handling

Brief Description, main components

The fuel handling system is basically similar to the one in pool type research reactor. A remarkable feature is that a water-free cylinder is designed to be laid around the reactor pressure vessel (RPV). It prevents the water in the shielding pool from discharging into RPV. Otherwise it may result in the damage of I&C device of the reactor. During refueling operations, the reactor must be shut-down. Some fuel in the reactor core may be replaced by fresh fuel. The reactor vessel must be disassembled before fuel loading. The fuel is discharged from the reactor core into a spent fuel pool located outside the containment.

Fuel handling system comprise a fuel storage facility configured to store a number of fuel assemblies, and a transport apparatus configured to transport fuel assemblies to the fuel storage facility.

Fuel movement from fresh to spent fuel bay

The reactor shielding pool contain water stored below ground level. In the refuelling modes, water-free cylinder may be at least partially removed after RPV upper head disassembled. Then RPV must be fully submerged into the pool in order to keep any I&C connections and/or penetrations through the upper head dry. Some fuel may be removed from core and replaced by fresh fuel after useful lifetime is completed. Passageway may connect reactor bay to a spent fuel pool and/or to a dry dock. Fresh and spent fuel can be moved from fuel storage facility by the passageway.

Fuel cycle and refuelling outage lengths

The reactor may be refueled higher frequently It can be kept at full power operation for 18 months and meet the basic refueling requirement for about 3 years in one cycle. HAPPY200 is designed for district-heating and have no refuelling outage.

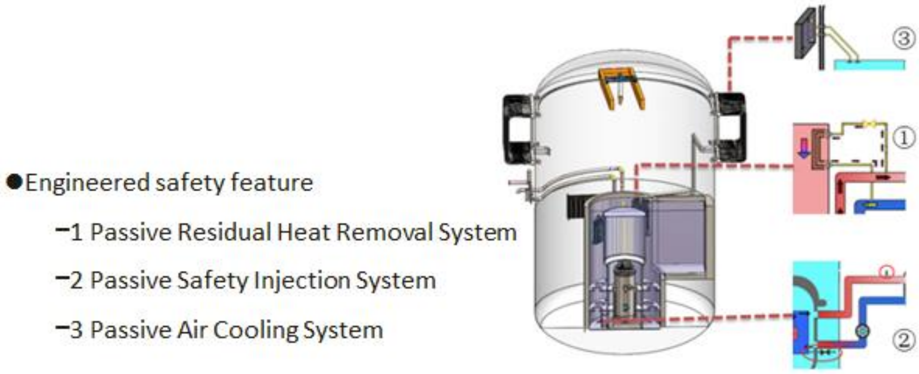
2.4. Reactor Protection

Core reactivity and shutdown

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.

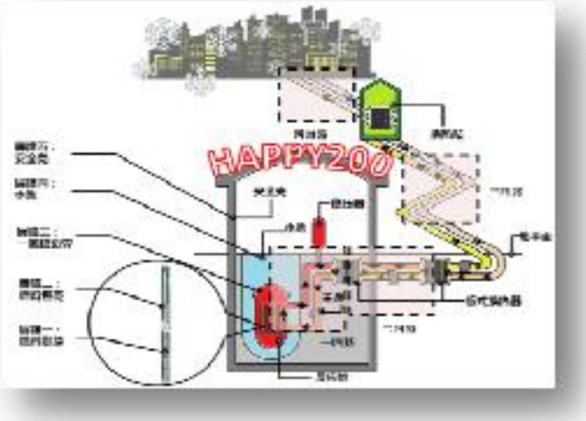
Core integrity

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 life time.



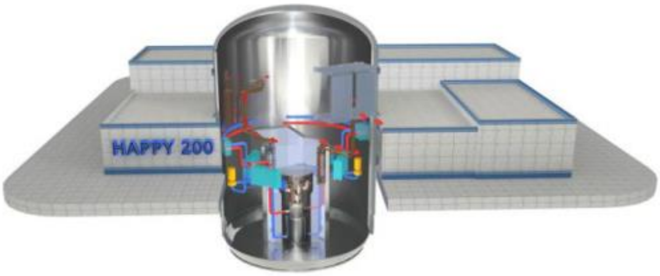
Fission product retention

There are five barriers of fission product, which provides fission product retention in the event of an accident; they are fuel pellet, fuel cladding, primary circuit pressure boundary, shield cooling pool and containment. 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.



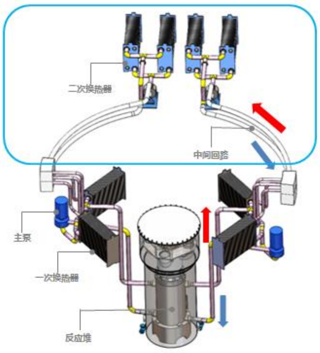
External hazards detection

The primary circuit pressure boundary is fully deployed underground .The containment is partially embedded, with half of the total height located below grade. These designs could maximize provide protection against external hazards, such as aircraft impact and tsunami.



2.5. 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 will contaminate the third loop.



2.6. Containment/Confinement

Description/Type

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.

Dimensions

The diameter of containment is 20 meter, its height is about 35 meter. It has the total free volume of about 3000 cubic meter, besides, there is a large cooling pool located inside the containment lower part, which has a water inventory of around 1000 cubic meter.

Design pressure/temperature/leak rate at design pressure

Design pressure of containment boundary is 0.25 MPaa, design temperature is 400 K, leak rate at design pressure is 1% of total volume of containment/ day

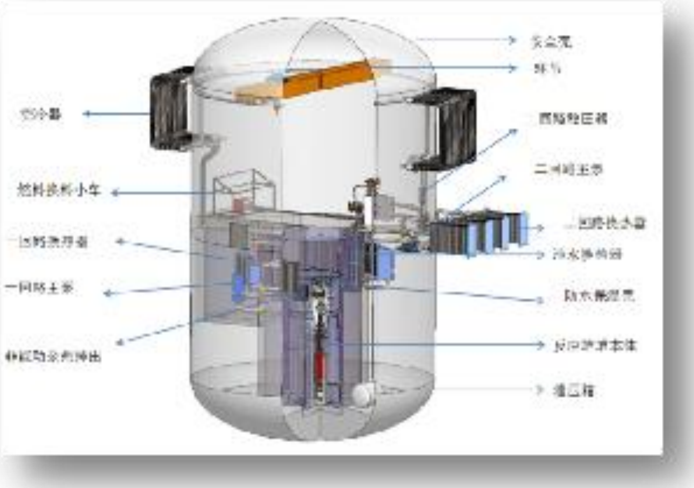
Isolation and fission product retention (including venting/filters)

The containment isolation measures and actions is considered in the design(mechanical penetration parts), during specific accident conditions and operation conditions, the containment isolation should be executed, to prevent possible transport of radioactive materials to outside of containment. Due to the inherent safety feature of the safety related system, there is no emergency filter venting system considered in the design.

Heat removal systems

The passive pool air coolingsystem(PAC) execute the ultimate heat removal function. It has 2 trains, each has the capacity to remove about 500 kw of decay heat at design condition. Part of the system, each of the 2 tube-type air coolers is assigned on top part of containment wall, and each of 2 circulation loops should penetrate into containment, connected with a tube-heat exchanger, which is submerged into the upper zone of shielding and cooling pool, and kept operated when the containment thermal-hydraulic condition is met(f.e. SCP saturated or containment pressure reach set value). The residual heat in the containment pool and air is removed through the natural circulation of coolant inside the cooling circuit.

Besides, the containment shell also act as heat removal interface during both normal and accident condition.



2.7. Electrical, I&C and Human Interface

Each relevant load of each channel of reactor protection system is set as level 1E level. Considerving the redundancy, there are two independent lines for power supply. For the safety related systems, emergency auxiliary bus power supplies are prepared.

The overall structure of the I & C system is divided into the following four layers according to functions: the "field layer", "control layer", "unit layer" and "whole plant layer".

The design principles to be considered for the I&C system are as follows:

- Defense in depth principle;
- Single failure criterion;
- Diversity design of I &C system;
- Control priority and switching;
- Hierarchical organizational structure.

The safety level nuclear instrument system and safety level process instrument system are composed of totally independent triple redundant channels. The logic processing part of reactor scram adopts three channels, while the logic processing part of special safety facility drive system, special safety facility and its support system adopts two trains A and B. Complete physical and electrical isolation between three channels, between two columns, and between channels and columns.

In order to prevent the influence of software common mode fault on the whole system, various measures are adopted in the instrument system and drive system. For example, the protection parameters are grouped reasonably and processed by different subsystems respectively. The fault of any subsystem will not affect the implementation of the function of the reactor protection system. At the same time, a variety of protection systems (using different control platforms from the protection system) are set to deal with common mode fault of the protection system software.

2.8. Unique Technical Design Features (if any)

1) All plant thermal system operated at low pressure level, especially the reactor and primary system operated at low temperature and low pressure, to avoid degrade of heat quality from high quality enthalpy steam to lower level, as well as make the system simplified and safer and high economy performance.

2) The reactor pressure vessel is submerge 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.

3) Instead of SGs,4 plate type heat exchangers are employed as the interface of primary and secondary heat transfer, heat transfer from core to urban heating network is realized through water-water heat transfer.

4) The primary system is deployed underground in the containment, which partially buried and sit on the base rock.

5) The engineering safety system is kept operated and circulated in passive mode at a indefinite time scale, by take advantage of nature forces and indefinite air cooling capability.

3. *Technology Maturity/Readiness*

SUMMARY FOR BOOKLET

HAPPY200 draws on the mature operation experience of light water cooled reactors, pool reactors and passive nuclear power technology. It adopts mature design and safety assessment. HAPPY200 basically adopt mature equipment, such as shorten fuel assembly, plate heat exchanger. This equipment has full operational experience, high reliability and high maintainability. 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.

3.1. Reactors under Licensing Review

HAPPY200 meets regulatory requirements for design and licensing in most countries

HAPPY200 draws on the mature operation experience of light water cooled reactors, pool reactors and passive nuclear power technology. It adopts mature design and safety assessment.

The first unit construction period is 18 months. Batch construction period is no more than 16 months.

HAPPY200 basically adopt mature equipment, such as mature shorten fuel assembly, plate heat exchanger, etc. This equipment has full operational experience, high reliability and high maintainability.

4.

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.

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.

5. *Safety Concept*

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, use of passive systems to prevent accidents and mitigate their consequences, and a system of barriers to the release of radioactive materials into the environment.

The inherent safety characteristics include rather low primary coolant pressure and temperature and power density, rather large reactivity feedback coefficient and thermal margin, reactor auto-shutdown, relatively single physical phenomena. Normal operation systems and safety systems are required to perform reactivity control, core cooling and confinement of radioactive materials in the required limits.

HAPPY200 uses completely passive systems to perform safety functions such as: gravity driven insertion of the control rods in the core as reactor safety control system, automatic depressurization system and pool water heat sink for emergency core coolant injection and residual heat removal, air heat sink for pool water cooling and core long term cooling.

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) and the large containment. The passive feed-bleed system consists of Automatic Depressurization System (ADS) and Passive Coolant Injection system.

Expert judgment and safety analysis of postulated accidents has been conducted for the reactor design and optimization. During the accidents, the system is depressurized by the ADS and the passive safety injection system will guide enough emergency cooling water from the large capacity pool, and the decay heat will be removed by PHRs and PACs indefinitely. In other words, there is no need for operator action. The safety systems will keep the reactor safe for at least a month.

5.1.Safety Philosophy and Implementation

The primary safety objective of HAPPY200 design is practical elimination of core melting and technical cancellation of off-site emergency, so that the reactor could meet the basic evaluation principle for heating reactor formed by the Chinese National Nuclear Safety Administration. To achieve this safety objective, the safety concept of HAPPY200 is based on inherent safety features, the defence in depth principle, use of passive systems to prevent accidents and mitigate their consequences, and a system of barriers to the release of radioactive materials into the environment.

Normal operation systems and safety systems are required to perform reactivity control, core cooling and confinement of radioactive materials in the required limits. Due to the low primary coolant pressure and temperature and power density, the thermal margin is large, not only at initial load but also at the end of life and during load following.

Redundancy of safety system equipment and channels and their functional and/or physical separation are provided to ensure high reliability. Safety systems are driven automatically by the control system, when controlled parameters achieve appropriate set points.

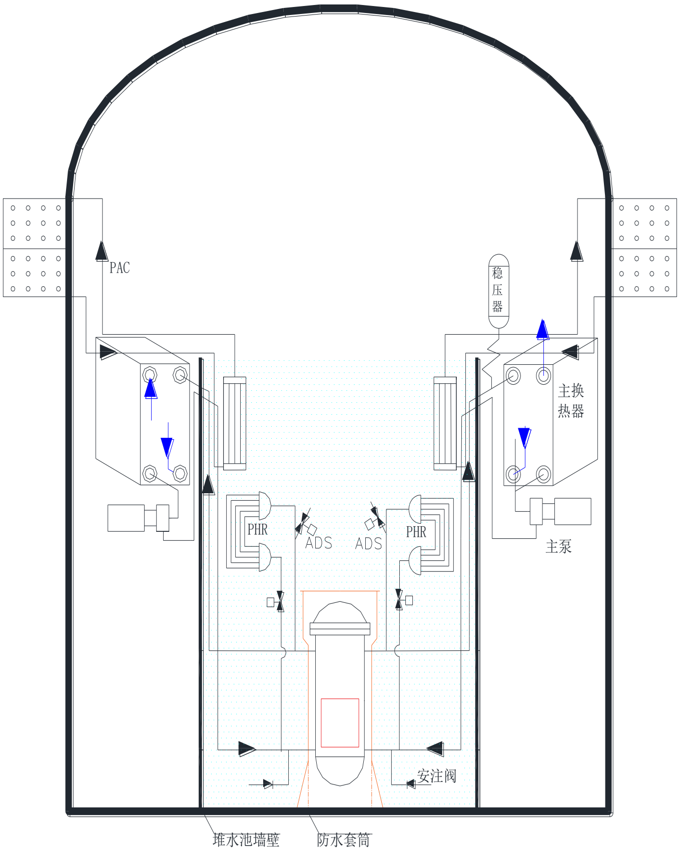
HAPPY200 uses completely passive systems to perform safety functions such as: gravity driven insertion of the control rods in the core as reactor safety control system, pool water heat sink for emergency core coolant injection and residual heat removal, automatic depressurization system and air heat sink for pool water cooling and core long term cooling. As a result, the safety systems are simplified.

Active and passive systems as well as inherent safety features; indication of whether the system is the main or backup system; level of passivity (“A” - “D”)

The inherent safety characteristics include rather low primary coolant pressure and temperature and power density, rather large reactivity feedback coefficient and thermal margin, reactor auto-shutdown, relatively single physical phenomena.

There is no need for operator action. The safety systems will keep the reactor safe for at least a month.

There are five barriers to maintain the radiation. They are the fuel pellet, the cladding, primary system, the large capacity pool and the containment. Besides, considering the implementation of ALARA and International Commission of Radiological Protection (ICRP) standards, the pressure of secondary system is higher than the primary system.



5.2. Transient/Accident Behaviour

Expert judgment and safety analysis of postulated accidents has been conducted for the reactor design and optimization. During the accidents, the system is depressurized by the ADS and the passive safety injection system will guide enough emergency cooling water from the large capacity pool, and the decay heat will be removed by PHRs and PACs indefinitely. In particular, this was shown in the limiting DBA, a guillotine break of cold leg and severe accidents.

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) and the large containment.

Passive Residual 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. It is sufficient to passively cool down the reactor and prevent hazardous superheating of the core.

Passive Feed-Bleed System

The passive feed-bleed system consists of Automatic Depressurization System (ADS) and Passive Coolant Injection system. The automatic depressurization system prevents the overpressure of the primary system and enhances the pool water injection through depressurization. The passive coolant injection system is designed to supply emergency core cooling with pool water during accidents with loss of the primary circuit integrity. The system uses passive principle of action to organize the coolant movement. The emergency mitigation of the primary coolant loss is ensured passively by draining water from the large capacity pool into the reactor due to the pressure head.

Passive Pool Air Cooling System

When the pool water level is reduced due to the evaporation or other causes, the passive pool air cooling system will be actuated to cool the pool water. It consists of two closed loops, each loop containing an external air cooler and an in-pool heat exchanger. The coolant in the system gets heated by the pool water and condenses in air cooled heat exchangers and flows back to the in-pool heat exchangers. The system uses the coolant natural circulation to cool the pool and the containment. After complete water evaporation of the pool, the air-cooled exchangers continue to provide cooling for unlimited time. Combination of air and water heat exchangers allows minimizing dimensions of the heat exchangers and maximizing the driving head.

Large Capacity Pool

The large capacity pool consists of the reactor pressure vessel, hot and cold legs, control and protection system and a large amount of water. The big amount of water in the reactor pool ensures the reliable heat transfer and provides the isolation from the primary system. During normal operation, it will provide radiation shielding, while during the accident condition, it act as a heat sink, ensuring core flooding and residual heat removal.

Containment System

HAPPY200 adopts a cylindrical/spherical containment system with the carbon steel shell to localize possible radioactive release. It is designed to withstand all stressors induced by all credible accident scenarios, including aircraft crashes and flooding. The containment of 20m in diameter and 35m in height provides space for condensing the steam generated from the large LOCAs

In addition, although the risk of core damage has been practically eliminated for HAPPY200, it is still assumed that the core may be partially overheated under some DEC conditions, and hydrogen may be generated. As a result, a hydrogen elimination system (HE) is designed and provided in a large space inside the containment, which is composed of several sets of passive hydrogen combiners.

Besides, the reactor dedicated pressure relief system, the reactor additional water supply system, the shielded cooling pool water supply system, the containment emergency filtration and discharge system , the hydrogen elimination system (HE) are the additional defence in-depth safety measures for dealing with beyond design basis accidents. When the design basis accident is further upgraded to the design extended condition, the operator can start the single system or jointly start multiple systems to ensure of the long-term effective cooling of the core and the containment integrity.

The safety goal is the CDF below 10-7 per year and the LERF below 10-8 per year, and there is no need for operator action for at least one month. However, the probabilistic risk assessment is still under way.

The whole reactor is seated in the water pool while the pool is put underground inside the containment. These designed helps to cope with the external events, e.g. Seismic, fire, flooding, aircraft impact.

6. *Fuel and Fuel Cycle*

SUMMARY FOR BOOKLET

Heating-reactor of Advanced low-Pressurized and Passive safetY system (HAPPY200) was designed for heat generating. The HAPPY200 reactor core consists of 37 fuel assemblies, loaded in a 21.5 cm square pitch octant mirror-symmetric configuration and designed to meet the energy requirements of three years of heat generation in a fuel cycle. Each fuel assembly consists of 264 fuel rods with a 192 cm core active zone and 1.26 cm fuel pitch. Core thermal power is rated at 200 MW. HAPPY200 should be constructed nearby cities. 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 cycle of 3 years, the reactor should be shutdown for six months every year, however, there is no need for refueling 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.

6.1.Fuel Cycle Options

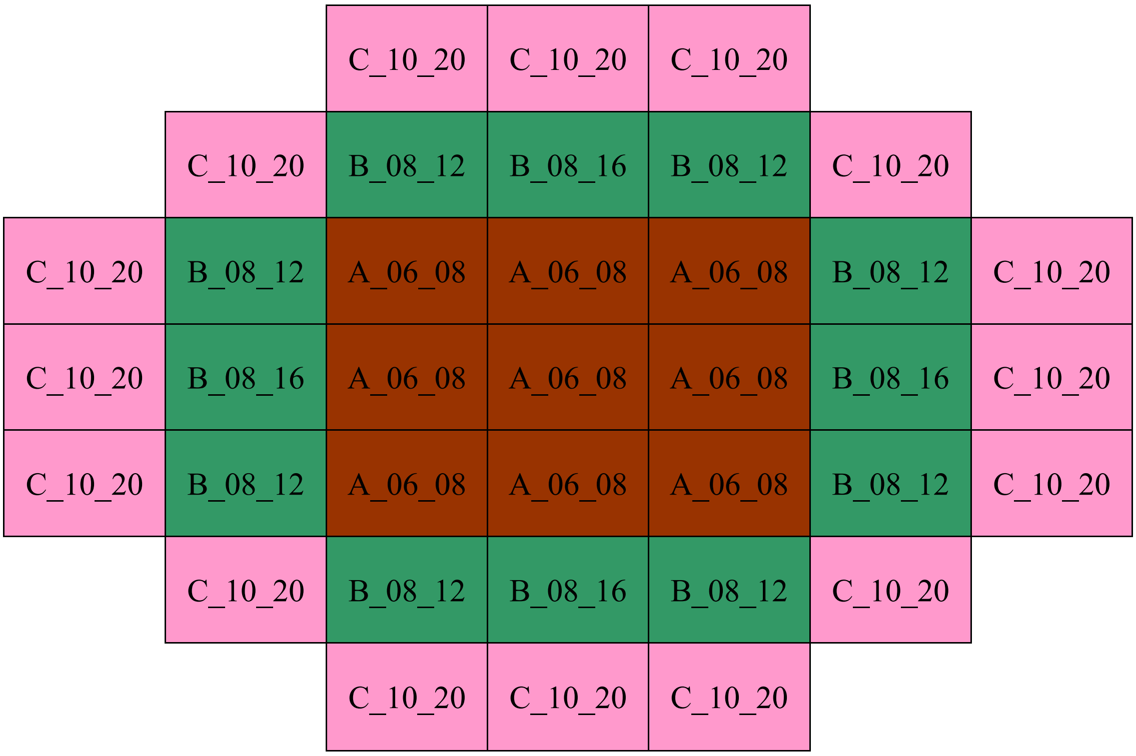
4 types of fuel assemblies are loaded in the core of the HAPPY200. The enrichment of fuel rods without burnable poison (BP) are 1.6%, 2.6%, 3.6%, the enrichment of fuel rods with BP are 1.12%, 1.56%, 1.8% respectively, in which BP is Gd2O3 mixed in the fuel pellet. The content of burnable poison in the fuel are 6%, 8%, 10% respectively. Information of the U-235 enrichment and burnable poison content of fuel assemblies is shown in Table 1.

Table 1. Fuel Assembly Information

Assembly ID	Fuel Enrichment without BP (%)	Fuel Enrichment with BP (%)	BP content (%)	Number of Fuel rods with BP
A_06_08	1.6	1.12	6	8
B_08_12	2.6	1.56	8	12
B_08_16	2.6	1.56	8	16
C_10_20	3.6	1.80	10	20

Fuel assemblies use 17×17 square array type, each fuel assembly consists of 289 pins, 264 of them are fuel elements, 24 of them are control rod guide tubes, 1 of them is central instrument tube. The active zone length of the assembly is 192 cm, the fuel pitch is 1.26 cm. In the fuel assembly containing the control rods, the control rods use silver, indium and cadmium (Ag-In-Cd) as the poison material.

The core and burnable poison loading pattern of HAPPY200 is shown in Fig.



		C_10_20	C_10_20	C_10_20		
	C_10_20	B_08_12	B_08_16	B_08_12	C_10_20	
C_10_20	B_08_12	A_06_08	A_06_08	A_06_08	B_08_12	C_10_20
C_10_20	B_08_16	A_06_08	A_06_08	A_06_08	B_08_16	C_10_20
C_10_20	B_08_12	A_06_08	A_06_08	A_06_08	B_08_12	C_10_20
	C_10_20	B_08_12	B_08_16	B_08_12	C_10_20	
		C_10_20	C_10_20	C_10_20		

Core and burnable poison loading pattern of HAPPY200 reactor

The pressure of the reactor is 0.6 MPa, and the average temperature of coolant is 100 °C, the coolant temperature of HAPPY200 is much lower than PWR of the nuclear power plant (NPP), so the density of coolant is much higher than PWR , it makes large difference from PWR of the NPP.

The HAPPY200 reactor does not use chemical shim (soluble boron) for reactivity control during normal operation, therefore, radioactive waste liquid produced by HAPPY200 would be much less than PWR which uses chemical shim. Another advantage of non-soluble boron in coolant is HAPPY200 can easily maintain a negative moderator temperature coefficient of reactivity through the cycle, although the density of coolant is much higher than PWR. 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. HAPPY200 uses 21 control rod clusters to provide enough reactivity compensating capacity

The maximum hot excess reactivity (HEX) is the amount of reactivity that must be controlled at normal full power operating conditions using control rods. Maximum HEX of HAPPY200 is 6302 pcm, which occurs at the beginning of the cycle. The overlap between control rod groups is 36 steps, one step length of control rod is 1.58 cm. The core can maintain full power operation for about 18 months, as there is about 6 months in a year to provide heat, the reactor can meet the requirement of heating for about 3 years in one cycle. The enrichment of uranium used by HAPPY200 is less than 5%,,and the average discharge burnup of fuel assemblies is about 40 GWd/tU.

7. Safeguards and Physical Security

SUMMARY FOR BOOKLET (optional)

HAPPY200 has many characteristics including low temperature , low pressure parameters, high thermal safety margin, negative power reactivity, simplified ESF(engineered safety feature), etc. And the system uses passive cooling system and anti-seismic system. A total of 5 safety barrier: fuel pellet, fuel cladding, primary circuit system, large volume shielding pool and steel containment.

During operation, an intermediate heat exchange circuit is set between the city heat network and the primary circuit. The intermediate circuit pressure is higher than the primary circuit to ensure that no radioactive material leaks into the urban heat network. Use a large pool (about 3000m3) as a large-capacity intermediate heat sink to remove residual heat into the atmosphere. The instrumentation and control (I&C) system provides the capability to monitor, control and operate plant systems.

The plant adopts double-layer factory design. The outer plant area adopts the strict security management of the conventional factory area. The inner plant area adopts stricter security measures. The nuclear island is located in the inner plant area to realize two security inspections on the nuclear island to eliminate the external threat caused by man-made.

7.1. Safeguards

7.2. Security

7.3. Unique Safeguards and/or Security Features (if any)

8. *Project Delivery and Economics*

SUMMARY FOR BOOKLET (optional)

The project is currently under the pre-pre-project status. The first demonstration plant is expected to be built in northeast of China The design has not been licensed yet. Planned commercial operation start in 2023.It is expected to be 20 months from FCD to completion of the construction and commissioning.

Demonstration project preliminary design is to be completed in 2020.12.Demonstration project PSAR is to be issued in 2021.2. FCD begin in 2022.Demonstration project construction and commissioning is to be completed in 2024.12.

More information will be kept up to date with the latest development.

8.1. Project Preparation and Negotiation

The project is based on fully self-reliant research & development and design. Therefore, there are no technology transfer issues.

Typically, some factors are considered such as the public acceptance, the political support in the long term energy strategy, the activity of safety and regulatory agencies, etc. Demonstration project is greatly supported by local government and public acceptance is high.

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.

Some factors have key impact on costs. Non full-year heating period are about 180 days. Waste stream emissions is becoming increasingly important if site locate in inland.

8.2. Construction and Commissioning

Demonstration project preliminary design is to be completed on 2020.12.

Demonstration project PSAR is to be issued on 2021.2. FCD begin in 2022.

Demonstration project construction and commissioning is to be completed on 2024.12.

Construction cost is expected to be ￥4750 CNY/kW including two units. The costs do not take into account the interest rates during construction.

Small reactor size allows to transportation by truck (as well as by rail or barge) and installation in proximity to the users. Low capital investments and short on-site construction time help to reduce costs.

8.3.Operation and Maintenance

The design life time of reactor are 60 years.

O&M costs would be lower than present PWR due to inherent and passive safety features and a long refuelling period, etc. It is expected that two units will require 50 staff. Average labour costs are ￥10 million CNY/y. The costs of materials are￥0.5 CNY/GJ.

The fuel cost is expected to be ￥2.261 million CNY per year. It need refuel every three years.

Total fuel storage costs are ￥39.537 million CNY. Either fresh or spent fuel are stored at the site during reactor operation On-site fuel storage area is located in the auxiliary buildings.

After the start-up of commercial operation, decommissioning costs are ￥6.17 million CNY per year.