Status Report - MHR-100 (Russian Federation)

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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)	87
Gross Power Output (MWe)	--

1.1 Introduction

The designs are based on the global experience in the development of experimental HTGR plants. Russia has more than 40 years of experience in the development of HTGR plants of various power (from 100 to 1000 MW) and for various purposes. It has established the experimental facilities for the R&D work, the fuel element and material fabrication technology, including the fabrication and mastering of pilot equipment, and various activities in hydrogen generation technology. Today, conventional power stations, with electric capacity ~300 MW(t), are deployed all over the territory of Russia. These are adapted to regional systems and provide the electric power needs. They consist mainly of cogeneration plants producing about 40% of electric power and 85% of heat generation. Analysis shows that SMRs with HTGR have therefore good prospects to add to or replace these regional generation. Innovative nuclear power systems to be implemented on this basis are therefore considered as an important area of the nuclear power industry development up to the middle of the century. Based on study of the power market development and demands, pre-conceptual work is performed for commercial MHR100 with modular helium reactor and several power conversion layouts for various power-industrial applications. The following options of MHR100 for industrial applications were studied:

- Electricity and district heat productions by core thermal power conversion to electric one in direct gas-turbine Brayton cycle – MHR-100 GT;
- Electricity and hydrogen generations by high-temperature steam electrolysis – MHR-100 SE;
- Hydrogen generation by steam methane reforming method MHR-100 SMR;
- High-temperature heat supply to oil refinery plant – MHR-100 OR.

The MHR-100 is intended for regional power generation and heat production in the Russian Federation. A single reactor unit design can be implemented in various plant configurations.

Major Technical Parameters of MHR-100 GT		
Parameters	Power Mode	Cogeneration Mode
Reactor heat capacity (MW)	215	215
Net power generation efficiency (%)	46.1	25.4
Helium temperature at reactor inlet/outlet (°C)	558 / 850	490 / 795
Low-pressure helium temperature at recuperator inlet (°C)	583	595
Helium flow rate through the reactor (kg/s)	139.1	134
Helium bypass flow rate from HPC outlet to recuperator outlet at high-pressure side (kg/s)	–	32.2
Helium pressure at reactor inlet (MPa)	4.91	4.93

Expansion ratio in turbine	2.09	1.77
Generator/TC rotation speed (rpm)	3000 / 9000	3000 / 9000
PCU cooling water flow rate (kg/s)	804	480
Delivery water temperature at inlet/outlet (°C)	–	70 / 145

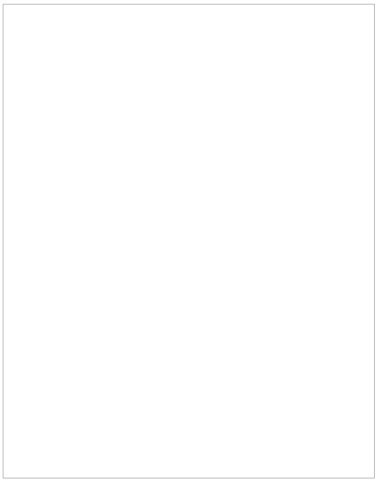


Figure 1. MHR-100 design concept

1.2 Development Milestones

2014	Conceptual design completed
2018	Feasibility study of plant application for large-scale hydrogen production
2020	MHR-100-SMR is taken as the basis for near-term development of non-electricity nuclear applications in Russia

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The reactor power and its design are universal for all the different power and process heat options with only

the coolant parameters that are different. The reactor unit power level (215 MW(t)) was selected according to: (i) the regional power industry and district heat supply needs; (ii) the manufacture needs in high- and medium-temperature heat supply for technological processes; and (iii) process capabilities of national enterprises in fabrication of RP main components including vessels.

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)	Baseload, Non-electric (heat production)	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	Hexagonal	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Conceptual Design	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# days every # months (specify purpose, including refuelling)

Operation / Maintenance Human Resources		# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design		n Units/Modules
Capacity to Electric Grid	87	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	Depends on configuration	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)	8 points (MSK 64)	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	4	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)		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	553	ºC
Core Outlet Coolant Temperature	950	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component		e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length		mm

- NSSS Largest Component Diameter		mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight		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	heat applications	-
Core Delta Temperature		ºC
Fuel/Core		
Single Core Thermal Power	215	MW(th)
Refuelling Cycle		months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	<20	%
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		MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)		MWd/kgHM
Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing		e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	control rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber		e.g. Gd2O3
Core Volume (active)		m3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary		n/(cm²*s)
Max. Fast Neutron Flux		n/(cm²*s)
Core Control Rod Absorber		-
Core Soluble Neutron Absorber		-
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Active/Passive	- / - / -
- core injection	Active/Passive	- / - / -
- decay heat removal	Active/Passive	- /- / -
- containment isolation and cooling	Active/Passive	- / - / -
- emergency AC supply (e.g. diesels)	Active/Passive	- / - / -
DC Power Capacity (e.g. batteries)		Hours

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

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Design Variants and Plant Arrangements Based on the Modular MHR-100

The modular reactor consists of the core with hexahedral prismatic fuel assemblies, uses helium as a coolant, and has inherent self-protection. The technical concept of studied reactor plant MHR-100 is based on:

- Modular high-temperature helium-cooled reactors with typical high level of inherent safety;
- Fuel cycle with fuel in the form of multilayer UO2-based coated fuel particles, high burnup and possibility to dispose the spent fuel blocks without additional reprocessing;
- High-performance high-temperature compact heat exchangers, high-strength casings of heat-resistant steel;
- Direct gas-turbine cycle with high-efficiency recuperation and intermediate coolant cooling;
- Experience in high-efficiency gas turbines application in power engineering and transport;
- Electromagnetic bearings used in power conversion system.

The coolant is circulated in the primary loops by the main gas circulator or by the power conversion unit (PCU) turbomachine (TM) compressors. The MHR-100 option consists of power and process parts. The power part is unified to the maximum for all options and is a power unit consisting of a reactor unit with a thermal power of 215 MW and a gas-turbine PCU for power generation and (or) heat-exchange units, depending on the purpose. The process part of MHR-100 is either a process plant for hydrogen production or circuits for high-temperature heat supply to various technological processes, depending on the purpose.

The unified gas-turbine PCU is planned to be used in MHR-100 GT and MHR-100 SE options. Vertical

oriented TM is the main feature of the PCU and consists of the turbo-compressor (TC) and generator with rotors, which have different rotation speed of 9000 rpm and 3000 rpm respectively. Electromagnetic bearings are used as the main supports. The generator is located in air medium outside the helium circuit. The PCU pre-cooler and intercooler are arranged around TC while the recuperator is located at the top of the vessel above the hot duct axis. Waste heat from the primary circuit is removed in the PCU pre-cooler and intercooler by the cooling water system, then in dry fan cooling towers to atmospheric air.

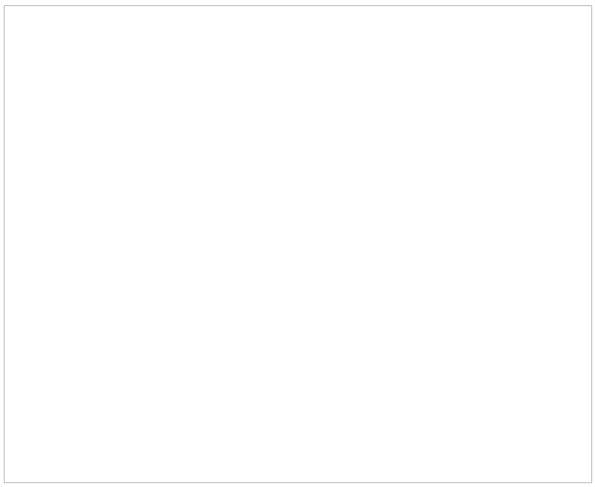


Figure 2. MHR-100 SE

Heat exchange blocks are intended to transfer heat power from the reactor to the consumer of power-technological applications. Depending on the working fluid, process type and probability of radioactivity ingress to the process product and contamination of equipment with radioactive products, two- or three-circuit RP configuration can be used. So, two circuit configurations are used in MHR-100 SE NPP for hydrogen generation and in MHR-100 SMR for steam methane reforming. Water steam is the main component of process fluid in these processes. The analysis shows that the effects of hydrogen-bearing products ingress in potential accidents with depressurization of the steam generator (SG) or high-temperature heat exchanger (HX) are reliably checked by reactor control and protection systems.

MHR-100 OR-based power source for heat supply to petrochemical applications and oil refinery plants has three-circuit thermal configuration. Heat from RP is transferred to the consumer via high-temperature intermediate helium-helium HX (IHX) and intermediate helium circuit and then to network circuit of petrochemical applications. This decision restricts radioactivity release to the network circuit and provides radiological purity of the process product and minimum contamination of the primary circuit with process impurities.

MAJOR TECHNICAL PARAMETERS				
MHR-100 SE			MHR-100 SMR	
Parameters	Values		Parameters	Values

Reactor heat capacity (MW)	215		Reactor heat capacity (MW)	215
Useful electric power of generator (MW)	87.1		Helium temperature at reactor inlet/outlet (°C)	450 / 950
Net power generation efficiency (%)	45.7		Helium flow rate through the reactor (kg/s)	81.7
Helium temperature at reactor inlet/outlet (°C)	553 / 850		Helium pressure at reactor inlet (MPa)	5.0
Helium flow rate through the reactor (kg/s)	138		Steam-gas mixture pressure at HX inlet (MPa)	5.3
Helium pressure at reactor inlet (MPa)	4.41		HX-TCF 1	
Expansion ratio in turbine	2.09		HX 1 capacity (MW)	31.8
Generator/TC rotation speed (rpm)	3000/ 9000		Helium/steam-gas mixture flow rate (kg/s)	12.1 / 43.5

Helium flow rate through turbine (kg/s)	126		Steam-gas mixture temp. at inlet/outlet (°C)	350 / 650
Helium temperature at PCU inlet/outlet (°C)	850 / 558		HX-TCF 2	
SG power (MW)	22.3		HX 2 capacity (MW)	58.5
Helium flow rate through SG (kg/s)	12.1		Helium/steam-gas mixture flow rate (kg/s)	22.2 / 60.9
Helium temperature at SG inlet/outlet (°C)	850 / 494		Steam-gas mixture temp. at inlet/outlet (°C)	350/750
Steam capacity (kg/c)	6.46		HX-TCF 3	
Steam pressure at SG outlet (MPa)	4.82		HX 3 capacity (MW)	125
			Helium/steam-gas mixture flow rate (kg/s)	47.4/101

			Steam-gas mixture temp. at inlet/outlet (°C)	350/870

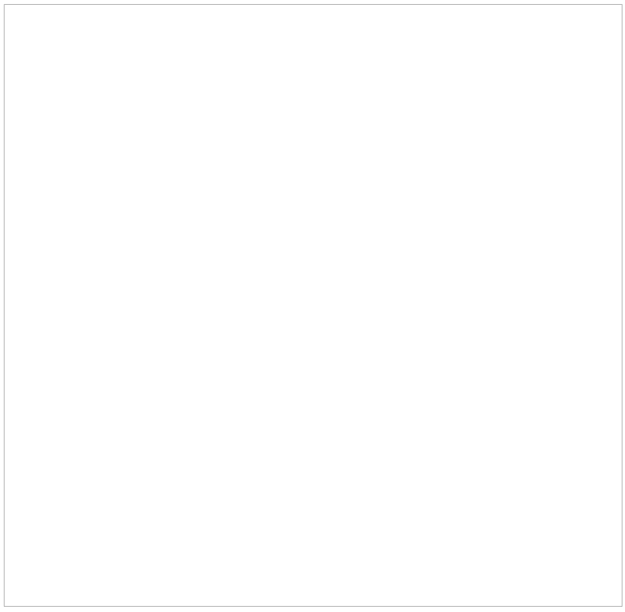


Figure 3. MHR-100 SMR

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

5. Technical NSSS/Power Conversion System Designn

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Power Conversion Unit

A power conversion unit is integrated in a single vessel and includes a vertical turbomachine, highly efficient heat exchanger, and coolers. The turbomachine includes a generator and turbo-compressor mounted on a single shaft on electromagnetic suspension. Gas turbine cycle of power conversion with the helium turbomachine, heat exchanger and intercooler provide thermal efficiency at 48%.

Reactor Core and Fuel Characteristics

Coated particle fuel is used. The fuel kernel (U oxide) is coated by a first porous layer of pyrocarbon, followed by a dense layer of pyrocarbon, a silicon carbide layer and an outer dense layer of pyrocarbon. Thousands of coated particles and graphite matrix material are made into a fuel compact

with hundreds of compacts inserted into fuel channels of each hexagonal prism graphite block (0.2 m × 0.65 m height). The core is a cylindrical arrangement of vertical stacks of fuel blocks (fuel columns). The standard fuel cycle is to utilize low enriched uranium (LEU) in a once through mode.

Figure 4. Reactor unit

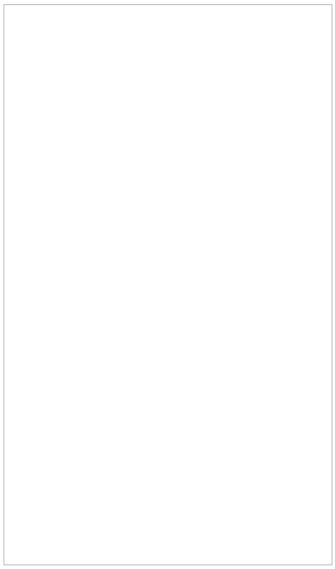


Figure 5. Power conversion unit

Reactivity Control

The two (2) independent reactivity control systems are used to perform reactor emergency shutdown and maintenance in a sub-critical state: (i) Electromechanical reactivity control system based on control rods in the channels and in the inner and outer reflectors; (ii) Reserve shutdown system based on spherical absorbing elements that fill-in channels in the fuel assembly stack over the whole height of a fuel assembly. Control rods with boron carbide absorbing elements located in the reflector are used during normal operation and hot shutdown, and rods located in the core are used for scram.

Reactor Pressure Vessel and Internals

The Reactor Pressure Vessel (RPV) made of chromium-molybdenum steel has dimension similar to that of standard VVER-1000. Prerequisites and conditions excluding brittle fracturing of the RPV include keeping the fast neutron fluence on and temperature of the RPV below the allowable limits. In-vessel structures, namely, prismatic fuel blocks, reflectors, and core support structure are made of graphite. Metallic internals are made of chromium-nickel alloy. Service life of the RPV and internals is 60 years.

Instrumentation and Control

Control and support safety systems are intended to actuate the equipment, mechanisms and valves, localizing and support safety systems in the pre-accidental conditions and in accidents; to monitor their operation; and to generate control commands for the equipment of normal operation systems used in safety provision algorithms.

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

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Design and Licensing Status

Optimization of reactor core design. Feasibility study of MHR-100-SMR plant application for large-scale hydrogen production, technical and economical evaluation of the plant potential to supply hydrogen to the expected market. Studies of safety issues, with the emphasis on mutual influence of nuclear and hydrogen production components of the facility.

MAJOR TECHNICAL PARAMETERS	
Parameters	Values
Reactor heat capacity (MW)	215

Helium temperature at reactor inlet/outlet (°C)	300 / 750
Helium flow rate through the reactor (kg/s)	91.5
Helium pressure at reactor inlet (MPa)	5.0
IHX capacity (MW)	217
Primary/secondary helium flow rate through IHX (kg/s)	91.5 / 113
Primary helium temp. at IHX inlet/outlet (°C)	750 / 294
Secondary helium temp. at IHX inlet/outlet (°C)	230 / 600
Secondary helium pressure at IHX inlet (MPa)	5.50

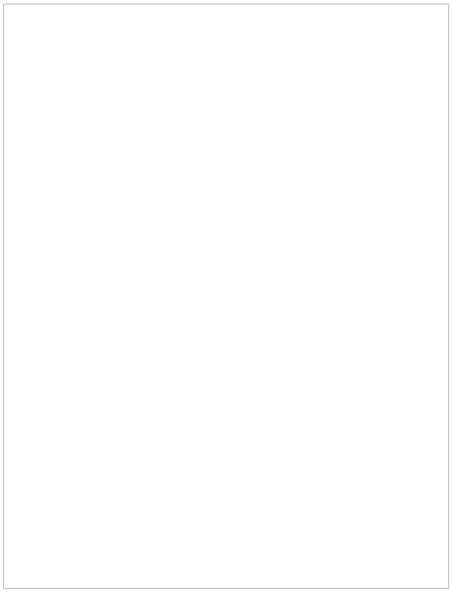


Figure 6. MHR-100 OR

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

7. Safety Concepts

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Safety Features

Safety objectives for the MHR-100 are achieved, first of all, by relying on the inherent safety features. These design features ensure thermal, neutronic, chemical and structural stability of the reactor. Safety is ensured by passive principles of system actuation. The decay and accumulated heat is removed from the core through RPV to reactor cavity cooling system and then to atmosphere by natural heat conductivity, radiation, and convection. In LOCA condition with failures of all active circulation systems and power sources, operation safety limit of the fuel is not exceeded.

Engineered Safety System Approach and Configuration

In addition to the inherent features, the MHR-100 incorporates safety systems based on: (i) Simplicity of both system operation algorithm and design; (ii) Natural processes for safety system operation under accident conditions; (iii) Redundancy, physical separation and independence of systems; (iv) Stability to the internal and external impacts and malfunctions caused by accident conditions; (v) Continuous or periodical diagnostics of system conditions; (vi) Conservative approach used in the design, applied to the list of initiating events, to accident scenarios, and for the selection of the definitive parameters and design margins.

Decay Heat Removal / Reactor Cooling Philosophy

High heat storage capacity of the reactor core and high acceptable temperatures of the fuel and graphite allow passive shutdown cooling of the reactor in accidents, including LOCA (heat removal from the reactor vessel by radiation, conduction and convection), while maintaining the fuel and core temperatures within the allowable limits The MHR-100 design provides for no dedicated active safety systems. Active systems of normal operation, such as the power conversion unit and the shutdown cooling system are used for safety purposes. These systems remove heat under abnormal operation conditions, during design basis accidents (DBA) and in beyond DBA.

Containment Function

Passive localization of radioactivity is provided by the containment designed for the retention of helium-air fluid during accidents with primary circuit depressurization. The containment is also designed for external loads due to seismic impacts, aircraft crash, air shock wave, etc. Activity release from the containment into the environment is determined by the containment leakage level, which is about 1%vol/d day at 0.5 MPa.

Plant Safety and Operational Performances

All safety systems are designed with two channels. Fulfilment of the regulatory requirements on safety,

proven by a compliance with both deterministic and probabilistic criteria, is secured by an exclusion of the active elements in a channel or by applying the required redundancy of such active elements inside a channel, as well as via the use of the normal operation systems to prevent design basis accidents.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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Fuel Cycle Approach

The MHR-100 fuel cycle approach is a once through mode without reprocessing. Fuel handling operations are performed using the protective containers to avoid fuel assembly damage and radioactive product release. Appropriately shielded containers are provided to protect the personnel against radiation impacts during dismantling of the reactor unit components at fuel reloading. These measures are also applied at spent fuel management.

Waste Management and Disposal Plan

Facilities for long-term storage of spent nuclear fuel (SNF) and solid/solidified radioactive waste (RW) are included in the complex of a MHR-T commercial 4-unit NPP. The capacity of the designed SNF storage is determined from the condition of capability to store fuel unloaded from the NPP for 10 years. The capacity of solid/solidified RW storage facility is designed to provide storage of waste generated during the 10-year period of NPP operation. After 10 years of storage at the NPP site, SNF and RW are to be removed for final underground disposal. Radiochemical SNF reprocessing is considered as an option for future only.

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

9. Safeguard & Physical Security

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9.1 Safeguards
9.2 Security

9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

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