Status Report - GT-MHR (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)	288
Gross Power Output (MWe)	--

1.1 Introduction

The GT-MHR (GT-MHR) couples a HTGR with a Brayton power conversion cycle to produce electricity at high efficiency. As the reactor unit can produce high coolant outlet temperatures, the modular helium reactor system can also efficiently produce hydrogen, e.g. by high temperature electrolysis or thermochemical water splitting.

The use of modular helium reactor units makes the system flexible and allows to use various power conversion schemes: with gas-turbine cycle, steam-turbine cycle and with a circuit supplying high-temperature heat to industrial applications. The modular high temperature gas-cooled reactor unit possesses inherent safety features with safe passive removal of decay heat providing a high level of safety even in the case of total loss of primary coolant.

The modular helium reactor design proved unit modularity with a wide power range of a module (from 200 to 600 MW(t)) and NPP power variation as a function of module number. This provides good manoeuvring characteristics of the reactor plant (RP) for regional power sources.

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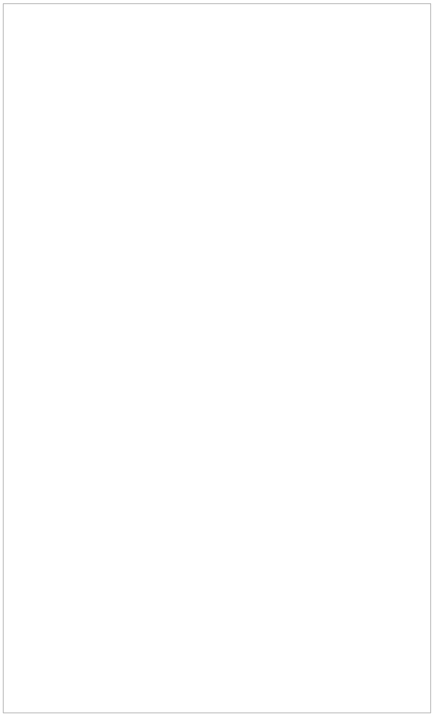


Figure 1. GT-MHR design concept

1.2 Development Milestones

1993	Minatom / General Atomics MOU on joint GT-MHR development for commercial units
1994	Russia proposes to build GT-MHR at Seversk to burn Russian WPu
1996	Framatome& Fuji Electric join the GT-MHR program
1997	Conceptual design completed
1998	GT-MHR becomes an option within the US/RF Pu disposition strategy
1999	Conceptual design review by international group of experts
2000	Work started on preliminary design
2002	Project review by Minatom of Russia and US DOE experts
2002	Reactor plant preliminary design completed
2003	Begin demonstration of key technologies
2014	Completion of demonstration of key technologies for Pu-fuelled core

Since 2014	Use of principal reactor unit design features as a basis for MHR-T design (U-fuelled option)

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The GT-MHR direct Brayton cycle power conversion system contains a gas turbine, an electric generator and gas compressors. The layout can be seen in the figure above. The GT-MHR gas turbine power conversion system has been made possible by utilizing large, active magnetic bearings, compact, highly effective gas to gas heat exchangers and high strength, high temperature steel alloy vessels. The use of the gas-turbine cycle application in the primary circuit leads to a minimum number of reactor plant systems and components. The GT-MHR safety design objective is to provide the capability to reject core decay heat relying only on passive (natural) means of heat transfer without the use of any active safety systems. The GT-MHR fuel form presents formidable challenges to diversion of materials for weapon production, as either fresh or as spent fuel.

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 (Hydrogen 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	Brayton	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid		e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	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	Preliminary 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	288	MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	9110	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)	7.2	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	490	ºC
Core Outlet Coolant Temperature	850	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	Reactor vessel	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	29000	mm
- NSSS Largest Component Diameter	8200	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	950	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	hydrogen production	-
Core Delta Temperature	360	ºC
Fuel/Core		
Single Core Thermal Power	600	MW(th)
Refuelling Cycle	25	months or “continuous”

Fuel Material	UO2 or PuO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	14-18	%
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	100-720	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)
- 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		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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The plant layout is shown in the following figure:

Figure 2. Plant layout

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

The Brayton power conversion system with direct gas turbine contains a gas turbine, an electric generator and gas compressors. The GT-MHR gas turbine power conversion system has been made possible by utilizing large, active magnetic bearings, compact, highly effective gas to gas heat exchangers and high strength, high temperature steel alloy vessels. The flow diagram is shown below:

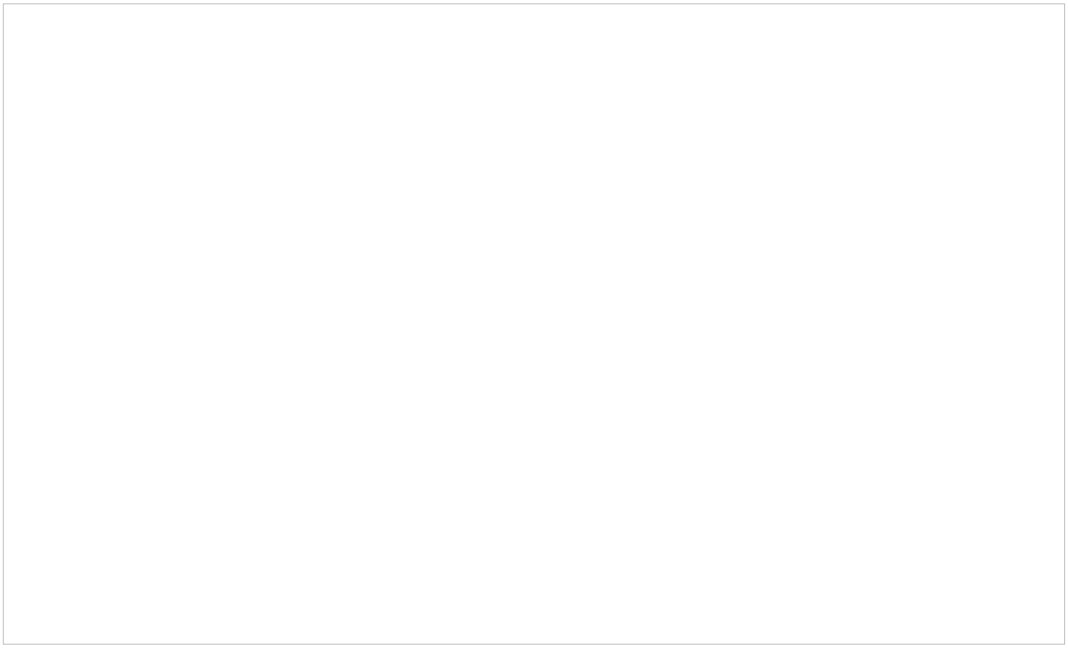


Figure 3. Power conversion system flow diagram

The main componenets of Figure 3 are as follows:

1. Reactor

2. Gas Turbine

3. Recuperator

4. Pre-Cooler

5. Low Pressure Compressor

6. Intercooler

7. High Pressure Compressor

8. Generator

9. Generator cooler

10. Bypass Valve

11~15. SCS Components

16. Surface Cooler Of reactor

17. Air Ducts

18. Heat Exchanger with Heat pipes

Reactor Core and Fuel Characteristics

Coated particle fuel is used. The fuel kernel (U or Pu 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 thousands of compacts inserted into the fuel channels of the hexagonal prismatic graphite blocks or fuel assemblies. The coated particles will contain almost all fission products with temperatures up to 1600oC. About 1 billion fuel particles of the same type were manufactured and tested in Russia. The standard fuel cycle for the commercial GT–MHR utilizes low enriched uranium (LEU) but alternative cycles including the disposition of plutonium were also studied in detail.

Reactivity Control

Two independent reactivity control systems based on different operation principles are used to execute reactor emergency shutdown and maintenance in a sub-critical state. These systems are: 1) Electromechanical reactivity control system based on control rods moving in the reactor core channels and in the inner and outer reflectors; 2) Reserve Shutdown System (RSS) based on spherical absorbing elements that fill-in channels in the fuel assemblies stacked 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, made of chromium-molybdenum steel, is 29 m in height with an outer diameter (across flanges) of 8.2 m. Prerequisites and conditions excluding brittle fracturing of the reactor vessel include keeping the fast neutron fluence on the reactor vessel and the vessel temperature below the allowable limits. In-vessel structures, namely, prismatic fuel blocks, reflectors, and core support structure are made of graphite, and metallic structures are made of chromium-nickel alloy. Service life of the reactor vessel and internals is 60 years.

Instrumentation and Control Systems

The GT-MHR NPP control and support safety systems (CSS) 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. The CSS are based on the principles of redundancy, physical and functional separation, and safe failure. The CSS sets are physically separated so that internal (fire, etc.) or external (aircraft crash, etc.) impacts do not lead to a control system failure to perform the required functions. The CSS provide automated and remote control of the equipment of safety systems from the independent main and standby control rooms. Principal technical features are selected using the concept of a safe failure - blackouts, short-circuits, or phase breaks initiate emergency signals in the channels or safety actions directly.

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

Reactor plant preliminary design and demonstration of key technologies for Pu-fuelled option completed.

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 objectives for the GT-MHR are achieved, first, by relying on the inherent safety features incorporated in the plant design. The design features, which determine the inherent safety and ensure thermal, neutronic, chemical and structural stability of the reactor unit, are the following:

1. Using of helium coolant, which has some specific properties. During plant operation, helium is not affected by phase transformations, does not dissociate, is not activated and has good heat transfer properties. Helium is chemically inert, does not react with fuel, moderator and structural materials. There are no helium reactivity effects;
2. Core and reflector structural material is high-density reactor graphite with substantial heat capacity and heat conductivity and sufficient mechanical strength that ensures core configuration preservation under any accident;
3. Nuclear fuel in the form of coated fuel particles with multilayer ceramic coatings, which retain integrity and effectively contain fission products under high fuel burnup and high temperatures;
4. The temperature and power reactivity coefficients are negative, what provides the reactor safety in any design and accident conditions.
5. Safety is ensured by application of passive principles of system actuation. The decay and accumulated heat is removed from the core through reactor vessel to reactor cavity cooling system and then to atmosphere by natural physical processes of heat conductivity, radiation, convection without excess of fuel safe operation limits including LOCA, in case of all active circulation systems and power sources failure.

Engineered Safety System Approach and Configuration

In addition to the inherent (self-protection) features of the reactor, the GT-MHR plant incorporates safety systems based on the following principles: 1) Simplicity of both system operation algorithm and

design; 2) Use of natural processes for safety system operation under accident conditions; 3) Redundancy, physical separation and independence of system channels; 4) Stability to the internal and external impacts and malfunctions caused by accident conditions; 5) Continuous or periodical diagnostics of system conditions; 6) 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.

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 during 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 GT-MHR 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 design basis accidents (BDBA). Emergency heat removal can also be carried out by the reactor cavity cooling system (RCCS). Heat from the reactor core is removed through the reactor vessel to the RCCS surface cooler, the heat tubes and then to the atmospheric air due to natural processes of heat conduction, radiation and convection. Water and air in the RCCS channels circulate driven by natural convection.

Containment Function

Passive localization or 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 the external loads, which may apply 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 % of the volume per day at an emergency pressure of 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 GT-MHR 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. Spent fuel shows good proliferation resistance characteristics, producing less materials of proliferation concern (total plutonium and 239Pu) per unit of energy produced.

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 GT-MHR 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 estimated total construction volume of the SNF reception and storage compartments is around 150 000 m3. 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