Status Report - SSR-W (Canada)

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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)	300
Gross Power Output (MWe)	--

1.1 Introduction

The Stable Salt Reactor - Wasteburner (SSR-W) is unique in its use of molten salt fuel replacing solid pellets in conventional fuel assemblies. This brings the major advantages of safe molten salts without the technical hurdles of managing a mobile liquid fuel. The reactor is fuelled with very low purity, reactor-grade plutonium unseparated from minor actinides and recycled from stocks of spent uranium oxide fuel and produced by a low-cost process called WAste To Stable Salt (WATSS). The reactor outputs its heat as a stream of molten chloride salts, which can be stored in large volumes at low cost, making the facility a high-value peaking plant rather than being restricted to baseload operation. This same system permits the entire steam cycle to be identical to that of coal-fired power stations and for it to be operated completely independently of the nuclear plant. The steam cycle is therefore not subject to nuclear regulations.

The SSR-W is designed for countries with significant stocks of spent nuclear fuel. The reactor burns all of the higher actinide component of that fuel, leaving a waste stream of relatively short-lived fission products only, as it can recycle actinides from its own spent fuel as well as from spent CANDU or LWR fuel. The fuel cost is expected to be negative, net of the reduced liability cost for disposal of the original spent fuel. It is designed to be capable of economically efficient electrical power peaking, but

with the reactor itself running at constant power. It therefore fills the need of national power systems for a low-carbon complement to intermittent renewable energy sources.

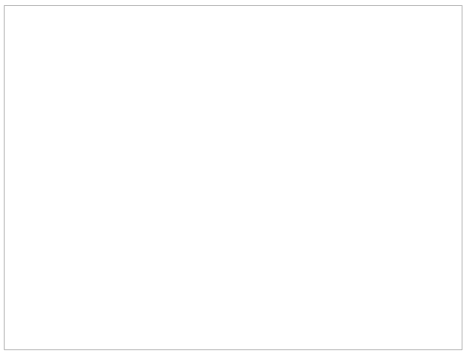


Figure 1. SSR-W coolant loop

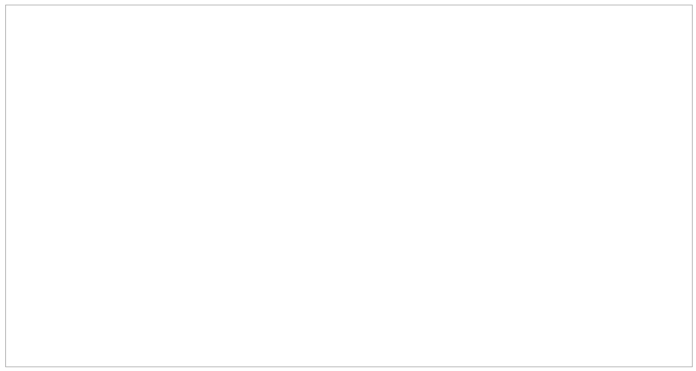


Figure 2. SSR-W render winter

1.2 Development Milestones

2014	UK patent granted for use of unpumped molten salt fuel in any reactor
2014	Independent capital cost estimate complete
2015	Pre- conceptual design complete and key claims validated by the UK's National Nuclear Laboratories
2017	Conceptual design completed and CNSC VDR commenced.
2018	Master patent on static fuelled molten salt reactors granted in major geographies. Several other patents progressing through PCT process.
2018	Moltex successful in UK Government Advanced Modular Reactor Competition.
2018	Moltex signs agreement with NB Power to advance the development of the first commercial demonstration SSR-W in Canada.

2020	Moltex signs ONWARDs agreement with Ontario Power Generation.
2021	Moltex receives funding from the Government of Canada's Strategic Innovation Fund.
2021	Moltex completes CNSC VDR Phase 1.
2022	Moltex announces strategic partnership with SNC-Lavalin Group
2023	North Shore Mi'kmaq tribal council and its seven First Nation member communities make financial investment in Moltex
2023	Successful completion of WATSS experiments using simulated fuel
2024	WATSS patents registered
2024	SSR-W integrated salt test loop built, and waste recycling demonstrated with advanced modelling techniques

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The entire design philosophy is to reduce plant costs by simplifying the design and eliminating hazards instead of merely containing them. This is done by combining the safety and operational benefits of molten salts with those of conventional reactor components. Risks to the public are practically eliminated by design, and not merely contained.

The key features of the design are expected to achieve:

- virtual elimination of the possibility of the release of volatile radiotoxic materials in any conceivable accident, terrorist act, or act of war;
- consequently, approval by regulators for deployment of the SSR-W on smaller sites with smaller emergency planning zones;
- a capital cost as low as $1000/kW when operated as a peaking plant, which is cheaper than fossil fuels, and without relying on subsidies;
- simple manufacture that does not require specialist factories;
- a fuel assembly form that is compatible with IAEA safeguards procedures used in reactors today.

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	Prototype/FOAK	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Non-electric (Wasteburner)	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	Molten Salts	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	MSR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	None	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	Liquid Fuel/Coolant	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape		e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Molten Salt	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	Fast	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	300	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	22500	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)		g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	0.101325	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	0.101325	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	575	ºC
Core Outlet Coolant Temperature	625	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	14000	mm
- NSSS Largest Component Diameter	7000	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	50	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		-
Core Delta Temperature	50	ºC
Fuel/Core		
Single Core Thermal Power	750	MW(th)
Refuelling Cycle	N/S	months or “continuous”
Fuel Material	Molten salt fuel within vented fuel tubes	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	N/A (uses recycled spent fuel)	%
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	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	Boron carbide shutdown assemblies	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	Passive	- / - / -
- core injection	Passive	- / - / -
- decay heat removal	Passive	- /- / -
- containment isolation and cooling	N/A	- / - / -
- emergency AC supply (e.g. diesels)	N/A	- / - / -
DC Power Capacity (e.g. batteries)		Hours
Events in which Immediate Operator Action is required		e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time		Hours (that are assumed when following EOPs)
Severe Accident Core Provisions		e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI

Core Damage Frequency (CDF)		x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions		e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)		x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)		Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort		Person-years (PY) [DP&P]
Construction and Commissioning Effort		PY [C&C]
Material and Equipment Overnight Capital Cost		Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Nuclear Island (NSSS)		
- Conventional Island (Turbine and Cooling)		
- Balance of Plant (BOP)		
- Commissioning and First Fuel Loading		
Factory / On-Site split in [C&C] effort		%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate		kg/s
System Steam Pressure		MPa
System Steam Temperature		ºC
System Feedwater Flow Rate		kg/s
System Feedwater Temperature		ºC
Reactor Core		
Active Core Height		m

Equivalent Core Diameter		m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density		MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The reactor biological shield (RBS) has a hexagonal cross section. The RBS is built up on the reactor basemat and both can effectively be considered as different parts of the same civil structure. There is a lining on the inside of the RBS Vessel that forms part of the reactor containment. The reactor tank is in the lower volume of the RBS vessel; the upper volume encloses the containment gas space above the reactor coolant level and provides a boundary for this gas space. The reactor tank is enclosed by the concrete RBS vessel, which provides protection against radiation from the reactor core and coolant.

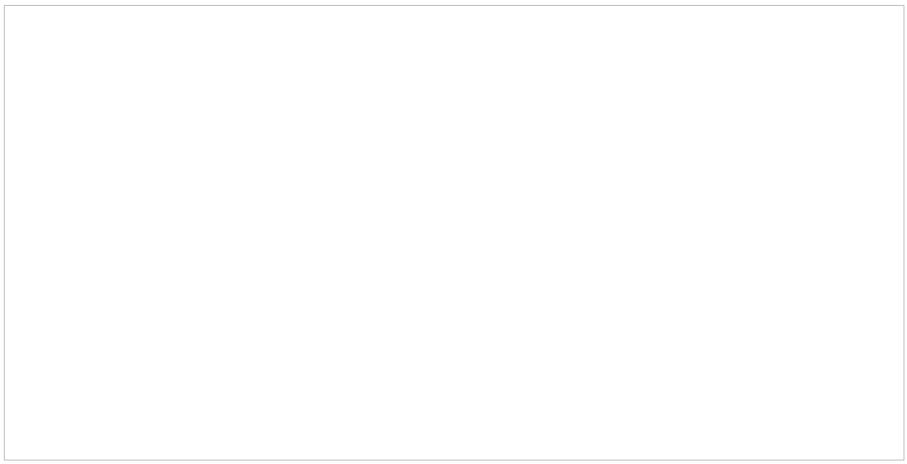


Figure 3. SSR-W civil structure

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

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

Power Conversion

A molten salt to steam boiler is proposed to generate steam. The turbine is currently being specified for a 300 MWe plant similar to modern fossil fuel plants. There can be a larger turbine of up to 900 MWe installed, to be coupled with the salt storage typically used in large solar facilities, or multiple smaller turbines. This will depend on the local electricity grid needs and economics.

Reactor Core

The reactor core's horizontal cross section is a circle mostly filled concentric hexagonal rings. The innermost rings of hexagons in the core are fuel assemblies, with shutdown assemblies spaced out along the periphery. The gaps between these shutdown assemblies are filled in with permanent reflector and shield assemblies. The gap between the outermost hexagonal ring and the circular tank wall is partially filled by the suction pipes and downcomers of the six coolant loops. The remaining space is filled with a partial hexagonal ring of slots for spent fuel assemblies.

All the hexagonal assemblies are held in position on a diagrid structure at the bottom of the core and by the collective interlocking arrangement of their support structures in the area above the coolant level, to form a tank cover. Reactor coolant flows up the inside of the fuel assemblies, absorbing heat as it rises. Having risen above the fuel assembly to the upper plenum, reactor coolant then flows via six loops to heat exchangers that are outside of the reactor tank, before re-entering the tank in the volume underneath the diagrid.

Reactivity Control

- No significant excess reactivity needs to be added to the core to compensate for fuel burn up because the combination of frequent on power refuelling and high negative temperature reactivity coefficient allow the core to generate constant power between refuelling steps. The small drop in reactivity is compensated by a small fall in average fuel salt temperature.
- No reactivity shims or control rods are required at any time under normal operating conditions, eliminating the potential for control failures that can lead to an increase in the core reactivity.
- Shutdown is achieved with shutdown assemblies. This is expected to control reactivity through radial neutron leakage.

Reactor Pressure Vessel and Internals

The reactor coolant loops take heat from the fuel assemblies and transfer this heat to the thermal storage system. This is achieved through six coolant salt pumps, which feed six primary heat exchangers by drawing coolant from the tank periphery through the suction pipes. This coolant is then discharged to the lower plenum via the downcomers and jet nozzles. The tube connections to the heat exchangers pass in angled paths through the concrete biological shield, to prevent a shine path (neutron or gamma radiation escaping past shielding). In normal conditions, the flow is forced by pumps to the lower plenum (below the diagrid) and sucked from the upper plenum (coolant volume above the height of fuel), while also having a portion of the coolant bypass the suction pipes and flow freely down the tank wall to the lower plenum.

Fuel Characteristics

The fuel salt is a mixture of sodium and magnesium chloride and actinide and lanthanide trichlorides. It is redox stabilised to render it non-corrosive to steel by inclusion of metal zirconium in each tube, which

maintains the salt in a strongly reducing state incapable of dissolving chromium from steel.

Fission Product Management

The volatile fission products traditionally of concern, such as caesium and iodine, are salts and remain trapped in the fuel. Noble gas radioactive isotopes are held up by the fuel pin vents, which hold it until the gas contains acceptably low radiation levels. Those gases are then filtered by the reactor atmosphere conditioning system.

Instrumentation and Control Systems

There is a separate protection and monitoring system. The protection system is hardwired for a four-channel coding system. The control system is a supervisory control and data acquisition (SCADA) system. The monitoring system is a distributed data acquisition and monitoring system with standard monitoring software.

5.1 Primary Circuit
5.2 Reactor Core and Fuel
5.3 Fuel Handling
5.4 Reactor Protection
5.5 Secondary Side
5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface
5.8 Unique Technical Design Features (if any)

6. Technology Readiness

SUMMARY FOR BOOKLET

Testing Conducted for Design Verification and Validation

The SSR-W and WATSS design is sufficiently developed to support an R&D plan that is now being executed. The novel componentry of the SSR-W includes the primary heat exchanger, the fuel assembly's gas venting facility, emergency heat removal system heat exchangers, and the fuel handling infrastructure. A medium-scale (<1tonne of molten salt) thermal hydraulic loop has been built to demonstrate the phenomena that need to be accurately modelled by the appropriate software.

Design and Licensing Status

Moltex was selected by NB Power and the Government of New Brunswick to progress development of the SSR-W in New Brunswick, Canada, with the goal of deploying its first reactor next to the Point Lepreau Nuclear Generating Station. In preparation for this, the SSR-W design is being subjected to the CNSC Vendor Design Review (VDR) process. The design has successfully completed Phase 1 of the VDR in 2021.

6.1 Deployed Reactors

7. Safety Concepts

SUMMARY FOR BOOKLET

Engineered Safety System Approach and Configuration

The design philosophy is to follow the internationally accepted principle of the risk mitigation pyramid. Therefore, the focus is to use inherent characteristics to eliminate hazards and to use engineering safety features to provide additional confidence and backup to the inherent physical characteristics.

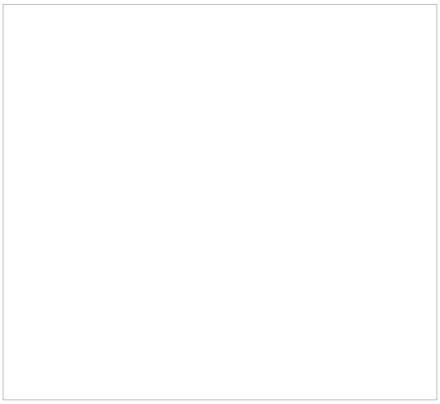


Figure 4. Heirarchy of controls

Decay Heat Removal System

Natural convection of the primary coolant salt would continue in the event of a reactor shutdown or pump failure. Heat would then be transferred to the tank walls, where a finned air duct to atmosphere around the tank walls would take decay heat away indefinitely in an accident scenario.

Emergency Core Cooling System

There is no safety injection system as the coolant has a very high boiling point and there is no credible leakage path to allow the core to be uncovered.

Containment System

There are no significant internal pressures within the SSR-W. The primary containment for the reactor is the tube wall. The secondary containment is the coolant salt, which absorbs fission products in the event of tube failure. The third is the tank itself. The fourth is the concrete structure. Above the tank is an argon space, which has a stainless steel liner surrounded by a ~1 m concrete wall serving as the biological shield. The reactor building walls are ~300 mm thick reinforced concrete. This serves as both a building structure and a shield.

Chemical Control

The reactor coolant salt chemistry is maintained in a reducing state through the use of an electrolytic cell (the redox control unit). The flow of coolant salt for the reactor coolant redox control unit is normally provided by the leak-off flow that is generated in the reactor coolant loop vacuum break line when the reactor coolant pumps are in normal operation

Spent Fuel Cooling Safety Approach / System

Several positions along the periphery of the reactor allow the fuel assemblies to cool down after being removed from the core. Afterward, they can be brought back into the WATSS process to allow them to be recycled into new fuel for the reactor.

Plant Safety and Operational Performances

The design intent is that the release of radioactivity in excess of the agreed operating discharge authorization is expected to be less than 10^-6 per year. The ramp rates of the plant will be driven by the steam side, not the nuclear side.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

Current commercial reactors run on the once-through natural uranium fuel cycle, which involves a single pass of the fuel through the reactor. Moltex plans to produce the fuel for the 300 MWe SSR-W (SSR-W300) from used fuel stocks using the WATSS process. WATSS separates out the fission products into a low-volume high-level waste stream, produces a high-volume low-activity depleted uranium alloy and the SSR-W300 fuel.

Waste Management and Disposal Plan

Moltex's WATSS and SSR-W technology consume and destroy a very large proportion of the long-lived higher actinides in spent fuel, while generating useful power. S A very small amount of other radionuclides present in CANDU fuel are not consumed and remain as waste which cannot be destroyed by any nuclear fission process. Most of these radionuclides will be encapsulated and can be safely disposed of in a repository.

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

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

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

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

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