Status Report - SHELF-M (Russian Federation)

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1. Overview

- ☐ **In Operation**
- ☐ **Under Construction**
- ☐ **Described in**

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	2028

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	10
Gross Power Output (MWe)	--

1.1 Introduction

The SHELF-M is a modernized SMR for small NPP based on SHELF reactor unit with an increased power capacity of 35 MW(t) and a rated power output of up to 10 MW(e) developed based on NIKIET's experience in marine nuclear reactors design. The plant modular design and small containment vessel makes it possible to deliver reactor unit on site fully assembled and tested, minimizing construction costs and time. Refueling and nuclear waste removal will be carried out at dedicated facilities. Optimized core design allows increasing refueling cycle for up to 8 years.

The SHELF-M is a SMR designed for land-based NPP that intended to supply electric power to remote areas with decentralized power supply. The plant does not require local water sources - residual and decay heat removed by external heat exchangers cooled by atmospheric air. The SHELF-M designed to operate with low personnel numbers with only 15 staff members required to be present of site during normal operation.

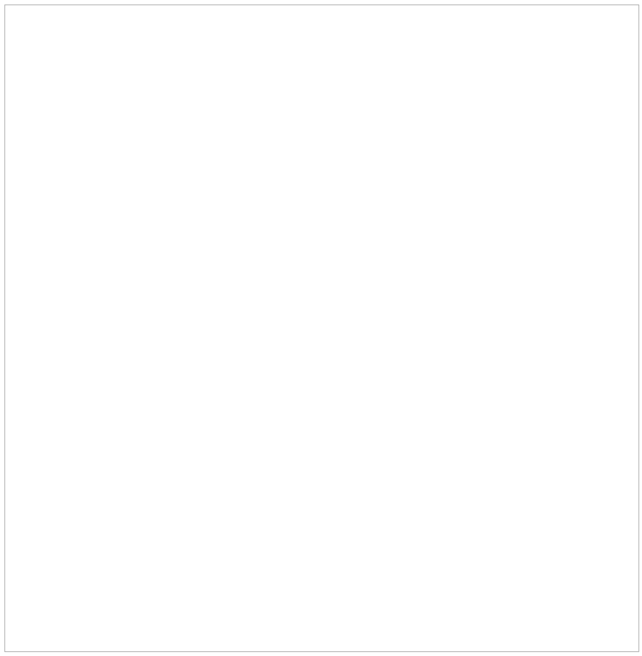


Figure 1. SHELF-M Design Concept

1.2 Development Milestones

2018	Start of the project SHELF-M
2019	Conceptual design (achieved)
2022	State contract for the development of NPP with SHELF-M reactor unit (achieved)
2022-2024	Detailed design (ongoing)
2027-2029	Licensing (planned)
2028	Start of construction (planned)
2030	Operation testing (planned)

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

Design philosophy

The SHELF-M based on proven technology derived from NIKIET's experience in design and development of marine propulsion PWRs with the addition of advanced passive safety systems. Integral RPV layout with a combined forced and natural primary coolant circulation makes it possible to achieve significant reduction in power unit weight and size.

Main NSSS design principles are: construction costs reduction and reliability improvement. Construction costs reduction achieved via modularization – NPP equipment shipped in form of fabricated modules, which are fail-safe tested on specialized facilities before shipment.

Passive systems used in maximum extent in project to decrease probability of personnel errors and equipment malfunctions while increasing reliability of NSSS.

Other rather important principles are insuring maneuverability and self-sufficiency. NPP capable of supplying consumer in daily and annual load variations and does not require external measures during normal operation (between scheduled maintenances) and accidents (during 72 hours from the begging of accident)

1.6 Licensing Application Support Documents

Design and Licensing Status

Licensing process to be started in 2027.

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)	Off - grid / Remote	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)		e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	H2O	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	PWR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size		e.g. PWR, SMR
Neutron Moderator	H2O	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Integral	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H2O	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	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	Detailed Design	e.g. Conceptual, Detailed, Final (with secure suppliers)

Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# 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		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	16800	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)	VIII by MSK-64 scale	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	14.7	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	3.7	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	271	ºC
Core Outlet Coolant Temperature	308	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		-
Core Delta Temperature		ºC
Fuel/Core		
Single Core Thermal Power	35	MW(th)
Refuelling Cycle	96	months or “continuous”
Fuel Material	Cermet (UO2 + metallic silumin)	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	up to 19.7	%
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	Average: 90. Maximum local: 162	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 driving mechanism	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	N/A	- / - / -
- core injection	Passive	- / - / -
- decay heat removal	Active/Passive	- /- / -
- containment isolation and cooling	Passive	- / - / -
- 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 SHELF-M plant consists of main building, administrative building, 4 stand-alone fan cooling towers, 4 emergency diesel generators, start-up boiler module, water storage tanks, fresh and spent fuel open storage area and auxiliary modules.

The main building based on lightweight steel frame structure and houses the reactor hall with power capsule, external concrete protection, and the turbine hall. The building is designed as quick assembly building based on prefabricated structures, that allows to significantly reduce construction costs and time.

The administrative building is assembled from standard containers and houses administrative offices and control room.

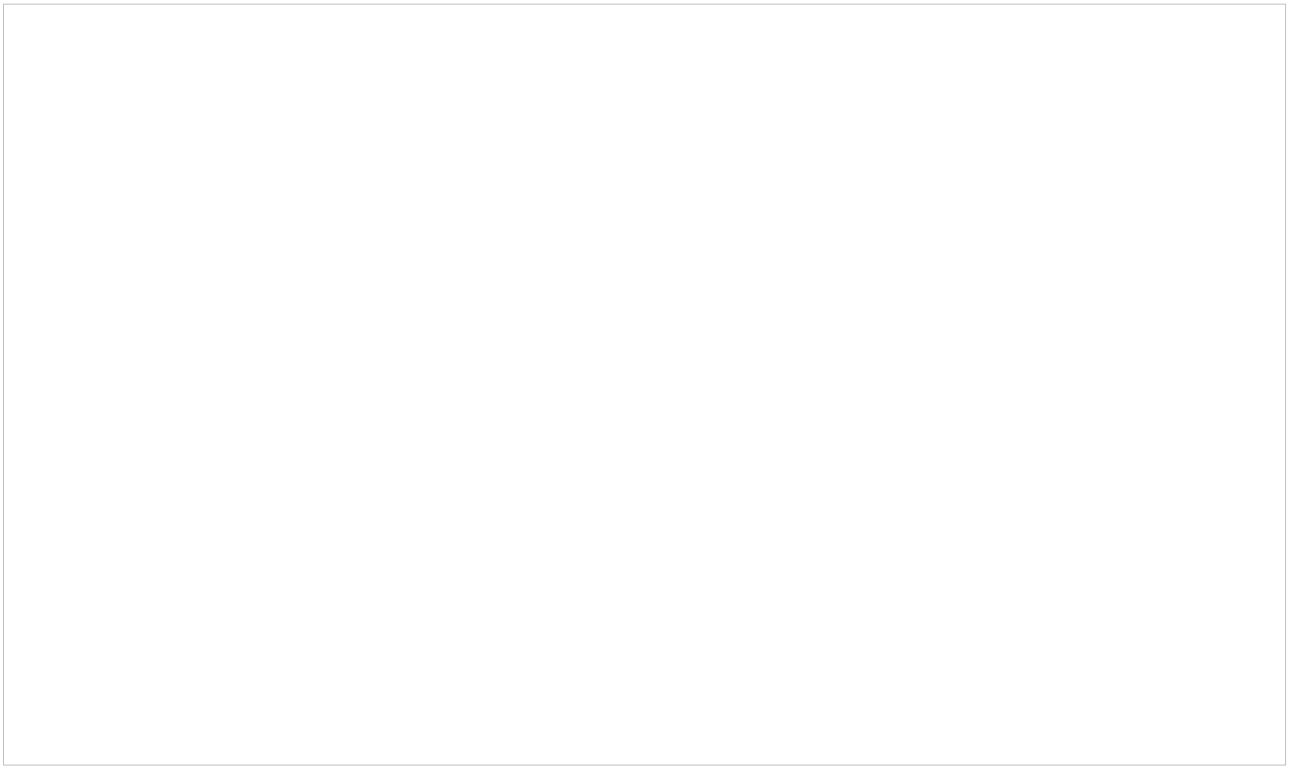


Figure 2. Plant layout arrangemnet

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

Nuclear Steam Supply System

The SHELF-M power unit implements a traditional two-circuit NSSS. SG provides overheated steam to two turbines located in the engine room adjacent to power capsule room and connected to power capsule with two independent steam pipelines. Each pipeline is equipped with shut-off valves installed both inside and outside of power capsule and can be independently isolated without reactor shutdown in case of leaks of primary coolant into the secondary coolant.

RPV and all necessary normal operation and safety systems assembled inside a cylindrical power capsule with 8 m in inner diameter and 10 m high. Capsule's shell serves as a containment. SHELF-M has optimized core with extended fuel cycle (up to 8 years) and higher thermal capacity (35 MW) compared to SHELF.

Reactor Core

The SHELF-M reactor core consists of 241 cylindrical fuel assemblies (FA) of different types with variable fuel enrichment. Fuel assemblies placed in nodes of a regular hexagonal lattice. Control rods are located between FA and united in nine groups. Each fuel assembly contains 55 fuel rods with cermet fuel placed in nodes of regular hexagonal lattice and 6 stationary rods of burnable absorber around fuel rods. Emergency protection rods are located inside 18 fuel assemblies in place of 19 central fuel rods. Cermet fuel consists of uranium dioxide fuel particles embedded in silicon-aluminum (silumin) matrix. Fuel rod cladding is made of chromium nickel alloy. High thermal conductivity of fuel matrix as well as absence of zirconium in structural elements of fuel rod improves design safety in transients and prevents hydrogen production in steam oxidation of zirconium alloys.

Reactivity Control

The reactor core contains two independent reactor shutdown systems. Control rods with boron carbide absorber at the top and dysprosium titanate at the bottom provide normal operation reactivity control and shutdown.

Emergency protection rods with boron carbide ensure reliable shutdown in case of emergency. The SHELF- M is also equipped with ultimate shutdown system - emergency liquid absorber injection system (ELAIS), which able to shutdown the core in case of severe accident by injecting boron acid in primary coolant. Boron regulation not provided during normal operation.

Reactor Pressure Vessel and Internals

The RPV accommodates the core with reactivity control rods, the primary coolant circuit, the mechanical filter, the thermal shielding, the steam generator and heat exchangers of emergency decay heat removal system.

The RPV has an elliptical bottom, cylindrical shells and two rector lids (central and peripheral). All pipelines connected to the lids at the top of the RPV to prevent the core drainage in case of LOCA.

RPV and reactor internals made of low-cobalt steel and alloys to prevent generation of long-lasting radioactive waste.

Reactor Coolant System and Steam Generator

Reactor coolant system based on conventional two-circuit methodology. The SHELF-M primary circuit cooling under normal operating conditions done using forced circulation by two primary coolant circulation pumps (PCCP). Cooling by natural circulation is also possible with thermal output at the 20 % level of thermal capacity.

The SHELF-M utilizes once-through steam generator with helically coiled tubes located inside the cylindrical annulus between the RPV and the core barrel. The SG comprises a tubing, collection and distribution chambers above and below the tubes, steam and feedwater lines inside the RPV. SG coil-pipes, alongside with emergency decay heat removal system (EDHRS) heat exchanger (HX) coil-pipes form a single coil with 48 independent modules grouped into 8 sections: 4 for SG and 4 for EDHRS HX, which makes it

possible to shut off individual section in case of primary coolant leaks.

Pressurizer

The SHELF-M adopts pressure compensation gas system common in Russian marine PWR. It utilizes an external pressurizer with no active components, such as sprinkler system or electrical heating. Pressurizer system consists of five separate vessels: gas collector, intermediate pressurizer, end pressurizer and two expansion vessels. Pressurizer connected to the reactor central lid by a pipeline with a restrictor to reduce coolant leak rate in large-break accidents.

Primary pumps

The SHELF-M utilizes two electrical primary coolant circulation pumps (PCCP) located on peripheral lid of the RPV.

Instrumentation and Control Systems

The automated process control system (APCS) of a NPP with SHELF-M reactor unit designed to control major and auxiliary electricity generation processes in all modes of the unit operation:

1. Normal operation comprises of phased automated initiation, operation at steady power levels in a range of 20 to 100 % of rated power with forced primary coolant circulation, operation at steady power levels at 20 % of rated power with natural coolant circulation, switchover from natural primary coolant circulation to forced circulation and scheduled automated deactivation.
2. Anticipated operational occurrences like emergency power reduction and operation with a decreased steam supply due to failures of the reactor facility's key components or feedwater supply and steam receipt systems.
3. Emergency: emergency deactivation in the event of reactor facility parameters deviating beyond the safe operation limits or in the event of equipment failures leading to the safe operation limits being violated.

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

Experimental testing sites and facilities are built and in operation. The SHELF-M's fuel rods reactor tests are under way.

Design and Licensing Status

Licensing process to be started in 2027.

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

7. Safety Concepts

SUMMARY FOR BOOKLET

Engineered Safety System Approach and Configuration

The SHELF-M designed with combined passive and active safety systems that comprises emergency decay heat removal system (EDHRS), emergency reactor cooling system (ERCS), emergency liquid absorber injection system (ELAIS) and overpressure protection systems.

Decay Heat Removal System

During normal shutdown, decay heat is removed from the reactor core by forced circulation of primary coolant to SG and then by secondary coolant to the condenser. In case of emergency (primary or secondary circuit pumps failure, loss of secondary circuit coolant etc.), emergency decay heat removal system (EDHRS) used to cool down the core. The system consists of 4 independent loops with two passive circuits in each loop (intermediate circuit and low-boiling circuit) with natural circulation of coolants and standalone heat exchangers between circuits. The heat transferred to the atmospheric air via heat exchangers, located on the roof of the reactor building.

Emergency Core Cooling System

The emergency reactor cooling system designed to supply the in-vessel circulation circuit with water during accidents with loss of the primary circuit integrity. The system is based on passive principals and doesn't require any manual or automatic activation. The system contains vessels with coolant under high pressure, which is passively injected into RPV in case of primary coolant pressure drop.

Containment System

The SHELF-M utilizes two containment systems. The first one - safety vessel, located inside power capsule, which encloses RPV and all primary circuit equipment. The second - power capsule shell, which contains safety vessel with RPV, steam and feedwater pipelines, EDHRS intermediate heat exchangers, reactor unit auxiliary equipment and tanks with liquid and solid radioactive waste. Both containment system designed to withstand pressure and temperature of primary coolant in case of large-break accidents. Both containments are unvisited during normal operation and filled with inert gas (nitrogen) with absolute pressure below atmospheric to prevent minor leaks of radioactive media and reduce the probability and possible consequences of fire inside containment volume. Both containments are equipped with overpressure protection systems.

Plant Safety and Operational Performances

The electric power of a single SHELF-M unit is up to 10 MW(e), and the thermal power is 35 MW(t). The current supplied to the consumer system is alternate and three-phase with voltage 0.4 kV ± 2 %, frequency 50 Hz ± 1 Hz. The NPP base operation mode is power operation in range from 20 to 100 % of rated power with the capability to vary the consumed power daily and annually. The power increase and decrease rate is 1 % (with forced primary coolant circulation). Design capacity factor - 0.9. Refueling outage time is 45 days once in 8 years.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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Fuel Cycle Approach

The SHELF-M implements a standard PWR fuel cycle. All fuel assemblies unloads at the end of refueling cycle. On-site (for FOAK plant) and remote (for subsequent plants) refueling strategies are designed. For the FOAK plant, the fresh and spent open-air fuel storage is located on site

Waste Management and Disposal Plan

Liquid radioactive waste management system is located inside power capsule. The system designed to gather radioactive leaks from reactor cooling systems and storage liquid waste inside power capsule.

Gaseous radioactive waste system designed to remove gaseous radioactive waste from within the power capsule during the scheduled maintenance (one a year). Nitrogen from within power capsule passes through filters, where radioactive aerosols are absorbed and stored.

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