Status Report - STAR (Switzerland)

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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)	10
Gross Power Output (MWe)	--

1.1 Introduction

"STAR" is a channel-type two-circuit light-water nuclear reactor with a thermal rate of 30 MW(t) and a nominal electric power output of 10 MW(e). Based on time-proven solutions utilized in multiple contemporary light-water reactor designs, "STAR" features a distinctive layout, wherein the coolant of a double-loop primary circuit circulates through individual pressurized channels instead of an outer pressure vessel, which is the main factor contributing to the mass and dimensions of traditional PWRs. The channels' design in the form of bayonet heat exchangers and the use of UO2 fuel enriched to 19 percent further decrease the reactor unit's size, which effectively enables it to be fully assembled in factory and delivered to the installation site by land, sea, or air, substantially decreasing its production and maintenance costs.

The "STAR" reactor is designed to serve as a versatile tool to fulfil the energy needs of remote or isolated localities, such as small settlements or power-intensive industrial areas. Depending on the configuration of the secondary island, it is capable of functioning as a district heating or electric power plant or operate in cogeneration mode. Additionally, it can be utilized as a source of heat or steam for water desalination or other industrial purposes.

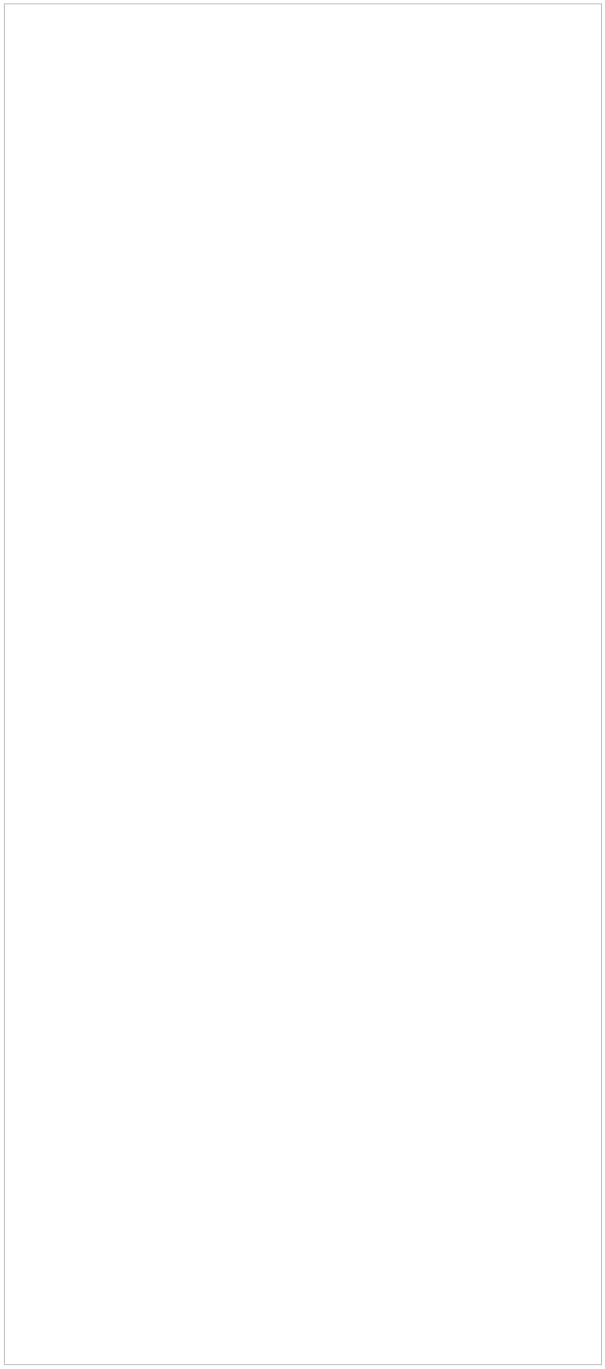


Figure 1. Representation of the STAR reactor.

1.2 Development Milestones

2015	Initial concept developed; patent priority date secured
2019	Concept submitted for peer review
2021	Conceptual design developed; preliminary feasibility study for a FOAK unit completed
2022	Conduction of feasibility study for FOAK unit and initiation of licensing procedures with local regulator and basic design

2024	Development of basic design and PSAR, conduction of site survey
2025	Launch of FOAK plant project, development of detailed design and extended SAR
2026-2027	Pilot unit installation and launch

1.3 Design organization or vendor company

al@starenergysa.com

1.4 Links to designer/vendor website

1.5 Design Description

Design philosophy

Since SMRs generally do not enjoy the economy-of-scale benefits offered by larger nuclear power plants, the main goal of the design is to provide a financially viable alternative to small-scale fossil fuel power stations while maintaining the required high safety standards. This goal is mainly achieved by combining well-tested technical solutions used in existing light-water reactors with a unique layout tailored for ease of manufacturing, assembly, transportation, and installation of the reactor. The design assumes that the fabrication process shall only require commercially available parts and materials to reduce the initial investment required for research and licensing. It also includes multiple redundant passive safety features following the “defence in depth” principle with a further goal to reduce the power plant’s total footprint, limit the required controlled zone to its boundaries, and enable deploying it near the end user.

Testing Conducted for Design Verification and Validation

Most parts and materials used for the “STAR” design are tested, commercially available and have been nationally or internationally certified. During the conceptual design stage, extensive physical calculations and modelling for the reactor unit were completed using MCNP, WIMSD4, and SSL DYNCO codes. Further means of validation, including probabilistic and deterministic safety analysis tools and live test facilities for various components, shall be developed on the later design stages

Power conversion

There are three primary possible variants of nuclear energy conversion at a “STAR” power plant: a nuclear electric plant referred to as “STAR-E”, a nuclear heating plant (“STAR-T”), and a combined nuclear power plant (“STAR-C”). The design of the secondary circuits for all three variants is based on the parameters of the reactor unit’s two steam generators with a combined output of 30 MWt. The admission pressure of steam produced in the steam generator is 4.4 MPa with a steam dryness of 99%. The feed water temperature is 220°C.

1.6 Licensing Application Support Documents

Interaction with Nuclear Safety Authority	Started; Site permit for FOK plant	To be developed

Interaction with Nuclear Safety Authority – Started, Site permit for FOAK plant – To be developed

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose		e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Off - grid / Remote, Non-electric	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location		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)	Thermal Power < 30 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	SMR	e.g. PWR, SMR
Neutron Moderator	H2O	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	Rankine	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	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Triangular	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	18	e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Basic 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	36000	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)	Degree VIII (MSK-64)	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	12.5	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	4.4	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	270	ºC
Core Outlet Coolant Temperature	300	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	7600	mm
- NSSS Largest Component Diameter	2300	mm

- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	20	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	30	MW(th)
Refuelling Cycle	120	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	19	%
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 and Er / Gd2O3 burnable absorber	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

SUMMARY FOR BOOKLET

The default design suggests deploying the reactor unit in an underground ferrocement reactor shaft to improve its containment capabilities, enhance resilience to external threats, and increase convenience of emergency water tank placement. However, other reactor building arrangements are also available. Secondary island and civil part buildings should be designed with consideration for the given country's legislation and environment.

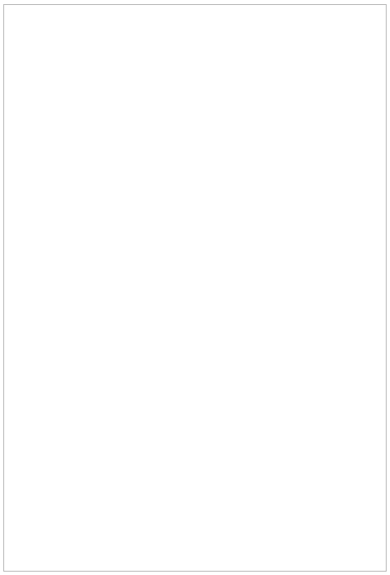


Figure 2. "STAR" module placement option inside an underground reactor shaft.

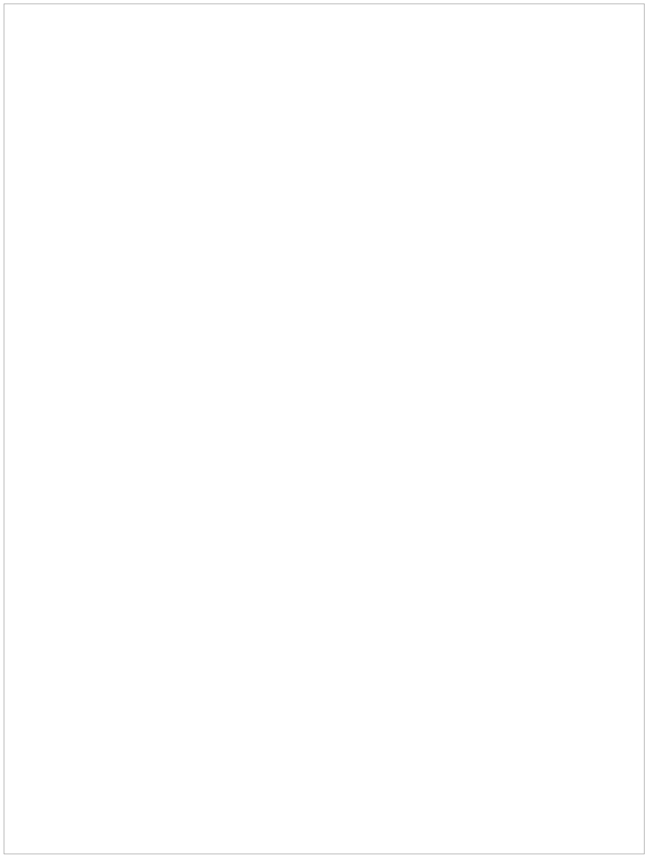


Figure 3. Example layout of a reactor building with an adjacent secondary island.

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

5.1 Primary Circuit

The primary circuit coolant system includes 138 pressure channels containing the reactor core's fuel assemblies, coolant inlet and outlet chambers, and two primary circuit loops, each featuring a pressurizer, a main circulation pump, and a triple-sectioned steam generator. The double-loop layout has been selected to reduce the overall size of the reactor module. The primary circuit is designed to hold an operating pressure of 12.5 MPa and maintain an outlet coolant temperature of 300°C.

5.2 Reactor Core and Fuel

Reactor core

The reactor core consists of 138 pressure channels, each designed as a bayonet heat exchanger with its outer tube welded into the lower plate of the primary coolant inlet chamber and the inner tube welded into the lower plate of the primary coolant outlet chamber. The coolant is fed to the core through the primary coolant inlet chamber, from which it flows along the outer section of a pressure channel and rises along the inner tube, which houses a fuel assembly. The tubes are manufactured from a zirconium-niobium alloy, and the space between the tubes is filled with a neutron-transparent material. The reactor core is encased into a neutron reflector consisting of stacked Al-Be alloy rings with a thickness of 100 mm.

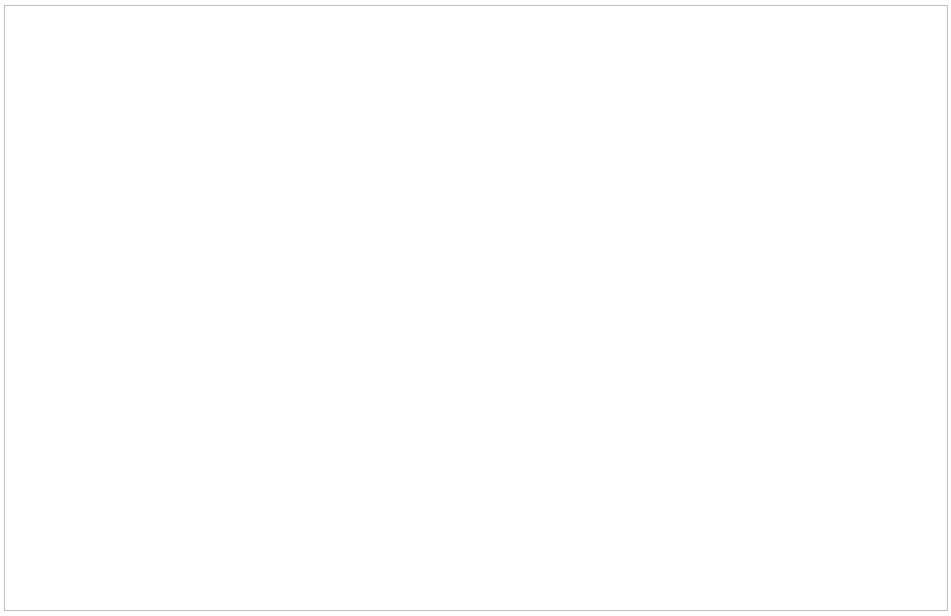


Figure 4. Reactor core layout.

Reactor Pressure Vessel and Internals

The “STAR” reactor does not feature a pressure vessel. Instead, the pressure of the coolant is contained by the elements of the primary circuit, which, together with the I&C systems, are bundled into a “monoblock” layout and encased into a sealed cylindrical thin-walled (1 cm thick) steel reactor vessel that ensures convenient transportation and installation of the reactor unit and serves as an additional containment barrier. The vacant space between the reactor vessel and the internals is filled with high purity helium. The total height of the reactor module is 7.6 meters with a diameter of 2.3 m.

Fuel characteristics

A “STAR” nuclear fuel assembly consists of 18 nuclear fuel rods placed in a triangular grid in two concentric circles around a central support rod, fixed in place with spacing meshes. The central support rod is used to attach the fuel assembly to the upper plate of the primary coolant outlet chamber and the drive mechanism. The fuel rods contain fuel pellets made of uranium dioxide with a maximum enrichment of 19%. Additionally, 6 of the 18 fuel rods contain Er or Gd_2O_3 burnable absorber, which compensates for loss of reactivity during normal operation of the reactor and extends its fuel cycle, which is set to 10 years. The nuclear fuel stays inside the core throughout the entire fuel cycle, including the scheduled maintenance periods.

The inner volume of the nuclear fuel rods is filled with high-purity helium to improve thermal conductivity of the gas mixture inside the fuel rods and to reduce the average volumetric fuel temperature.

5.3 Fuel Handling
5.4 Reactor Protection

Reactivity Control

Reactivity control is performed with burnable erbium and gadolinium oxide absorbers in a number of the fuel assemblies and 10B reactivity control rods evenly distributed inside the core. Boric acid is not intended for reactivity control during normal operation; however, it can be used for ensuring safe shutdown of the core during accident conditions. Additional reactivity control is also provided by the negative thermal feedback of the moderator.

5.5 Secondary Side

The secondary circuit connects to the reactor vessel from the outside through openings for feed water and steam output pipelines, interfaces with the primary coolant circuit through two steam generator arrays inside the reactor vessel and provides the final output of the reactor module. Like the primary circuit, the secondary circuit has forced circulation, so the secondary island must be equipped with a high-pressure feed water pump. The circuit's output has a temperature of 256°C with a feed water temperature of 220°C.

Unlike other reactors currently in operation, the reactor contains two steam generators, each consisting of three separate sections connected through inlet and outlet pipelines. Each steam generator is designed as a once-through unit with an inlet of the primary coolant in its upper part and the outlet in the lower part. The upper part of a steam generator contains centrifugal and louvered separators. The combined thermal power rate of all the steam generators is 30 MW.

5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface

On the conceptual level, the I&C system is divided into the following main blocks:

- Primary and reserve control rooms;
- Reactor control and protection system, including remote controls and two independent emergency shutdown systems;
- Process parameters control system;
- Internal reactor control system;
- Normal operation control systems;
- Miscellaneous automatic systems

5.8 Unique Technical Design Features (if any)

Compact, low-weight design without a pressure vessel; flexibility of operation; intrinsic passive safety

6. Technology Readiness

SUMMARY FOR BOOKLET

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 design of the “STAR” reactor follows the principle of inherent safety and provides for both long-term heat removal after reactor shutdown and emergency cooling during design basis accidents, including mechanically triggered safety measures requiring no power source or human input.

Decay Heat Removal System / Reactor Cooling Philosophy

During normal operation, sufficient radiation and thermal protection is achieved with several layers of shielding, including the reactor core’s reflector, a cushion of pure inert gas, an airtight reactor vessel, and a reactor shaft shielding. In the event of an emergency reactor shutdown, the design of “STAR” offers systems for both short-term emergency cooling and long-term residual heat removal. The short-term emergency cooling system is triggered in a loss of coolant accident by several mutually independent mechanical sensors. The system injects pressurized water from an emergency tank into the reactor vessel to provide cooling to the core and prevent its exposure. The long-term cooling system is designed to passively remove decay heat from the first circuit through steam generators; it has been estimated that the first circuit shall maintain natural circulation of coolant even in the event of failure of both main circulation pumps. Finally, in the occurrence of a guillotine rupture of a primary circuit pipeline, additional cooling shall be provided by a steam condenser installed at the top of the reactor vessel.

Spent Fuel Cooling Safety Approach / System

Initial calculations and modelling show that, given proper handling and fractioning, spent fuel from a “STAR” reactor cools passively and does not require temporary on-site storage in a spent fuel pool. Requirements to equipment and procedures for waste management shall be elaborated at further stages of the design.

Containment System

The design’s containment system is based on the “defence in depth” philosophy and includes a set of technical and administrative measures aimed at preventing environmental exposure to radiation and radioactive substances from the reactor.

The set of barriers includes:

- Fuel pellet matrix;
- Fuel rod casings;
- Pipelines end equipment of primary coolant circuit;
- Reactor core pressure channels;

- Reactor core shielding;
- Airtight reactor vessel;
- Ferrocement reactor shaft

Chemical Control

The functions of and requirements for the chemical control systems shall be elaborated on further stages of the design.

7.1 Safety Philosophy and Implementation

From the beginning of development of “STAR”, reasonable safety requirements to be imposed for the reactor’s design features are as follows:

- Core damage frequency – less than 1E-6/reactor year
- Large early radioactivity release frequency – less than 1E-7/reactor year

7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

The design assumes six fuel loading throughout the reactor’s lifetime: the initial loading and 5 reloads every 10 years. Apart from description and requirements for refuelling equipment and procedures to be developed on later design stages, current regulations and best practices concerning handling of HALEU fuel are applicable to this design.

By design, the “STAR” reactor facility does not release liquid or solid radioactive waste during normal operation. Any solid or liquid radioactive waste collected during refuelling and maintenance shall be disposed of in accordance with applicable regulations and practices.

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