Status Report - SMART (Korea, Republic of)

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1. Overview

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

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	2030

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	90
Gross Power Output (MWe)	100

1.1 Introduction

The System-integrated modular advanced reactor (SMART) is an integral PWR with a rated electrical power of 107 MW(e) from 365 MW(t).
SMART adopts advanced design features to enhance safety, reliability and economics. The advanced design features and technologies were verified and validated during the standard design approval review. To enhance safety and reliability, the design configuration incorporates inherent safety features and passive safety systems. The design aim is to achieve improvement in economics through system simplification, component modularization, reduction of construction time and high plant availability. SMART has been developed to be suitable for high-temperature steam demand or electricity production within small grids.

Figure 1. SMART Plant Layout

1.2 Development Milestones

1999	Conceptual Design Development
2002	Basic Design Development
2007	SMART-PPS (Pre-Project Service)
2012	Technology verification, Standard Design Approval (SDA)
2015	Pre-project engineering agreement signed between Republic of Korea and Kingdom Of Saudi Arabia for the deployment of SMART in the Gulf country
2019	SMART100 Standard Design Approval applied to the Nuclear Safety and Security Commission (NSSC).

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

https://www.kaeri.re.kr/eng/

1.5 Design Description

SMART is an integral-type reactor containing major components such as a core, pressurizer, steam generators, and reactor coolant pumps in a single reactor pressure vessel. This integrated arrangement of the reactor vessel assembly enables the large bore pipe connections to be removed, resulting in an inherent elimination of large break loss of coolant accidents (LBLOCAs). Eight (8) modular type once-through steam generators consist of helically coiled tubes to produce superheated steam under normal operating conditions. A small water inventory of the secondary side of steam generator reduces the possibility of a post-trip recriticality during a main steam line break accident. Four (4) canned motor reactor coolant pumps, which has no pump seals, inherently prevent a loss of coolant associated with a pump seal failure. Four (4) channel control rod position indicators contribute to the simplification of the core protection system and to the enhancement of the system reliability. The in-vessel pressurizer is designed to control the system pressure at a nearly constant level over entire normal operating condition. The low power density design with a slightly enriched (< 5 w/o) UO 2 fueled core ensures a thermal margin of greater than 15%, which can accommodate any anticipated operational occurrences (AOOs). Reactivity control during the normal operation is achieved using soluble boron and control rods, and burnable poison rods are introduced for a flat radial and axial power profile, which result in an increased thermal margin of the core.

1.6 Licensing Application Support Documents

Standard Safety Analysis Report (SSAR)

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, Dispatchable, Off - grid / Remote, Non-electric (Steam supply for oil sand sites)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	On Coast, Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Dual Unit	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	SMR	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 (4 pumps)	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	Square	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	17x17	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	Design Licensed (in Country)	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	95	%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages	30 days after every 30 months (refuelling)	# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources	32/240	# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design	2	n Units/Modules
Capacity to Electric Grid	214	MWe (net to grid)
Non-electric Capacity	Optional	e.g. MW(th) heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption	<30	MWe
Plant Footprint	10000	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	20-100%, 5% per minute	x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	15	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	5.76	MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)	205.9	kg
Nominal Coolant Flow Rate (primary)	2057	kg/s
Nominal Coolant Flow Rate (secondary)	190.4	kg/s
Core Inlet Coolant Temperature	295.7	ºC
Core Outlet Coolant Temperature	322	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	14450	mm
- NSSS Largest Component Diameter	6500	mm
- NSSS Largest Component Thickness	331	mm
- NSSS Largest Component Weight	1000	tonne
Reactor Vessel Material	Carbon Steel	e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design	Once-through Helical	e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory	<1000	kg
Pressurizer Design	Integral steam	e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume	47/23	m3 / m3 (total / liquid)
Containment Type	Dry/ half underground	Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3
Spent Fuel Pool Capacity and Total Volume	30/--	Years of full-power operation / m3
Non Electric Application	Desalination, District Heating	-
Core Delta Temperature	27.3	ºC
Fuel/Core		
Single Core Thermal Power	365	MW(th)
Refuelling Cycle	30	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	<5	%
Average Neutron Energy		eV
Fuel Cladding Material	Zr	e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	17x17	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.)	54	MWd/kgHM

Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing	none	e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control rods and Boron Solution	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber	Gd2O3	e.g. Gd2O3
Core Volume (active)	5.269	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	Ag-In-Cd	-
Core Soluble Neutron Absorber	H3BO3	-
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	Passive	- / - / -
- emergency AC supply (e.g. diesels)	N/A	- / - / -
DC Power Capacity (e.g. batteries)	72	Hours
Events in which Immediate Operator Action is required	None	e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time	72	Hours (that are assumed when following EOPs)
Severe Accident Core Provisions	IVMR	e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)	6E-8	x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions	H2 ignitors, PARs	e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)	6E-9	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)	36	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	160.8	kg/s
System Steam Pressure	5.76	MPa
System Steam Temperature		ºC
System Feedwater Flow Rate	13.4	kg/s
System Feedwater Temperature	200	ºC
Reactor Core		
Active Core Height	2	m
Equivalent Core Diameter	1.8316	m
Average Linear Heat Rate	10.965	kW/m
Average Fuel Power Density	23.079	kW/kgU
Average Core Power Density	69.27	MW/m3
Outer Diameter Of Fuel Rods	9.5	mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

SMART plant has been designed to have a seawater intake structure and other buildings including chlorination building in the yard. Power block accommodates reactor containment and auxiliary buildings (RCAB), turbine generator buildings and one compound building shared by two units of SMART. The RCAB houses reactor containment, auxiliary and fuel handling areas to adapt the small and modular plant concept.

The balance of plant (BOP) design consists of turbine generator buildings and electric power systems. Each turbine generator building is located adjacent to the RCAB and the layout is designed to avoid any impacts to safety-related systems by turbine missiles. Each building contains a turbine unit, a turbine generator, and all collateral equipment for a complete operating system. The turbine generator building is sometimes referred to as the Turbine Island. The balance of facilities is stationed and constructed as near as practical to support the Nuclear and Turbine Islands. The compound building provides access control area for both units, a hot machine shop as well as radwaste treatment area.

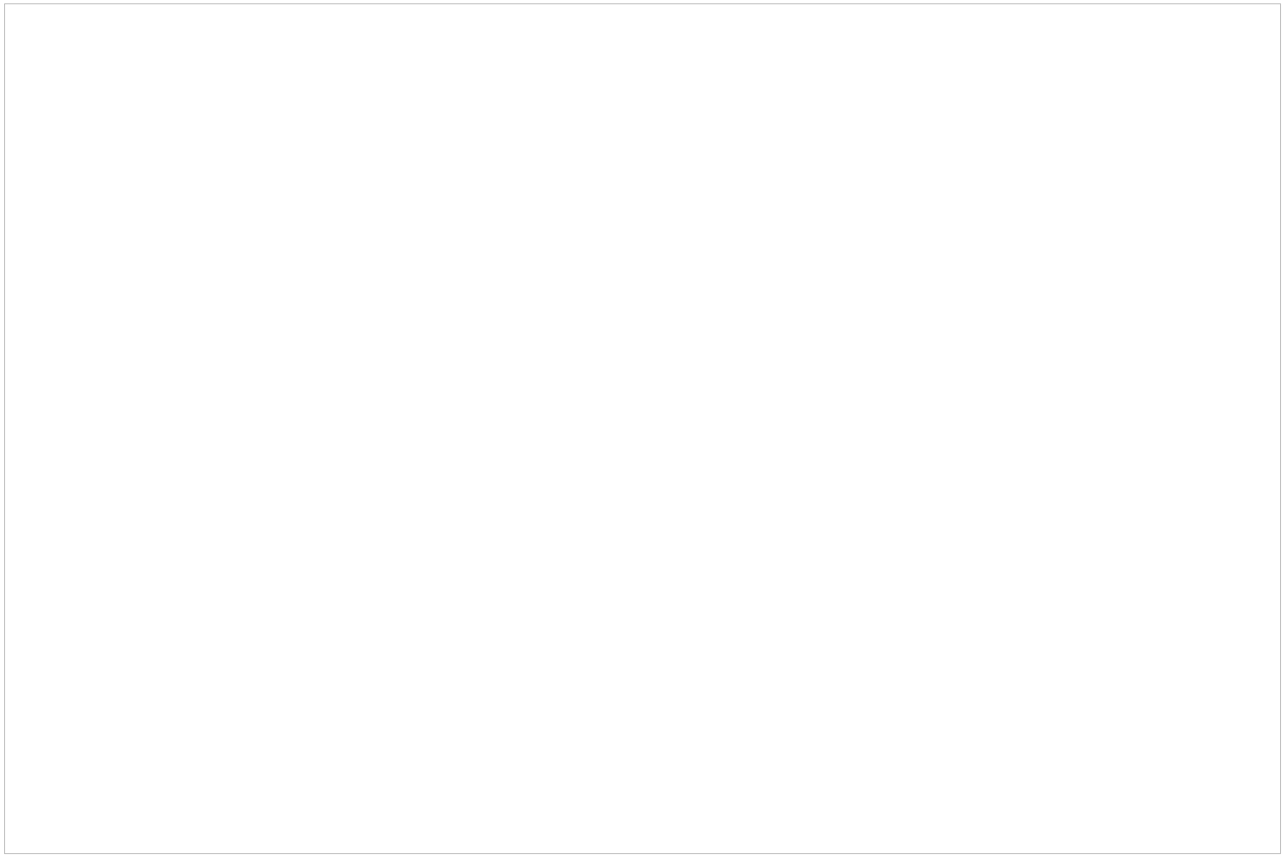


Figure 2. SMART plant layout

4.1 Site Requirements during Construction

Sample site plans, e.g. on-coast, inland, etc

General site criteria of NPP can be applicable to the selection of SMART plant site. For inland deployment of SMART where plant cooling water resources are scarce, however, those water requirements may be waived or priority may be lowered, if a proper provision for plant cooling is secured by other means. Where the plant does not have abundant water, it can discharge waste heat to the air using cooling towers which mostly use the physics of evaporation. Where access to water is even more restricted, or environmental and aesthetic considerations are prioritized, dry cooling techniques using air-cooled condensers may be chosen.

Buildings and structures (reactor, turbine and other buildings)

The Reactor Containment and Auxiliary Building (RCAB) houses, protects, and supports plant equipment and provides personnel and equipment access, support for systems and components under operating loads, radiation shielding, structural components to withstand loads due to design basis external and internal events, physical separation between divisions of safety-related equipment, and barriers to minimize or prevent the release of radioactive materials. The containment area of RCAB is a steel lined reinforcing concrete structure which consists of a rectangular shape walls and arched roof on the reinforced concrete basemat slab. The containment area of RCAB retains its integrity at pressure and temperature conditions associated with the most limiting design basis accident without exceeding the design leakage rate.

Containment layout and structure (separation of radiation areas, accessible areas, etc.)

In order to maintain radiation exposure ALARA throughout the layout and shielding design, the SMART plant is divided into several radiation zones. The zones are used in the development of plant procedures to provide reasonable assurance that maintenance, inspection, and testing activities are performed in the lowest radiation zone possible.

Spent fuel facilities

The spent fuel storage racks provide on-site storage capability for a core offload during the design life. The spent fuel storage racks are located in the spent fuel pool. The Spent Fuel Pool Cooling and Cleanup System (SFPCCS) is a non-safety-related system with the exception of piping and components required for containment isolation and safety-related makeup flow paths to the spent fuel pool. The SFPCCS removes the decay heat generated by the spent fuel assemblies stored in the pool, and purify the contents of the pool.

4.2 Site Considerations during Operation

Emergency planning and response

Small EAB (Exclusion Area Boundary) of SMART may ease the relevant clauses of the general site criteria. Small EAB and low plant cooling requirement are ones of the many advantages of SMART when compared with large NPPs. This enables SMART plant to be deployable inland and near to consumer area, where the grid system is usually small and isolated, or area that need long transmission distance, replacing expensive thermal plants and saving precious oil and gases.

Design provisions for decommissioning after major accident and at planned end-of-life

The SMART design includes features and operational programmes to minimize contamination of the facility and environment, facilitate decommissioning, and minimize the generation of radioactive waste throughout the life-cycle of the facility. The design takes into consideration of life-cycle planning of the facility, and identifies the operational programmes and procedures to address SSCs maintenance, site radiological environmental monitoring, and the documentation of operational incidents for decommissioning planning. These control measures are designed to work in conjunction with the operational procedures for the collection, processing, sampling, storing, monitoring, and disposal of waste during normal operation, including Anticipated Operational Occurrences (AOOs).

4.3 Grid Integration

Grid interface/code requirements (power (MWe), voltage (kV), frequency (Hz))

The design criteria, including General Design Criteria of 10 CFR 50, Appendix A, USNRC Regulatory Guides, KEPIC, and IEEE Standards are considered in the design of Class 1E system and equipment (Power 107 MWe, voltage 230kV, frequency 60Hz).

Load following capability, experience, and effect on waste generation

Load following capability from 20% to 100% of total net electric output power with 5% ramp rate.

Ability of plant to operate on house load: Yes

Ability to load reject without shutdown: Yes, up to 55% nominal power

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

The SMART design adopts an integrated primary system, modularization and advanced passive safety systems to improve the safety, reliability and economics. Safety performance of SMART is assured by adopting passive safety systems together with severe accident mitigation features. Improvement in economics is achieved through system simplification, in-factory fabrication, reduction of construction time and high plant availability.

The SMART has an integral reactor coolant system (RCS) configuration that enables the elimination of a large break loss of coolant accident (LBLOCA) from the design basis events. The nuclear steam supply system (NSSS) consists of the RCS forming a reactor coolant pressure boundary, secondary system, chemical and volume control system (CVCS), component cooling water system (CCWS), passive residual heat removal system (PRHRS), passive safety injection system (PSIS), automatic depressurization system (ADS), containment pressure and radioactivity suppression system (CPRSS), etc.

The low power density design with a slightly enriched UO2 fuelled core ensures a thermal margin of greater than 15%. In the core, there are 57 fuel assemblies of 2 m long, standard 17x17 square of UO2 ceramic fuel with less than 5% enrichment, similar to standard PWR fuel. A two-batch refuelling scheme without reprocessing provides a cycle of 870 effective full power days for operation.

The Reactor Pressure Vessel (RPV) houses the reactor core, 8 steam generators (SGs), 4 canned motor reactor coolant pumps (RCPs), 25 control rod drive mechanisms (CRDMs) and reactor internals such as the core support barrel assembly and

the upper guide structure assembly.

The RCS transfers core heat to the secondary system through the SGs and plays a role of a barrier that prevents the release of reactor coolant and radioactive materials to the reactor containment. The major components of the RCS are a reactor vessel assembly containing the core, pressurizer space, SGs, RCPs, CRDMs, and related pipes, valves, and instrumentations. The forced circulation flow of the reactor coolant is formed along the flow path by the RCPs during normal operation. The RCS and its supporting systems are designed with sufficient core cooling margin for protecting the reactor core from damage during all normal operation and anticipated operational occurrences (AOOs).

High reliability and performance of I&C systems is achieved using advanced features such as digital signal processing, remote multiplexing, signal validation and fault diagnostics, and sensing signal sharing for protection and control system. The ex-core neutron flux monitoring system consists of safety and start-up channel detectors which are located within the RPV, and digital signal processing electronics. The in–core instrumentation system consists of 29 detector assemblies which are developed as mini type for SMART with four stacked rhodium self–powered neutron detectors.

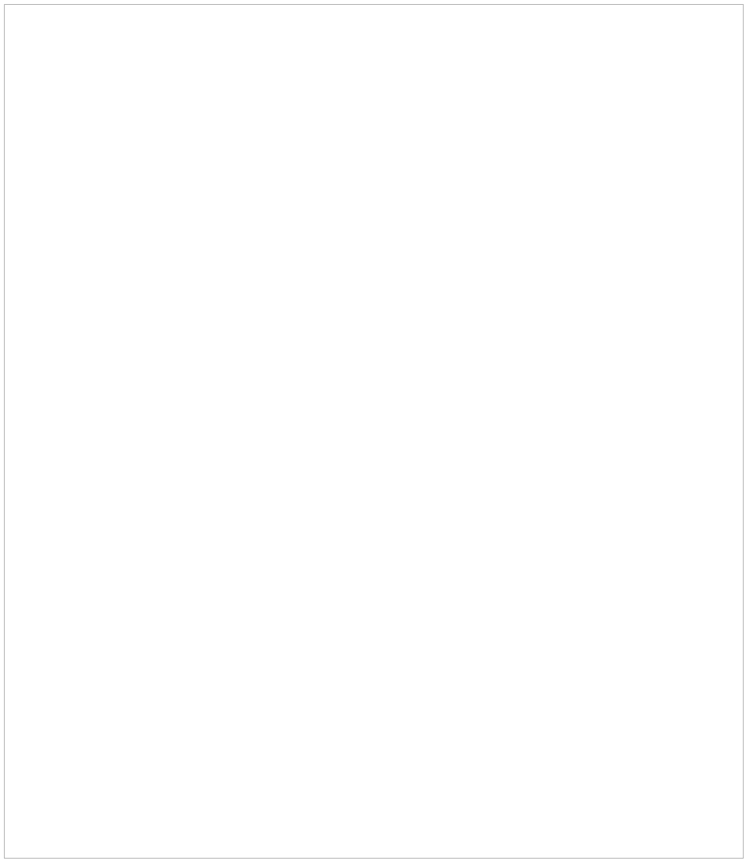


Figure 3. SMART Reactor

Figure 4. SMART Passive Safety Systems

5.1 Primary Circuit

Primary circuit component description and layout (e.g. primary vessel(s), internals, steam generators, pumps, pressurizer, etc)

(NSSS) The SMART has an integral reactor coolant system (RCS) configuration that enables the elimination of a large break loss of coolant accident (LBLOCA) from the design basis events. The nuclear steam supply system (NSSS) consists of the RCS forming a reactor coolant pressure boundary, secondary system, chemical and volume control system (CVCS), component cooling water system (CCWS), passive residual heat removal system (PRHRS), passive safety injection system (PSIS), automatic depressurization system (ADS), containment pressure and radioactivity suppression system (CPRSS), etc.

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(RPV) The RPV houses the reactor core, 8 steam generators (SGs), 4 canned motor reactor coolant pumps (RCPs), 25 control rod drive mechanisms (CRDMs) and reactor internals such as the core support barrel assembly and the upper guide structure assembly.

(Steam Generator) The SMART has 8 modular type once-through SGs with helically coiled tubes to produce superheated steam under normal operating conditions. The SGs are located at the circumferential periphery between the core support barrel and RPV above the core to provide a driving force for natural circulation flow in emergency conditions. The small inventory of the secondary side (tube side) water in each SG prohibits a return to power following a main steam line break accident. In case of an accident, the SG can be used as the heat exchanger for the PRHRS.

(Pressurizer) The in-vessel pressurizer uses the free volume in the upper part of the RPV. The primary system pressure during normal operation is maintained nearly constant due to the large pressurizer steam volume and the heater control. Due to the large volume of the pressurizer, condensing spray is not required for load manoeuvring operation. The reactor over-pressure at the postulated design basis accidents can be reduced through the actuation of pressurizer safety valves.

(Primary pumps) The RCPs are installed horizontally on the external wall of the reactor pressure vessel. It is a mixed flow pump adopting a canned motor. It consists of the pressure retainer, the impeller and diffuser, the shaft assembly, and the motor. No coupling is needed to connect the impeller shaft and the motor shaft. All of the pump parts are enclosed by the pressure retainer. Therefore, there is no mechanical seal device to prevent the reactor coolant from leaking through the pressure retainer. The component cooling water flowing in the helical tubes removes the heat on the motor. The reactor coolant pump sucks the reactor coolant through the annulus between the core support barrel and upper guide structure, and then it discharges the reactor coolant to the space above the steam generator.

Auxiliary systems (e.g. decay heat removal, shutdown cooling, chemistry control, etc.)

(Engineered Safety System Approach and Configuration) Safety systems of SMART are designed to function automatically on demand. These consist of the PRHRS, PSIS, and CPRSS. Additional safety systems include the ADS and pressurizer safety valves, and a severe accident mitigation system.

(Decay Heat Removal System) After the reactor is shutdown, when the normal decay heat removal mechanism utilizing the secondary system is not operable for any reason, the PRHRS brings the RCS to a safe shutdown condition within 36 hours after accident initiation and maintains the safe shutdown condition for at least another 36 hours. Therefore, the safety function operates for 72 hours without any corrective action by operators for the postulated design basis accidents. The safety function of PRHRS is maintained continuously for a long-term period when the emergency cooldown tank (ECT) is replenished periodically by a refilling system designed according to Regulatory Treatment of Non-Safety System (RTNSS) requirements.

(Emergency Core Cooling System) The PSIS provides emergency core cooling following postulated design basis accidents. Emergency core cooling is performed using 4 core make-up tanks (CMTs) and 4 safety injection tanks (SITs). Core cooling inventory is maintained through passive safety injection from CMTs and SITs. The CMTs that are full of borated water provide makeup and borating functions to the RCS during the early stage of an SBLOCA or non-LOCA. The top and bottom of CMT are connected to the RCS through the pressure balance line and safety injection line, respectively. The safety injection function of the PSIS is maintained long term as the SITs are replenished periodically.

Operating modes

Six operating modes are classified according to core reactivity condition, power level, reactor coolant average temperature, and reactor closure head and stud bolt tensioning with fuel in reactor pressure vessel.

1. Power Operation
2. Startup Operation
3. Hot Standby
4. Safe Shutdown
5. Cold Shutdown
6. Refuelling Operation

5.2 Reactor Core and Fuel

Design and licensing factors that limit fuel burnup

The low power density design with a slightly enriched UO2 fuelled core ensures a thermal margin of greater than 15%. In the core, there are 57 fuel assemblies of 2 m long, standard 17x17 square of UO2 ceramic fuel with less than 5% enrichment, similar to standard PWR fuel. A two-batch refuelling scheme without reprocessing provides a cycle of 870 effective full power days for operation.

Fuel suppliers or supply chain

KEPCO NF taking charge of designing and manufacturing nuclear fuel in Korea, was established in 1982 to localize the nuclear fuel cycle technology. KEPCO NF have been successfully supplied to all nuclear power plants for PWR and PHWR in Korea. KEPCO NF has supplied over 21,000 fuel assemblies for all PWRs in Korea since 1989. From this, a large database resulting from fuel supply experience has been established and formed a basis for improving reactor core and fuel design and fabrication.

5.3 Fuel Handling

Brief Description, main components with fuel movement from fresh to spent fuel bay

The fuel handling system is an integrated system of equipment, tools, and procedures for refueling, handling and storage of fuel assemblies from receipt of a new fuel shipping container to shipment of a spent fuel cask. The equipment is designed to handle the

new and spent fuel assemblies in dry or wet condition from the time they arrive at the site until they are placed in a cask for shipment from the site. Underwater transfer of fuel assemblies provides a transparent radiation shield, as well as a cooling medium for removal of decay heat. Fuel handling equipment provides for the safe handling of fuel assemblies under specified conditions. The major components of the system consist of the refueling machine, the spent fuel handling machine, the new fuel elevator, and etc. This equipment is provided to transfer the new and spent fuel assembly between the fuel storage facility, the upper containment area, and the fuel shipping and receiving areas during initial core loading and refueling operations. A fuel assembly is inserted in or removed from the core using the refueling machine. Fuel assemblies which are irradiated during normal operation are always maintained in the underwater condition.

Fuel cycle and refuelling outage lengths

SMART refuelling cycle is 30 months.

5.4 Reactor Protection

Core reactivity and shutdown

Reactivity control during normal operation is achieved by control rods and soluble boron. Burnable poison rods are introduced to give flat radial and axial power profiles, which results in an increased thermal margin of the core. SMART adopts a typical magnetic-jack type control rod drive mechanism which has been widely used in the commercial nuclear power plants.

Reactor regulating system (RRS) provides a mechanism to improve the capability of the reactor to follow turbine load changes keeping main steam pressure and reactor coolant temperature within specified values by means of reactivity adjustments utilizing the control rod assemblies. The RRS provides automatic control of the reactor coolant temperature and reactor power, in conjunction with the operation of NSSS control system during plant operation between 20% and 100% power.

The regulating CRA group is used to compensate for changes in reactivity associated with routine power level changes. Soluble boron is used to maintain shutdown reactivity at the cold zero power conditions. Soluble boron can also be used to compensate for changes in reactivity due to power level changes and minor changes in reactivity which might occur during normal reactor operation. The reactivity worth requirements of the full complement of CRAs are primarily determined by the power defect, the excess CRA worth with the stuck rod criteria. The amount of reactivity available from full insertion of the CRAs located at the bank insertion limit under all power operating conditions, even when the largest worth CRA fails to insert, will provide for excess CRA worth after cooldown to hot zero power, plus any additional shutdown reactivity requirements assumed in the accident analyses.

Fission product retention

Containment Pressure and Radioactivity Suppression System (CPRSS) removes the fission products from the containment area following the accident by dissolving them in the radioactive material removal tank. The CPRSS removes fission products released from the reactor pressure vessel to the containment for 72 hours following the accident without AC power sources or operator actions.

5.5 Secondary Side

Feed water systems

The secondary system receives superheated steam from the NSSS. It uses most of the steam for an electricity generation, seawater desalination and the pre-heaters. The main steam pressure is controlled so as to be constant during a power operation. A load change is achieved by changing the feedwater flow rate. Seawater desalination system such as the MED, MSF, and RO may be used in conjunction with the secondary system by using proper interfacing methods.

The feedwater system supplies feedwater from the deaerator storage tank to the eight

steam generators. The system also provides the path for PRHRS, for RCS heat-up operation up to 0% power condition through the steam generators with closed circulation of the steam generated by preheating system, for shutdown cooling operating along with component cooling system.

Turbine generator description

Turbine is a machinery to change heat energy from steam generator to mechanical energy torque), and generator convert mechanical energy to electric energy. The turbine generator is designed and manufactured in accordance with the manufacturer's design criteria and manufacturing practices, procedures, and processes as well as its Quality Assurance Program.

The Turbine Island comprises those buildings that house the Turbine Generator building and electrical switchgear area for power distribution. The Turbine Island is adjacent to the Nuclear Island. The Turbine Generator Building shall be arranged to avoid any impacts to the safety-related systems by the turbine missiles. It is a Seismic Category II structure which is separated from the Reactor Containment and Auxiliary Building with a seismic gap.

5.6 Containment/Confinement

Description/Type

The reactor containment and auxiliary building(RCAB) consists of the containment area and the auxiliary area. The containment area is composed of the upper containment area(UCA), the lower containment area(LCA), the in-containment refuelling water storage tank(IRWST), and the radioactive material removal tank(RRT). The containment area above the operating floor has a rectangular wall and an arched roof.

The containment area is a reinforced concrete structure in the shape of a rectangular with an arched roof and a continuous steel liner anchored to a reinforced concrete basemat that extends beyond the containment area to support other plant structures. A protective layer of concrete (fill slab) covers the portion of the liner over the foundation slab. The containment area concrete provides biological shielding for normal and accident conditions. The containment area completely encloses the reactor vessel assembly, safety inject tank and core makeup tank, and it is designed to provide an essentially leak tight barrier against the release of radioactive materials subsequent to postulated accidents. The internal structures and compartment arrangement provide equipment missile protection and biological shielding for maintenance personnel.

Design pressure/temperature/leak rate at design pressure

Isolation and fission product retention (including venting/filters)

Refer to 2.4 Reactor Protection

Heat removal systems

The containment system is designed to contain radioactive fission products within the containment building and to protect the environment against primary coolant leakage. This safety function is realized by the CPRSS as a passive safety system. The containment system is composed of a lower containment area (LCA), an upper containment area (UCA), an in-containment refueling water storage tank (IRWST), and the CPRSS, besides these, it includes CPRSS Heat Removal System (CHRS). In case of main steam line break (MSLB) or LOCA, some of the released energy is absorbed into the IRWST and the rest is removed to environment by the CHRS. Fission products are scrubbed in the IRWST water. For combustible gas control, passive autocatalytic hydrogen recombiners are equipped inside the LCA and UCA

5.7 Electrical, I&C and Human Interface

Turbine and Generator type/model, speed, rated power, voltage, frequency

SMART Turbine is a machinery to change heat energy from steam generator to mechanical energy torque), and generator convert mechanical energy to electric energy. Turbine generator can increase or decrease load within ± 5% load per minute and step 10%. The turbine consists of a single-flow, high-pressure turbine and double-flow low pressure turbines driving a direct-coupled generator. The flow of main steam is directed from the steam generators to the high-pressure (HP) turbine through the turbine stop valves and turbine control valves. The function of the generator is to convert rotational energy produced by the turbine into electrical power. The generator terminal voltage at 60 Hz is 15 kV and the permissible variation shall be in accordance with IEEE.

Safety related electrical systems

The electric power system of SMART consists of the onsite power system and the offsite power system. The transmission grid system consists of interconnected hydro, thermal, and nuclear power plants supplying energy at frequency of 60 Hz with various voltages. The offsite power system consists of a single 230 kV Switchyard and the offsite power is provided by two transmission lines from transmission grid. These 230 kV transmission lines transmit the produced electricity to the offsite power system and to provide the offsite power to auxiliary loads of the unit.

The 125 V DC power system and 120 V AC I&C power system provide a reliable, continuous source of power to Class 1E I&C loads and valves. Although the 125 V DC power system and the 120 V AC I&C power system are treated separately, they form an integrated system which consists of four independent and physically separated load groups that supply power to I&C channel A, B, C, and D. Four channels are separated in such a way that a single failure cannot cause multiple channel malfunctions or interactions between channels. Each instrumentation bus is powered from a separate battery to provide stable and noise free power to its

respective control channel. The 125 V DC power system and 120 V AC I&C power system are Seismic Category I systems and are located in the auxiliary area.

I&C design architecture and applicable standards

The Man-Machine Interface Systems (MMIS) of NSSS consists of I&C systems and control rooms in SMART. The SMART MMIS to which digital information processing technologies and a communication network scheme are applied has a multi-layer structure. The I&C systems of SMART are composed of protection systems, control systems, monitoring systems, and an instrumentation system. Control rooms for SMART include a main control room (MCR) and a remote shutdown room (RSR). High reliability and performance of I&C systems is achieved using advanced features such as digital signal processing, remote multiplexing, signal validation and fault diagnostics, and sensing signal sharing for protection and control system. The ex-core neutron flux monitoring system consists of safety and start-up channel detectors which are located within the RPV, and digital signal processing electronics. The in–core instrumentation system consists of 29 detector assemblies which are developed as mini type for SMART with four stacked rhodium self–powered neutron detectors.

Control room layout

The MCR is the place where the operators reside in any operating condition and perform their work in order to operate SMART with safety excluding evacuation situation caused by a fire, high-level radiation, toxic gases, etc. The safety of SMART depends upon the quality of the tasks to be performed by the operators. As such tasks are performed through the human-machine interface (HMI) in accordance with a pre-established operation procedure, it is important to develop HMI designs and operation procedures suitable to the tasks in order to guarantee the safety of SMART.

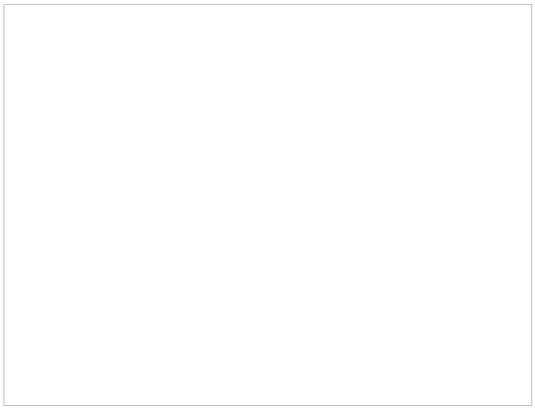


Figure 5. SMART Main Control Room

5.8 Unique Technical Design Features (if any)

6. Technology Readiness

SUMMARY FOR BOOKLET

From 2009 to 2012, the SMART Technology Validation and Standard Design Approval (SDA) Project was carried out jointly with Korean nuclear power-related organizations. As a result, the SDA for SMART was officially issued on July 2012. New safety review process of enhanced design is in progress, and its SDA is expected to be issued by the end of 2024.

The SMART design conforms to the Rule of the Nuclear Safety and Security Commission (NSSC) “Regulations on Technical Standards for Nuclear Reactor Facilities, Etc.” and the U.S. Federal Regulations, given in 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, General Design Criteria (GDC) for Nuclear Power Plants.

Strict Quality Assurance (QA) policy and programs are applied in the development of SMART to support trust by ensuring that all the important safety-related requirements are fully observed throughout the construction and lifetime of nuclear power plants.

6.1 Deployed Reactors
6.2 Reactors under Licensing Review

Licensing Status (which regulator, phase, etc.)

From 2009 to 2012, the SMART Technology Validation and Standard Design Approval (SDA) Project was carried out jointly with Korean nuclear power-related organizations. As a result, a full set of licensing documents, including a Standard Safety Analysis Report (SSAR), were submitted to the Korean Nuclear Safety and Security Commission (NSSC) at the end of December 2010, and the SDA for SMART was officially issued on July 2012. To cope with the enhanced safety demands after the Fukushima accident, a safety enhancement research for SMART construction was performed from 2012 to 2016. The technical improvement of SMART with a fully passive safety system was completed in 2018. Meanwhile, the safety review process is in progress, and the SDA of enhanced design is expected to be issued by the end of 2024.

Compliance with worldwide design and licensing regulations

The SMART design conforms to the Rule of the Nuclear Safety and Security Commission (NSSC) “Regulations on Technical Standards for Nuclear Reactor Facilities, Etc.” and the U.S. Federal Regulations, given in 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, General Design Criteria (GDC) for Nuclear Power Plants. Benefitting the international experience of APR1400 technology, SMART design complies with the relevant IAEA Safety Requirements even though those requirements are not considered for the plant design.

Design standardization / simplification, main components that are new designs

SMART was developed by harmonizing innovative concepts and the proven commercial technology, combining the innovative concepts and the commercial technology proven in pressurized water-cooled reactor. Innovative technologies have been implemented; such as integral reactor, modularization of on-site installation and maintenance, passive safety system and the fully digitized control system. SMART is designed to an integral reactor, and there is no mid-loop operation for shutdown operation. Additionally, SMART is equipped passive safety system, and safety related pumps are not required. These characteristics of SMART results in simplification of design as described below improving plant performance and maintainability.

QA programs, including safety analysis computer software

The success of SMART project can be possible due to the systematic establishment and

implementation of Quality Assurance Program (QAP), which supports trust by ensuring that all the important safety-related requirements are fully observed throughout the construction and lifetime of nuclear power plants. Strict Quality Assurance (QA) policy and programs are applied in the development of SMART. The QA program includes:

- Design Control
- Procurement Document Control
- Instructions, Procedures, and Drawings
- Document Control
- Control of Purchased Items and Services
- Identification and Control of Items
- Control of Processes
- Inspection
- Test Control
- Control of Measuring and Test Equipment
- Handling, Storage and Shipping
- Inspection, Test and Operating Status
- Control of Nonconforming Items
- Corrective Action
- Quality Assurance Records
- Quality Assurance Audit

Expected reliability and maintainability of systems and equipment

The enhancement of safety and reliability is realized by incorporating inherent safety improving features and reliable passive safety systems. The low power density design with about 5 w/o UO2 fuelled core is proven to provide sufficient thermal margin to

accommodate any design basis transients with regard to the critical heat flux. This feature ensures the core thermal reliability under normal operation and any design basis accidents. Other improved design features include the canned motor reactor coolant pump which has no pump seals and thus loss of coolant associated with pump seal failure is prevented. Four channel control rod position indicators contribute to the simplification of the core protection system and to the enhancement of the system reliability. Furthermore, an advanced man-machine interface system (MMIS) using digital techniques and equipment reduces the human error factors, and consequently improves the plant reliability.

Institutions involved in R&D and design

KAERI has been developing SMART technologies with participation of major nuclear industries. The roles of each entities are following.

- KAERI: NSSS System Designer
- KEPCO NF: Core design and fuel fabrication
- KEPCO E&C: architect engineering services and other related services.
- Doosan Enerbility: Major equipment supply

6.3 Reactors in the Design Stage

7. Safety Concepts

SUMMARY FOR BOOKLET

The safety approach for design and operation of SMART is based on the defence-in-depth philosophy. Multiple barriers such as fuel pellet, cladding, reactor coolant pressure boundary, and reactor containment prevent radioactive release to environment. Multiple and diverse systems are designed to remove heat for the protection of those barriers.

Inherent safety features incorporated into the SMART design enhance the accident resistance of SMART. The integral arrangement of the primary system removes large size pipe connections between major components and thus, fundamentally eliminates the possibility of LBLOCA. The canned motor RCP eliminates the need for an RCP seal, and basically eliminates a potential for a SBLOCA associated with the seal failure.

ALARA (as low as reasonably achievable) principle is implemented in SMART design, including radiological zoning and proposed control of personnel access to different zones, dose limitation for different groups for a generic reactor design, radiation monitoring process and instrumentation proposed for normal operation, AOOs and DBAs, and radiation protection provisions in the design of the facility to be used for radioactive waste handling/processing/ storage.

Safety systems of SMART are designed to function automatically on demand. Reactor safety is considerably enhanced by introducing the passive safety systems such as the passive residual heat removal system (PRHRS), the passive safety injection system (PSIS), the automatic depressurization system (ADS) and the containment pressure and radioactivity suppression system (CPRSS). The passive safety systems maintain the SMART plant in a safe shutdown condition following the design basis accidents such as LOCA and non-LOCA events without any operator action or AC power for at least 72 hours.

7.1 Safety Philosophy and Implementation

Safety concept, design philosophy and licensing approach

The safety approach for design and operation of SMART is based on the defence-in-depth philosophy. Multiple barriers such as fuel pellet, cladding, reactor coolant pressure boundary, and reactor containment prevent radioactive release to environment. Multiple and diverse systems are designed to remove heat for the protection of those barriers. Safety systems of SMART, a sensible mixture of proven technologies and advanced design features, are designed to function automatically on demand. They consist of PRHRS, PSIS, Containment Pressure and Radioactivity Suppression System (CPRSS), reactor overpressure protection system, and severe accident mitigation system.

Operational safety margins, at initial load, end-of-life, and during load following

Power manoeuvring operation of SMART is simpler than that of large PWR because only a single bank movement and small

insertion is required to induce small reactivity change. This feature minimizes coolant temperature change, relatively high lead bank worth due to a small number of fuel assemblies and the short core height leading to rapidly damping the xenon oscillation. The daily load following performance simulation of SMART core shows that radial peaking factor, 3D peaking factor and the axial offset were satisfied within design limit.

Active and passive systems as well as inherent safety features; indication of whether the system is the main or backup system; level of passivity ("A" - "D")

Inherent safety features incorporated into the SMART design enhance the accident resistance of SMART. SMART contains major primary components such as a core, eight (8) steam generators, a pressurizer, four(4) reactor coolant pumps, and twenty-five (25) control rod drive mechanisms (CRDMs) in a single reactor pressure vessel (RPV). The integral arrangement of the primary system removes large size pipe connections between major components and thus, fundamentally eliminates the possibility of LBLOCA. The canned motor RCP eliminates the need for an RCP seal, and basically eliminates a potential for a SBLOCA associated with the seal failure. The modular type once-through steam generators are located relatively high above the core to provide a driving force for natural circulation flow. This design feature along with low flow resistance enables the capability of the system to have residual heat removal with natural circulation when normal means to transfer residual heat from the core are not available. A large volume of semi-passive PZR can accommodate a wide range of pressure transients during system transients and accidents. Low core power density lowers the fuel element temperature rise under accident conditions and increases the thermal margin. Negative moderator temperature coefficient (MTC) yields beneficial effects on a core self-stabilization, and limits the reactor power during accidents.

The reactor can be shutdown under any circumstances by inserting control rods or boron injection. The passive safety system of SMART maintains the plant in a safe shutdown condition following design basis accidents such as LOCA or non-LOCA without safety grade AC power or operator actions within 72 hours. The PRHRS prevents over-heating and overpressurizing of the primary system in case of emergency situations where normal heat removal using the secondary system is unavailable. It removes the decay heat and sensible heat by natural circulation. The core is maintained undamaged without any corrective action taken by the operator for at least 72 hours. The reactor containment is resistant to any kind of seismic activity and can withstand possible air-crash incident.

Radiation protection goals and measures, implementation of ALARA and International Commission of Radiological Protection (ICRP) standards

ALARA(as low as reasonably achievable) principle is implemented in SMART design, including radiological zoning and proposed control of personnel access to different zones, dose limitation for different groups for a generic reactor design, radiation monitoring process and instrumentation proposed for normal operation, AOOs and DBAs, and radiation protection provisions in the design of the facility to be used for radioactive waste handling/processing/ storage. The radiation protection objective is to provide that during normal operation, or during anticipated operational occurrences, radiation exposures within the NPP or due to any planned release of radioactive material from the NPP are kept below prescribed limits and ALARA. Provisions shall be made for the mitigation of the radiological consequences of any accidents considered in the design. In order to maintain radiation exposure ALARA throughout the layout and shielding design, the plant is divided into several radiation zones. The zones are used in the development of plant procedures to provide reasonable assurance that maintenance, inspection, and testing activities are performed in the lowest radiation zone possible.

7.2 Transient/Accident Behaviour

Description of limiting design basis and severe accidents

The SMART safety analysis methodology was strictly validated using SMART-ITL which is the SMART integral effect test facility located at KAERI. The safety analysis shows that it remains in a safe shutdown condition after all design basis events. Since the Fukushima accident, the mitigation measures to cope with a severe accident have become key safety issues. This shows that maintaining continuous core cooling capability is essential. In a series of realistic simulations, the passive residual heat removal system of SMART effectively removed decay heat, maintaining the reactor in a stable condition for 20 days without external power sources or operator actions. With regard to aircraft crash resistance, the reactor containment and auxiliary building of SMART is designed to withstand an aircraft collision (using the case of a Boeing 767) without damage to the reactor or spent fuel pool.

Safety systems to cope with design basis accidents (dba)

Safety systems of SMART are designed to function automatically on demand. Reactor safety is considerably enhanced by

introducing the passive safety systems such as the passive residual heat removal system (PRHRS), the passive safety injection system (PSIS), the automatic depressurization system (ADS) and the containment pressure and radioactivity suppression system (CPRSS). The passive safety systems maintain the SMART plant in a safe shutdown condition following the design basis accidents such as LOCA and non-LOCA events without any operator action or AC power for at least 72 hours.

After the reactor is shutdown, when the normal decay heat removal mechanism utilizing the secondary system is not operable for any reason, the PRHRS brings the RCS to a safe shutdown condition within 36 hours after accident initiation and maintains the safe shutdown condition for at least another 36 hours. Therefore, the safety function operates for 72 hours without any corrective action by operators for the postulated design basis accidents. The safety function of PRHRS is maintained continuously for a long-term period when the emergency cooldown tank (ECT) is replenished periodically by a refilling system designed according to Regulatory Treatment of Non-Safety System (RTNSS) requirements.

The PSIS provides emergency core cooling following postulated design basis accidents. Emergency core cooling is performed using 4 core make-up tanks (CMTs) and 4 safety injection tanks (SITs). Core cooling inventory is maintained through passive safety injection from CMTs and SITs. The CMTs that are full of borated water provide makeup and borating functions to the RCS during the early stage of an SBLOCA or non-LOCA. The top and bottom of CMT are connected to the RCS through the pressure balance line and safety injection line, respectively. The safety injection function of the PSIS is maintained long term as the SITs are replenished periodically.

Safety systems to cope with severe accidents (beyond design basis accidents)

Severe accidents are caused by the failures of safety equipment and thus the performance of the corresponding safety function is lost. For this reason, severe accident is a beyond design basis accident which can release a large amount of radioactive fission products due to the core degradation. It is necessary to prevent and mitigate the severe accidents, which can cause the containment failure. The system to prevent and mitigate the severe accident is installed in order to achieve the requirements. The preliminary accident management program should be prepared to cope with the severe accident. The severe accident mitigation strategy is as follows:

The safety depressurization system of the Automatic Depressurization System (ADS) to prevent the Direct Containment Heating (DCH) by High Pressure Melt Ejection (HPME) is installed to make low pressure in the Reactor Coolant System (RCS) before the reactor vessel failure during a severe accident.

The system that cools down the outer wall of the reactor vessel is installed in order to cool the molten core material inside the reactor vessel using Cavity Flooding System (CFS) with In-Containment Refuelling Water Storage Tank (IRWST), which is an In-Vessel corium Retention through External Reactor Vessel Cooling (IVR-ERVC) to prevent reactor vessel failure.

Hydrogen mitigation system of the Passive Autocatalytic Recombiner (PAR) in the upper and low containment areas is installed to remove hazards from hydrogen combustion considering the amount of hydrogen to be generated by 100% fuel cladding oxidation.

The SMART has the pathway to release the hydrogen in core to the Lower Containment Area (LCA) through the break points, PSV, and ADS valves, and to the Upper Containment Area (UCA) through the Radioactive material Removal Tank (RRT).

The Ancillary Containment Spray System (ACSS) is provided to prevent a catastrophic failure of the UCA of the reactor containment area. The ACSS flow rate provides sufficient heat removal to prevent the upper containment pressure from exceeding the containment performance criteria, and function to remove the fission products in the UCA of the reactor containment area during a severe accident.

Severe accident management guidelines (SAMG) status

The SMART will be operated by EOP (Emergency Operating Procedure) for design basis accidents and design extension conditions (DEC) without core melt, and SAMG (Severe Accident Mitigating Guideline) for DEC with core melt. The main objective of the SAMG is to prevent a release of radioactive material into the environment during DECs with core melt (Severe Accident). In SMART, the entry condition of the SAMG uses the CET (Core Exit Temperature) of 650 ºC.

Safety goals (e.g. CDF, LERF, operator action time)

In accordance with Top-Tier requirements for SMART, the following criteria are incorporated in SMART design:

- The Core Damage Frequency (CDF) for internal events shall be lower than 10-E7 per reactor year.
- The Large Early Release Frequency (LERF) for internal events shall be lower than 10-E8 per reactor year.
- Provisions for safety under external events, e.g. Seismic, fire, flooding, aircraft impact

The postulated seismic design ground motions need to cover the potential SMART plant sites. These design ground motions are referred to as Design Basis Earthquake (DBE). The free-field peak ground accelerations in horizontal and vertical directions for the DBE are set to 0.3g for use in seismic design of the SMART.

The design concept of the SMART fire protection is to minimize both the probability and the consequences of fire such that in the event of a fire the plant may be brought to a safe shutdown both with and without the availability of offsite power. This is accomplished by using a defense-in-depth approach that includes a suitable combination of fire-resistant materials, separation by barriers, fire detection and suppression systems, and fire brigade. The SMART plant is protected from external flooding such as probable maximum precipitation (PMP), probable maximum flood (PMF) on the plant site, PMF on streams and rivers, probable maximum surge and seiche flooding, and probable maximum tsunami.

Aircraft crash evaluation on the SMART reactor containment and auxiliary building that contain nuclear fuel and equipment necessary for removing heat generated by nuclear fuel is performed to demonstrate that the structural configuration of the SMART plant can meet the regulatory requirements for aircraft crash. Detailed and realistic analyses consistent with the guidance in NEI 07-13 are performed for design specific assessments of the plant configuration to ensure that the reactor core remains cooled, or the containment remains intact and spent fuel cooling or spent fuel pool integrity is maintained.

Probabilistic risk assessment – status and results

Based on RG 1.216 Regulatory Position 3.1 a, selection of accident sequences based on a Level 1 probabilistic risk assessment (PRA) study is made. The more likely severe accident sequences to be analysed for the severe accident analyses are selected using a combination of deterministic and probabilistic approaches. Basically, the sequences whose core damage frequency (CDF) is high are involved in the severe accident analyses.

The design phase PRA for the SMAR is performed. To speculate on the information regarding the frequency of the severe accident scenario associated with LERF in the SMART100 and the results are In the at-power internal events of SMART100 design, the most dominant containment failure mode is the containment bypass caused by a Steam Generator tube rupture (SGTR) with a failure of isolating the tube-ruptured SG. for internal events for all operational modes is well below the probabilistic safety goal of the SMART for LRF, 10E-7/yr.

Emergency planning measures

Exclusion area boundary (EAB) was set not to exceed the dose criteria of 250 mSv during the worst two hours after the initiation of the accident which assumes substantial fission product release from the reactor core in accordance with USNRC 10 CFR 50.34 and regulatory guide 1.183. The source terms are based on USNRC NUREG-1465 which defines the amount, timing and chemical forms of the fission products released from the core. Size of EAB depends on the meteorological conditions of the site where the plant is located. For SMART, it was determined to be 300 meters from the reactor center.

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

The SMART reactor core is fuelled with uranium dioxide pellets enclosed in HANA tubes with welded end plugs. The reactor core consists of 57 fuel assemblies classified by two regions with two different U-235 enrichments in the first fuel cycle.

All the spent fuel produced from SMART is permanently disposed without any type of recycling.

Soluble boron and CRA absorbers are flexible means of controlling long-term and short-term reactivity changes, respectively.

8.1 Fuel Cycle Options

Description of reference fuel and fuel cycle (e.g. once through, closed, with reprocessing)

The reactor core is fuelled with uranium dioxide pellets enclosed in HANA tubes with welded end plugs. The reactor core consists of 57 fuel assemblies classified by two regions with two different U-235 enrichments in the first fuel cycle. The core thermal power is 365 MWt.

Nuclear fuel cycle is categorized into the two phases; the front-end of the fuel cycle, which consists of mining, milling, conversion, enrichment, fabrication; and the back-end, covering recycling or permanent disposal of the spent fuel. All the spent fuel produced from SMART is permanently disposed without any type of recycling.

Alternative fuel options and cycles (current, future)

Only low enriched UO2 (< 5%) fuel is used in SMART design. MOX fuel is not considered in current stage. However, in point of core design capability, there is no special reason that application of partial MOX fuel is not possible.

Control of excess reactivity over fuel life cycle

Soluble boron and CRA absorbers are flexible means of controlling long-term and short-term reactivity changes, respectively. Soluble boron is used to compensate for slow reactivity changes made due to burnup, changes in xenon concentration, etc. The reactor is supposed to be operated essentially in an unrodded condition at power. Boric acid is used for reactivity changes associated with large but gradual changes on water temperature, xenon concentration, and fuel burnup. For the short-term control, the control rods are controlled manually or automatically. The control rods are divided into two functional types; shutdown CRA groups for reactor trip, regulating CRA groups for reactor power and power distribution control. The CRA insertion at power is limited by the Bank Insertion Limit (BIL) for short-term reactivity changes.

Spent nuclear fuel and disposal plans

In accordance with the requirement of related codes and standards (ANSI/ANS 57.2), the spent nuclear fuel shall be stored in spent fuel pool for five years at least.The spent nuclear fuel will be stored in spent fuel pool using storage racks. Generally, the storage capacity of spent fuel storage racks depends on the owner's requirements. Current SMART design of has 30 years storage capacity for spent nuclear fuel.

Fuel handling systems

Refer to 5.3 Fuel Handling

Failed fuel detection

Fuel rod integrity in the reactor operating condition can be monitored by analyzing primary coolant activity analysis. Especially, existence of fuel failure, failed fuel rod number, exposure of fuel failure, defect size of failed fuel, and failed fuel cladding degradation can be evaluated by analyzing the coolant activity. If the monitoring results indicate leakage in the loaded fuel, inspection techniques, such as ultrasonic test, are used to identify the leaking fuel rod(s) during refueling outage

8.2 Resource Use Optimization

8.3 Unique Fuel/Fuel Cycle Design Features

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

9.1 Safeguards

Technical features to facilitate implementation of IAEA safeguards

International Atomic Energy Agency (IAEA) is planning to facilitate the verification activities of inspectors by developing a safeguards approach to the reactor as early as possible and preparing a Safeguards Technical Report (STR) before commercial operation of the Small Modular Reactor (SMR) begins. To this end, the IAEA is developing various approaches to the application of Safeguards by Design (SBD) to SMRs with countries such as Republic of Korea. KAERI established a safeguards approach from the early design stage of SMART in cooperation with the IAEA. In 2023, the Safeguards Technical Report (STR) for SMART100 was submitted to the IAEA.

9.2 Security

9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

10.1 Project Preparation and Negotiation

SMART-C is the customized and optimized model of SMART tailored to supply electricity and steam for off-grid/remote and oil sand industries in Canada. Compared to the SMART, the diameter of integral reactor is significantly reduced for the better inland transportation. Considering harsh environment of the candidate site, some portion of NSSS and the BOP are also simplified for the better constructability. The SMART-C optimized for oil-sand recovery in Canada is equipped with the mid-loop system containing the mid-loop steam generators and/or heat exchangers to generate high-pressure and high-temperature steam. The mid-loop system enables to transfer only the heat from the nuclear reactor to the oil-sand facility by blocking physically direct connection or mixing of working fluids for heat transfer.

10.2 Construction and Commissioning

The FOAK SMART-C will be deployed in Chalk River site under the Canada National Laboratory (CNL)'s SMR invitation program. The target timeframe to implement SMART-C plant in the initial target market is 2031

10.3 Operation and Maintenance