Status Report - FUJI (Japan)

Downloaded on: Nov 17, 2026 2:27 PM CET

Published Date : Oct 14, 2024 4:41 PM CET

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)	200
Gross Power Output (MWe)	207

1.1 Introduction

The Molten Salt Reactor (MSR) was originally developed at Oak Ridge National Laboratory (ORNL) in 1960s, and three experimental MSRs were constructed. One of them was operated for 4 years without severe problems. Thus, it is verified that the MSR technology is feasible. MSR-FUJI was developed since the 1980s by a Japanese group (International Thorium Molten-Salt Forum: ITMSF), based on the ORNL's results to deploy it in the world.

Molten salt is stable and inert at high temperature and can be used at very low pressure. Since core meltdown or steam/hydrogen explosion is impossible, high safety can be achieved. MSR-FUJI is size-flexible as from 25 MW(e) to 1000 MW(e) as shown in reference 1, But, a latest and typical design (FUJI-U3) is 200 MW(e), which can be categorized as small-sized reactors with modular designs (SMR). The thermal output of FUJI-U3 is 450 MW(t) and thus a 44% thermal efficiency can be attained. In addition, the simple core structure and high fuel efficiency should facilitate a favourable economic performance.

Molten fuel salt can contain thorium (Th) as fertile material and 233U as fissile material, and the FUJI-U3 design can attain a self-sustaining fuel cycle with a conversion factor of 1.0. Since MSR-FUJI applies the Th-cycle, generation of plutonium (Pu) and minor actinide (MA) is very small compared with

Light Water Reactors (LWR). Furthermore, it can consume Pu, and can thus contribute to reduce the proliferation risk caused by Pu from LWR spent fuel. It can also be used to transmute long-lived MA to shorter ones.

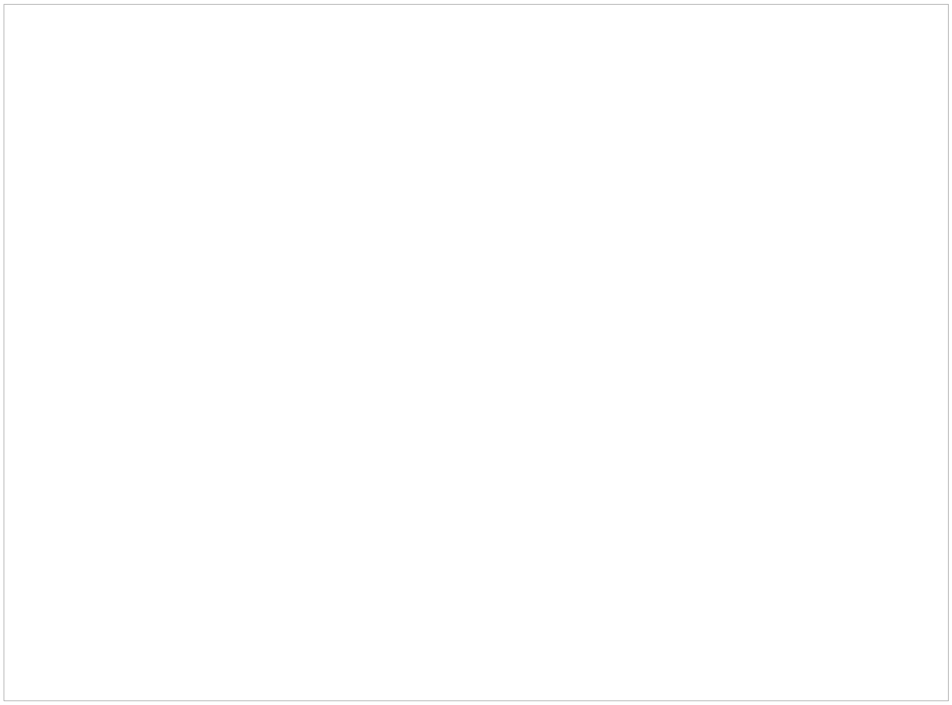


Figure 1. FUJI cut model

Figure 2. Schematic diagram of FUJI

MSR-FUJI can be applied not only to electricity generation, but also to transmutation of Pu and/or MA.

Besides these purposes, it can be used as a heat source for water supply by desalination of seawater or for hydrogen production, utilizing its high exit temperature of 704°C.

[1] Yoshioka, R., Kinoshita, M. “Liquid Fuel, Thermal Neutron Spectrum Reactors”, Chapter-11 of the book “Molten Salt Reactor and Thorium Energy”, Elsevier Inc., USA, 2024(2nd edition).

1.2 Development Milestones

1980	Start of conceptual designs of MSR-FUJI reactors
1980	Completion of conceptual design of Accelerator Molten-Salt Breeder (AMSB) design for a large production of fissile material (similar to Accelerator Driven System ADS)
2008	Completion of conceptual design of FUJI-U3 as a typical SMR, a pilot plant (mini-FUJI) , a large-sized plant (super-FUJI), and a Pu-fuelled plant (FUJI-Pu)
2024	Conceptual design of a micro-sized MSR (miniFUJI II) as one of SMR

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The design philosophy of MSR-FUJI is to achieve a high level of safety, good economic performance, contributing to non-proliferation, and to achieve fuel cycle flexibility.

MSR-FUJI is based on the ORNL’s results, and has been optimized as a small sized plant and further simplified by removing the online reprocessing facility. Based on the operating experience at three experimental MSRs in ORNL, it has been verified that MSR-FUJI is feasible. The steam generator (SG) is however a major unverified component but it can be developed based on Fast Breeder Reactor (FBR) experience and the recent supercritical power station technology.

MSR-FUJI adopts a passive safety system to improve the safety, reliability as well as the economics. Molten fuel salt can be drained to a sub-critical drain tank through a freeze valve. Since gaseous fission products (FP) are always removed from molten fuel salt, the risk at accidents is minimized. MSR-FUJI is operated at very low pressure (0.5 MPa), and a thick reactor vessel and pipes are not required. There are no fuel assemblies or complex core internal structure, with the only component of graphite moderator within a reactor vessel. Based on these design principles, in-factory fabrication would be simple.

1.6 Licensing Application Support Documents

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Non-electric (Transmutation of Pu and/or minor actinides, heat source for water supply, desalination of sea water, hydrogen production)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)		e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	Molten Salts	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	MSR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	Graphite	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout		e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)

Secondary Side Fluid	Molten Salts	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Liquid Fuel/Coolant	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	n/a	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Molten Salt	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Conceptual Design	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	30	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	200	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	<5000 (RB+SGB+TGB)	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)	Same as LWRs	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	0.5	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	0.5	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	565	ºC
Core Outlet Coolant Temperature	704	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	Reactor vessel	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	5400	mm
- NSSS Largest Component Diameter	5340	mm
- NSSS Largest Component Thickness		mm

- NSSS Largest Component Weight	60	tonne
Reactor Vessel Material	Hastelloy N	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	Multiple including Transmutation of Pu and/or minor actinides, heat source for water supply, desalination of sea water, hydrogen production	-
Core Delta Temperature		ºC
Fuel/Core		
Single Core Thermal Power	450	MW(th)
Refuelling Cycle	Continuous	months or “continuous”
Fuel Material	LiF-BeF2-ThF4-233UF4 (71.76-16-12-0.24 mol%)	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	2.0 (0.24%233U + 12.0%Th). Pu or LEU can be used	%
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	No mechanical limit for 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		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	- / - / -
- core injection	Passive	- / - / -
- decay heat removal	Passive	- /- / -
- containment isolation and cooling	Passive	- / - / -
- emergency AC supply (e.g. diesels)	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

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Major buildings of MSR-FUJI are a reactor building, a SG building with a main control room, and a T/G building.

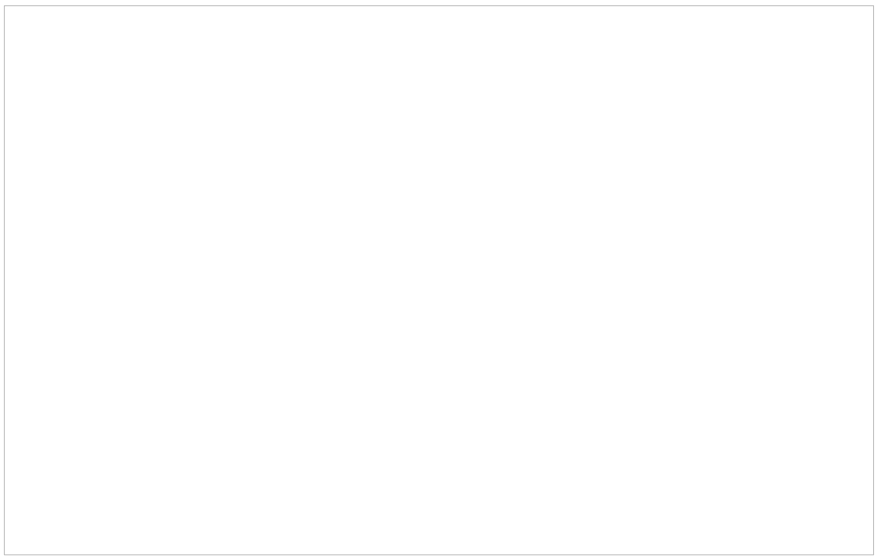


Figure 3. Bird's eye view of MSR-FUJI

Reactor Building

he reactor building contains a high temperature containment, drain tanks, a radio-waste storage, and other facilities required for the reactor. This reactor building is a cylindrical shape with a hemispherical dome, which is made of concrete with steel liner as its inner layer. The reactor building is founded on a

common base-mat together with other buildings.

Control Building

The main control room (MCR) is located at a SG building, which is next to a reactor building. The MCR is a key facility to cope with normal and emergency situations, so it is designed to ensure that plant personnel successfully perform the tasks according to the proper procedures.

Balance Plant

Turbine Generator (T/G) contains the supercritical T/G to produce electricity. Also, it contains condensers for disposed steam, which use outside water (sea water etc.) for cooling. The electric power systems include the main generator, transformers, emergency diesel generators, and batteries, besides external power lines. In case of station blackout, it can be shut down and cooled without electricity.

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

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

Power Conversion

The nuclear steam supply system (NSSS) consists of a reactor core, pipes, pumps, a heat exchanger (HX), and a steam generator (SG), which supplies steam to a turbine/generator (T/G). The schematic diagram of MSR-FUJI shows only one loop, but a loop can be redundant depending on a plant size or a need for flexibility.

MSR-FUJI is designed to produce an exit temperature of 704°C in molten fuel salt, and its heat is transferred to the secondary salt through a HX. Then, its heat produces 538°C supercritical steam of 252 kg/cm2 at a SG, and generates electricity by a supercritical T/G. Owing to its high temperature, MSR-FUJI can achieve 44% thermal efficiency.

The primary loop (molten fuel salt loop) is operated with forced circulation by a centrifugal pump during normal operation. The system also has a natural circulation capability in emergency conditions.

Reactor Core

The core structure is made of hexagonal shaped graphite moderator blocks. The blocks contain holes that serve as the flow paths of the molten fuel salt that flow upwards through the blocks circulated by

the primary pump. The molten fuel salt then goes to a heat exchanger to transfer the heat to the secondary coolant salt.

The concentration of the fuel composition can be adjusted at any time through the fuel concentration adjustment system. Since there are no fuel assemblies in the core, refueling shutdown is not required, and continuous operation is possible. In order to achieve a core conversion factor of 1.0, it is recommended to refresh the fuel salt every 7 years. Periodic maintenance shutdown will be required as in any power plant.

Reactivity Control

Reactivity control for long-time operation can be performed anytime by a fuel concentration adjustment system. In normal daily operation, reactivity or power level can be controlled by core flow or by core temperature. Control rods are withdrawn in normal operation and are inserted by gravity in case of emergency shutdown.

Reactor Vessel and Internals

The reactor vessel is made of Hastelloy N. Since the operating pressure is very low (0.5 MPa) a 'pressure vessel' is not required. The only one core internals is the graphite moderator blocks.

Fuel Characteristics

The molten fuel salt is a liquid form of fluoride (LiF-BeF2) with ThF4 and a small amount of 233UF4. A typical composition is LiF-BeF2-ThF4-233UF4 (71.76-16-12-0.24 mol%).

Molten fluoride can be used at very low pressure owing to its very high boiling temperature and very low vapor pressure. The melting temperature of the above fuel composition is 499°C. It can dissolve uranium (U) or Pu as fissile material so that low enriched uranium (LEU) or Pu can be used. Fuel assembly fabrication is not required for molten fuel salt, and radiation damage or fuel cladding failure does not occur.

Instrumentation and Control Systems

Instrumentation and control (I&C) systems in the MSR-FUJI design are the same as recent LWR designs. It must support operators in making decisions and efficiently operating the plant during plant start-up, shutdown, normal operation, surveillance testing, and accidental situations. It adopts the man-machine interface more useful, and expands the scope of automatic control.

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

6. Technology Readiness

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Testing Conducted for Design verification and Validation

MSR-FUJI is based on 3 experimental reactor experience. But some of technologies such as a supercritical SG or remote maintenance equipment have to be established.

Design and Licensing Status

Preliminary designs for various applications have been completed. Three experimental MSRs were constructed, and one of them was operated for 4 years without severe problems. Although the detailed design is not yet started, safety criteria and guidelines for MSR licensing are proposed with numerical results for major accident analysis.

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 Configuration

In case of pipe break, leaked molten salt is drained to an emergency drain tank without passing through a freeze valve. A pressurization accident is very unlikely owing to its low vapor pressure. Therefore, an emergency core cooling system (ECCS), containment cooling system (CCS), makeup water pools, and automatic depressurization system (ADS) are not required. In order to protect against a freeze accident in a molten fuel salt loop, a high temperature containment is equipped with heaters.

Decay Heat Removal System

In normal shutdown condition, decay heat is transferred to a secondary loop and a steam-line loop, and disposed to the ultimate heat sink (seawater etc.). If all pumps in a primary or secondary loop stop, fuel salt is drained to a drain tank through a freeze valve. Decay heat at the drain tank is cooled by a passive heat removal system, and finally its heat is disposed to the outside environment through an air-cooled system that does not require electricity.

Emergency Core Cooling System (ECCS)

As is explained above, redundant and diverse ECCS and makeup water pools are not required. This would simplify the plant, and eliminate concerns of failures in safety systems.

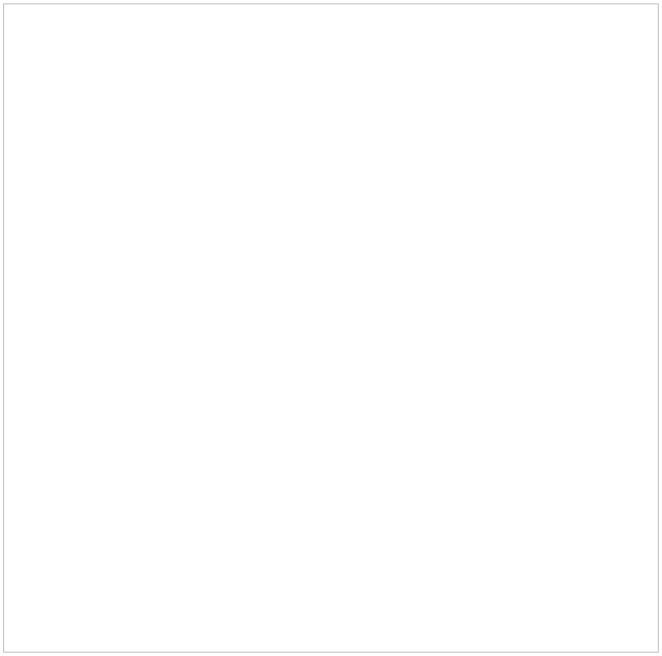


Figure 4. Vertical cross-section of MSR-FUJI

Containment System

Since the risk of pressurization accidents is very unlikely, the containment size can be minimized. Although molten salt is not flammable, inert gas (N2) is enclosed within a containment in order to maintain fuel salt purity in case of a pipe break accident. The MSR-FUJI design has 3 levels of containment. The 1st is the reactor vessel and pipes made of Hastelloy N. The 2nd is a high temperature containment composed of three layers, which contains a reactor vessel, pipes, and a heat exchanger. In order to avoid a freeze accident, this containment is equipped with heaters. The 3rd level is a reactor building composed of two layers. As explained above, a pressurization accident is very unlikely due the low vapor pressure. Therefore, a containment cooling system and makeup water pools are not required.

Plant Safety and Operational Performance

Overall safety is described above. In case of a station blackout (SBO: Loss of all AC electricity) the MSR-FUJI can be shut down and cooled without electricity. Core meltdown or steam/hydrogen explosion is physically excluded by design, and no ECCS is needed. Long-time and daily operations are described in Section-3(d). Based on those features, load following is performed without control rods.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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Fuel Cycle Approach

As explained in Section-1 and 3, FUJI-U3 design can attain a self-sustaining fuel cycle. MSR-FUJI is simplified by removing the online reprocessing facility. Only gaseous fission products (FP) are always removed from molten fuel salt. Spent fuel salt is discharged, and reprocessed at the off-site pyro-reprocessing facility. Some usable actinides can be sent back to the reactor.

Waste Management and Disposal Plan

Actinides such as U/Pu/Th/MA separated at the off-site reprocessing facility are recycled to MSR. FPs and salt are stored at disposal facility. These facilities are to be developed in parallel with MSR deployment.

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