

Development of SFR in Korea

ANSN SMR Workshop
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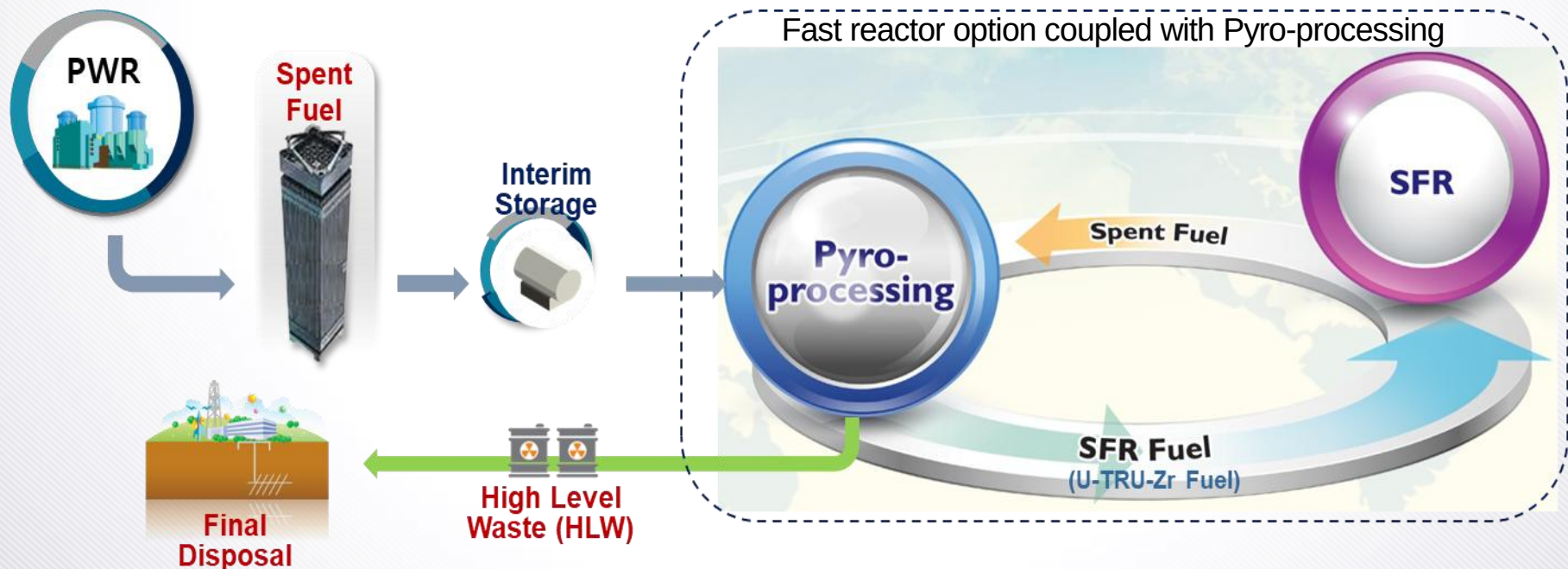


Korea Atomic Energy
Research Institute

01 Introduction

Initiation Motive for SFR Development in Korea

- » Pending issues on long-term Spent Nuclear Fuel (SNF) management
- » **Fast Reactor coupled with Pyro-processing** could be one of the options for national policy of SNF management
 - To reduce the amount of Spent Nuclear Fuel and its toxicity

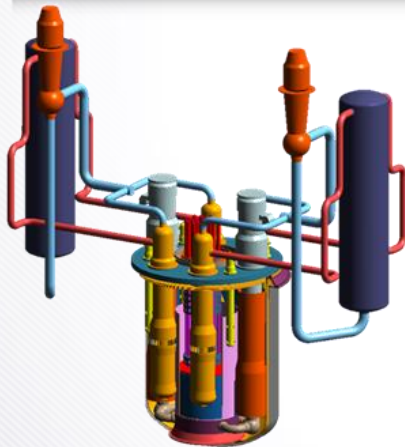


TRU: **T**rans**U**ranics (Pu+MA), MA: **M**inor **A**ctinides (Np, Am, Cm), FP: **F**ission **P**roducts

Evolution of SFR Development in Korea

- » KALIMER-600: Conceptual design for the Korean SFR
 - » Pool-type, Metal fuel, Passive safety features, etc.
- » [Track-1] PGSFR: TRU-transmutation demonstrator with pyro-processing
- » [Track-2] SALUS-100: SFR-based advanced SMR as a spin-off design from the PGSFR

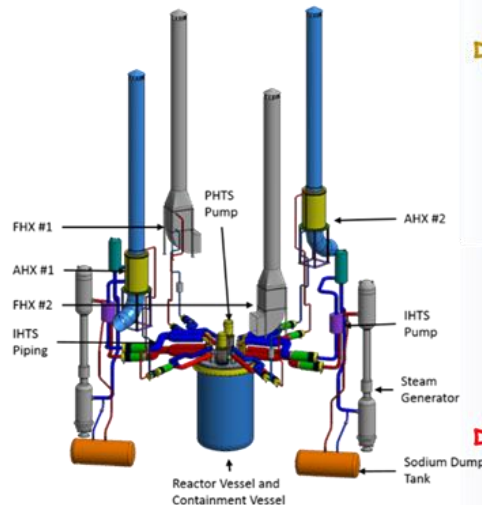
KALIMER-600



- » Fundamental SFR technology development
- » Target SFR design for TRU transmutation
- » Advanced design options to meet the GIF goals

PGSFR ('12-'20)

- » [Track 1] Technology demonstrator for TRU transmutation

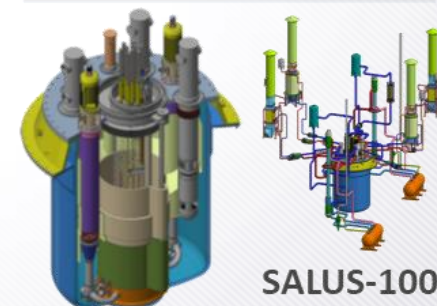


- » [Track 2] SMR features with U-10%Zr fuel for initial loading
(Spin-off technologies from the PGSFR concept)

PGSFR Construction (TBD)

- » Domestic technology demonstration for TRU transmutation
- » Specific plan for resumption would be prepared by 2025

SFR-based Power Rx.



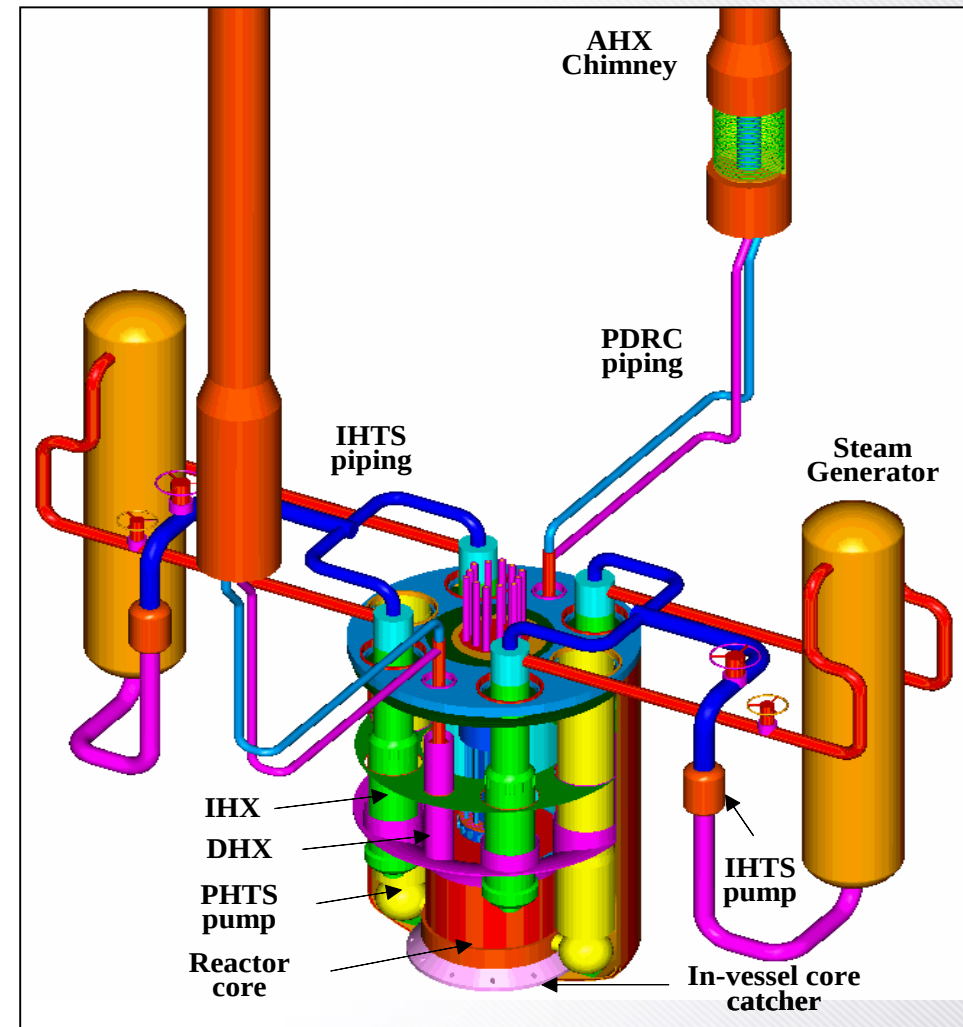
SALUS-100

KALIMER-600

- » One of Reference Designs in GIF SFR
 - JSFR, KALIMER, SMFR, ESFR

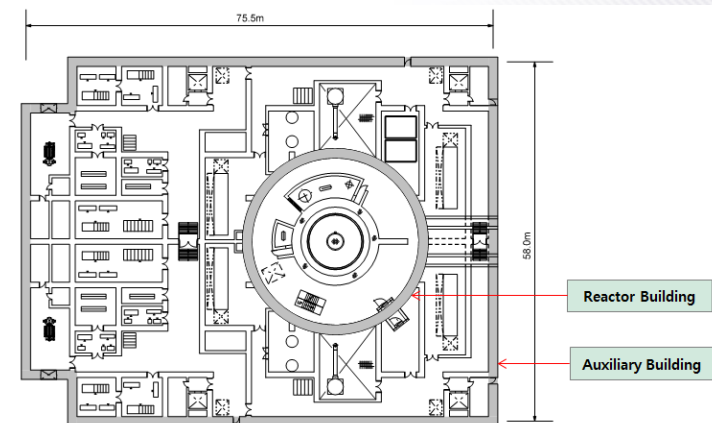
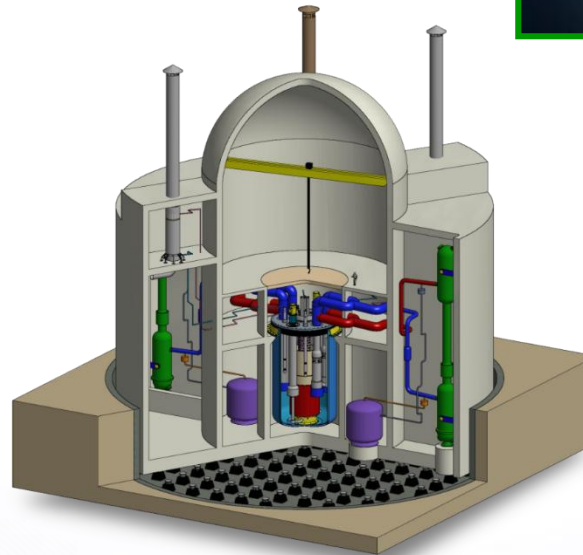
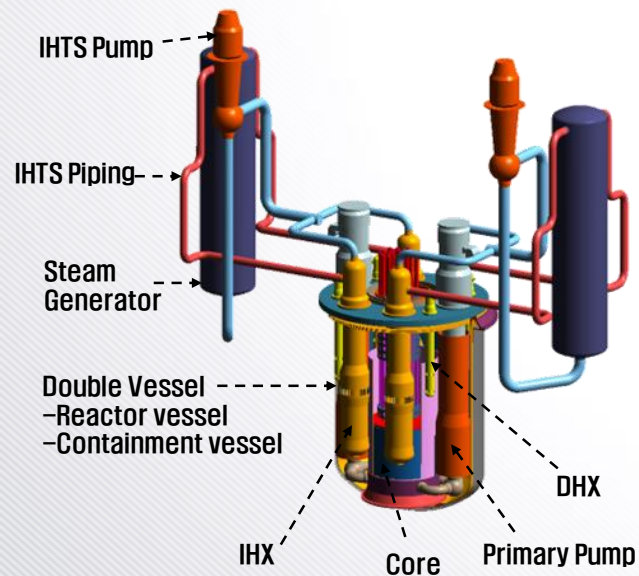
- » Paper Plant but **Iconic Design** for Korea
 - Concept Established
 - Pool-type, Metal fuel, Passive safety features

- » Key Features
 - Power : 600 MWe (1523 MWth)
 - Core In/Out Temp : 390/545 C
 - Cycle length : 1.5 yrs
 - Fuel type : Metal Fuel (U-TRU-10%Zr Alloy)
 - Cladding : HT9M
 - Burn-up : 80 GWd/t
 - Core dia. : 5.2 m



PGSFR

- » **Demonstration of TRU Burner Technology**
 - » World's First of A Kind Reactor for Transmutation
- » **Most Realistic Attempt**
 - » Engineering Design Completed
 - » Topical Reports Submitted to Regulator
 - » Ready for Construction Approval Application
 - » Legacy for Future SFR R&D



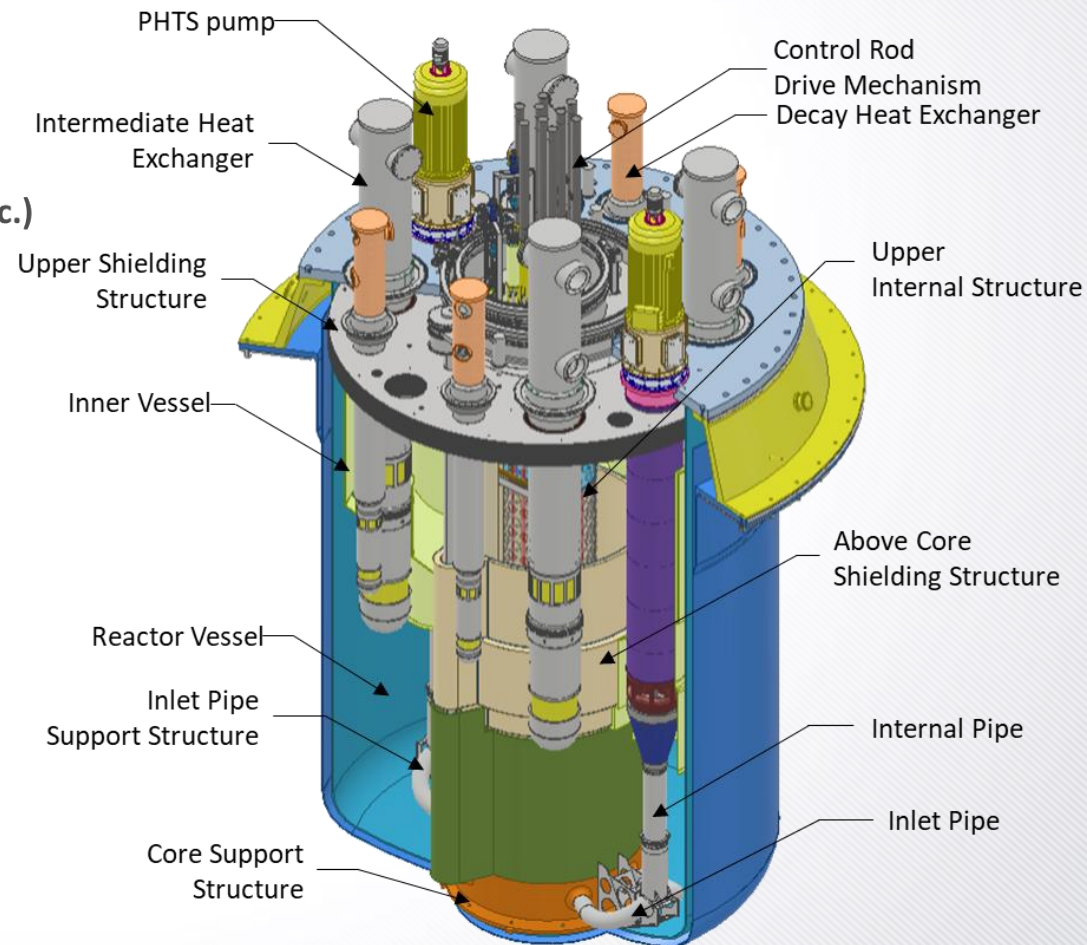
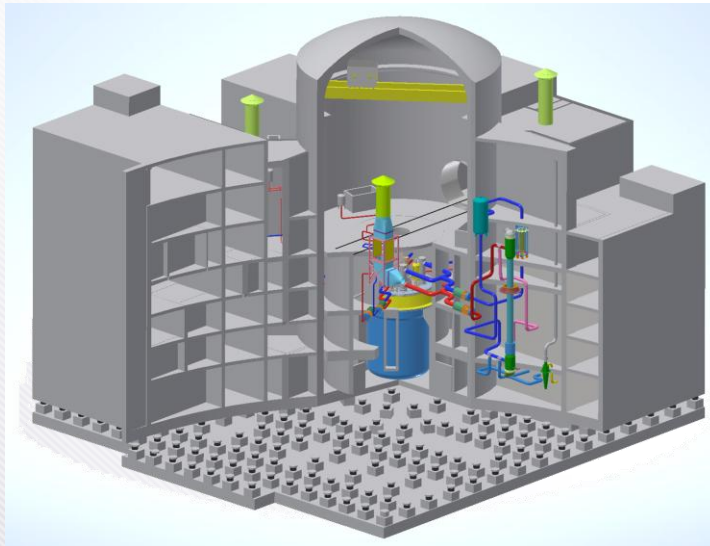
SALUS-100

» SMR for Distributed Energy Resources

➤ Small, Advanced, Long-cycled, Ultimate Safe SFR

» Competitive Product Preparation

- Basic Design Completed
- Improvements in Details (FC92, Cr coating, etc.)
- IAEA Technical Safety Review
- Multi-purpose Consideration



Recent Achievement

» IAEA TSR* for SALUS-100

* Technical Safety Review

➤ SALUS-100 Design features

- Integrated pool-type SFR with a long fuel cycle (~20 years)
- Metallic alloy fuel (U-10%Zr) with < 20 wt.% U-235 enrichment

➤ IAEA TSR-DS (Design Safety)

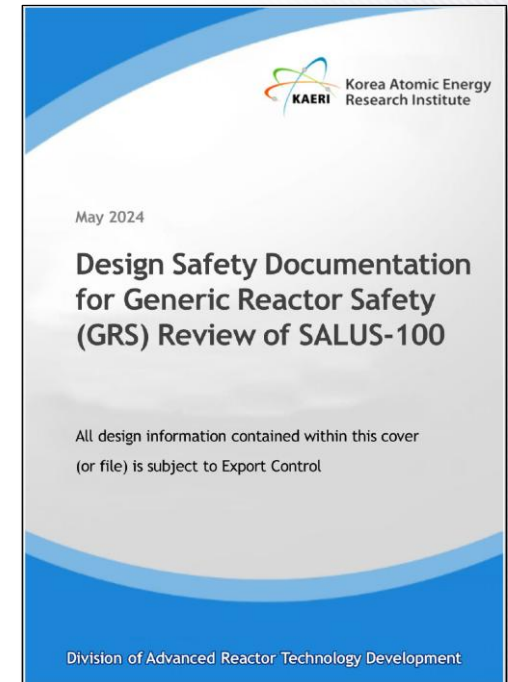
- Generic safety review service to support NPP deployment based on the IAEA safety standards
- To identify key regulatory issues early to avoid or minimize risks that the developer may encounter during the actual licensing phase

➤ TSR Review area of SALUS-100

- Compliance of international requirements and standards
- Safety concerns and Potential issue for licensing
- Adequacy to undertake pre-licensing review

» Key Timeline

- TSR Preparatory Meeting (Feb 2024) / TSR Review Meeting (Oct 2024)
- IAEA published the final report (Feb 2025)



TSR document set of SALUS-100

02

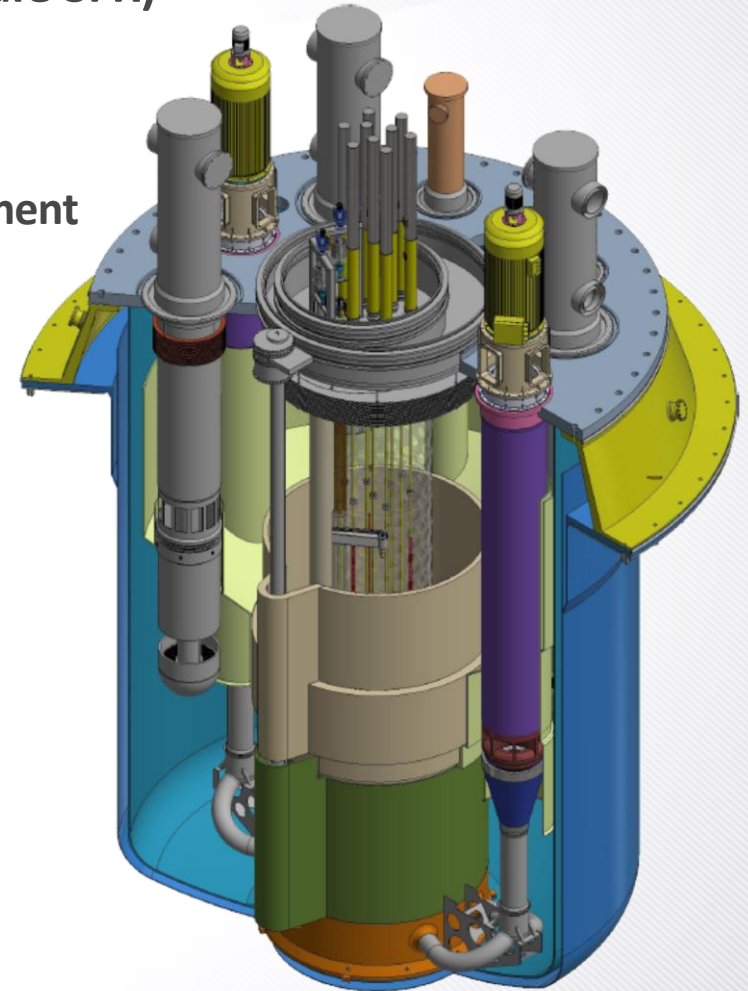
Overview of SALUS-100

SALUS-100: Overview

» SALUS (Small, Advanced, Long-cycled and Ultimate Safe SFR)

- Integrated pool-type SFR
- Electric output: 100 MWe (267 MWt)
- Metallic alloy fuel (U-10%Zr) with < 20 wt.% U-235 enrichment
- FC92 cladding with Cr barrier
- Steel reflected without blanket
- Refueling cycle: approx. 20 years
- Reactor Core Inlet/Outlet Temp.: 360/510 °C
- Net plant efficiency: 37.4%
- Power conversion: Superheated steam Rankine Cycle
- Steam generator: Shell-and-tube type with straight-tube
- Long-term cooling with natural circulation
- DHRS: Active DHRS (2-train) + Passive DHRS (2-train)

➔ Most design features of PGSFR are incorporated



SALUS -100 Solid Modeling

Top-tier Design Requirements of SALUS-100

Categories		Requirements	Remarks
General	General requirement	Power production for versatile usage	Small power reactor based on SFR technology
	Fuel	U-10%Zr	Three Enrichment-split core
	Electric capacity	100 MWe	Minimum power capacity for sufficient neutron flux for fuel/cladding qualification
	Core outlet temperature	510°C	New fuel/cladding development, high temperature structural design, high thermal efficiency
	Design life time /refueling interval	More than 60yr / ~20yr	-
	SSE(Safe Shutdown Earthquake)	0.3g	-
Safety	CDF	10^{-6} /reactor-yr	Requirement of Gen-IV reactor
	Grace time for operator action	More than 2 hours in DBE and DEC	-
	SBO	More than 72 hours in SBO	-

Design Concept of SALUS-100

Fuel Handling System

Dual Rotating Plug, Fixed Arm + Direct Lift Machine IVTM, Fuel Transfer Port, EVT

Reactor Enclosure System

RV (H: 16.6 m, OD: 10.5 m), CV (OD: 11.0 m), 20cm gap, Forged Solid Head

CRDM

6 Primary CRs, 3 Secondary CRs

Passive shutdown feature was implemented for secondary CRs

Reactor Core and Fuel Design

U-10%Zr Metal Fuel, 112 FAs, ~145cm Height, 267MWth power Max. 20 years refueling interval

Decay Heat Removal System

2 PDHRS + 2 ADHRS, Capacity of ~ 2.5%, Cold Pool DHX

ADHRS has more than 50% of passive decay heat removal capability

Primary Heat Transport System

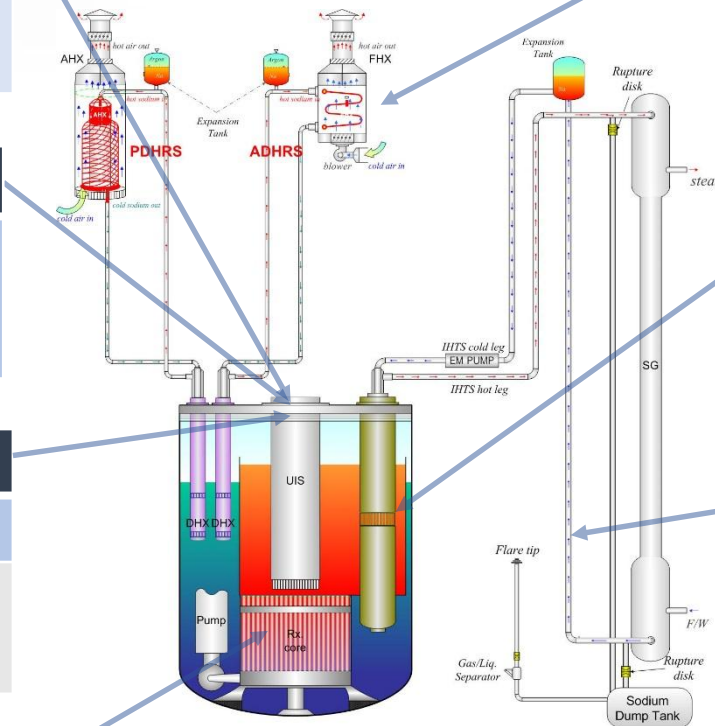
Pool type, 4 IHX, 2 Mechanical Pump, Cylindrical inner vessel

Intermediate Heat Transport System

2 Loops, 2 SGs(single wall tube), 2 EM Pumps, SWRPRS

Other systems

Sodium Purification Systems for PHTS/IHTS/DHRS, Primary Cover Gas Processing System, Superheated Steam Rankine Cycle for PCS, Instrumentations for Failed Fuel & SG Leak Detections



03

SALUS-100 Design Specifications

Core Design

» Major core performance parameters

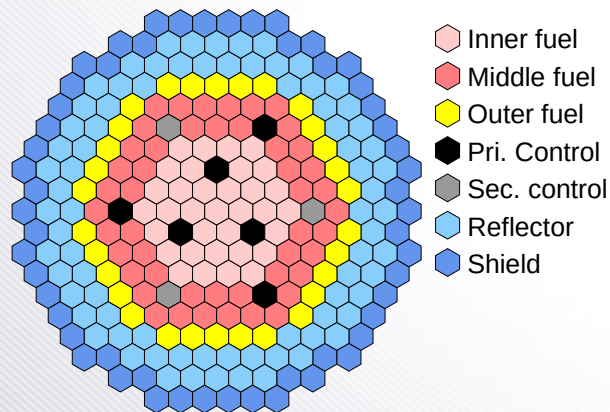
- Similar core diameter with PGSFR to maintain SSC location & layout
- 20 years cycle length
- Sufficient control rod worth guarantee

» Major core characteristics parameters

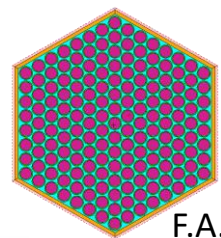
- All reactivity feedback coefficient showed negative except sodium density coefficient
→ but, **sum of temperature feedbacks still maintains negative**

» Calculation Tools

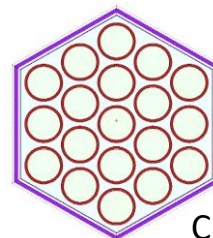
- Parametric study (MC²-3/REBUS-3), Detail design (McCARD)



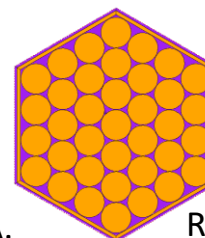
<Core Radial Configuration>



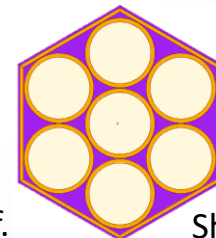
F.A.



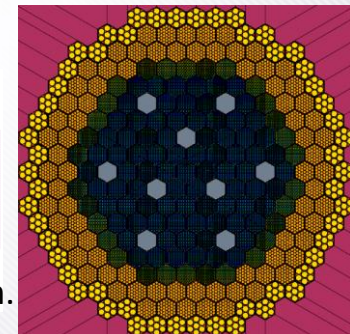
C.A.



Ref.



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<Heterogeneous model by McCARD>

Metal Fuel Design

» Fuel rod design

➤ FC92 cladding (FMS)

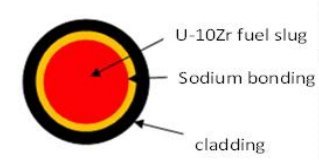
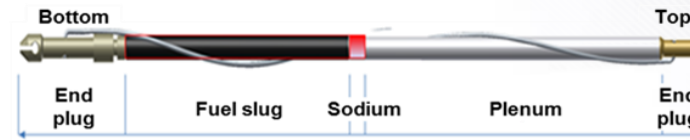
❖ Higher creep strength than conventional HT9

➤ Cr barrier

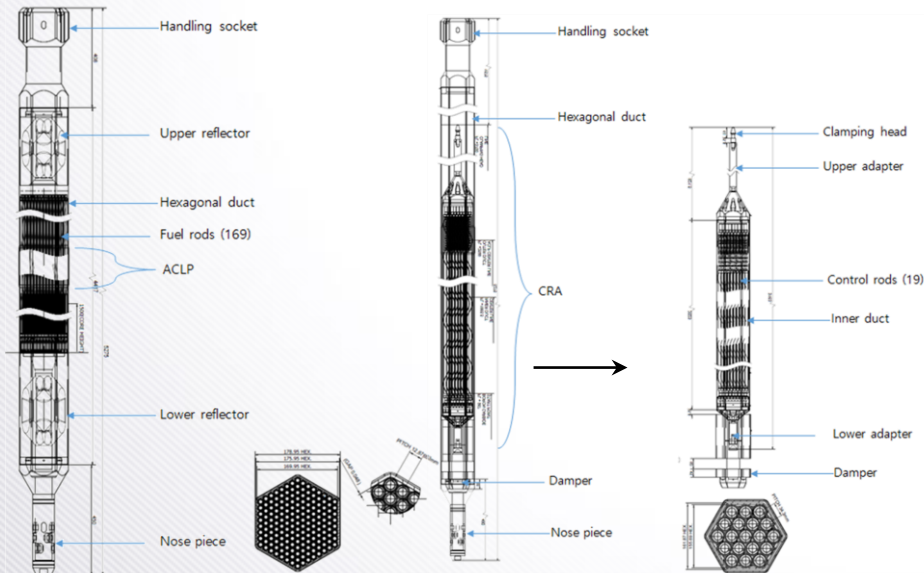
❖ To prevent FCCI (Fuel-Cladding Chemical Interaction)

» Fuel assembly & Non-fuel assembly design

➤ HT9 for FA, B₄C for absorber, 316SS for CR cladding, HT9 for R and S cladding

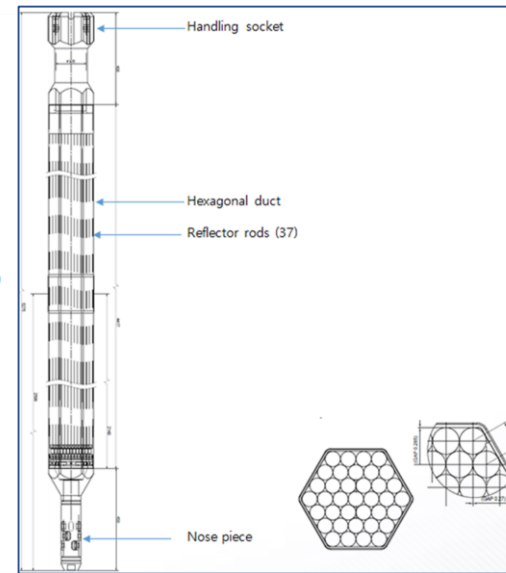


<Fuel rod>

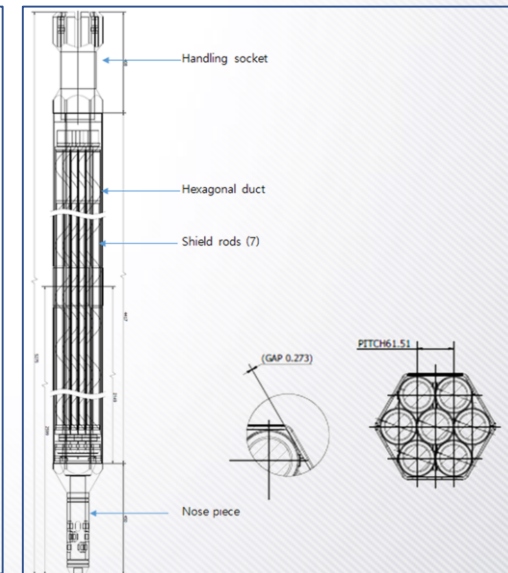


<Fuel assembly>

<Control rod assembly>



<Reflector assembly>



<Shield assembly>

Fluid System Design

» Reactor vessel and Reactor internals

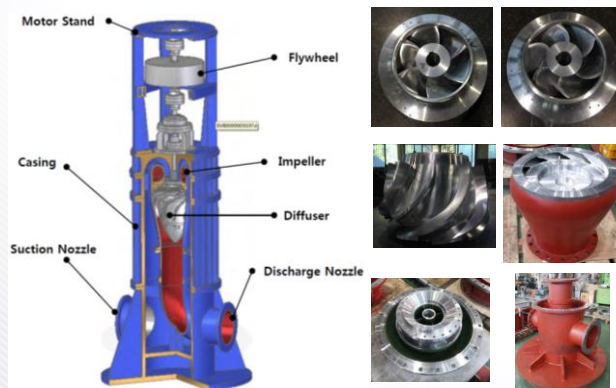
- Simple RV design: No penetration & attachment
- Arrangement ensuring sufficient natural circulation
- Ensuring flow path in case of RV leak with CV
 - Providing a passage for ISI of RV using RCV in gap

» Primary pump

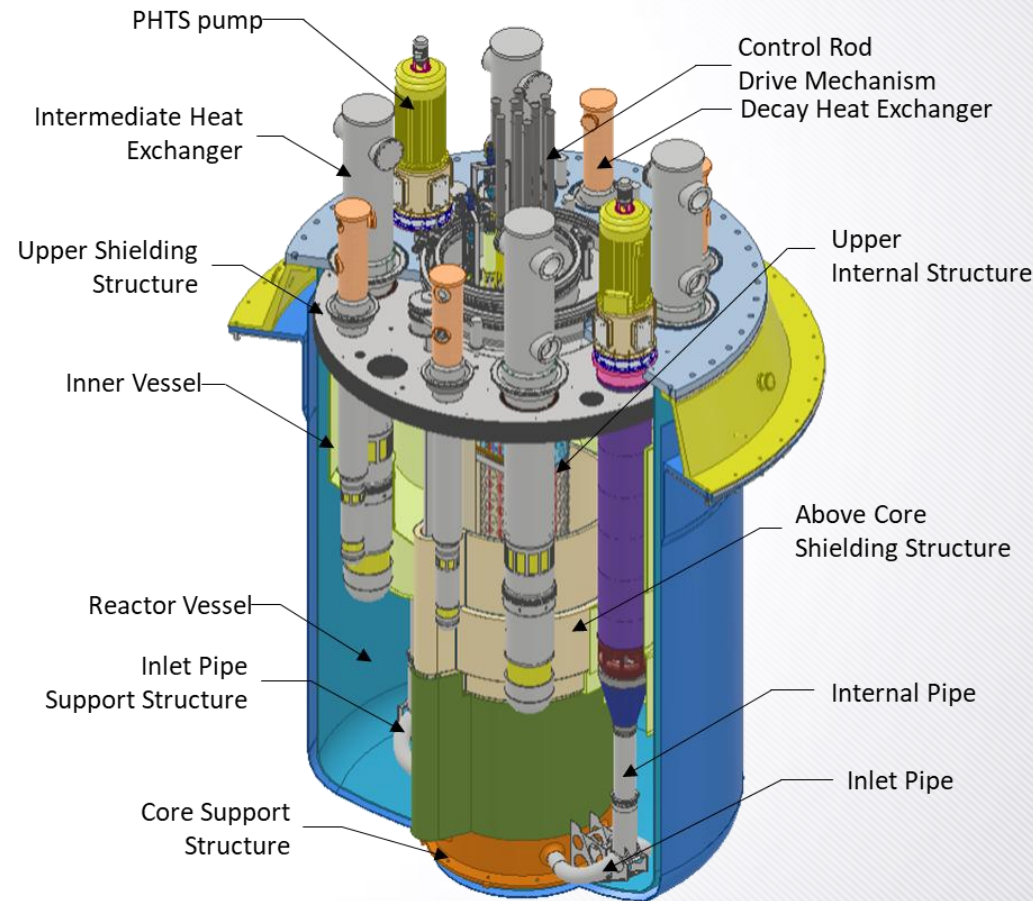
- Vertical, Single stage, Centrifugal type

» Intermediate Heat Exchanger (IHX)

- Shell-and-tube, Vertical straight, Counter-current flow
- Material : 9Cr-1Mo-V steel



<model pump assembly>

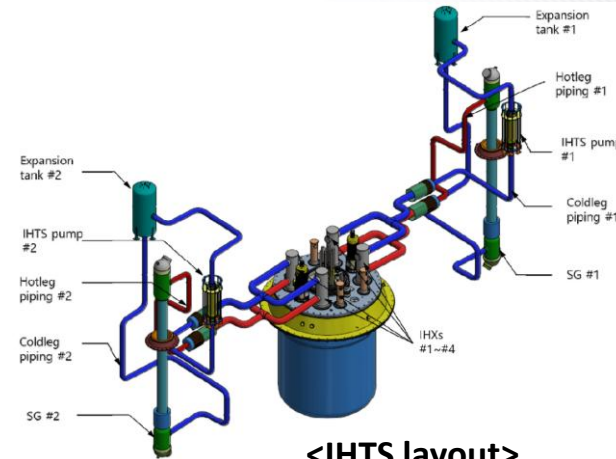


<PHTS Layout>

Fluid System Design

Intermediate Heat Transport System (IHTS)

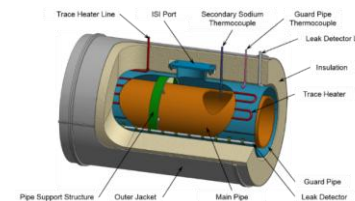
- 1 EM pump, 1 SG and 1 expansion tank in each loop
- Double wall piping inside reactor building
- Shell-and-tube, once-through type, straight tubes with triangular arrangement SG
- Vertically installed single stator ALIP EM pump



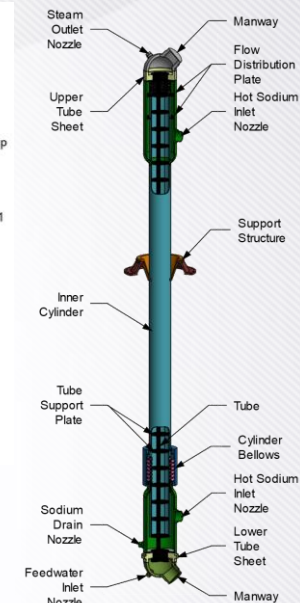
<IHTS layout>

Decay Heat Removal System (DHRS)

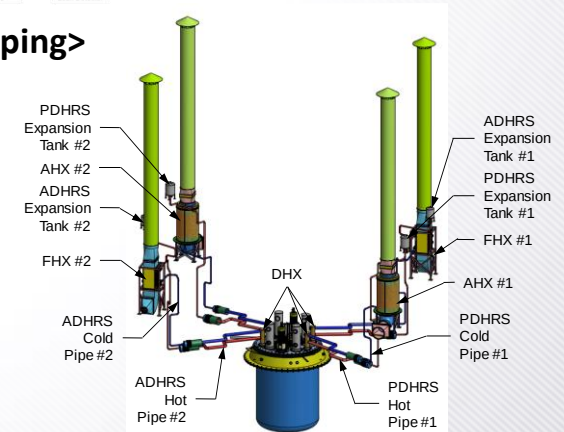
- 2 passive systems and 2 active systems
- Heat Exchangers
 - DHX is counter-current flow type sodium-to-sodium heat exchanger with straight tubes
 - AHX is counter-current flow type sodium-to-air heat exchanger with helically coiled tubes for passive system
 - FHX is counter-current flow type sodium-to-air heat exchanger with finned tubes for active system



<Double piping>



<Steam generator>



<DHRS layout>

Mechanical System Design

» Reactor enclosure system

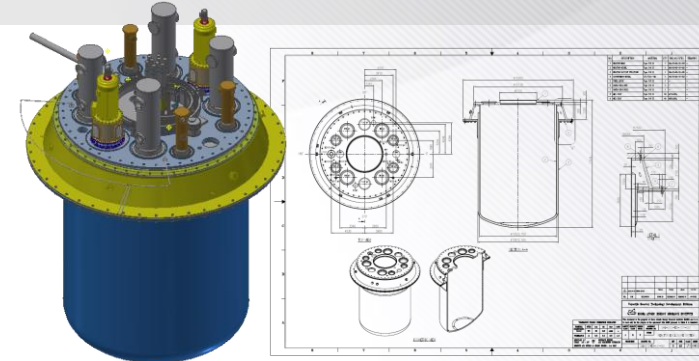
- Satisfy system/functional/structural requirements and design limits
- Structural analyses of the reactor enclosure system were performed through fluid-structure interaction analysis

» Reactor internal structure

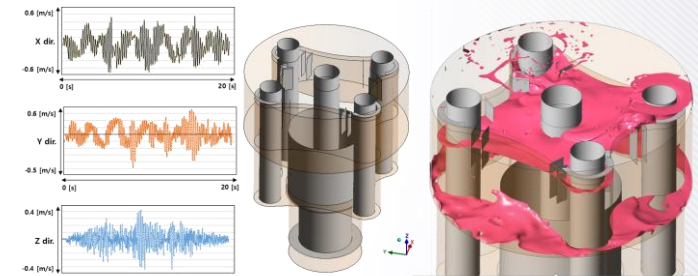
- Structural integrity by simplifying the SALUS reactor internal structures into a cylindrical shape was improved

» Upper internal structure

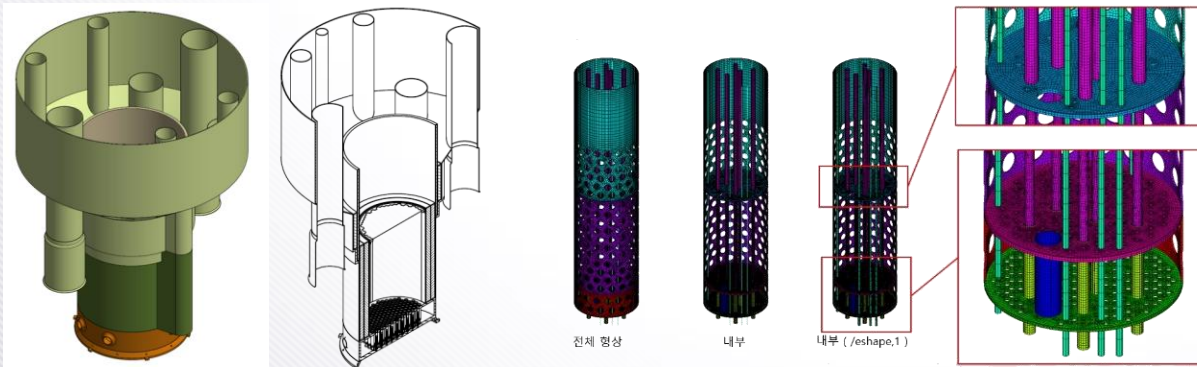
- Cantilevered UIS submerged in sodium was designed



< Reactor enclosure system >

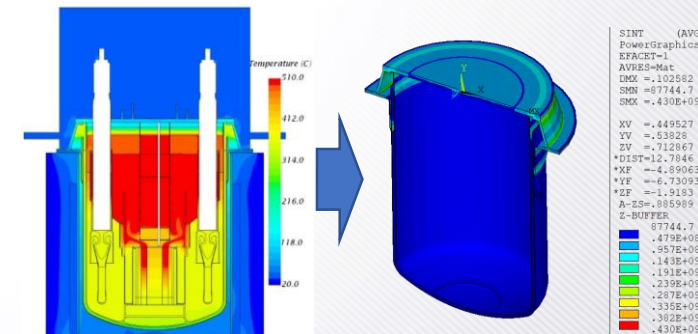


<Seismic sloshing behavior analysis>



< Reactor Internal Structures >

< Upper Internal Structure >



CFD analysis

Structural analysis

< Structural analysis of RES >

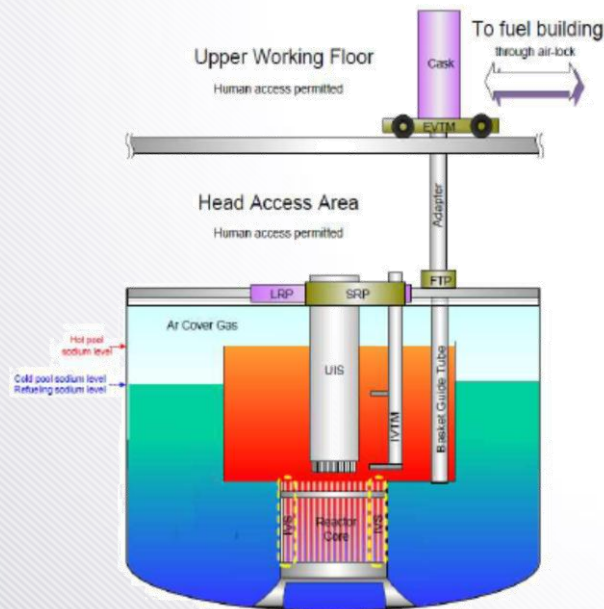
Mechanical System Design

» CRDM component

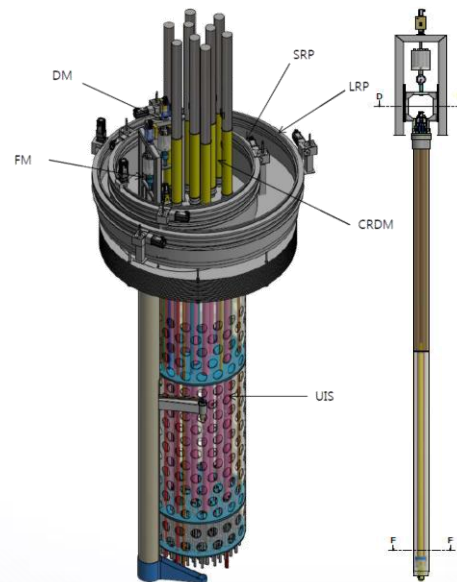
- Cover gas sealing using bellows
- Magnetic holding force for triggering 2nd CRA drop

» Fuel handling system

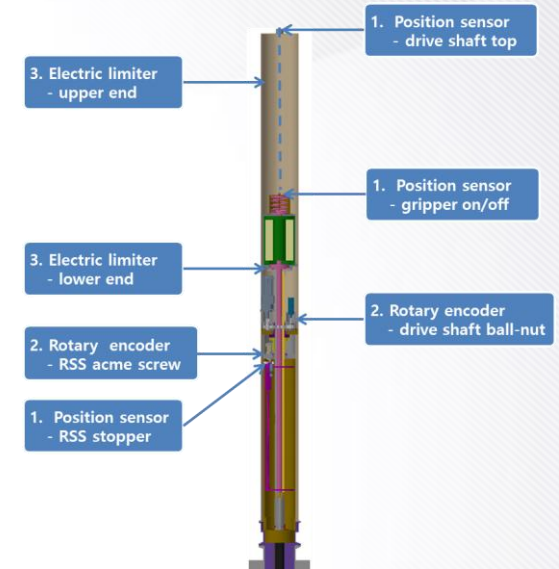
- Double rotating plug type
- Includes two fuel handling machines



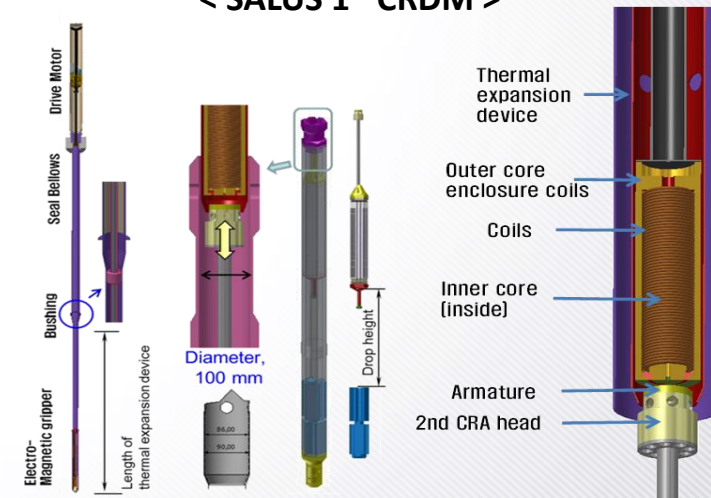
< Fuel handling scheme >



< In-vessel transfer machine >



< SALUS 1st CRDM >



< SALUS 2nd CRDM >

Mechanical System Design: ISI and M&R

» Background for ISI technologies

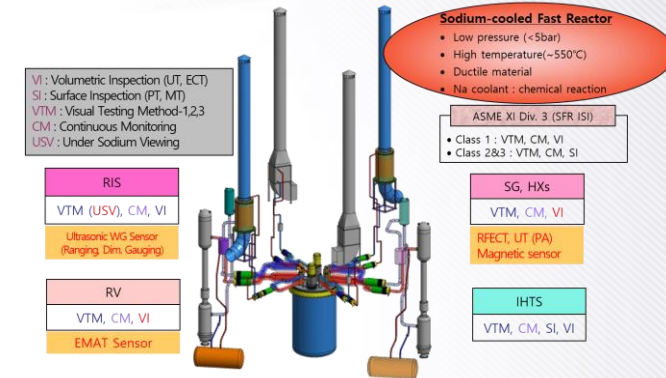
- In-service inspection and maintenance & repair strategies for PGSFR were established based on ASME Sec. XI Div. 3 (Rules for inspection and testing of components of liquid-metal cooled plants)
- Inspection methodologies (visual/surface/volumetric examination, continuous monitoring) specified for components were established and inspection devices have been developed

» In-service Inspection design(ISI)

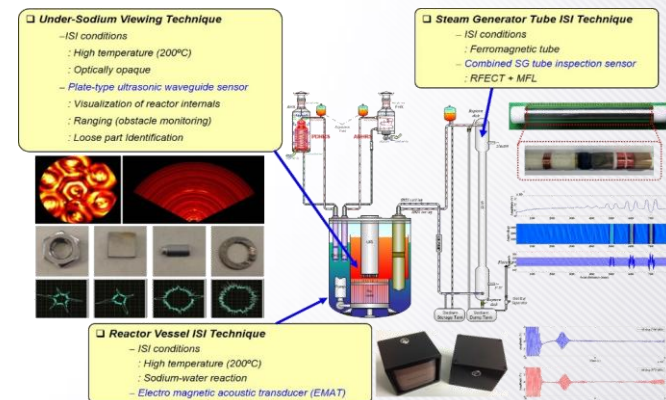
- For long-cycle small modular reactor, in-service inspection strategy is under establishment based on ASME Sec. XI Div. 2 (Requirements for Reliability and Integrity Management (RIM) program for Nuclear power plants)

» Maintenance & Repair design (M&R)

- Maintenance & repair strategy is under establishment based on ASME Sec. XI Div. 2



< PGSFR ISI strategy >

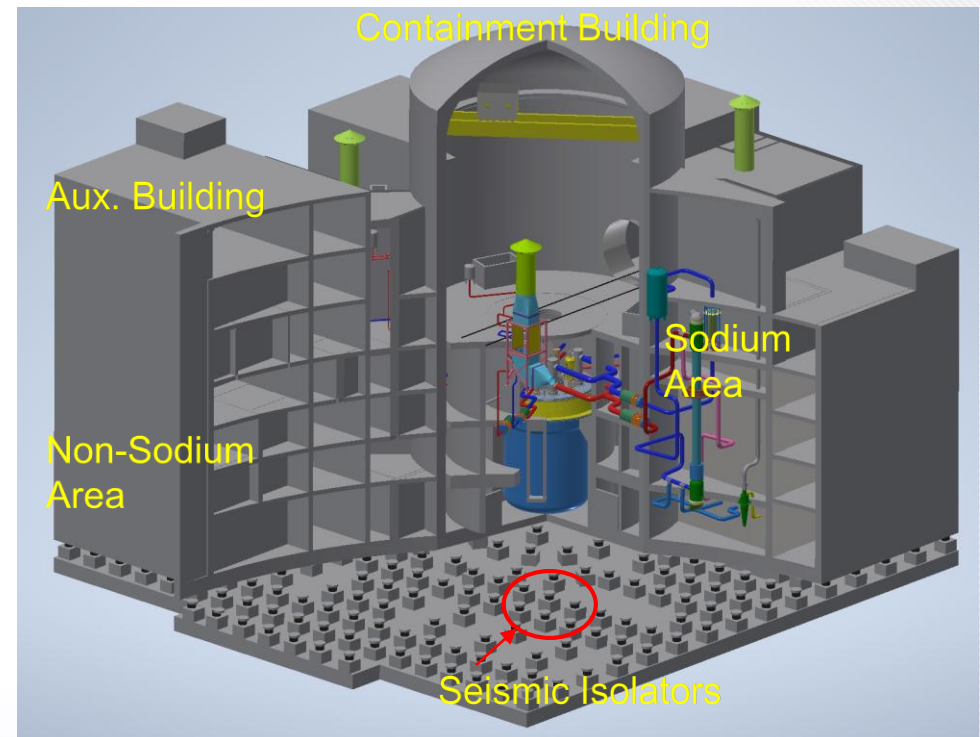
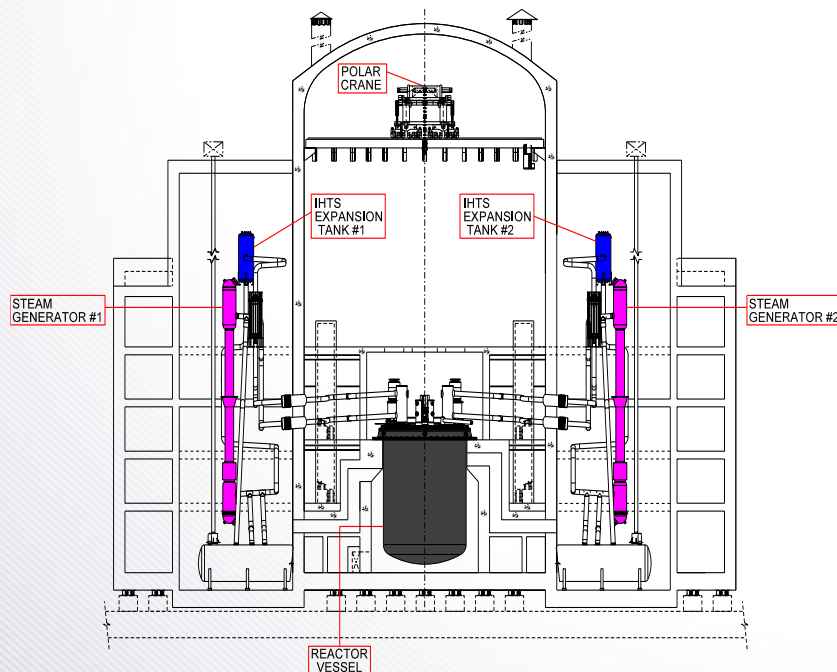


< Development of ISI devices >

Overall Plant Layout

» Reactor Building Arrangement

- Reactor building is pre-conceptually designed based on PGSFR concept
- It is rectangular shape of auxiliary building with cylindrical dome containment
- Fuel storage building will be integrated with reactor building
 - Air cooled dry storage
- Seismic isolation design is applied



04 Summary

Summary

» Continuous SFR Development History since `90s

- Successful Legacy Transfer (No technological gap)
- Early and Active Participation in International Collaboration

» Two Directions of SFR Development in Korea

- “TRU Transmutation” and “Long-cycled Power Generation”
- Experience on Various Size (600, 150, and 100 MW Designs)

» Current R&D Activities

- First “Go-along with Private Sector” Project will be starting soon
- SALUS+ or New Design



Thank you for your attention

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