

31 March – 4 April, 2025
Regional Workshop on Safety Benefits and Challenge in the
Development of the Adoption Small Modular Reactors

i-SMR

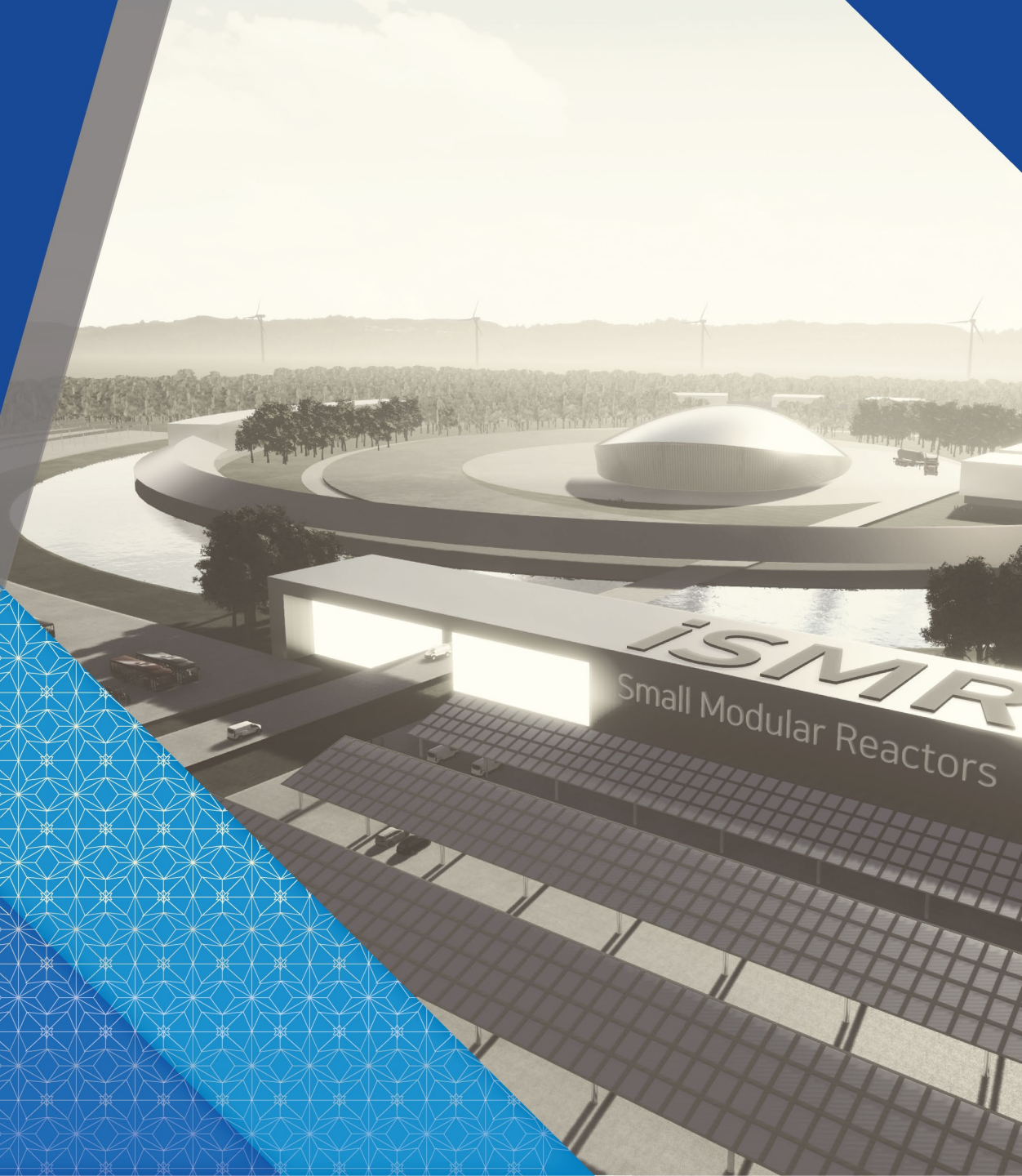
Passive Safety Systems

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Central Research Institute



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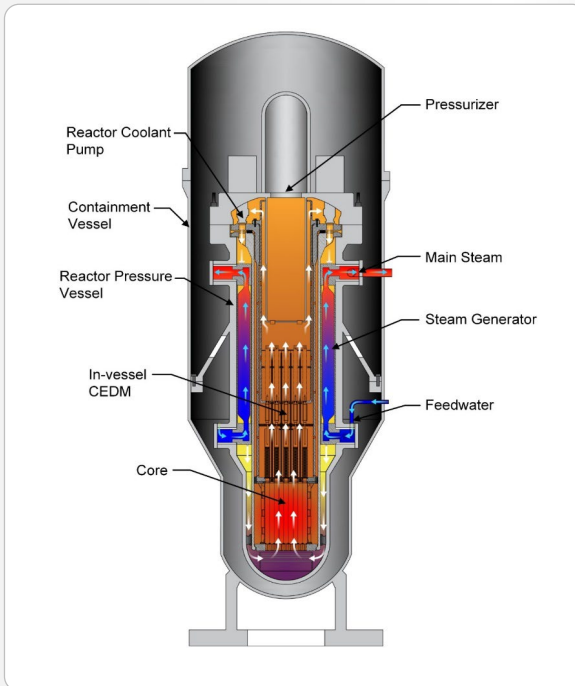
- 1 | Introduction
- 2 | Passive Safety Systems
- 3 | i-SMR Validation Tests
- 4 | Summary and Future Plan

1. Introduction (1/2)

✓ **Safety** : Enhanced safety by Passive safety system without safety-class DC power and operator's actions

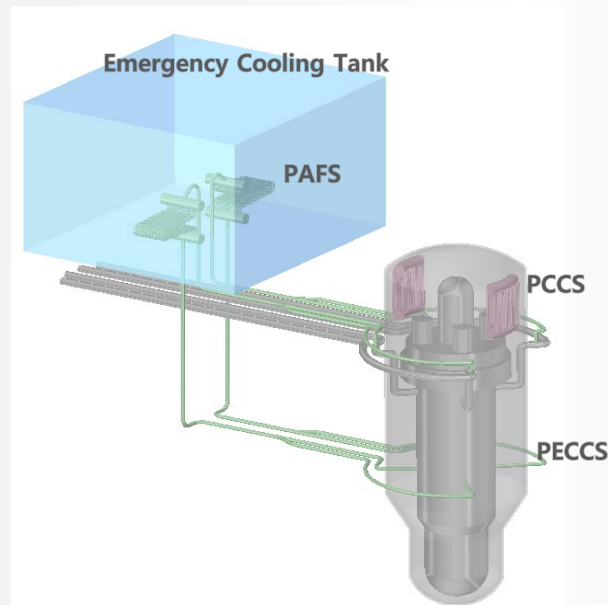
Integrated Reactor Design

- Integrating main equipment of reactor system
- LB-LOCA exclusion (pipeless)
- [IV-CRDM and Fuel] Preventing a rod ejection accident

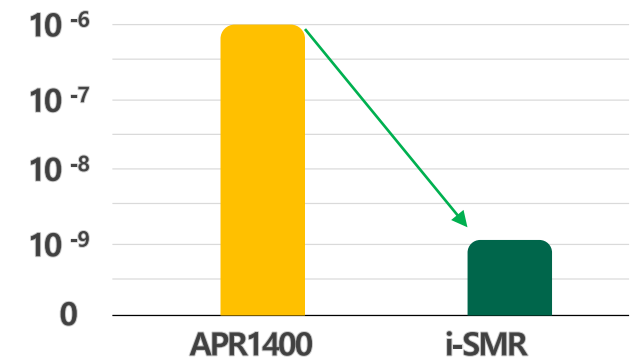


Fully Passive Safety System Design

- Passive safety system with natural circulation
- Safety system without safety-class DC power and operator's action
- Station Blackout (SBO) response time : ≥ 72 hours (Safety Shutdown condition by ultimate cooling)



CDF (Core Damage Frequency)



1,000 times safer than large NPPs

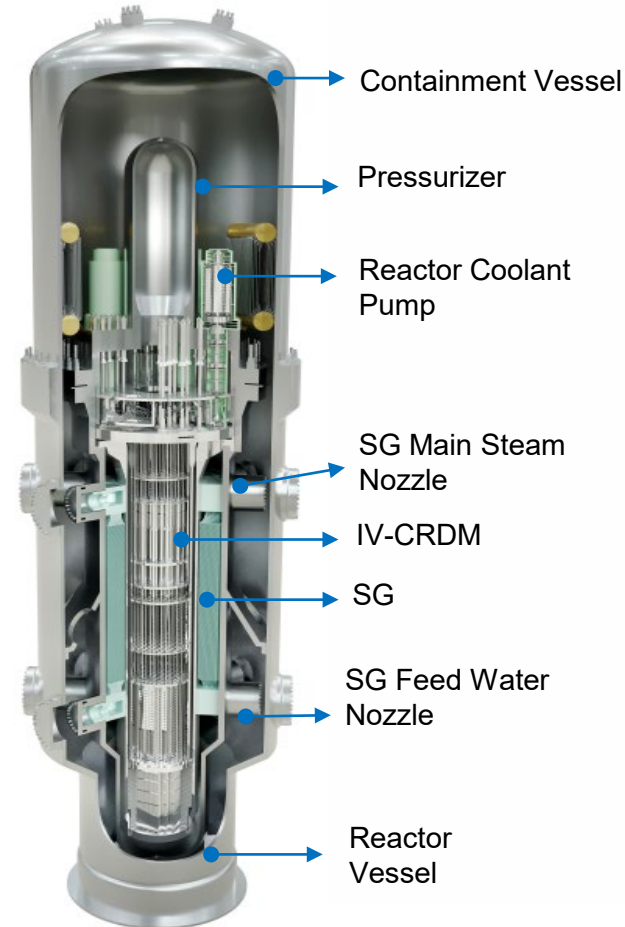
1. Introduction (2/2)

✓ Geometry and design status of i-SMR NSSS



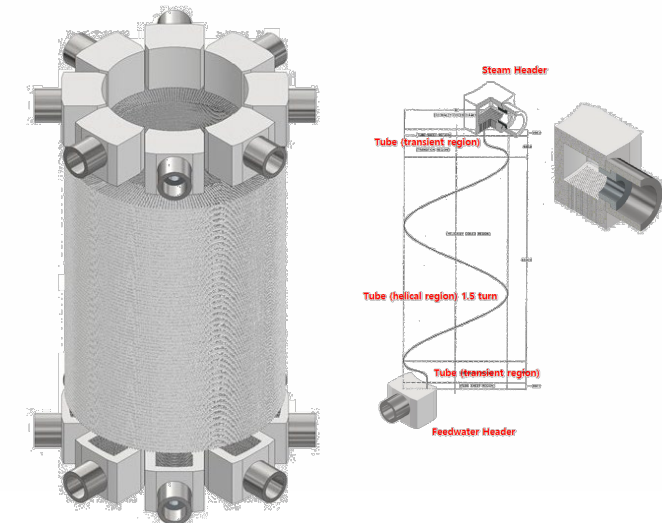
Major Components of i-SMR NSSS

- Containment Vessel
- Pressurizer
- Integrated Reactor Vessel
- Reactor Coolant Pump (4 pumps)
 - Vertically installed, canned motor pumps
 - A canned motor pump does not need pump seals
- In-Vessel Control Rod Drive Mechanism
 - Mounted on the Reactor Internals in the RV
 - Elimination of Control Element Assembly ejection accident
- Steam Generator
 - Helical once-through type
 - Provide the maximum heat transfer area in limited space



<Major components of i-SMR>

Component		No.
Containment Vessel (CV)		1
Reactor Vessel (RV)		1
Pressurizer (PZR)		1
Reactor Coolant Pump (RCP)		4
Steam Generator (SG) Helical Type		1
SG Nozzle	Feed Water	8
	Main Steam	8
CRDM		48



<Helical-SG>

2. i-SMR Passive Safety Systems (1/7)

✓ Requirement and systems of i-SMR ESFs



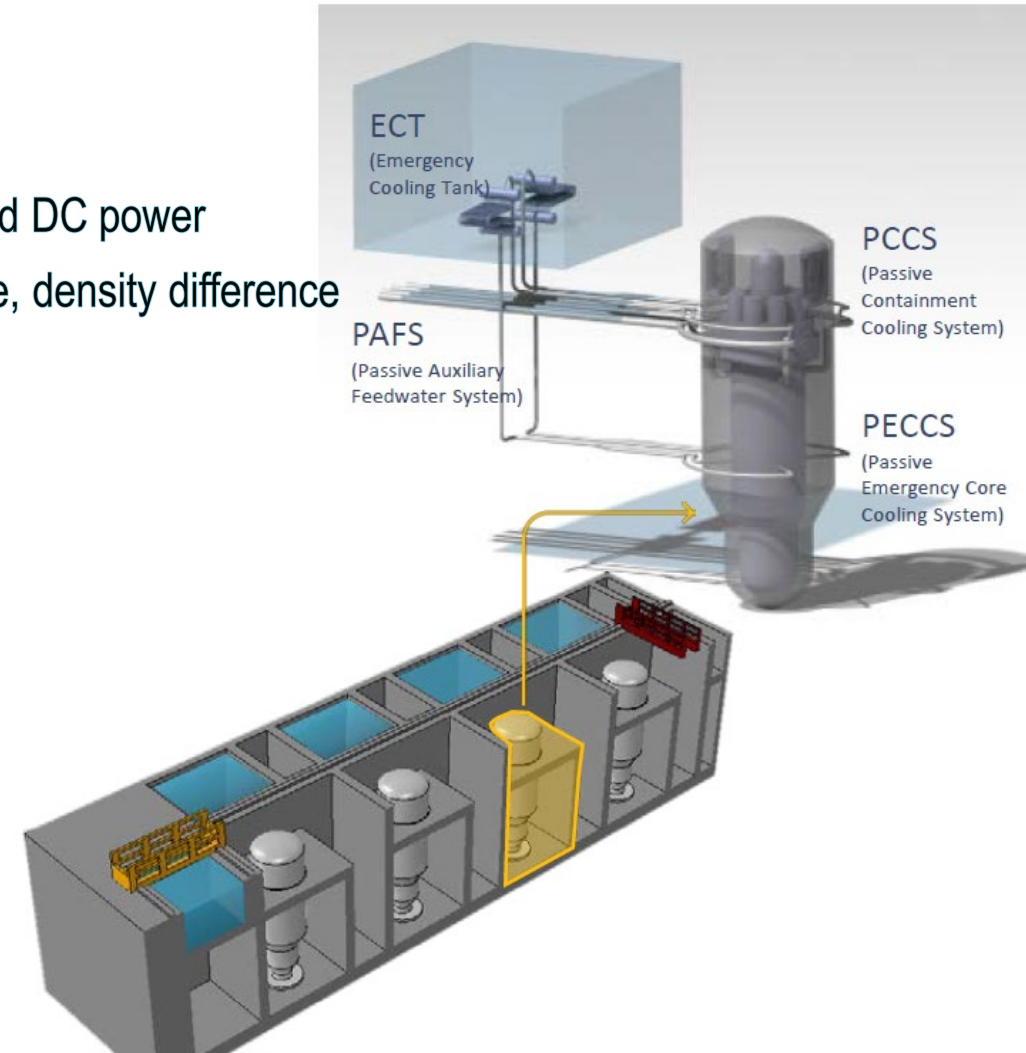
Top-tier requirements for safety system

- Designed to reliably perform safety functions without any safety-grade AC and DC power
- Designed to operate on natural forces such as gravity, temperature difference, density difference
- Designed to be fail-safe so that if a component fails or loss of power
- Located underground against the external hazard such as aircraft crashes
- Safety systems between modules are designed to be physically separated



Passive Safety Systems

- PCCS (Passive Containment Cooling System)
- PAFS (Passive Auxiliary Feedwater System)
- PECCS (Passive Emergency Core Cooling System)
- CIS (Containment Isolation system)



2. i-SMR Passive Safety Systems (2/7)

☑ i-SMR Safety Systems for Defense-in-Depth

DiD Level (IAEA SSR 2/1 and WERNA report)	Plant State	Safety Function / System			
		Control of Reactivity	Heat Removal	Overpressure Protection	Containment Isolation
2	AOO	CRDM	PAFS ¹⁾ , PECCS ²⁾ , PCCS ³⁾	PSV or POSRV	CIVs ⁴⁾
3a	DBA 1	CRDM	PAFS, PECCS, PCCS	PSV or POSRV	CIVs
	DBA 2	CRDM	PAFS, PECCS, PCCS	PSV or POSRV	CIVs
3b	DEC-A	CRDM, EBS	PAFS, PECCS, PCCS	PSV or POSRV	CIVs
4	DEC-B	- Primary system depressurization - Inject water to cool the corium - Inject water to flooding gap between RV and CV			

1) PAFS : Passive Auxiliary Feedwater System

3) PCCS : Passive Containment Cooling System

2) PECCS : Passive Emergency Core Cooling System

4) CIVs : Containment Isolation Valves

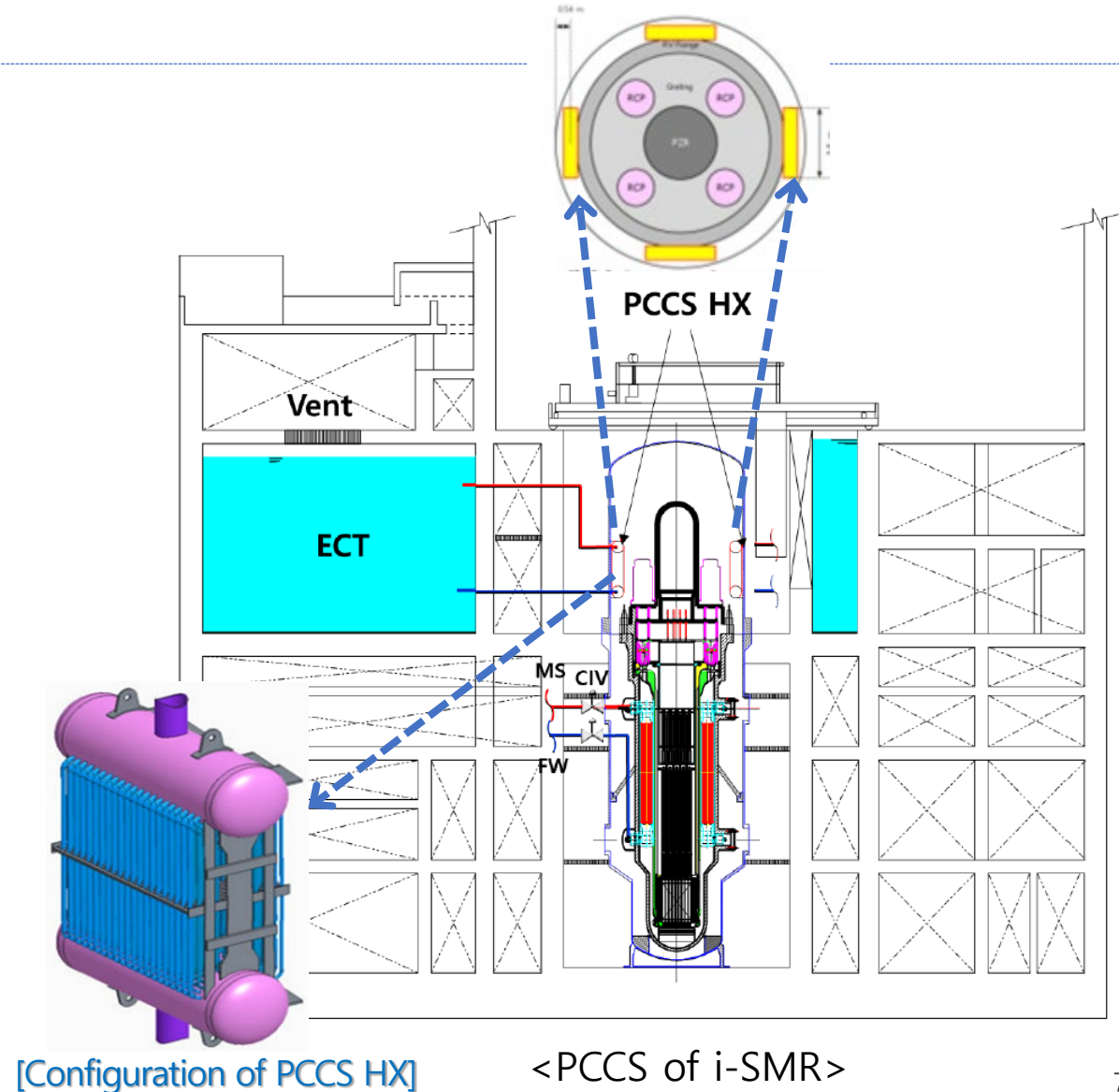
2. i-SMR Passive Safety Systems (3/7)

☑ Passive Containment Cooling System, PCCS



PCCS : Passive Containment Cooling System

- Composed of : One (1) PCCS heat exchanger, Connecting pipes to ECT for each train
- Capacity : $33 \% \times 4$ trains
- Operation :
 - In the normal operation, the water from the ECT continuously circulates inside the PCCS.
- After accident,
 - ① The steam is discharged into the CV and condenses on the PCCS HX.
 - ② It causes the water in the PCCS HX to evaporate, cooling the CV compartment.
 - ③ The gravity-driven PCCS loop continuously drives the PCCS flow until the ECT inventory is depleted.



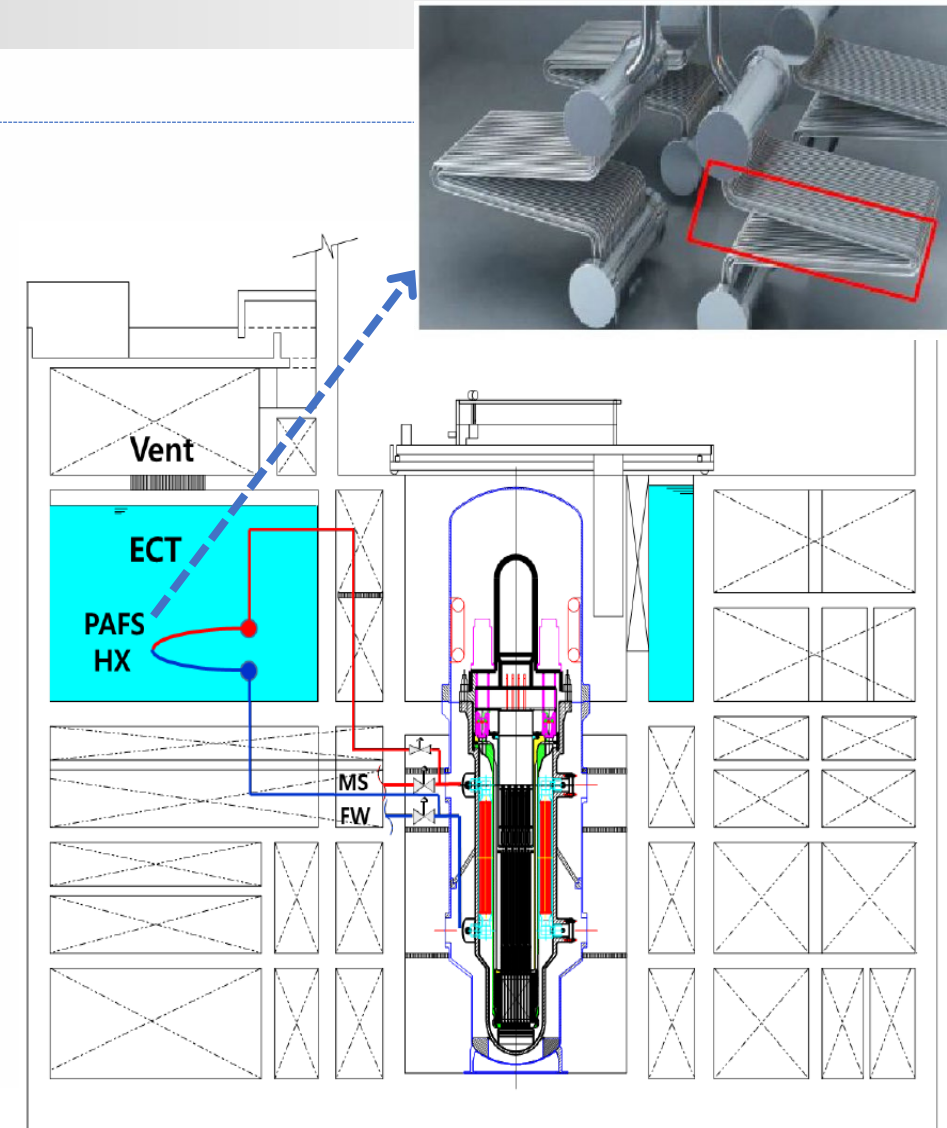
2. i-SMR Passive Safety Systems (4/7)

☑ Passive Auxiliary Feedwater System, PAFS



PAFS : Passive Auxiliary Feedwater System

- Composed of : One (1) PAFS heat exchanger, and Connecting pipes for each train
- The PAFS HX, submerged in the ECT, is connected to the main steam line and the feed water line outside of the CV.
- Capacity : $50\% \times 4$ trains, brings the RCS to safe shutdown condition within 36 hours and maintains the condition at least another 36 hours.
- Operation :
 - In the normal operation, the water flow inside the PAFS is blocked.
- After accident,
 - : When the PAFS is actuated, the steam generated in the SG by the decay heat of the RCS is transferred to the PAFS HX where it is condensed and then returned to the SG.



<PAFS of i-SMR>

2. i-SMR Passive Safety Systems (5/7)

☑ Passive Emergency Core Cooling System, PECCS

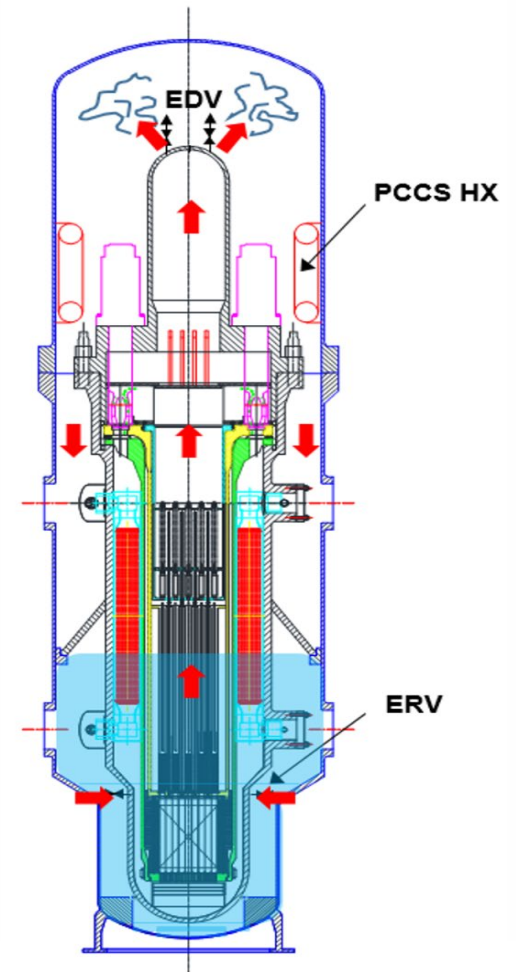


PECCS : Passive Emergency Core Cooling System

- Composed of : Two (2) EDVs and two(2) ERVs
- Operation :
 - In the normal operation, EDVs and ERVs are closed.
- After accident,
 - ① When the PECCS is actuated, emergency cooling of the core is initiated by relieving the RV's pressurized steam into the CV through the EDVs.
 - ② The steam is condensed due to heat transfer to the PCCS HX, and condensed water accumulates in the annulus between the RV and CV.
 - ③ After the condensate level of the CV becomes higher enough compared to the RCS coolant level, the condensed water in the CV is recirculated back to the RV through the ERVs.

* EDV : Emergency Depressurization Valve

* ERV : Emergency Recirculation Valve



<Passive ECCS of i-SMR>

2. i-SMR Passive Safety Systems (6/7)

☑ Containment Isolation System (CIS)



Containment Isolation valves (CIVs)

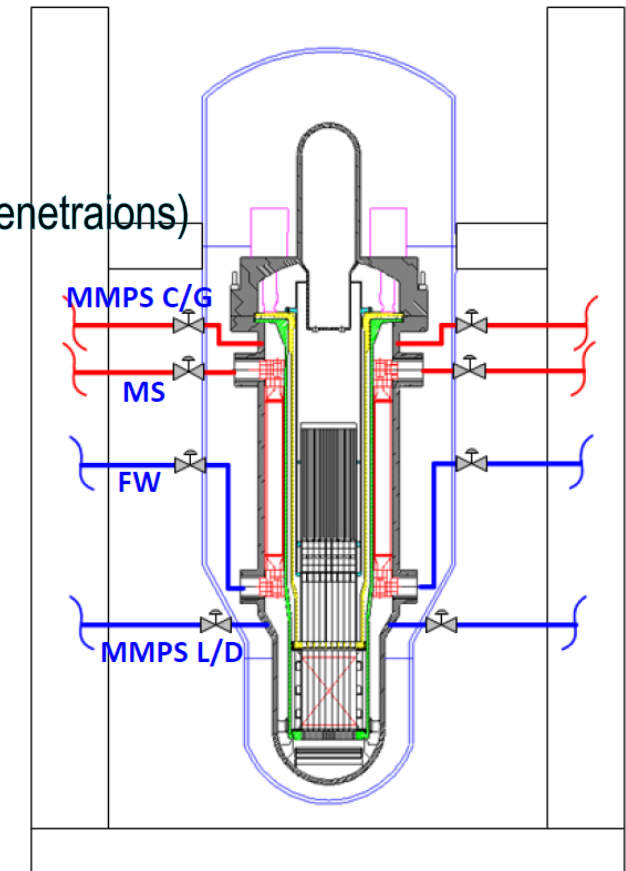
- Design

- There are more than roughly 20 penetration openings in the CV of i-SMR (Mechanical penetrations, Electrical penetrations, I&C penetrations, access and inspection port penetrations)
- The design provides two isolation valves in a single valve body outside of CV

- Location of CIVs

Location	-
MMPS charging line	Two Valves in a single valve body outside of CV
MMPS letdown line	
PZR spray line	
CCWS supply line	
CCWS return line	
Containment Vacuum System line	
RV high-point vent line	
Main steam line / Feed-water line	

*MMPS: Modular Makeup and Purification System
CCWS: Component Cooling Water System



<CIS of i-SMR>

2. i-SMR Passive Safety Systems (7/7)

✓ Preliminary analysis to confirm the performance of ESFs

• Scope

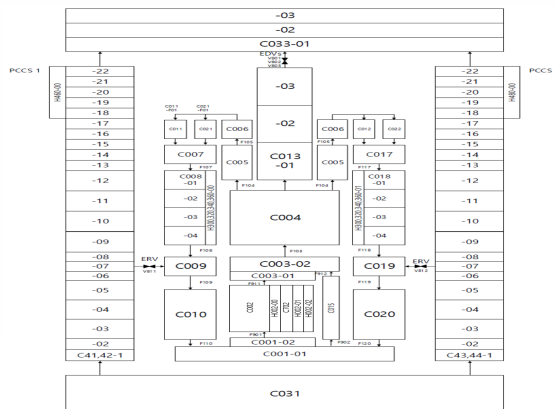
- AOO(Anticipated Operational Occurrence)
- DBAs(Design Base Accidents) and BDBA(Beyond DBA)

• Methodology

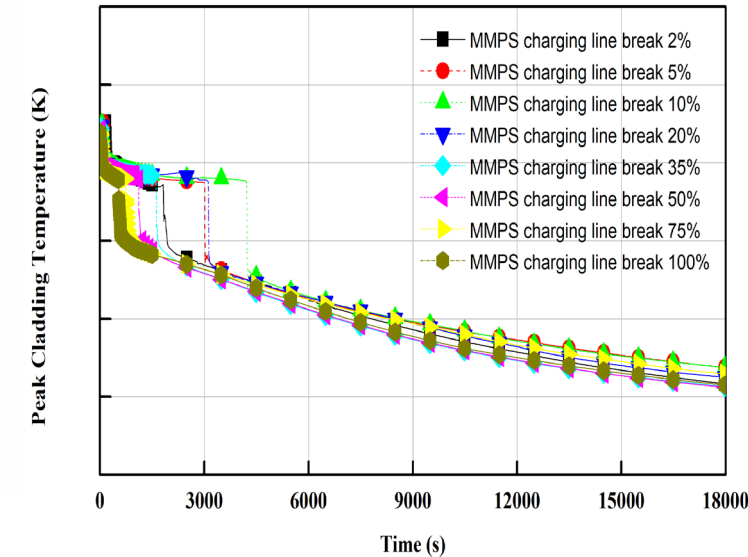
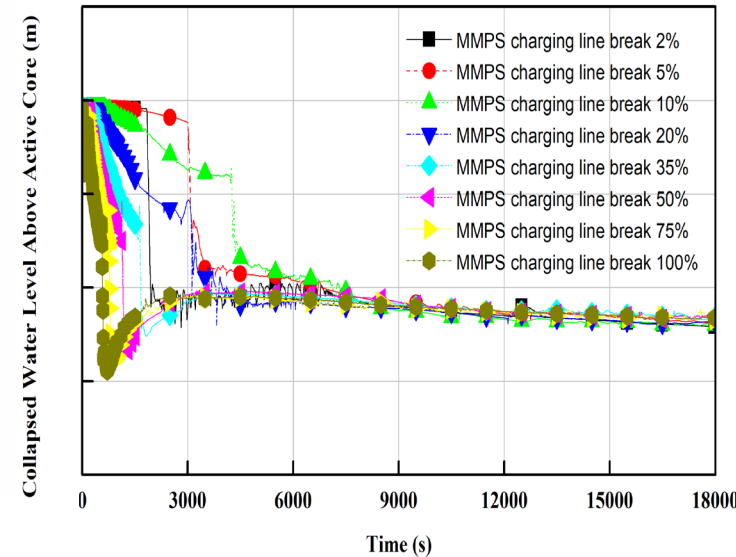
- T/H Analysis Code : SPACE (Safety and Performance Analysis Code for Nuclear Power Plant)
- Initial and boundary conditions : Conservative

• Degree of completeness

- Preliminary analysis for representative events



Nodalization



SBLOCA (MMPS Charging Line Break) Analysis Results

☑ Thermal-hydraulic Phenomena in i-SMR



Passive Safety Systems

- PCCS : condensation heat transfer with nearly pure steam on outer wall of heat exchanger (high-pressure and high-temperature)
- PAFS : well-validated technology in APR+ and SMART
- PECCS : feasibility test of natural circulation using EDV and ERV (recirculation using hydraulic head)



Reactor Coolant Systems

- Core : pressure drop, flow distribution, critical heat flux
- SG : heat transfer of two-phase flow in helical SG
- RCP : flow induced vibration, partial or total loss of flowrate
- Integral loop : pressure drop along the flow path

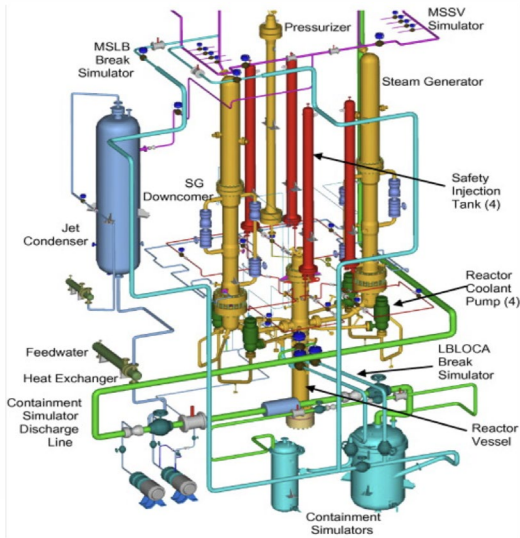
3. i-SMR Validation Tests (2/5)

✔ Expertise and Experience for Validation Tests

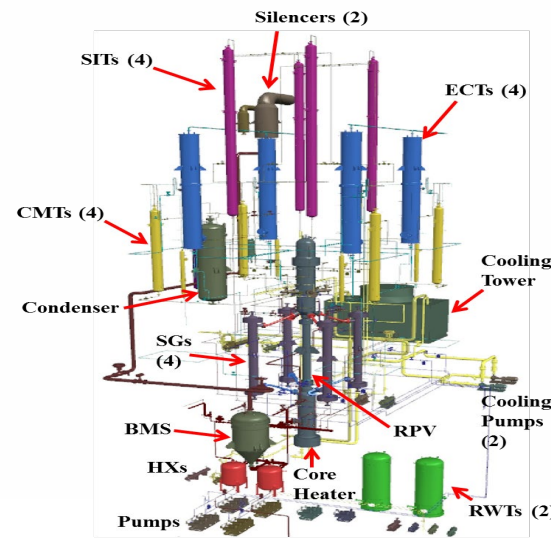


Integral Effect Test Facilities

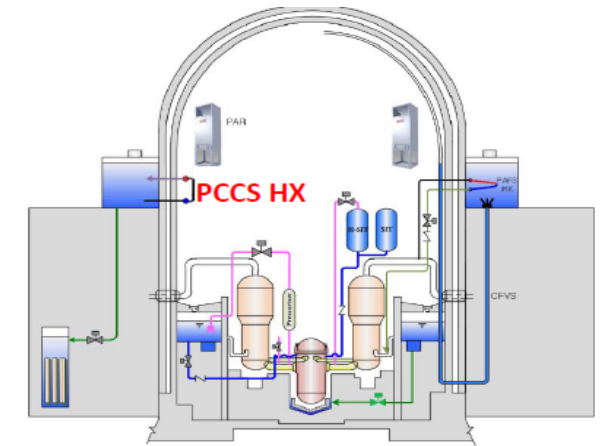
- Intense experience in IET (two types of IETs, ATLAS & SMART)
- Used for licensing (APR1400, APR+ and SMART)
- We have a Plan to design and install IET facilities for i-SMR



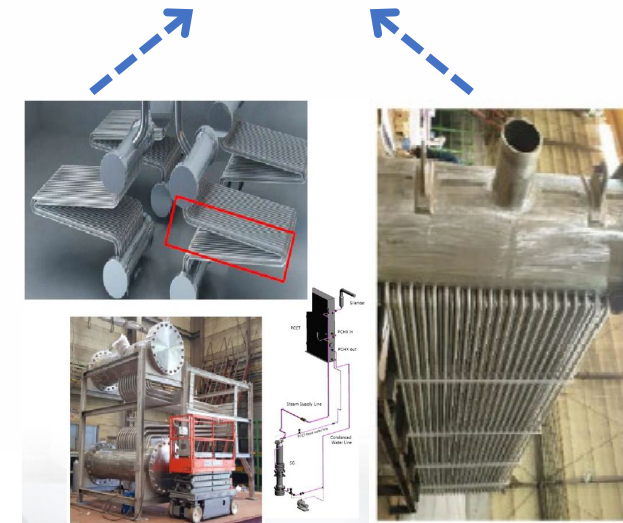
ATLAS Integral Effect Test Facility



SMART Integral Effect Test Facility



Schematic diagram of iPOWER



PAFS

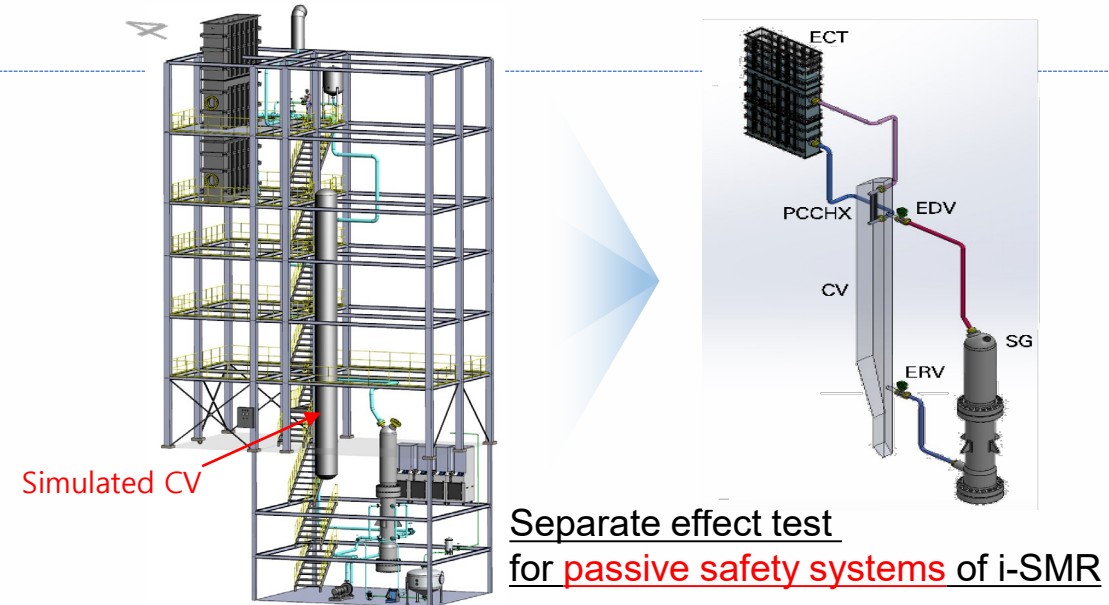
PCCS

✓ Separate Effect Tests



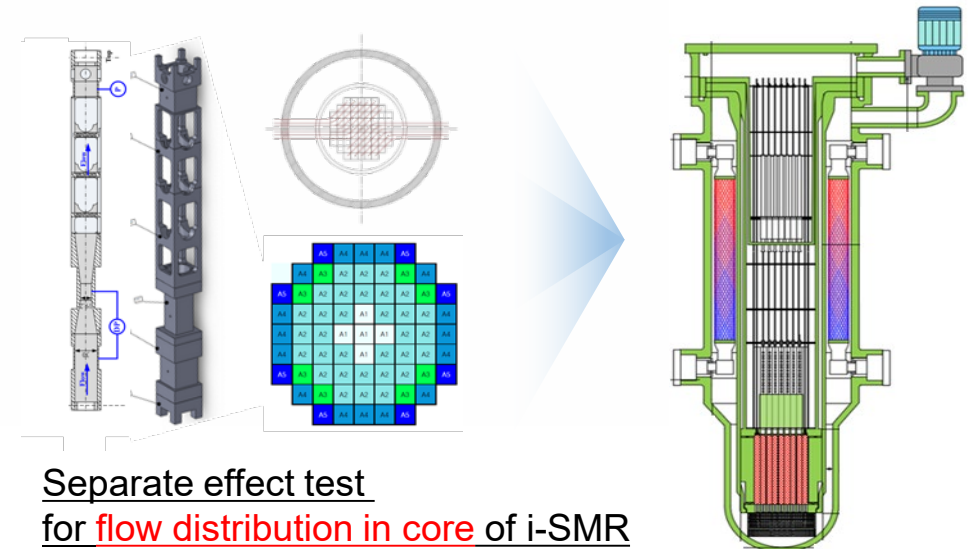
Separate Effect Test #1

- To validate the cooling performance of the passive safety systems
 - 1) single tube HX in PCCS
 - 2) tube bundle HX in PCCS
 - 3) feasibility of ERV in PECCS



Separate Effect Test #2

- To evaluate the flow distribution characteristics in the core
 - 1) pressure drop along the flow path in RV
 - 2) flow distribution at core inlet/outlet region
 - 3) production of DataBase for licencing



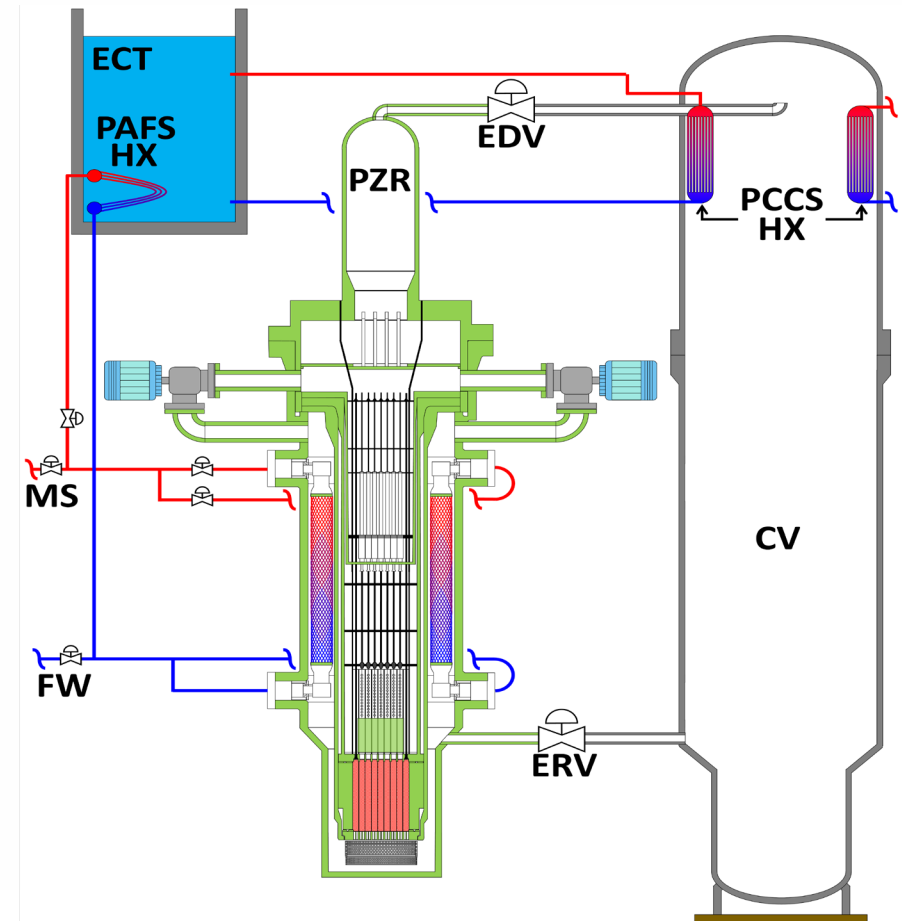
3. i-SMR Validation Tests (4/5)

✓ Integral Effect Test (1/2)



Test Purposes

- The IET is designed and constructed
 - to resolve licensing issues of i-SMR,
 - to confirm combined capability of new passive safety systems,
 - and, to validate the safety analysis code and related models
- Basic design for IET facility
 - Global scaling ratio : $H=1/2$, $A=1/49$, $V=1/98$
 - Integral type helical SG + separated RCPs and CV
 - PAFS / PCCS : 4 Trains
 - ECT : 2 Trains (combined effect by PAFS and PCCS)
 - EDV / ERV : 2 / 2 (separated break line and recirculation line in ERV)



Integral effect test facility for i-SMR



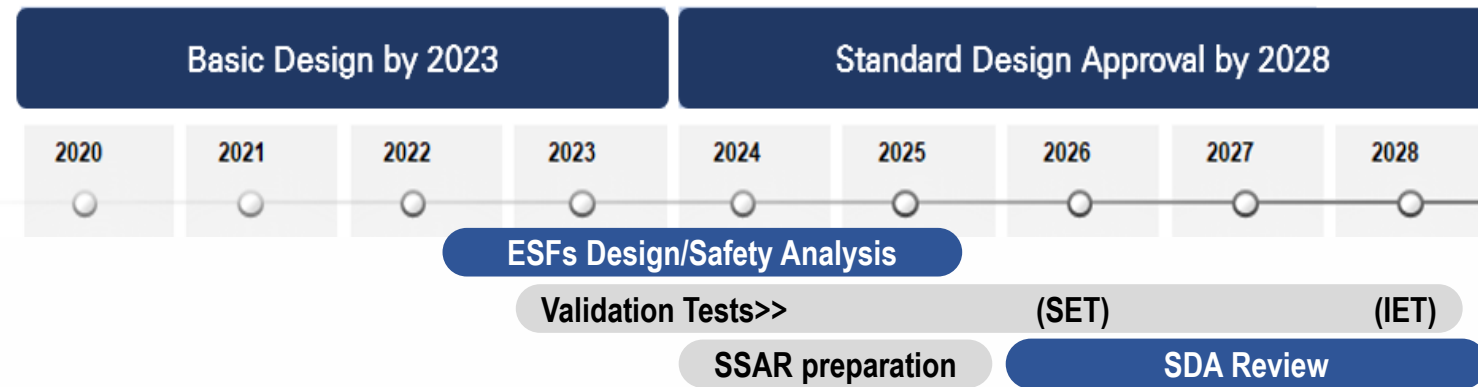
i-SMR Passive Safety Systems

- PCCS, PECCS, PAFS and CIS
- The SET & IET are designed and constructed
 - to resolve licensing issues of i-SMR,
 - to confirm combined capability of new passive safety systems



Validation test plan

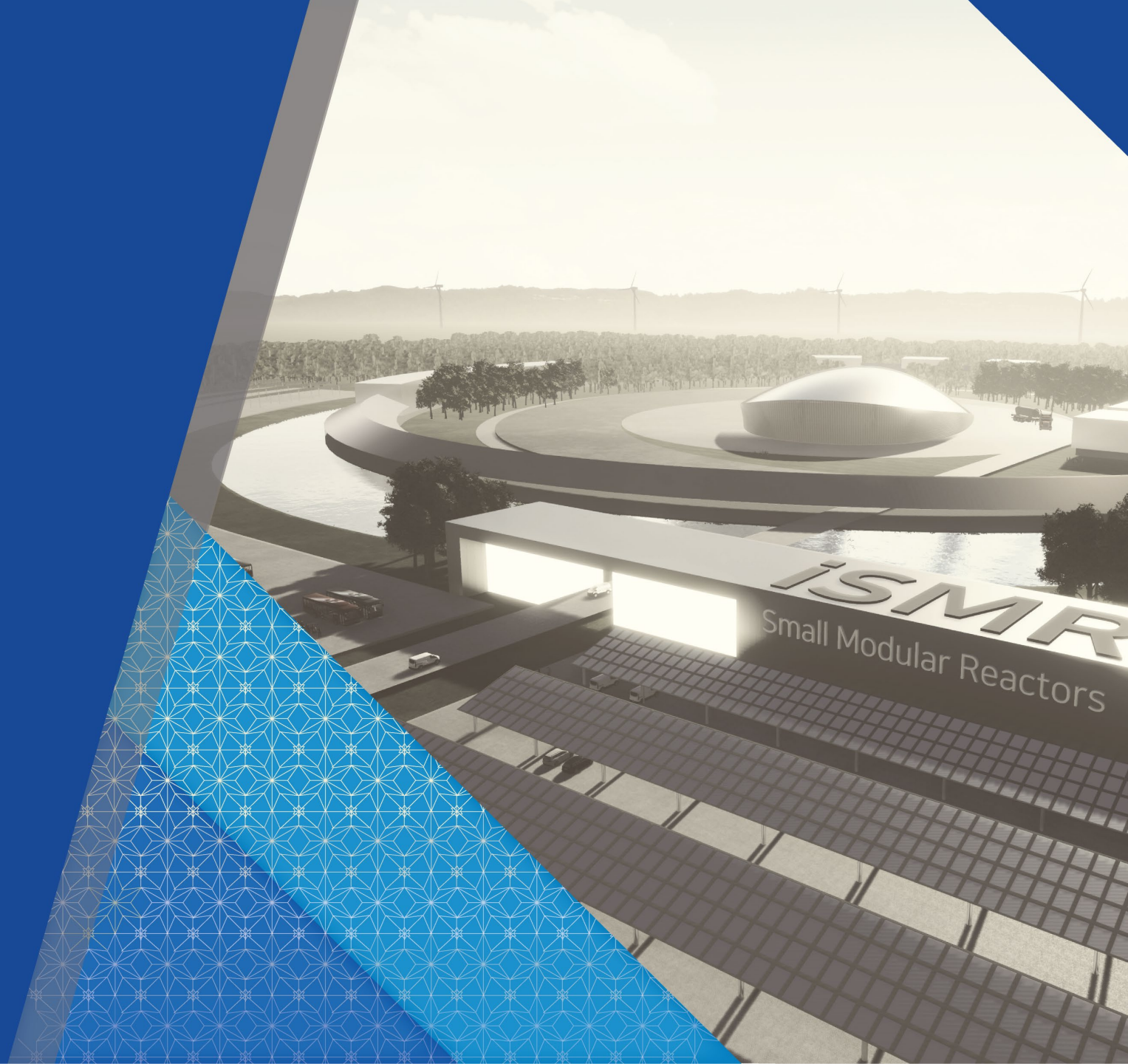
- Separate Effect Test
 - Facility & Commissioning to be completed by March 2026 , - Experimental Data and Final Report : ~ 2026
- Integral Effect Test
 - Facility to be completed by 2026
 - Commissioning (2027), Experimental Data and Final Report : ~ 2028



Thank You for your listening



Korea Hydro & Nuclear Power Co., Ltd.



✓ Major Top Tier Requirements



General

- Pressurized Water Reactor (PWR)
- Power output : 170 MWe / Module

- Design life : 80 years
- Site : site envelope, seismic design 0.3~0.5 g



Safety

- Core Damage Frequency : $\leq 1.0 \text{ e-9 /M}\cdot\text{Y}$
- Large Early Release Frequency : $\leq 1.0 \text{ e-10/M}\cdot\text{Y}$
- EPZ : within the site boundary
- Operator time to action : ≥ 72 hours

- Station Blackout response time : ≥ 72 hours
- Fuel thermal margin : $\geq 15\%$
- Unfavorable Exposure Time (UET) : Zero
- Completely passive core/containment cooling

Economics

- Construction cost : \$3500/kWe
- LCOE : \$65/MWh
- Construction time : First Rx 24 months / plant 42 months
- Module design for factory manufacturing, land transport

- Plant availability factor : $\geq 95\%$
- Operation multiple modules in one MCR
- 3 operators in MCR



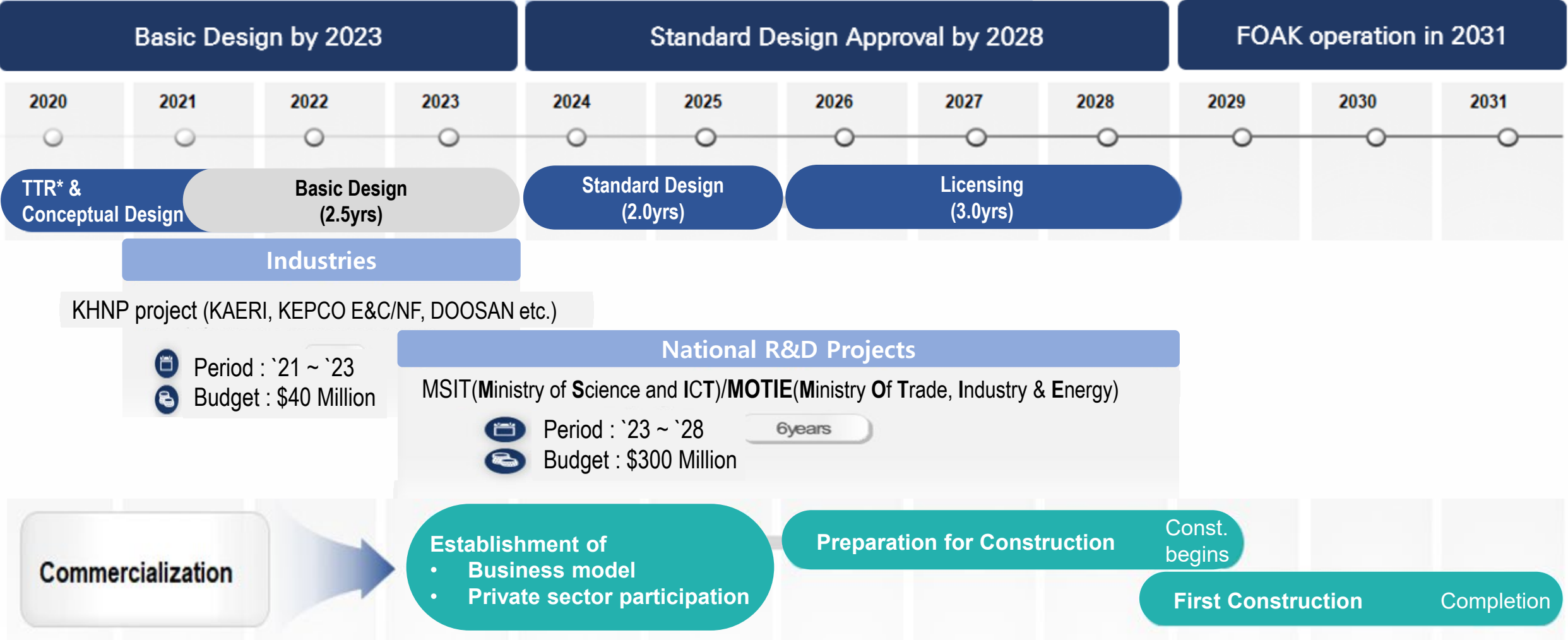
Flexibility

- Boron free core
- Easy flexible operation
(Daily load following, sudden output fluctuations, frequency control, etc.)

- Refueling cycle : ≥ 24 months

Supplement. i-SMR Recent Development Status (2/2)

☑ **Target Goal: Standard Design Approval(SDA) by 2028, First Of A Kind(FOAK) Operation in 2031**



* TTR: Top-Tier Requirement

➤ **National BPLE** has determined FOAK operation in 2034.**

** BPLE: Basic Plan for Long-term Electricity Supply and Demand