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Session 8.2 Assessment and experimental testing of passive safety systems in SMRs

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# Passive safety system and safety demonstration of innovative small modular reactor (i-SMR)

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PART I

# Overview of i-SMR

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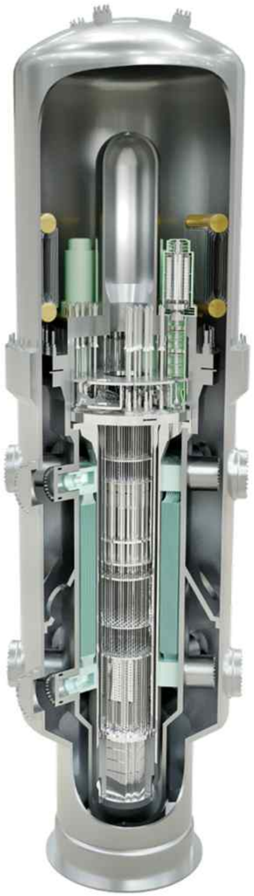
## ◆ Top-tier requirements

### GENERAL

- **PWR**
- **170MWe POWER**
- 80 years design life time



### SAFETY

- **CDF : 1.0 × 10-9 /M·Y**
- **Fully Passive Safety System**
- EPZ : Within EAB

### ECONOMICS

- Overnight cost : $3,500 /kWe
- LCOE : LCOE $65 /MWh
- **Modular design and Factory manufacturing**
- Construction time ≤ 42 month (4 modules)

### FLEXIBILITY

- **Boron Free Operation**
- Multipurpose Utilization
- Load Following Operation

# I Overview of i-SMR



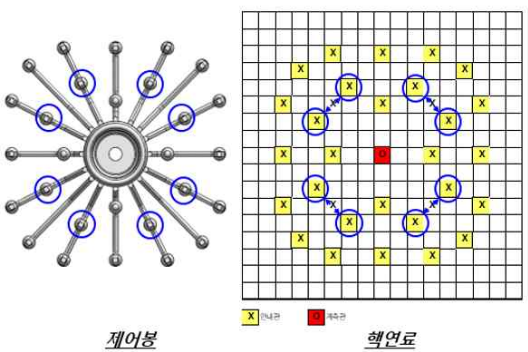
## ◆ Nuclear Steam Supply Steam (NSSS) Design (1/2)

### Fuel and Core design

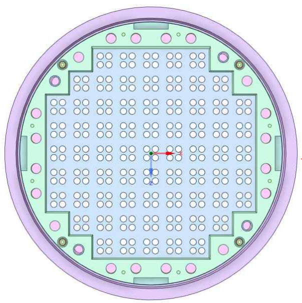
- Thermal power = 520MWth
- Active height = 2.4m, Type = 17x17
- Seismic design = 0.5g
- Steel reflector
- **Reactivity control**
  - ✓ **IV-CRDM, Burnable absorber, MTC**

### Steam Generator Design

- **Type = Monobloc, once-through helical type**
  - ✓ Compact design than cartridge type SG
- Superheating degree = 30 °C
- **Orifice = Eliminate density wave oscillation**

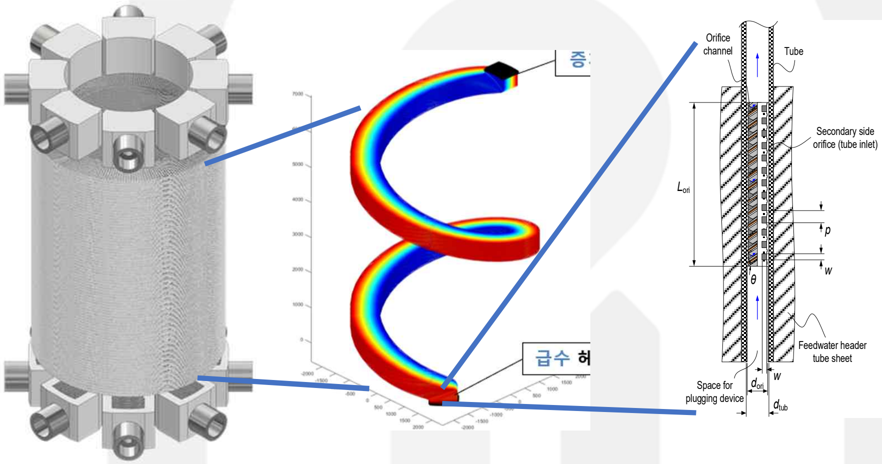



<Control Rod and Fuel>



< Steel reflector>

< i-SMR>




< Helical SG >

< Inlet Orifice>

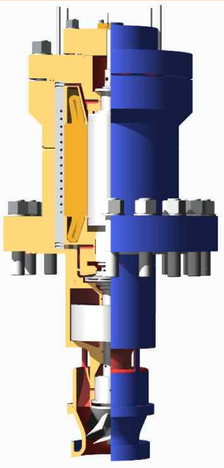
## ◆ Nuclear Steam Supply Steam (NSSS) Design (2/2)

### Reactor Coolant Pump

- **Type = Seal-less canned motor (No seal LOCA)**
- No. of pump = 4, Power = 400kW / pump
- **Characteristics**
  - **Improved primary flow stability** from flow instability (vs Natural circulation reactor)
  - Increase Rx thermal power ➔ economics

### In-Vessel Control Rod Driving Mechanism

- Design Pressure = 17MPa
- Design temp = 343 °C
- **Type = in-Reactor vessel type**
- **Characteristics**
  - **Eliminates CEA Ejection accidents**



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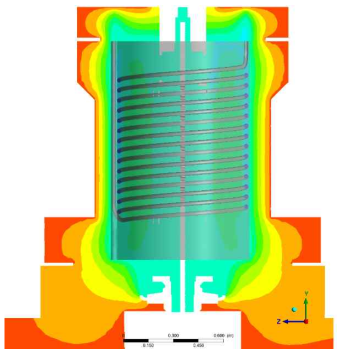

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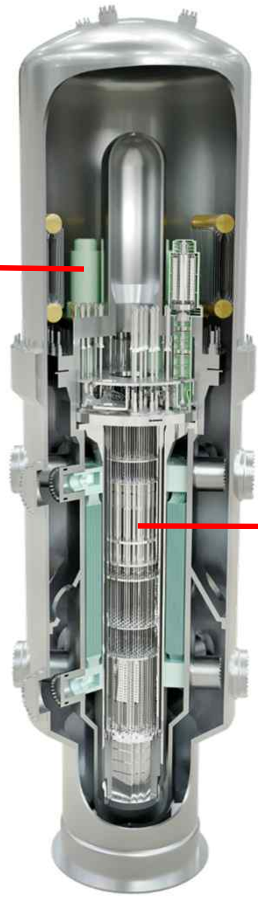

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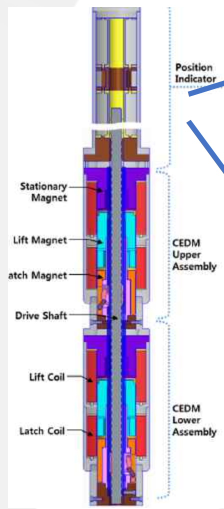


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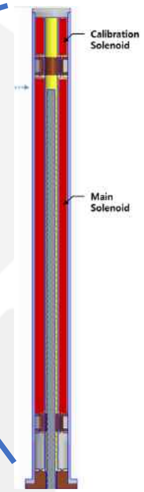


< Position Indicator>

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PART II

# Passive Safety System of i-SMR

# II Passive Safety System of i-SMR

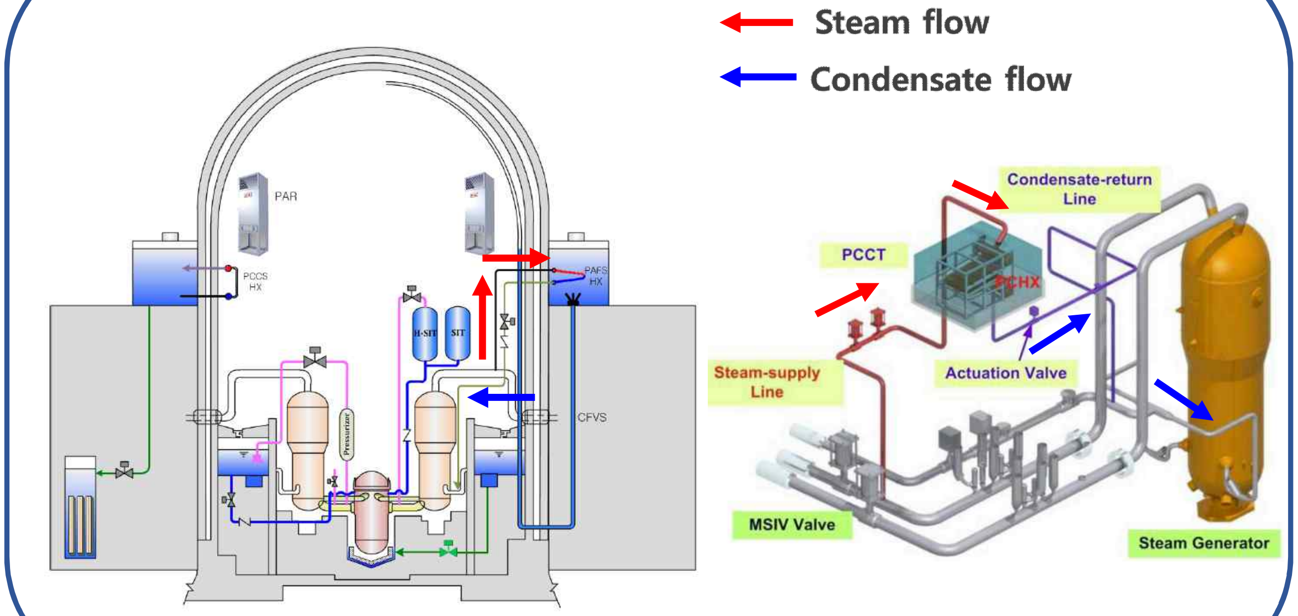


## ◆ Top-tier requirements for safety system

1. Designed to reliably perform safety functions without any safety-grade AC and DC power
   - ➡ Remote area, off-grid deployments
2. Designed to operate on natural forces such as gravity, temperature differences, density differences.
   - ➡ Fully passive safety system
3. Designed to be fail-safe so that if a component fails or loss of power
   - ➡ Fail-safe design
4. Located underground against the external hazard such as aircraft crashes
   - ➡ Preparedness for extreme external hazard
5. Safety systems between modules are designed to be physically separated and operate independently
   - ➡ Maintain safety function independence between modules

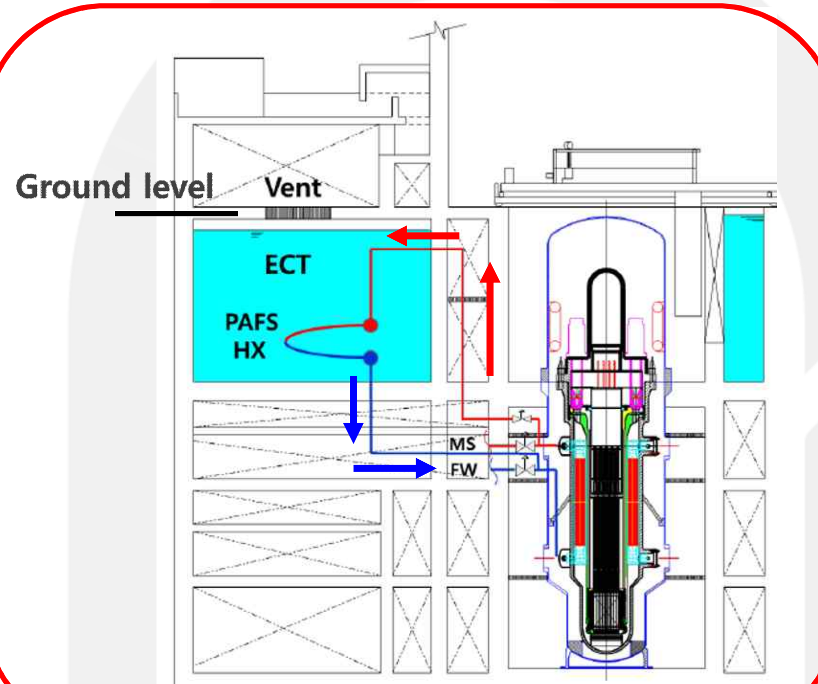
## ◆ Passive Auxiliary Feedwater System (PAFS)

- ➢ Design Basis : cooling the reactor below safe shutdown conditions (215°C) within 36 hours
- ➢ **System configuration : 50% x 4 train passive heat exchangers design**
  - ✓ HX tube dimension of i-SMR is same with prototype of APR+
  - ✓ **16 years of design experiences and experimental database**




< iPOWER PAFS>

< APR+ PAFS >



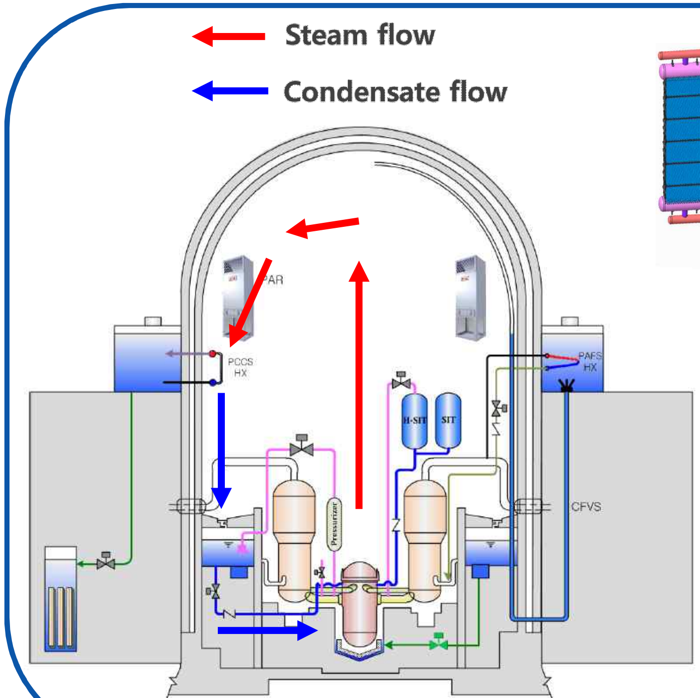

< i-SMR PAFS>

# II Passive Safety System of i-SMR

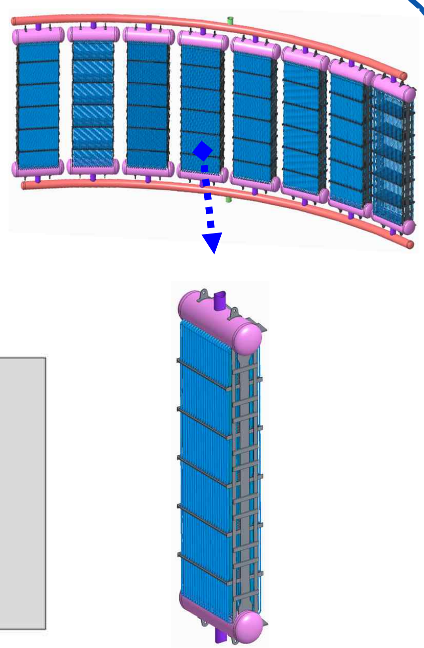


## ◆ Passive Containment Cooling System (PCCS)

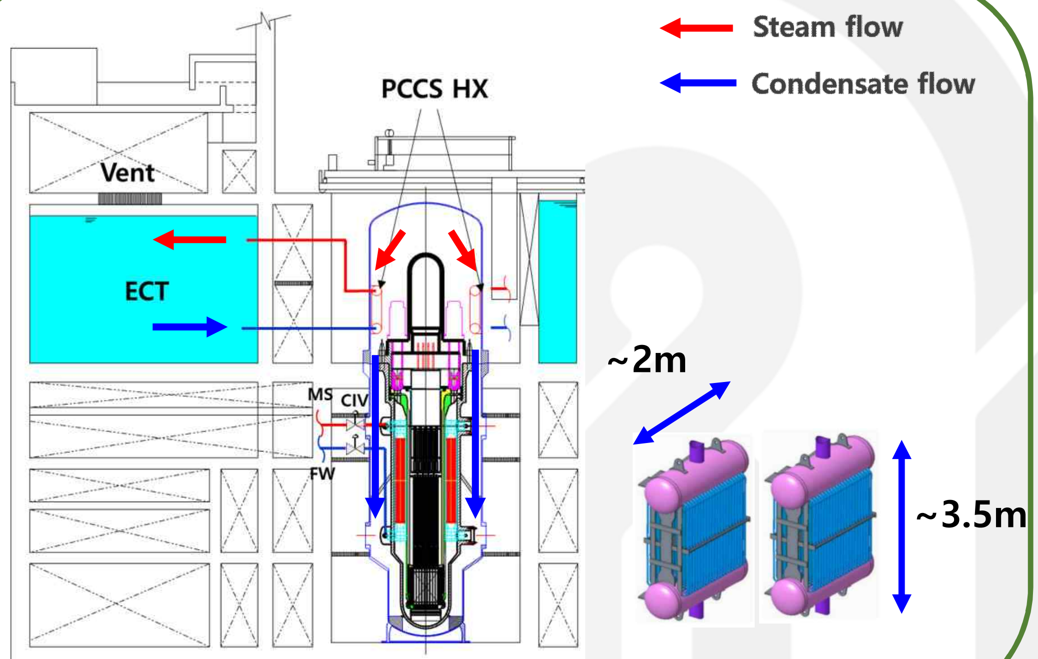
- Design Basis : Maintain within CV design pressure in SBLOCA; reduce to ½ of peak pressure within 24 hours
- **System configuration : 100% x 2 train passive heat exchangers design**
  - ✓ HX tube diameter of i-SMR is same with prototype of i-POWER
  - ✓ No actuation valves in PCCS




< iPOWER PCCS>



< PCCS HX module>




< i-SMR PCCS>

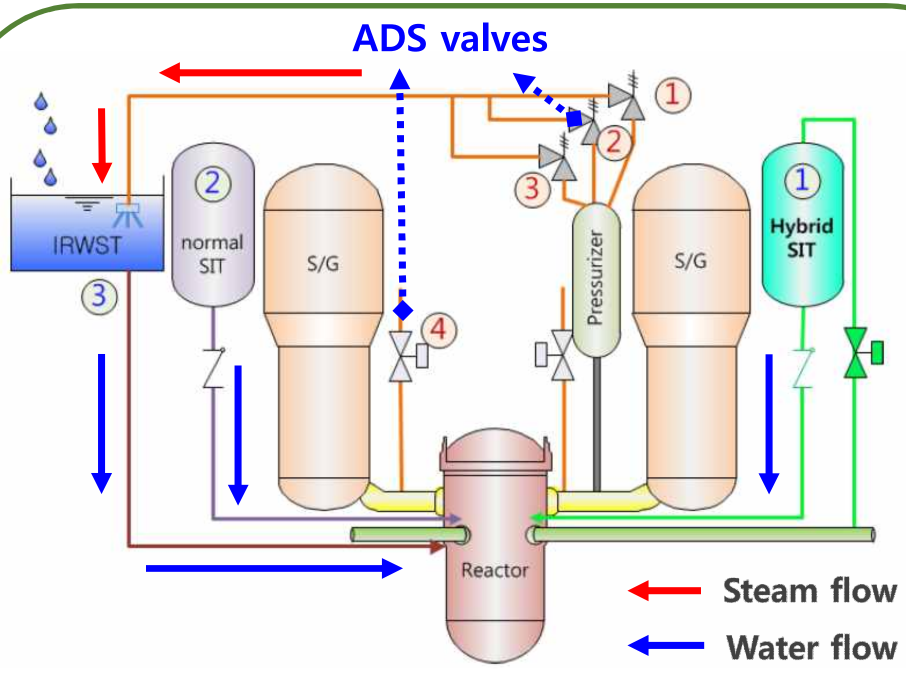
< PCCS HX >

# II Passive Safety System of i-SMR

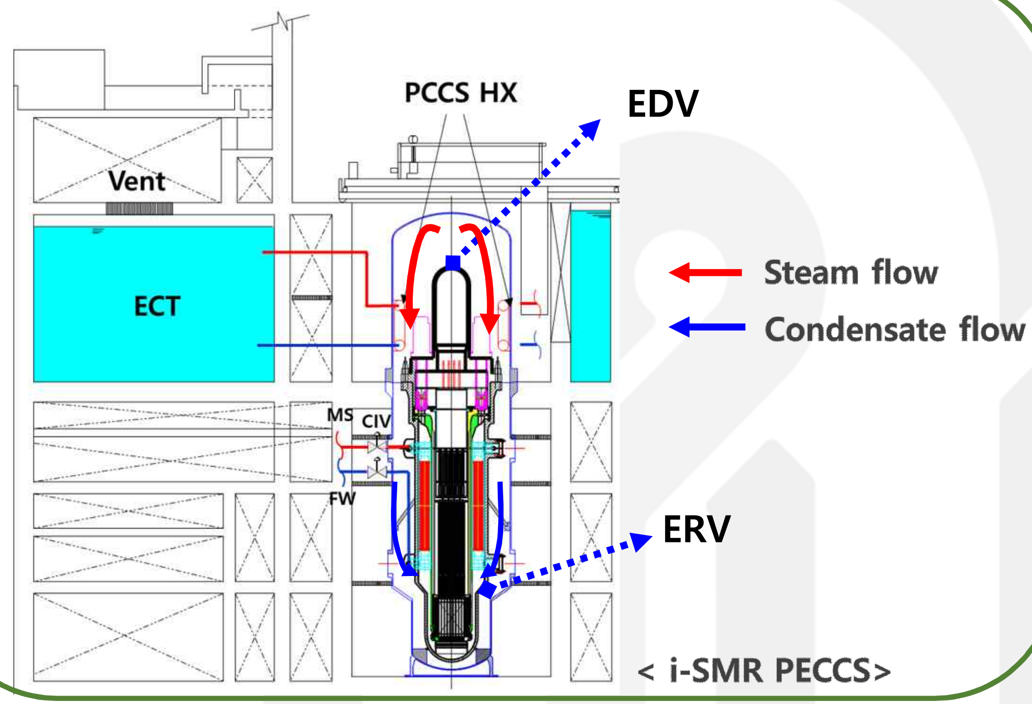


## ◆ Passive Emergency Core Cooling System (PECCS)

- ➢ Design Basis
  - ✓ Prevent exposure of the core level by **releasing RCS pressure and returning PCCS condensate into core**
- ➢ System Configuration
  - ✓ 100% x Emergency Depressurization Valve (2 train), Emergency Recirculation Valve (2 train)



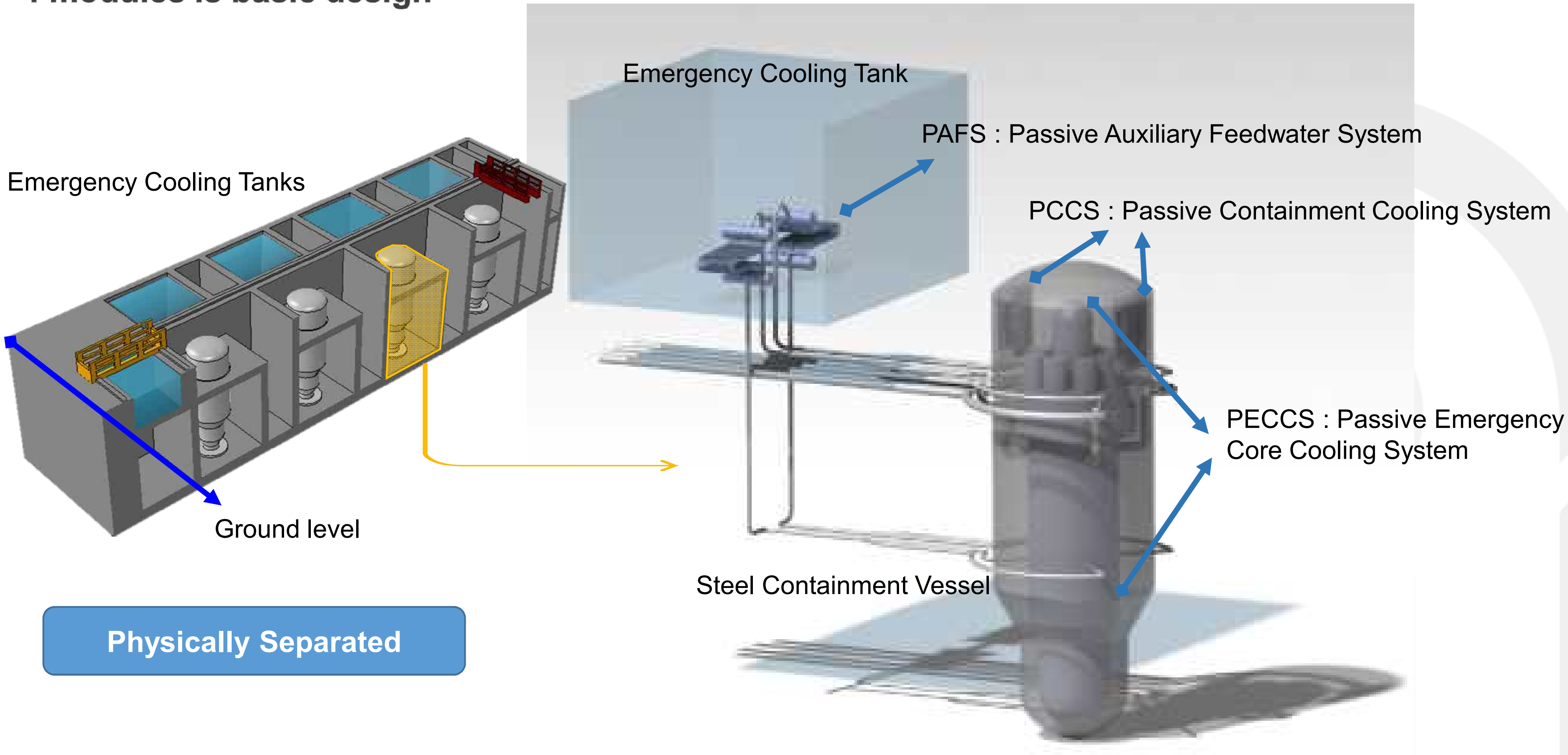

< iPOWER PECCS>




< i-SMR PECCS>

◆ **Overview of passive safety system in i-SMR plant**

➢ **4 modules is basic design**




**Physically Separated**

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PART III

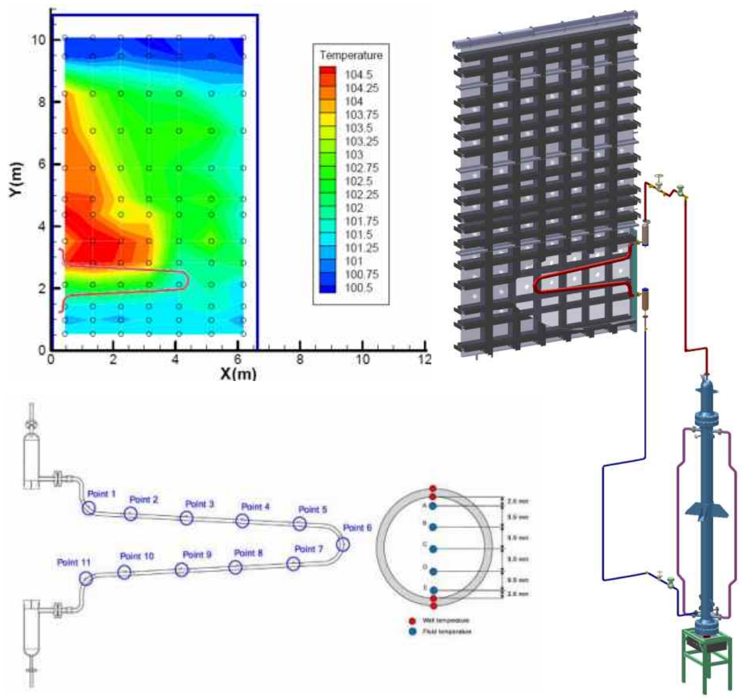
# Thermal-Hydraulics Experimental Test

◆ **Objectives of i-SMR PIRT (2024, On-going)**

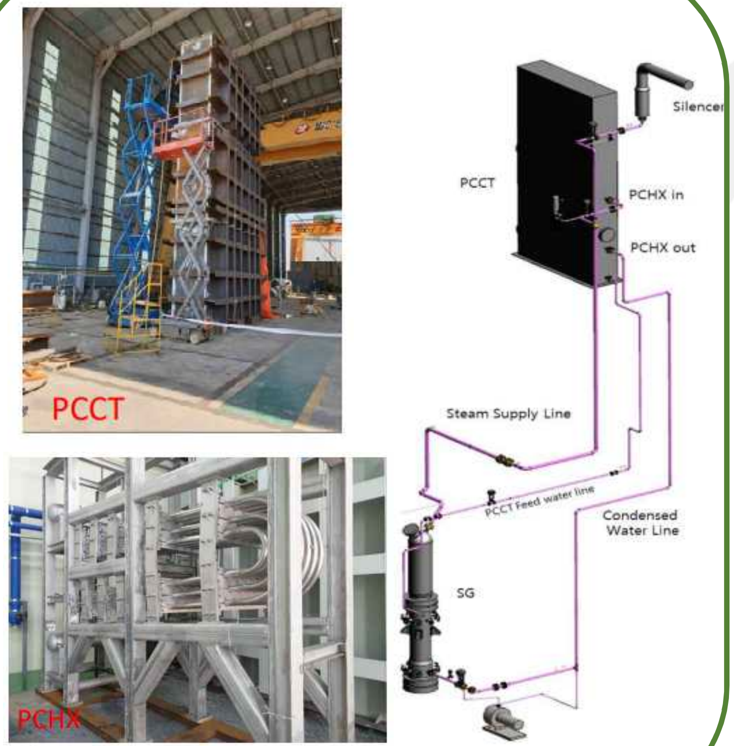
- Update & validation for Safety Analysis Code (SPACE, Safety and Performance Analysis CodE)
- Designing of Test Facilities (SET, IET) & Experiments
  - ✓ SSCs : RCS, PAFS, PCCS, PECCS valves, Containment Vessel
  - ✓ **Selected Thermal-hydraulics phenomena**
    - SG : Flow instability inside Helical tube
    - PAFS : Superheated and Saturated Steam Condensation
    - PCCS : Superheated and Saturated Steam Condensation in High Pressure
    - PECCS : Recirculation flow and two-phase pressure drop in ERV
    - Containment Vessel : Flashing and Condensation

## ◆ Separate Effect Test (SET) (1/3)

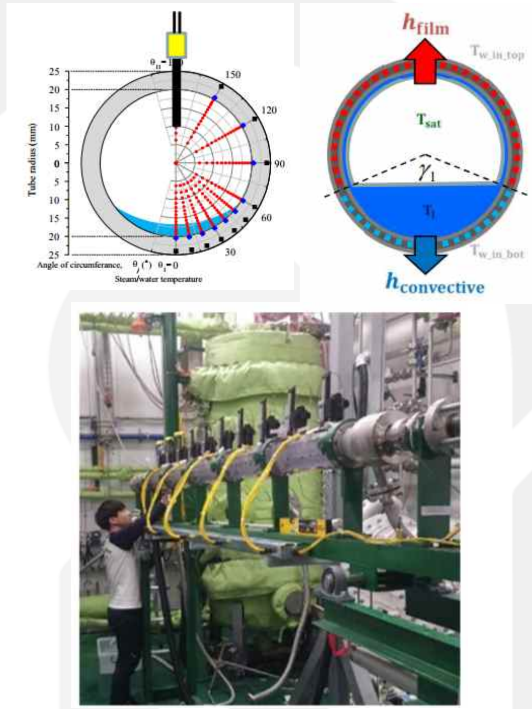
- **Single tube condensation test, Bundle tube test, and APR+ PAFS Integral effect test had been carried out**
- Development of condensation model for PAFS is completed




< PASCAL test (Single) >



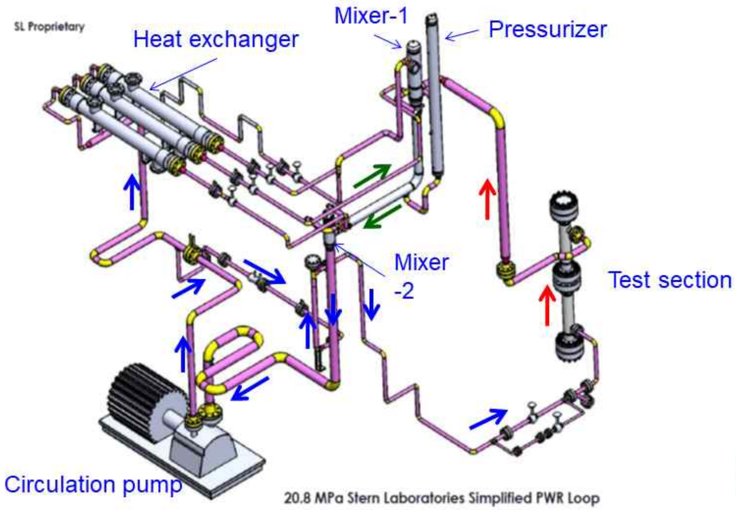

< LAPLACE test (Bundle)>



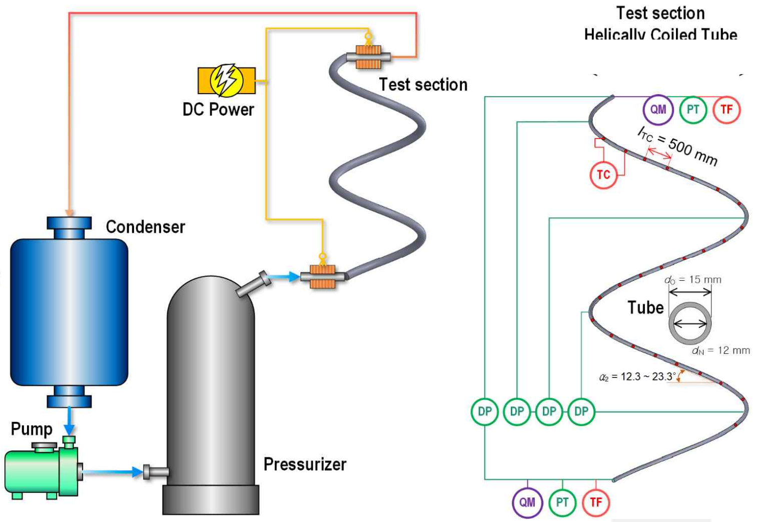

< PICON test (Model Development)>

◆ **Separate Effect Test (SET) (2/3)**

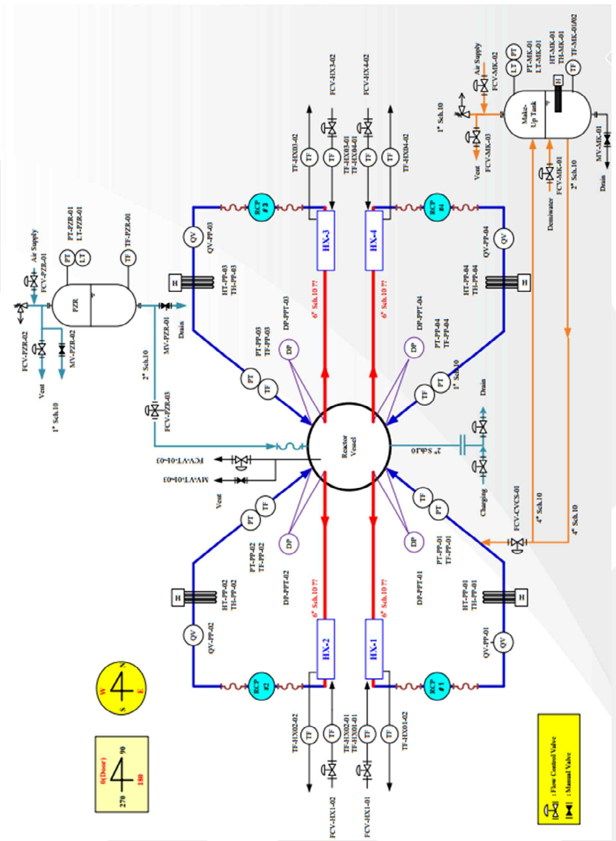
- **Prototype of helical coil steam generator tube test**
  - ✓ Pressure drop, HTCs, Density wave oscillation
- **Core inlet flow distribution Test**
  - ✓ Quantification of core inlet flowrate for each FA
- **Critical Heat Flux (CHF) test** for i-SMR fuels
  - ✓ CHF correlation update and expanding flow velocity range




< CHF test >



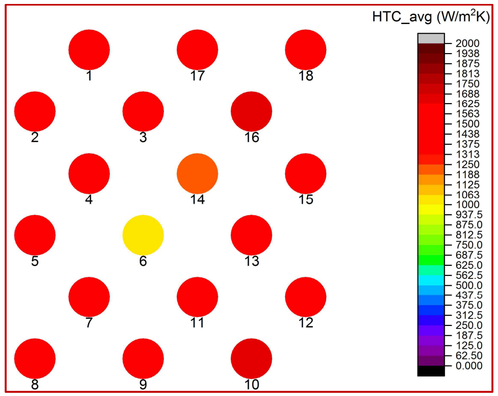

< Helical coil SG test >



< Core flow distribution test >

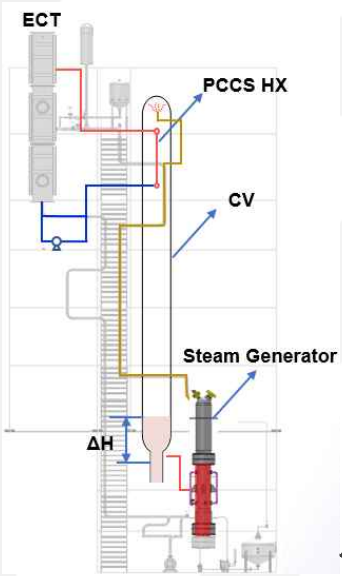
## ◆ Separate Effect Test (SET) (3/3)

- **PCCS condensation test** : Obtaining condensation HTCs of PCCS HXs for single tube and bundle tubes
  - As-is(iPOWER) : Low P(<0.5MPa), High non-condensable gas fraction (0.1<Wa<0.7)
  - **To-be(i-SMR) : High P(<5MPa), Low non-condensable gas fraction (0<Wa<0.1)**
- **PCCS-PECCS natural circulation test**
  - **Measuring the natural circulation flow rate of ERV coupled with PCCS condensation**
  - Preserving the pressure drop of natural circulation and ERV K-factor for prototype




< PCCS performance test for i-POWER >

< Manufacturability Validation >




< i-SMR SET facility>

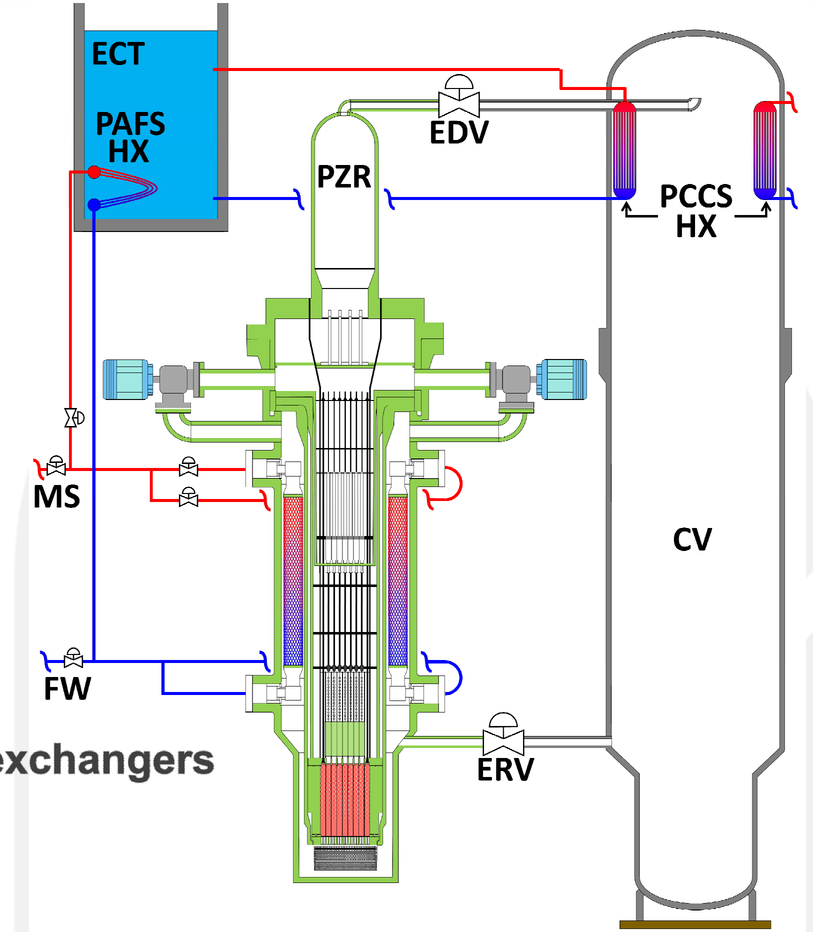
# III Thermal-Hydraulics Experimental Test



## ◆ Integral Effect Test (SET) Plan

- Objectives
  - ✓ **to confirm design concepts of new passive safety systems**
  - ✓ **to validate the safety analysis code and related models.**
- Simulation Accidents : (Phase 1) Major DBA, (Phase 2) BDBA
- Facility design
  - ✓ Scaling ratio : H=1/2, A=1/49, V=1/98
  - ✓ Integral type SG + separated RCPs and CV

- **Important Phenomena**
  - ✓ **RV and CV wall boiling and recirculation flow in LOCA**
  - ✓ **thermal stratification and natural Convection in ECT**
  - ✓ **Superheated steam condensation in PAFS and PCCS heat exchangers**
  - ✓ **Overall safety performance**




< i-SMR IET facility>

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PART IV

# Conclusions

# IV Conclusions



1. i-SMR have chosen a strategy for near-term deployment by applying the design concepts and existing database of passive safety features from the advanced PWR

2. Innovative technologies and new design features are being systematically validated through PIRT, SET/IET, code validation and final safety analysis

3. Potential challenges and unknown phenomena will be addressed through planned experiments, analysis and complementary experiments prior to construction phase

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# Thank you for your attention