# I&C Design Considerations for SMRs

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International Atomic Energy Agency

**Regional Workshop on Safety Benefits and Challenges in the Development of the Adoption of SMR (April.2 2025)**

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KOREA HYDRO & NUCLEAR POWER CO., LTD

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# 1 Development of SMR in Korea

## SMR has strength that conventional(large) NPPs doesn't have

**Definition**

SMR(Small Modular Reactor) : A reactor with an electric power of less than 300MW capable of factory production of a reactor module.

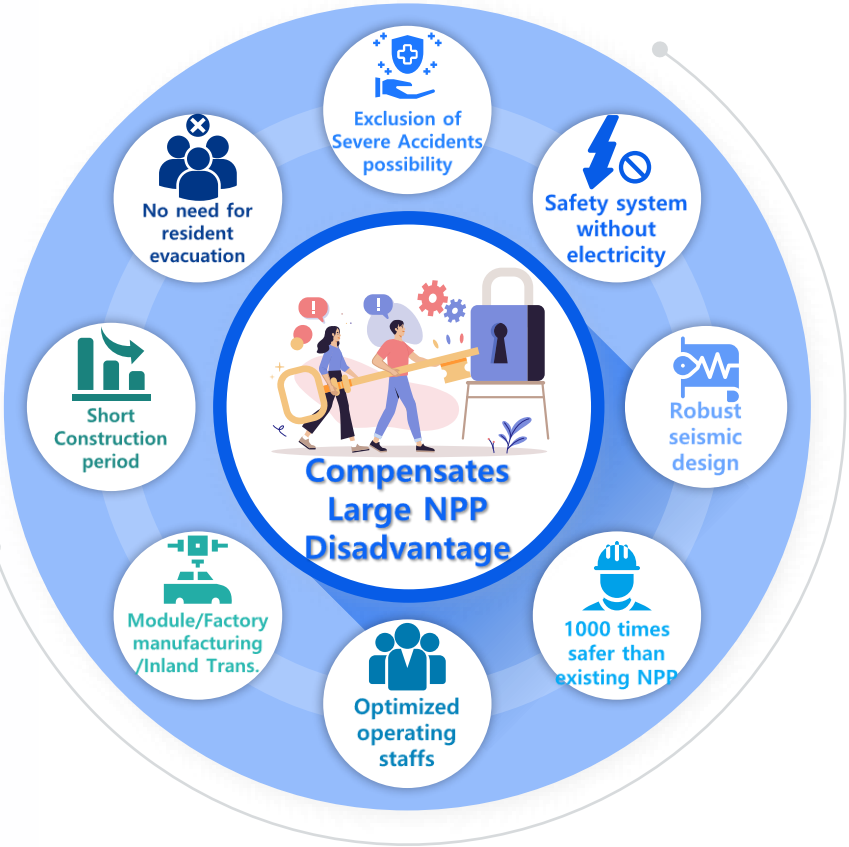
### Advantages of SMR

**Safety**
- Effective in alleviating accidents due to its inherent safety characteristics
- Reduced radioactive release due to small number of nuclear fuel bundles

**Economics**
- Reduced initial investment
- Reduced construction delay risk by factory manufacturing and equipment modularization

**Flexibility**
- Applicable to smaller power grids
- Easy control to supplement renewable energy intermittency
- Ease to overcome siting constraints
- Suitable for wide application (desalination, process heat, hydrogen)

※ Reference
- 13th INPRO Dialogue Forum "Small Modular Reactors Update on International Technology Development Activities"
- OECD NEA 2021, "Small Modular Reactors: Challenges and Opportunities"

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# Major Design Requirements for i-SMR

## Design Requirements

### General

- Pressurized Water Reactor (PWR)
- Power output : ≤ 300 MWe / M

### Safety

- Core Damage Frequency (CDF) : ≤ 1.0 e-9 /M·Y
  Large Early Release Frequency (LERF)
  : ≤ 1.0 e-10/M·Y
- EPZ : within the site boundary
- Operator time to action : ≥ 72 hours
- Station Blackout (SBO) response time : ≥ 72 hours
- Fuel thermal margin : ≥ 15%
- Unfavorable Exposure Time (UET) : Zero
- Completely passive core/residual heat/containment cooling

### Economics

- Construction cost : ≤ $4,000/kWe
- LCOE : ≤ $65/MWh
- Construction time : First module for 24 months
  All modules for less than 42 months
- Module design for factory manufacturing
  and land transportation
- Plant availability factor : ≥ 95%
- Available to operate multiple modules in one MCR
- Can be operated with 3 or fewer operators
- Adopt non-safety classed electric system with
  equivalent QA, etc.

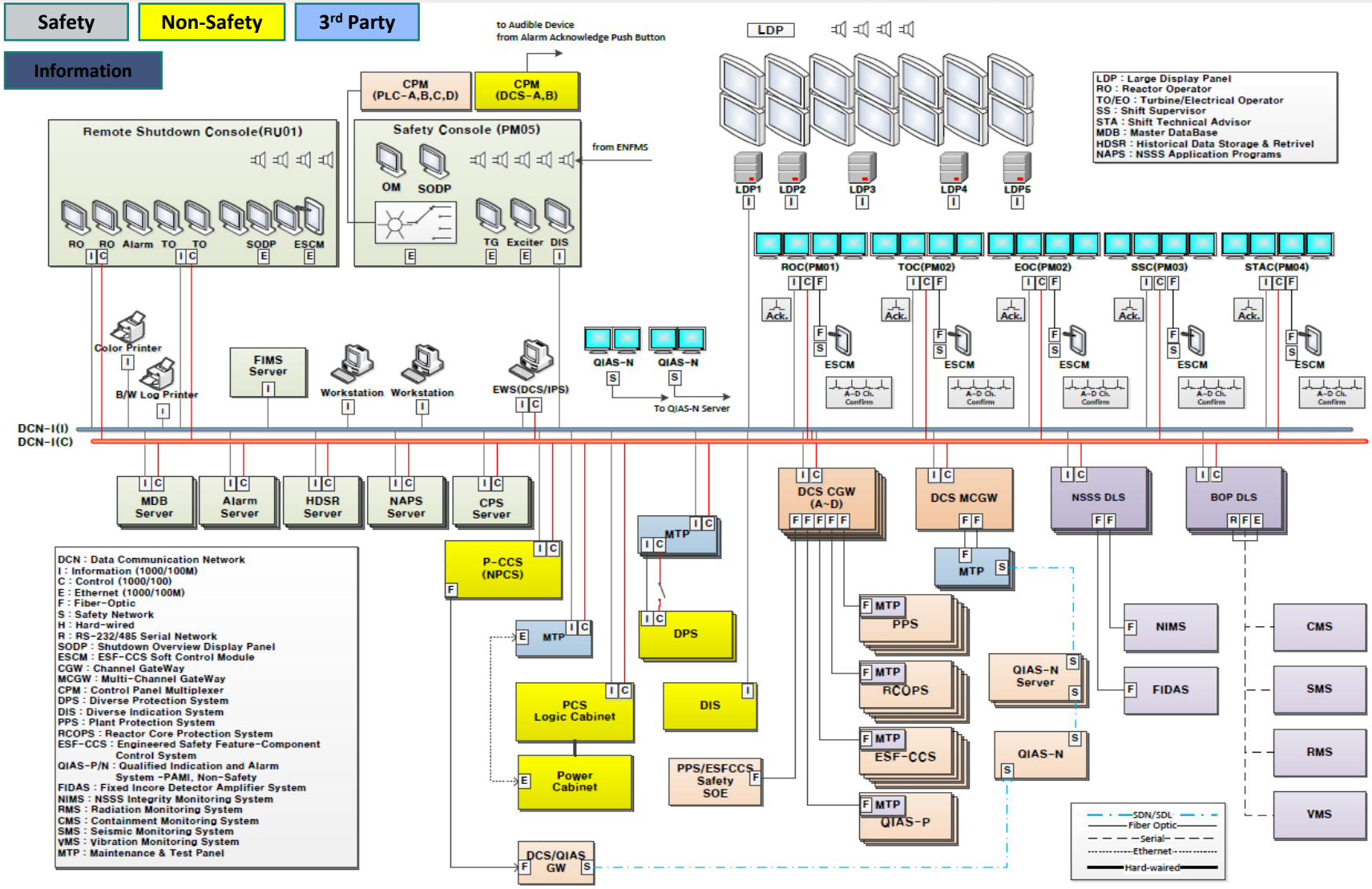
### Flexibility

- Boron free core
- Easy flexible operation
  (Daily load following, sudden output fluctuations, frequency control, etc.)
- Refueling cycle : ≥ 24 months

### Others

- Spent Fuel Pool capacity
  : Spent fuels for plant design life
- Decommissioning design consideration
- Design life : 80 years
- Site : site envelope, seismic design 0.5 g
- Cyber Security

# Large PWR MMIS Design

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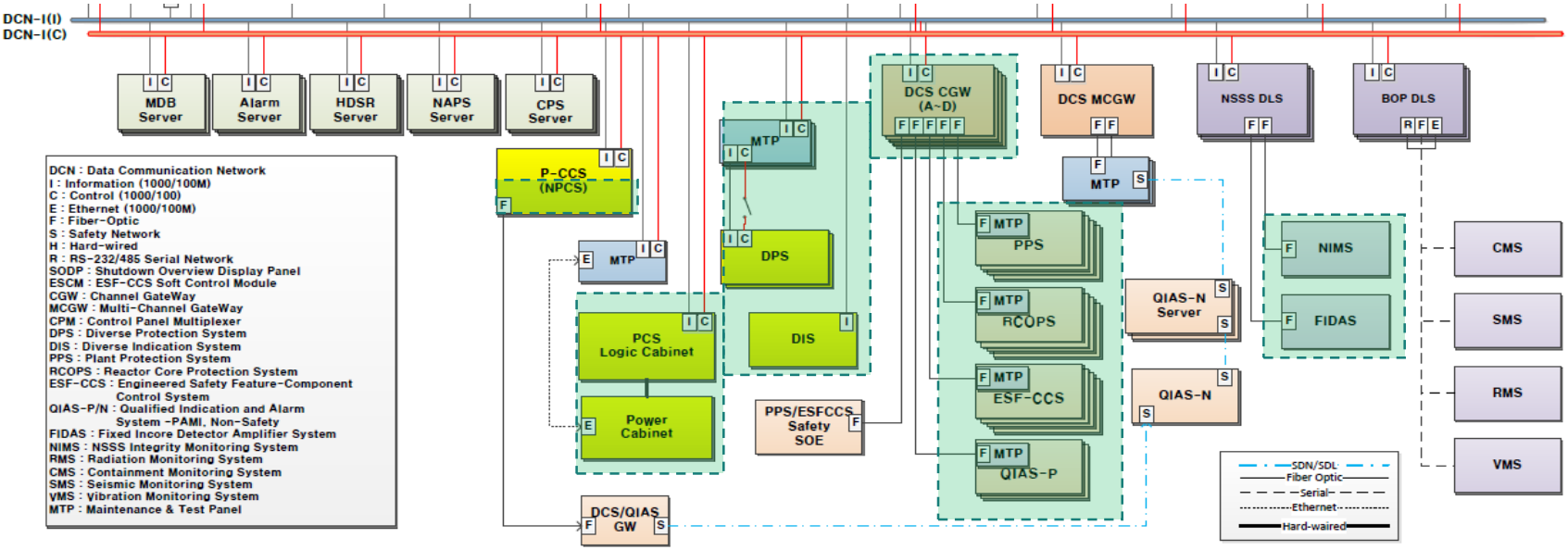
# Multi-Modules MMIS Design

## Module Level System X 4(Modules)

- Reactor Protection System
- ESF Control System
- Core Protection System
- Accident Monitoring System
- Diverse Protection System
- Diverse Indication System
- NSSS Process Control System
- Rod Control System
- ENFMS, In-Core Instrumentation System

## Plant Level System

- Habitability Protection System
- Component Control System
- Monitoring Systems
- Information System

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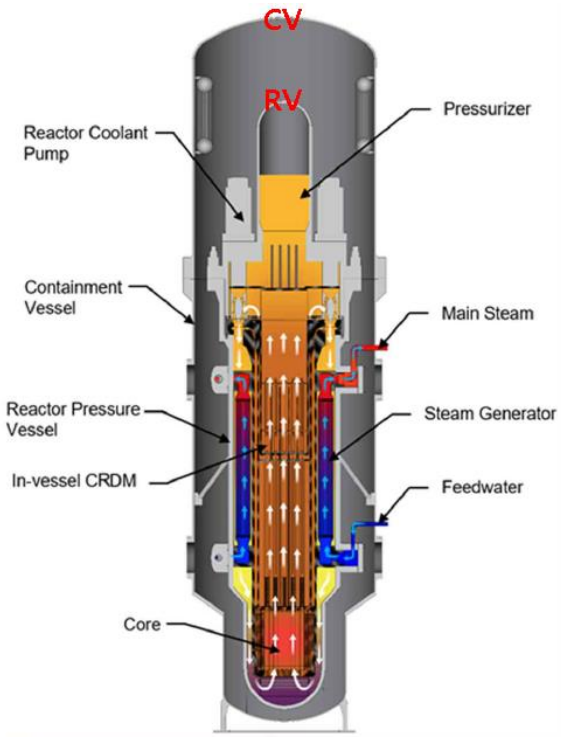
# 2 Key I&C Challenges for SMR

- Construction Cost Requirement Considerations:
  - Design simplification is critical to reduce installation cost and design overhead.
- Maintenance Cost Considerations:
  - To reduce long-term O&M cost, the I&C system should support:
    - Predictive Maintenance
    - Automated Surveillance Test
    - Minimized manual maintenance efforts
- SMRs are designed with a challenging safety goal of 1.0E-9/year CDF.
  - Therefore, the reliability of I&C systems must be extremely high.
- Harsh Environment
  - Instrumentation shall withstand extreme environments.
- Multi-Module Monitoring and Control
  - Multiple reactor modules should be monitored and controlled from a single main control room.

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# 1 Design Considerations for Protection System

## Design Consideration for i-SMR

- Design history of protection systems for large PWR plants
  - Analog RPS(Reactor Protection System)
  - Digital RPS + DPS(Diverse Protection System)

- Digital systems increase the number of equipment.
  - APR1400 : 12 cabinets for RPS, 3cabinets for DPS
    (Redundancy positively impacts system unavailability.)

- Unavailability of protection system affects Core Damage Frequency(CDF).

- Key I&C design considerations in SMR:
  - Reduce the number of components.
  - Minimize unavailability.

- Adoption of Internal diversity is recommended to SMR protection systems.
  - Key factor of unavailability is CCF factor.

- ESF system is automatically optimized for fully passive safety functions.
  (Control function is not included.)

## Regulatory Position

- SECY-93-087 contains four points on DI&C CCF Policy;

Point 1 – "...assess the defense-in-depth and diversity of the proposed I&C system to demonstrate that vulnerabilities to common mode failures have adequately been addressed."

Point 2 – "...analyze each postulated common-mode failure for each event that is evaluated in the accident analysis section of the safety analysis report(SAR) using best estimate methods... demonstrate adequate diversity within the design for each of these events."

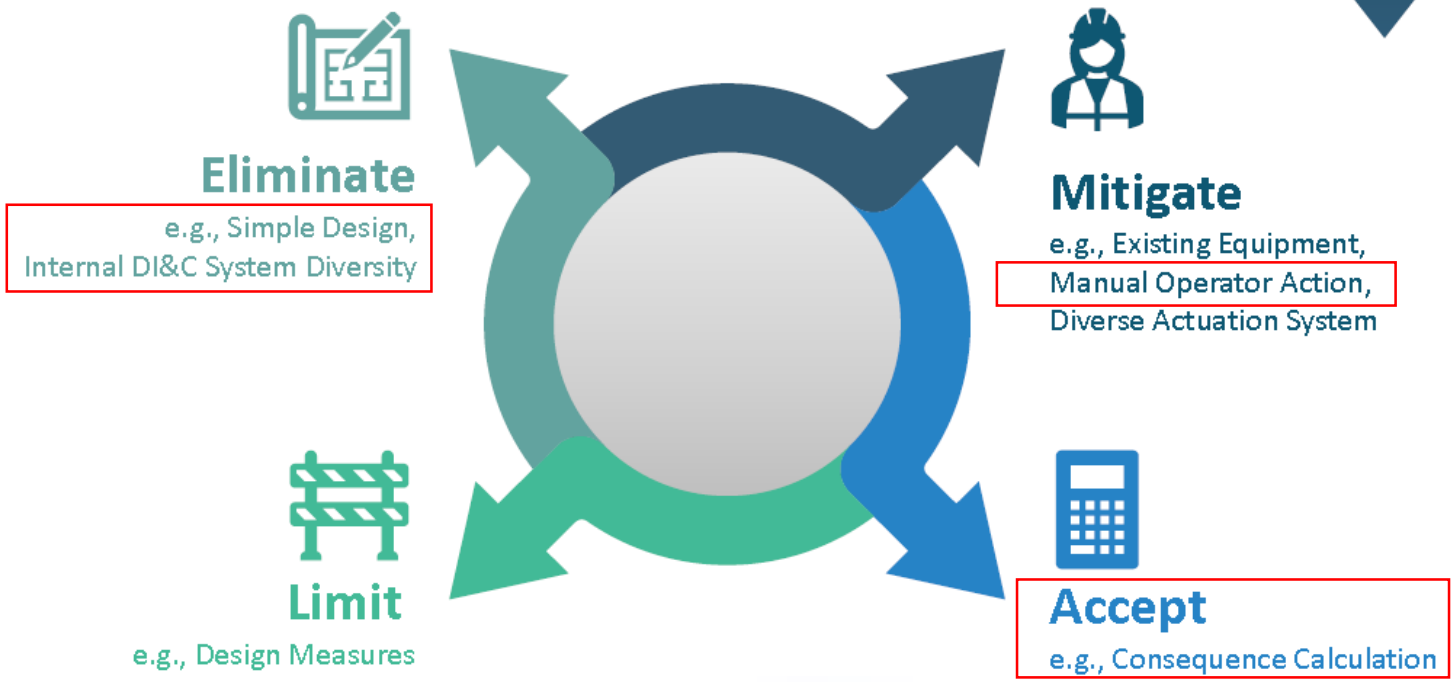
Point 3 – "...If a postulated common-mode failure could disable a safety function, then a diverse means... shall be required to perform either the same function or a different function."

Point 4 – "A set of displays and controls located in the main control room shall be provided for manual, system-level actuation of critical safety functions and monitoring of parameters that support the safety functions.."

## Regulatory Position

### Background - Current DI&C CCF Policy (contd.)

Methods used under the current policy to address DI&C CCF:




[NRC position]

## Regulatory Position - ATWS

- ATWS Rules
  - ATWS(AOO + Failure of Reactor Trip) safety goal : 1.0E-5/year
  - If Reactor Trip, AFWS, Turbine Trip are necessary, diversity is required from sensors to actuators

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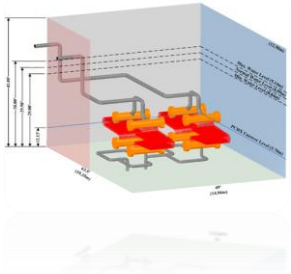
# 1 Design Considerations for Instrumentation

SMR has strength that conventional(large) NPPs doesn't have

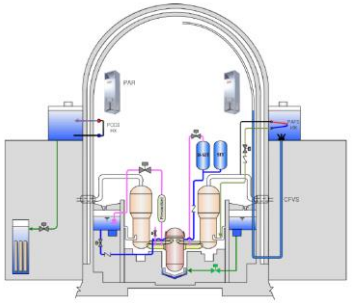
**Proven tech. from Large conventional PWR**

**APR1400 & APR+(1500MW, GenIII+ PWR)**

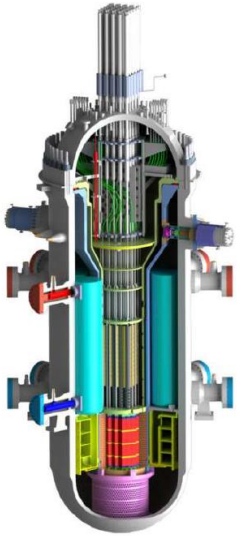
**Passive systems**



**iPOWER(1250MW, Passive PWR)**

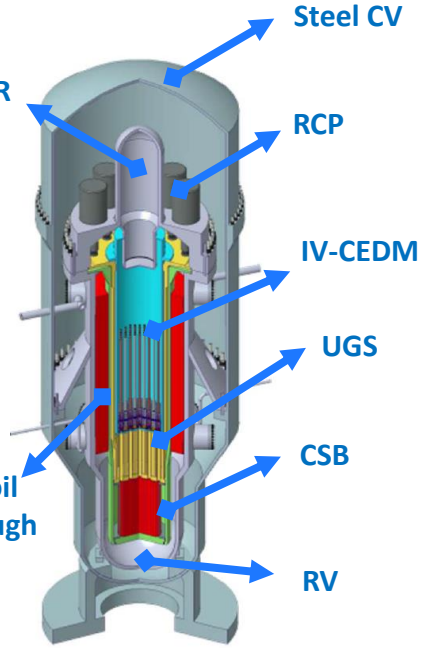


**SMART(100MW)**



**World's first standard design Approval SMR (2012)**

**i-SMR(170MW)**




**More Safe**
**More Economical**
**More Flexible**

- However, from the perspective of instrumentation system design, the condition are significantly more challenging.

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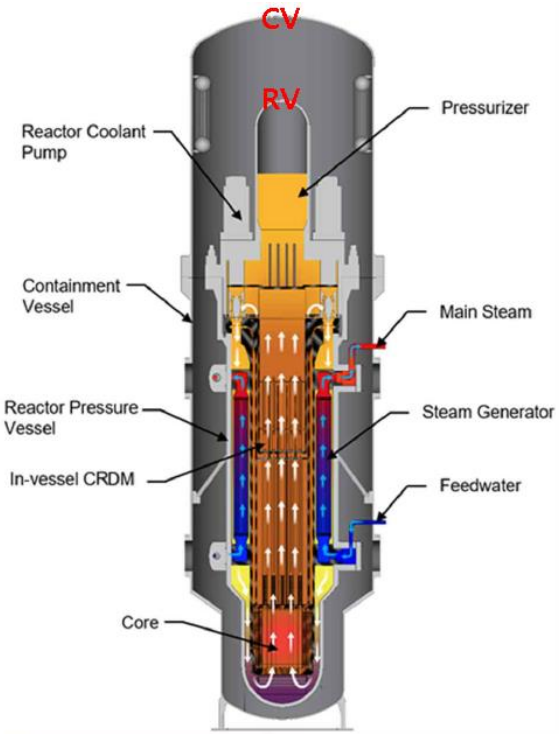
# 2 Design Considerations for Instrumentation

The type of instrumentation should be determined during the initial design phase.




- NSSS Process Instrumentation
  - RCS Pressure Sensor
  - RCS Level Sensor
  - RCS Flow
  - RCS Temperature Sensor
  - In-Core Instrumentation(Core Exit Temperature, Neutron Flux)
  - Ex-core Detector

- The NSSS process instrumentation should be addressed early in the reactor design stage, due to:
  - Extreme environmental conditions
  - Limited installation space
  - Challenges in installing taps or sensing lines
- The survivability under harsh conditions should be reviewed.
- Maintainability of instrumentation should also be evaluated.

# Design Considerations for Instrumentation

- Reactor trip and ESFAS variables should be reviewed early in the design stage. Coordination between safety analysis, I&C, fluid, and mechanical system design is essential.

- Instrument uncertainty may increase under harsh environmental conditions, and shall be reflected in safety limit margins.

- Low flow velocity may result in slow sensor response, which can affect system performance.

- If digital sensors are used, they shall be addressed in the I&C diversity and defense-in-depth analysis.
  If the results of the Common Cause Failure (CCF) coping analysis are not satisfactory, then sensor diversity should be considered in the design.

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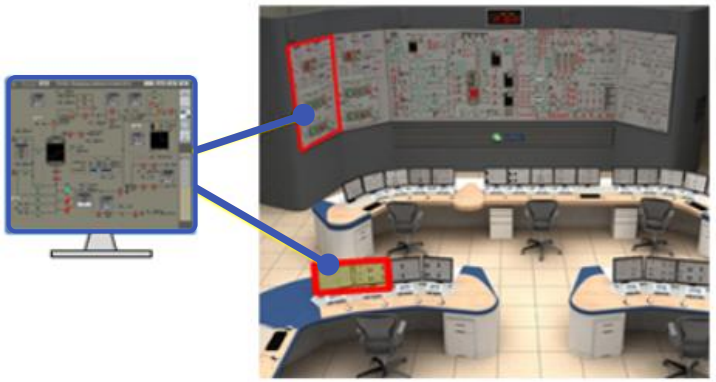
## Design Considerations for Human-System Interface

- Design considerations should address automation across multiple modules, new information systems, revised operating procedures, and any changes that affect human-system interaction.
- Alarm management in a multi-modules control room is more complex and presents significant human factors challenges.
- Operators monitor multiple modules, so the monitoring interface shall be simple and intuitive.
  - Strategies for post-accident and inadequate core cooling monitoring should be clearly defined.
- For staffing plan validation and human factors engineering (HFE) activities, a simulator should be developed early in the design process.

### Integrated Control Room for Multi-Modules

- Expanded operation automation including start-up, shutdown, power operating, etc.
- Integrated control room for multi-modules with minimized operators



# 2 Additional Design Considerations

- To ensure economic feasibility, automation of O&M activities is essential (e.g., automated testing, calibrations, etc.)
  - Over 70% of O&M costs are related to labor.

- Design should include features such as online monitoring to reduce maintenance workload(e.g., sensors for condition monitoring, fault diagnosis algorithms, etc.).

- Increased automation can also add to system complexity.
  → It is important to understand potential failure modes as part of the safety analysis.

- Early engagement with regulators is recommended.

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# 1 Summary and Remarks

- In SMR design, I&C presents significant challenges that must be addressed carefully.
- To ensure economic feasibility, the system should be as simple as possible, minimizing the number of components.
- NSSS instrumentation also faces unique challenges, requiring close collaboration with safety analysis, fluid, and mechanical design teams.
- Since multiple modules are monitored and controlled from a single main control room, comprehensive operator validation and HFE engineering activities are essential.
- Based on its experience in reactor design and digital MMIS development, KHNP is developing an MMIS that ensures both safety and economic feasibility.

# THINK SAFETY

**Thank you**

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