A Conservative Preliminary Analysis for Multi-Module PSA of SMRs Considering Dependencies of Shared Systems

23. July, 2026

KHNP Central Research Institute
Safety Assessment Group

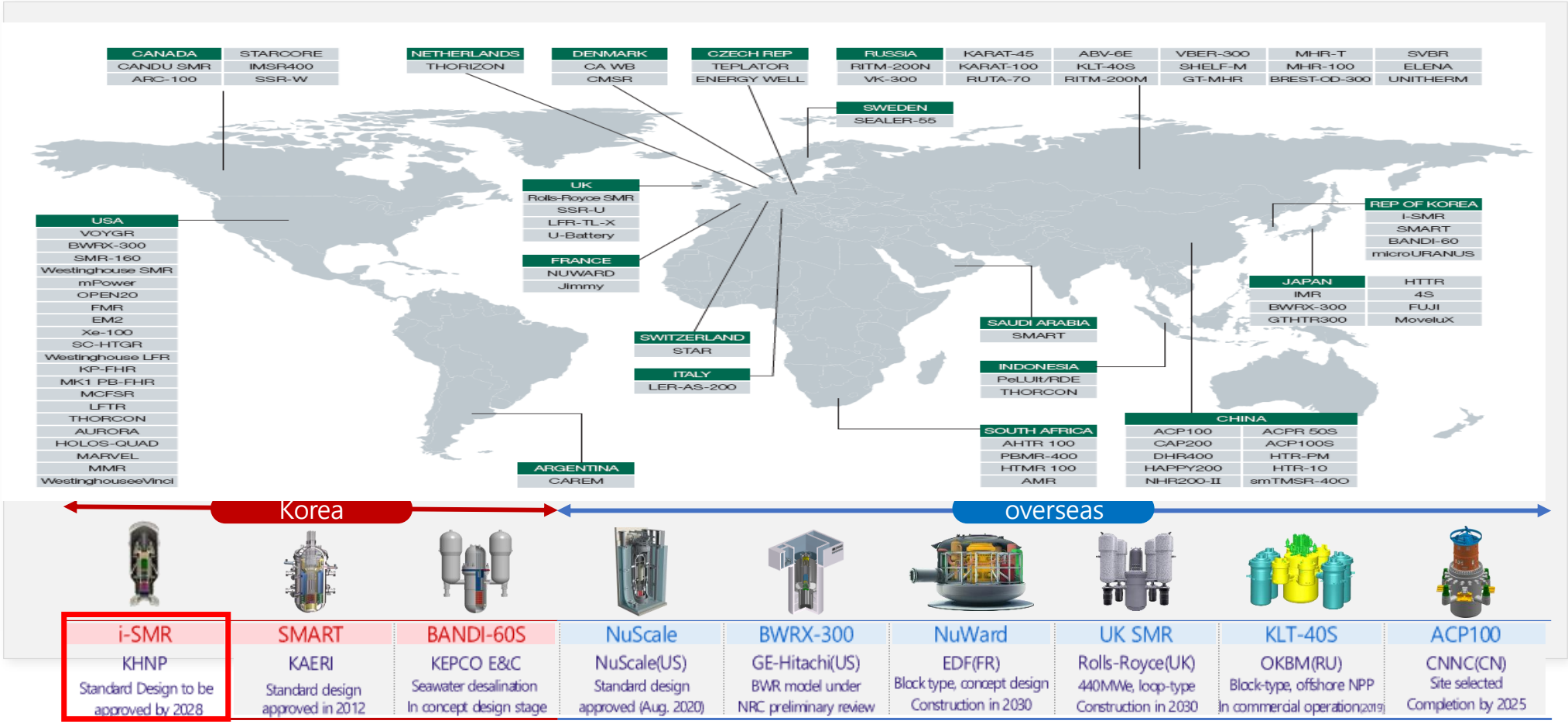
SEJIN BAEK

KOREA HYDRO & NUCLEAR POWER CO.,LTD

Contents

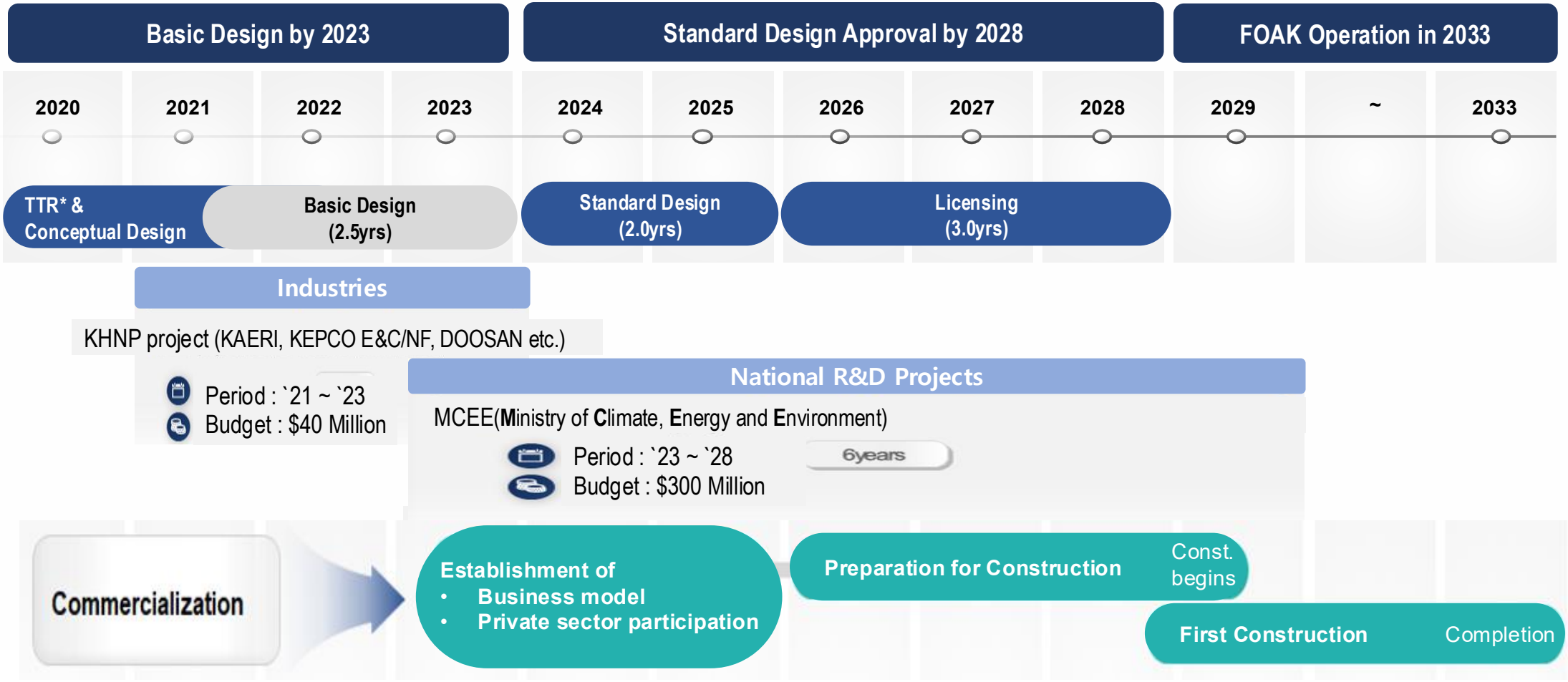
1. Introduction

- Over 80 types of SMRs under developed Worldwide
- Most SMR concepts adopt multi-module deployment strategies



1. Introduction (Korean i-SMR Development Status)

Target Goal: Standard Design Approval(SDA) by 2028, First Of A Kind(FOAK) Operation in 2033



➢ **After National BPLE** determined, detailed implementation plan will be fixed.**

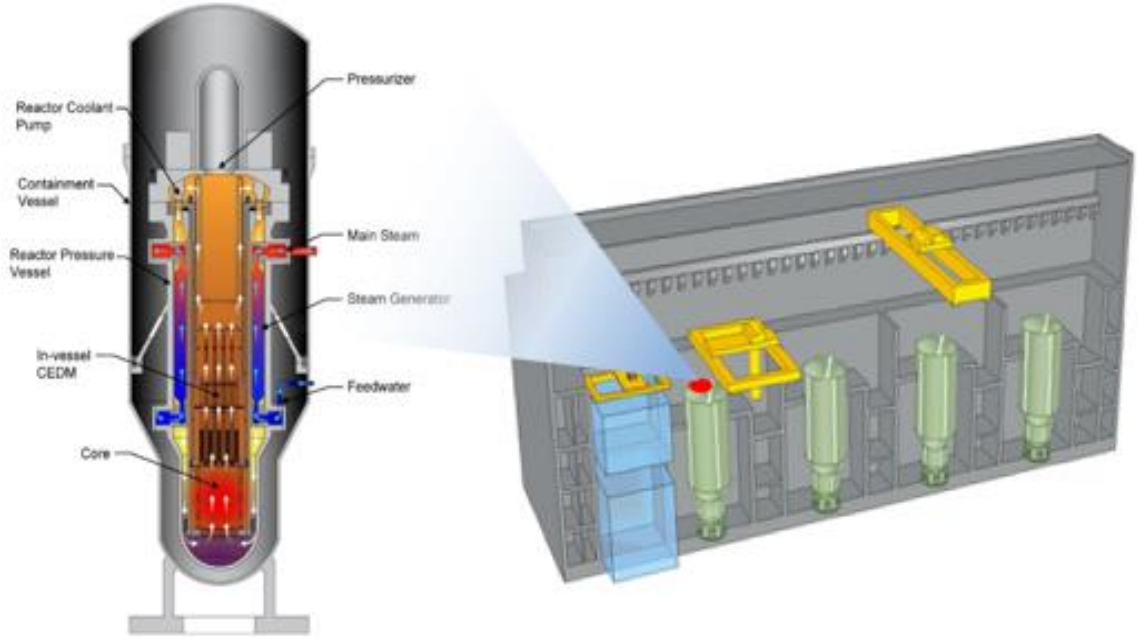
* TTR: Top-Tier Requirement

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

2. Objective

☑ A conservative Preliminary Analysis for Multi-Module PSA of SMRs Considering Dependencies of Shared Systems

- Conservative estimation of multi-module SMR PSA risk
  - Detailed multi-module SMR PSA modeling not performed
  - Using single module SMR PSA model results
  - Consideration of multi-module adjustment factors



3. i-SMR Design Characteristics

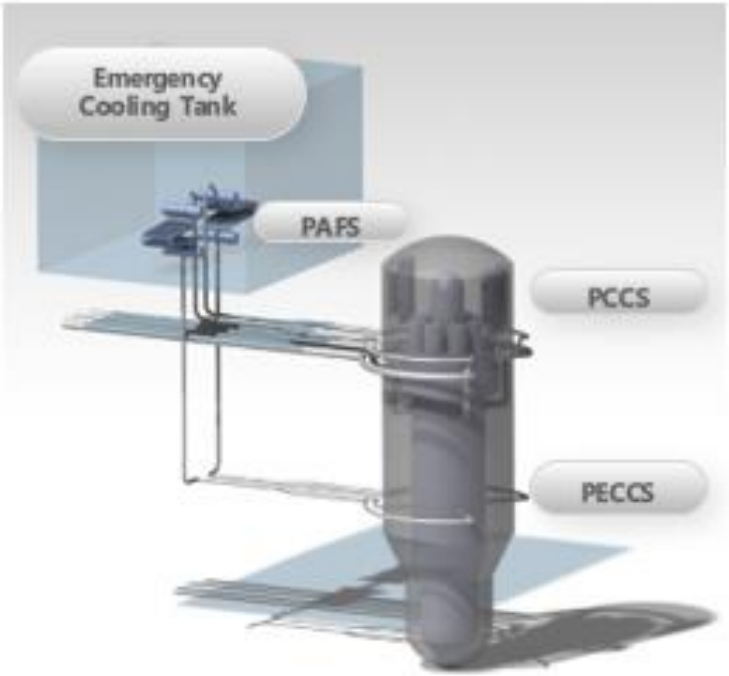
☑ General design characteristics and safety goal for i-SMR

General

- PWR (Pressurized Water Reactor)
- Power Output : 170 MWe/Module
- Site : Operational both along the coast and inland
- Design Life : 80 years

Safety

- CDF (Core Damage Frequency) : 1.0e-9/MY
- LERF (Large Early Release Frequency) : 1.0e-10/MY

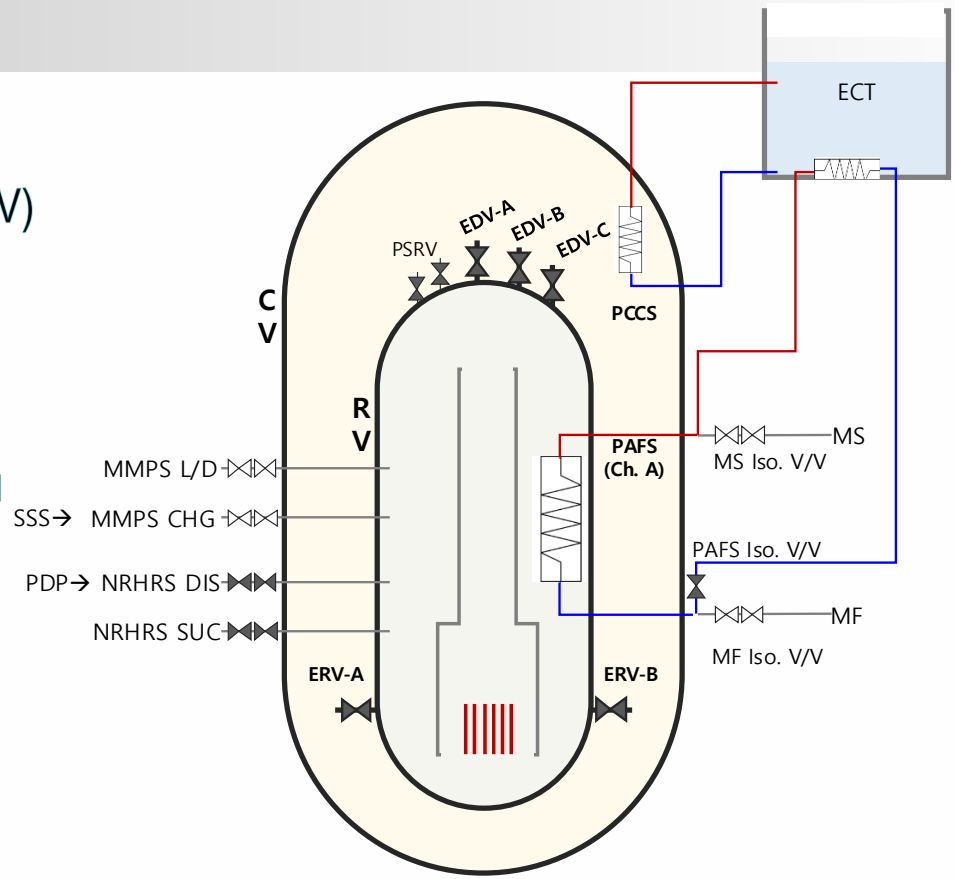


3. i-SMR Design Characteristics

☑ Safety Systems for i-SMR

- Safety Systems
  - PAFS (2 ECT, 4 PAFS HXs, PAFS Iso. V/V, MS/MF Iso. V/V)
    - Rx shutdown signal interlock operation
  - PECCS (3 EDV, 2 ERV)
    - RV low level signal
    - SOPM (Opens based on RV-CV differential pressure open) applied
  - PCCS (2 ECT, 2 PCCS HXs)
    - Operation at all times (No signal required)

- Non-Safety Systems
  - NRHRS W/ PDP
  - MMPS W/ SSS
  - Others (EPS, I&C, etc.)



- ECT: Emergency Cooling Tank
- EDV: Emergency Depressurization Valve
- EPS: Electrical Power System
- ERV: Emergency Recirculation Valve
- MMPS: Modular Makeup and Purification System
- NRHRS: Normal Residual Heat Removal System
- PAFS: Passive Auxiliary Feedwater System
- PCCS: Passive Containment Cooling System
- PDP: Positive Displacement Pump
- PECCS: Passive Emergency Core Cooling System
- PSRV: Pressurizer Safety Relief Valve
- SOPM: Spurious Operation Prevention Module
- SSS: Secondary Shutdown System

3. i-SMR Design Characteristics

☑ Initiating Events for i-SMR

	Initiating Event	Description	Identifier
1	Loss of Coolant Accident Inside Containment Vessel	A conservative 2-inch break in the MMPS charging or discharge line inside the containment isolation valve.	LOCA-IC
2	Loss of Coolant Accident Outside Containment Vessel	A conservative 2-inch break in the MMPS charging or discharge line outside the containment isolation valve.	LOCA-OC
3	Inadvertent Opening of PSRV	Inadvertent opening and failure to reclose (stuck-open) of the Pressurizer Safety Relief Valve (PSRV).	LOCA-PSRV
4	Steam Generator Tube Rupture	One or more steam generator tube ruptures exceeding the makeup capability of the MMPS charging pump.	LOCA-SGTR
5	Interfacing System LOCA	Failure of the isolation valve in the NRHRS charging/discharge line, allowing high-pressure coolant to enter the low-pressure system.	ISLOCA
6	Large Secondary-Side Break Inside Containment Vessel	Large steam line or feedwater line break inside containment.	LSSB-IC
7	Large Secondary-Side Break Outside Containment Vessel	Large steam line or feedwater line break outside containment.	LSSB-OC
8	Loss of Component Cooling Water	Reactor trip caused by failure of supporting cooling systems such as the Component Cooling Water System or Equipment Water System.	LOCCW
9	Loss of Main Feedwater	Complete loss of main feedwater due to failure of all feedwater pumps, condensate pumps, or associated valves.	LOMF
10	Loss of 125 VDC Train A	Loss of 125 VDC Train A/B leading to automatic actuation of safety systems and reactor trip.	LODC-A
11	Loss of 125 VDC Train B	Same accident sequence as Train A.	LODC-B
12	Loss of 125 VDC Train C	Loss of 125 VDC Train C/D leading to automatic actuation of safety systems and reactor trip.	LODC-C
13	Loss of 125 VDC Train D	Same accident sequence as Train C.	LODC-D
14	Loss of 6.9-kV AC Bus 02M	Loss of AC Bus 02M resulting in reactor coolant pump trip and reactor trip.	LOKV-CB-02M
15	Loss of 6.9-kV AC Bus 02N	Same accident sequence as Bus 02M.	LOKV-CB-02N
16	Single-Module Loss of Offsite Power	Loss of offsite power affecting a single module.	LOOP-P
17	Plant-Wide Loss of Offsite Power	Loss of offsite power affecting all modules.	LOOP-T
18	Anticipated Transient Without Scram (ATWS)	Reactor trip failure following an initiating event.	ATWS
19	General Transient	General transients resulting in automatic or manual reactor trip.	GTRN

4. Methodology

How to?

Single Module PSA

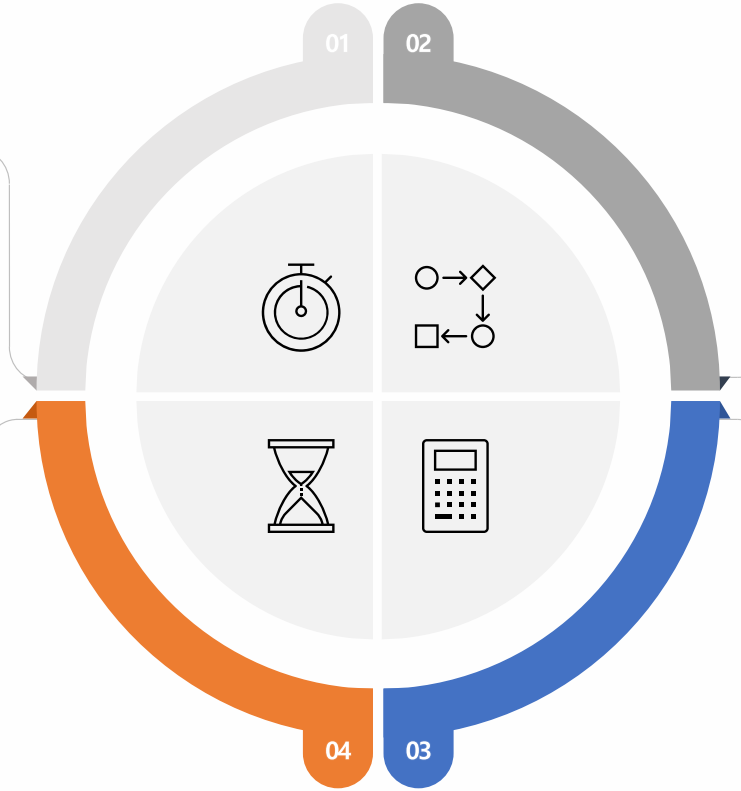
1

- Development of i-SMR single module PSA model
- AIMS-PSA tool (Q Engine: FTREX)

Identify Shared Systems

2

- List up shared systems
- 2 or All Modules Shared



Multi-Module Risk Estimation

4

- Recalculate the single module PSA model by reflecting adjustment factors

Assumptions

3

- Initiating Events
- Operator Actions
- CCFs(Common Cause Failures)
- Distribute Adjustment Factors

4. Methodology

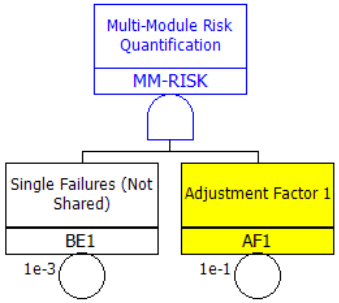
☑ Assumptions for Conservative Preliminary Analysis for MM-PSA

1. Using single module internal event level 1 PSA model results
2. Excluding seismic events
3. Affects 2 or all modules when CCF occurs in a shared system
4. Failure of operator action(HFE) affects all modules

Shared Systems	Number of shared modules
NRHRS	2
CCW, ESW	4
EPS	4
Integrated MCR	4

Multi-Module Risk Quantification

- Multi-module risk estimation
  - Basic Events(single module base) * Adjustment factors
    → Quantify



Multi-module adjustment factors

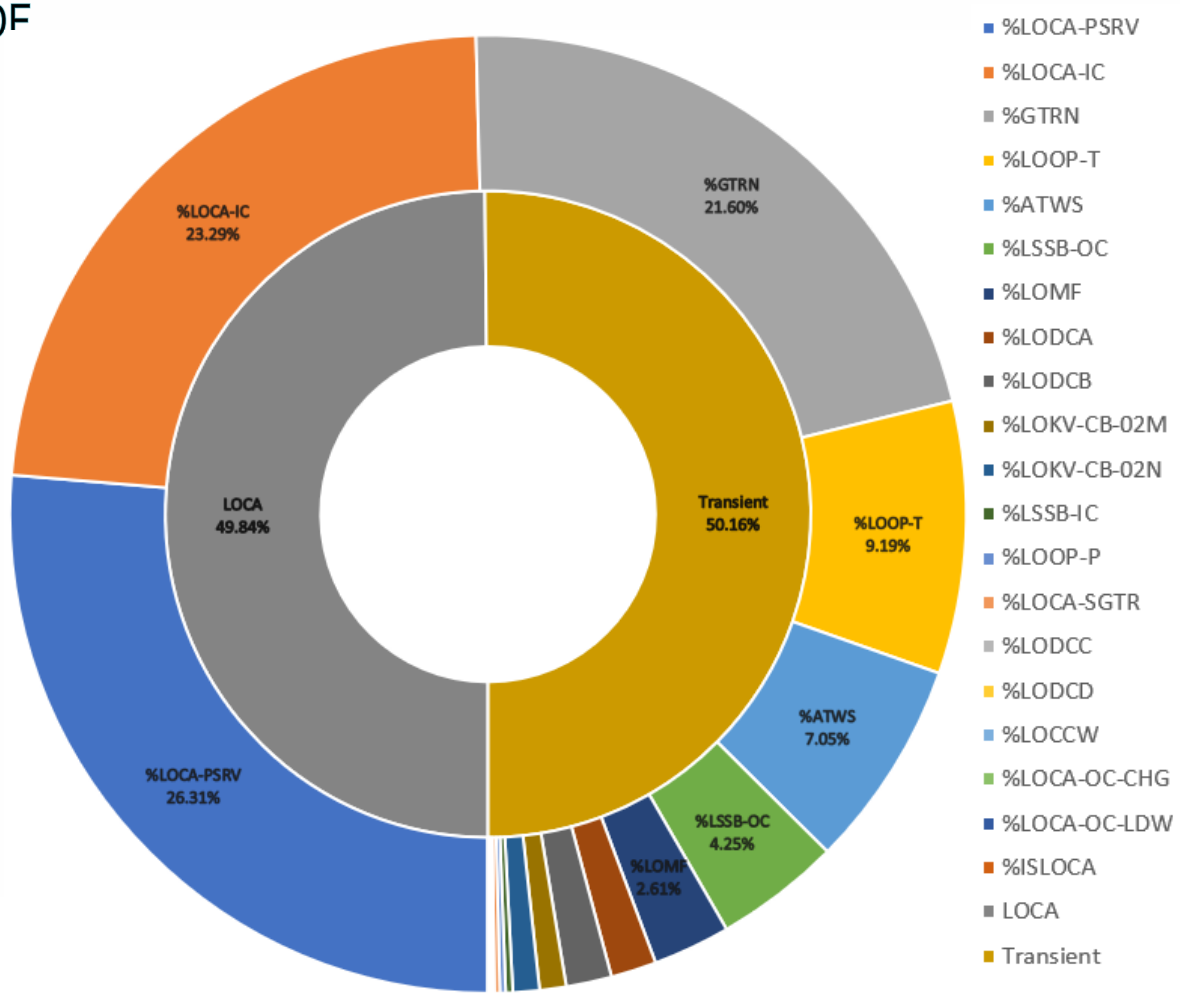
Classification	Description	Adjustment Factor	Application Example
Initiating Event	Loss of RCS inventory, LOCA or pipe break	0.01	LOCA-IC/OC
	Loss of RCS inventory, not from pipe break	0.1	LOCA-PSRV
	CCF Initiating event	0.5	LODC
	Site wide event	1.0	LOOP
	General Reactor Trip	0.1	GTRN
Basic Event	(Not shared) Single failures / CCF	0.1 / 0.3	Independent Systems
	(Shared) Single failures / CCF	1.0 / 1.0	Shared Systems
	Human failures	3	All HFE

5. Results

Multi-module CDF mean value by internal event:

- ✓ Approximately **2%** of a single module CDF
- ✓ LOCA: 49.84% / Transient: 50.16%

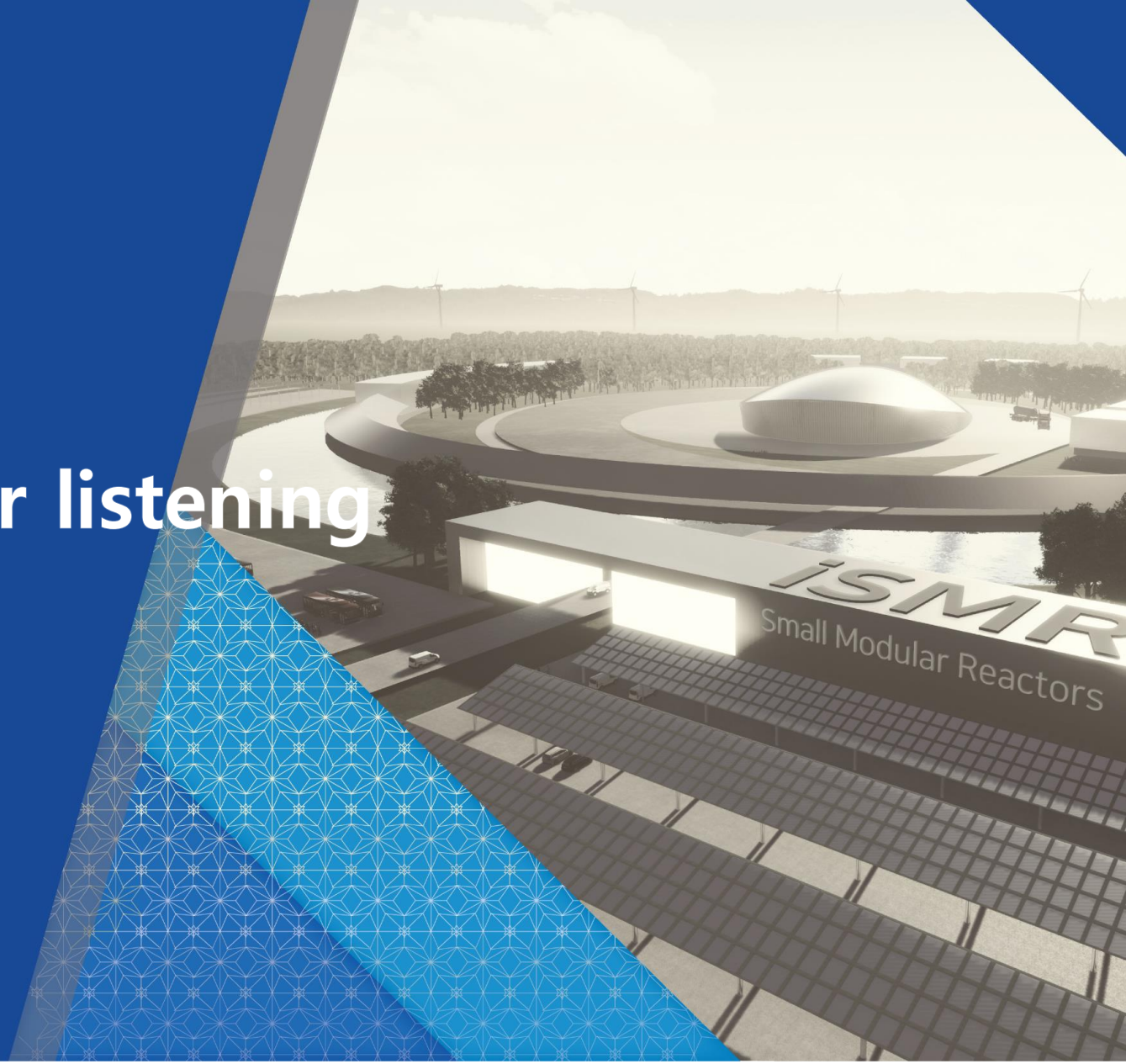
Initiating Event	Proportion[%]
%LOCA-PSRV	26.31%
%LOCA-IC	23.29%
%GTRN	21.60%
%LOOP-T	9.19%
%ATWS	7.05%
%LSSB-OC	4.25%
%LOMF	2.61%
%LODCA	1.54%
%LODCB	1.54%
%LOKV-CB-02M	0.90%
%LOKV-CB-02N	0.90%
%LSSB-IC	0.24%
%LOOP-P	0.19%
%LOCA-SGTR	0.19%
%LODCC	0.06%
%LODCD	0.06%
%LOCCW	0.04%
%LOCA-OC-CHG	0.03%
%LOCA-OC-LDW	0.03%
%ISLOCA	0.00%



6. Conclusions

- Multi-module risk is significantly lower than risk from a single module
  - ✓ The likelihood of multiple modules being damaged simultaneously is very low.
  - ✓ Potential multi-module events are mitigated by safety systems that are functionally independent of shared systems and other modules.

Thank You for your listening



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