Development of PIRT of Thermal-Hydraulic Phenomena for SMART100-DECs to Implement T-H Model and Validation Items in SPACE

AGENDA
PRESENTATION

1. Introduction (PIRT - SPACE - SMART100 - Objectives)
2. Methodology (7 Steps)
3. Results & Discussion (Part1 - Part2)
4. Conclusion

Introduction

- **PIRT** is used:
  - To identify the key phenomena associated with the intended application.
  - To rank the relative importance and current state of knowledge for each identified phenomenon.
    - This ranking provides guidance of code development and improvement for the specific simulation of the plant behaviors.
    - This PIRT has been achieved by experts in the related field.

- **SPACE** (Safety and Performance Analysis CodE for nuclear power plants):
  - Firstly, it has been developed for the safety analysis of operating PWRs and the design of advanced water reactors.
  - Secondly, it adopts advanced physical modeling of two-phase flows, mainly two-fluid three-field models that consists of gas, liquid, and droplet fields.
  - Thirdly, Nuclear Safety and Security Commission (NSSC) approved the use of the SPACE for licensing applications of Korean PWRs in 2017.
  - Finally, it has been improved continuously to extend its application for the Design Extension Conditions (DECs).

Introduction

❖ **SMART100** (System Integrated Modular Advanced Reactor):

- It was upgraded from the standard design of SMART and developed by Korean Atomic Energy Institute (KAERI).
- It adopts a helically coiled steam generator, and internal pressurizer inside the Reactor Pressure Vessel (RPV).
- It has fully Passive Safety Systems (PSSs)
    - Passive Safety Injection System (PSIS)
    - Passive Residual Heat Removal System (PRHRS)
    - Automatic Depressurization System (ADS).

❖ **Objectives** are to:

- Develop and generate the PIRT of important T-H phenomena for expected DECs of SMART100.
- Implement T-H models and validation items in SPACE for the reference reactor and scenarios.

Methodology

❖ **Step 1** (Review, Verify, and Identify the Plant Design Data and Characteristics)

- The basic design of SMART100 is to provide core cooling capability during all Design-Basis-Accidents (DBAs) without additional operational actions for at least 72 hours
- Has new passive safety featured components and systems:

4-trains

PSIS (CMT - SIT)

Connected to RPV, provides heat removal from the core without AC power or operator action and supplies borated water into the RCS to prevent core uncover.

4-trains

PRHRS (ECT - HX - MT)

Connected to the secondary system and removes the RCS heat by natural circulation

2-trains

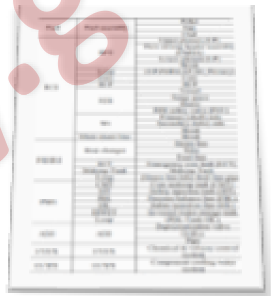
ADS

Connected to the upper part of the reactor closure head and rapidly depressurizes the RCS

Methodology

❖ **Step 2** (Define Important High-Level Systems and Components)

- Was useful to partition SMART100 into high-level systems, subsystems, and components to identify the influence on the main phenomena/processes.
- Was divided to 8 main systems:
  - Fuel-RCS-PSIS-PRHRS-ADS-CVCS-CCWS-Containment



TABLE

❖ **Step 3** (Derive Key Accident and Scenarios)

- Was required to identify the DEC scenarios for SMART100
- Thirteen DECs scenarios are initially considered. And the most appropriate five scenarios for SMART100-DECs were selected for PIRT development are:

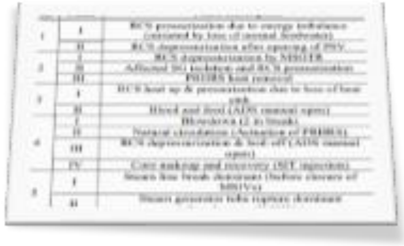
❖ **Step 4** (Define the Primary Evaluation Criteria)

- Based on regulatory safety requirements, Figure of Merits (FoMs) was used as primary evaluation criteria to judge the relative importance of phenomena/process in key accident scenarios for SMART100-DECs.
- Selected FoMs for each key accident of SMART100-DECs, that have been determined by expert panel are:
  - RCS Pressure
  - Core Mixture Level
  - Radioactive Discharge
  - Peak Clad Temperature (PCT)

No.	Accident	FoMs
1	ATWS	RCS pressure
2	MSGTR	Radioactive discharge
3	TLOFW	Core mixture level
4	Loss of safety injection/recirculation concurrent with SBLOCA	Core mixture level, PCT
5	MSLB+SGTR	Radioactive discharge

❖ **Step 5** (Partition Scenario into Convenient Time Phases)

- The selected scenarios have been divided into time phases according to the dominant T-H phenomena/process. "Generated Table"



TABLE

Methodology

❖ **Step 6** (Identify Plausible Phenomena/Processes by Phase and Component)

- Experts who have extensive experience and knowledge in the design and safety analysis of nuclear power reactors and in thermal-hydraulics discussed all the anticipated phenomena and processes for each scenario. "Results & Discussion Part"

❖ **Step 7** (Rank importance and Knowledge Levels)

- Last step was to rank the **Importance Level** and **Knowledge Level** of each phenomenon/process in the key accidents for SMART100-DECs.
  - **Importance Level** of a phenomenon/process was regarding to the FoMs, used scale of low, medium or high
  - **Knowledge level** of a phenomenon/process used same scale with different description

TABLES

❖ PART 1

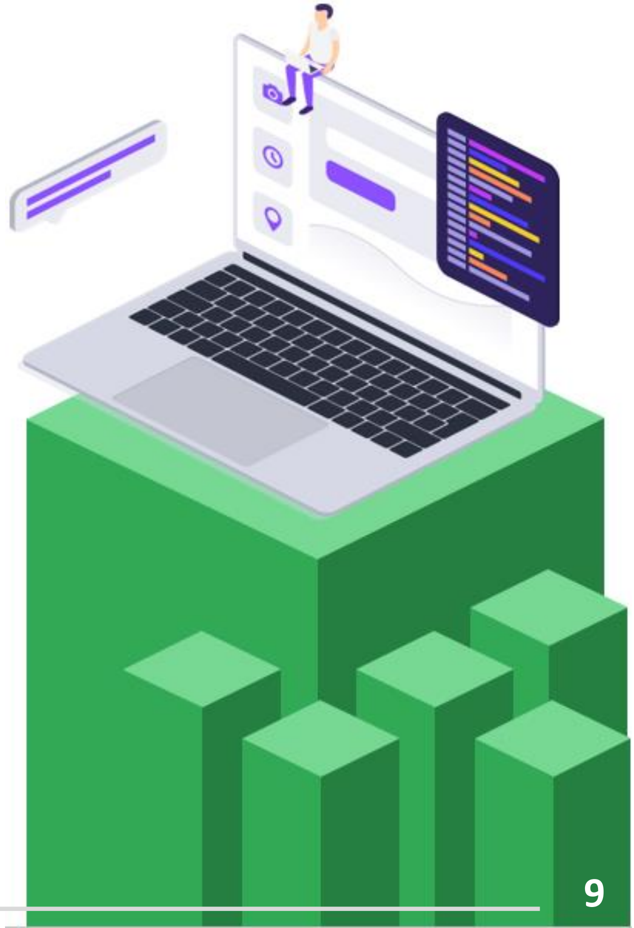
T-H Model and Validation Items in SPACE

I. Improvement in PSIS tanks components models

- Based on the design of SMART100, the water inventory of primary side is maintained by CMT or SIT injection flow and it is determined by hydraulic condition in the tank. Thus, the estimation of thermal-hydraulic condition on the CMT or SIT is important. **Therefore, the validation of component model for the CMT and SIT of SMART100 is required.**

II. Validation of boron transport model

- Boron reactivity is important in long term shutdown reactivity. The boron from CMT and SIT reaches the core by boron transport. The SPACE code has models to calculate boron transport and was review in terms of governing equation and discretization scheme. **Further review of boron transport using code to code comparison with RELAP5 may be carried out.**



❖ PART 1

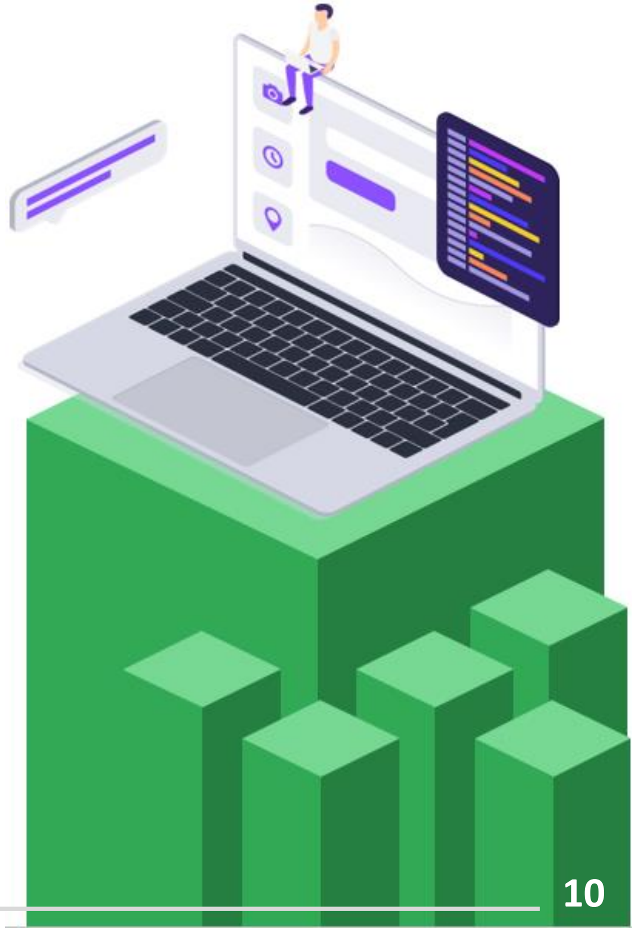
T-H Model and Validation Items in SPACE

III. Component model for helically coiled tubes and break of the SG

- SMART100 adopts helically coiled tubes inside of SG built in the reactor vessel. Since the estimation of heat transfer at intact tubes and break flow at ruptured tubes has significant impact in this analysis, **the proper component model for helically coiled tubes which has more complex geometry than the SG tubes of conventional PWR is needed.**

IV. Validation of the component model for the PRHRS

- PRHRS consists of heat exchanger for heat transfer between secondary side and ECT as a heat sink. Since ECT water level has an effects on the heat transfer capability of PRHRS, estimation of ECT water level is important. **Thus, the validation of component model for the PRHRS of SMART100 is required.**



Results & Discussion

❖ PART 1

T-H Model and Validation Items in SPACE

V. Addition to Decay Heat Model

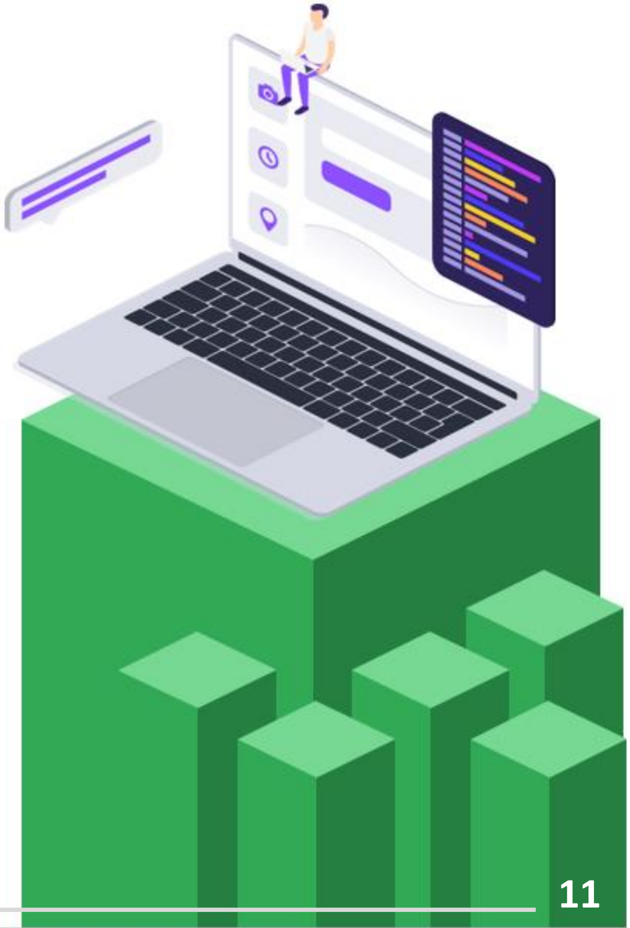
- SPACE code supports the four decay heat standards such as ANS-5.1-1973, 1979, 1994, and 2005 at present. **Decay heat model based on ANS-5.1-2014 is expected to be added to SPACE to calculate the decay power more precisely**

❖ PART 2

PIRT of importance T-H phenomena for expected DECs of SMART100

- The results of PIRT development of importance ranking for the selected key accidents were summarized in following table, and it can be used to improve and evaluate the capability of the SPACE for the SMART100-DECs.

PIRT TABLE



Conclusion

❖ Firstly

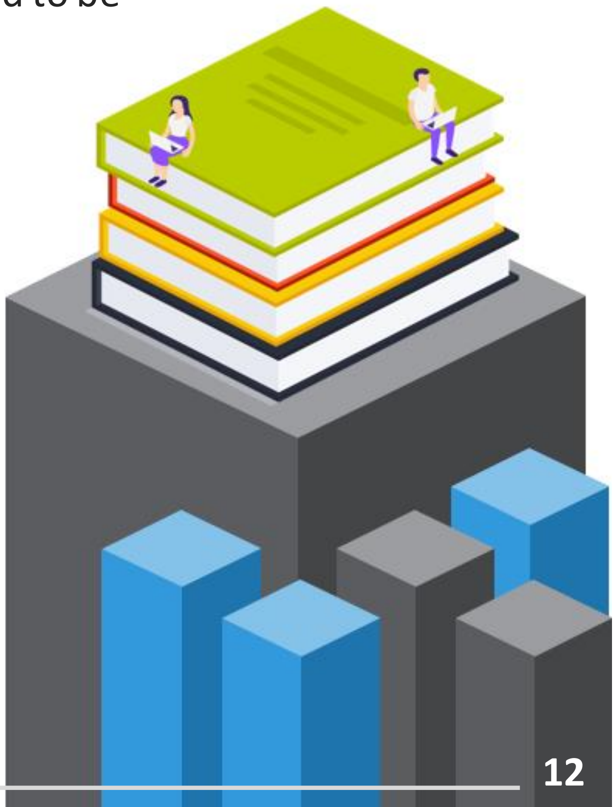
- The PIRT for SMART100-DECs was developed and generated with identifications of the expected T-H phenomena during the transients and accident conditions of the key scenarios.

❖ Secondly

- T-H models and validation items for reference reactor and accidents scenarios have been derived to be implemented in SPACE

❖ Finally

- This work have been done by experts from seven different entities (K.A.CARE, KAERI, FNC, KEPCO NF, KEPCO E&C, PNU and KHNP) who have extensive experience and knowledge in the design and safety analysis of nuclear power reactors and Thermal-hydraulics.



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System	Subsystem	Component
Fuel	Fuel assembly	Pellet
		Gap
		Clad
RCS	RPV	Upper plenum (UP)
		Flow mixing header assembly (FMHA)
		Lower plenum (LP)
		Break
	Loop	(UP,FMHA,LP,SG_Primary)
	Core	Core
	RCP	RCP
	PZR	Vessel
		Surge space
		Heater
		PZR safety valve (PSV)
	SG	Primary (shell) side
		Secondary (tube) side
		Break
	Main steam line	Break
PRHRS	Heat changer	Steam line
		Tube
		Feed line
	ECT	Emergency core tank (ECT)
	Makeup Tank	Makeup Tank
	Loop	(Steam line-tube-feed line-pipe)
PSIS	CMT	Core makeup tank (CMT)
	SIT	Safety injection tank (SIT)
	PBL	Pressure balance line (PBL)
	SIL	Safety injection line (SIL)
	IRWST	In-vessel water storage tank
	Loop	(PBL-Tank-SIL)
ADS	ADS	Depressurization valve
		Orifice
		Pipe
CVCS	CVCS	Chemical & volume control system
CCWS	CCWS	Component cooling water system
Containment	LCA	Lower containment area (LCA)

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No.	Phase	Phase Description
1	I	RCS pressurization due to energy imbalance (initiated by loss of normal feedwater)
	II	RCS depressurization after opening of PSV
2	I	RCS depressurization by MSGTR
	II	Affected SG isolation and RCS pressurization
	III	PRHRS heat removal
3	I	RCS heat up & pressurization due to loss of heat sink
	II	Bleed and feed (ADS manual open)
4	I	Blowdown (2 in break)
	II	Natural circulation (Actuation of PRHRS)
	III	RCS depressurization & boil-off (ADS manual open)
	IV	Core makeup and recovery (SIT injection)
5	I	Steam line break dominant (before closure of MSIVs)
	II	Steam generator tube rupture dominant (after closure of MSIVs)

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○ Importance Level

Rank	Description
High	Phenomenon has dominant impact on the FoMs
	Phenomenon should be explicitly and accurately modeled
	Uncertainty should be individually determined and then combined statistically with other uncertainty sources
Middle	Phenomenon has moderate influence on the FoMs.
	Phenomenon should be well modeled; accuracy maybe somewhat compromised
Low	Phenomenon has small effect on the FoMs.
	Phenomena should be represented in the code, but almost any model will be sufficient.
	Combined uncertainty of phenomena may be determined in a bounding fashion or maybe eliminated when justified.

○ Knowledge level

Rank	Description
High	Fully known with small uncertainty
Middle	Partially known with high uncertainty
Low	Very limited knowledge with very high uncertainty

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System	Process/Phenomena	SMART100 DECs and Phases														
		ATWS		MSGTR			TLOWF		SBLOCA + Loss of SI				MSLB + SGTR	
		I	II	I	II	III	I	II	I	II	III	IV	I	II
Fuel	Fission power	H	H	H	L	L	H		L	L	L	L		
	Decay power	L	L	L	H	H	H	H	M	H	H	M	M	H
	Reactivity feedback (MTC)	H	H	M	L	L	L		L	L	L	L	H	M
	Reactivity feedback (FTC)	M	L	M	L	L			L	L	L	L	M	L
	Reactivity feedback (Boron)	L	H										M	M
	Shutdown worth								L	L	L	L	H	H
	Local power peaking								L	H	L	L		
	Gap conductance								L	M	L	L		
	Cladding deformation								L	M	L	L		
RCS	Discharge (Critical) flow (break at RPV)								H	H	H	H		
	Natural circulation	L	L				L	L	L	L	M	L		
	Boron transport	L	H											
	Wall heat transfer (covered)	L	L	H	L	L	L	L	L	L	L	L	H	L
	Wall heat transfer (Uncovered core)	L	L				L	H	L	H	M	L		
	Asymmetric power distribution								L	L	L	L	M	L
	Asymmetric flow distribution								L	M	M	L	L	L
	Interfacial friction		L				L	M						
	flow resistance			L	L	M			L	L	L	L		
	Pump performance (single/two-phase)	L	L	M	M	L	L	L	M	L	L	L	M	L
	Coast down of RCP					L	L	L	M	L	L	L		L
	Flashing			M	L	L			L	L	L	L		
	Level swelling	H	H				H	M	L	L	L	L	M	L
	CCFL (surge space)							M	L	L	L	L		
	Discharge (Critical) flow (at PSV)		H				H		L	L	L	L		
	Heat transfer to secondary side at SG	L	L	H	H	H	L	L	L	M	M	L		
	Direct condensation at SG primary side						L	M	L	L	L	L		
	Water mixture level change at SG	L	L	L	L	L	L	M	L	L	L	L		
	Flow resistance at SG (primary side)			L	L	M			L	L	L	L		
	Wall heat transfer at SG (secondary side)	L	L	H	H	H	L	L	L	M	M	L	H	L
	Flashing at SG (secondary side)								L	L	L	L	M	L
	Discharge (Critical) flow at SG break			H	H	L							H	L
	Discharge (Critical) flow at MSL break												H	
PRHRS	Hx steam line flow resistance				M	M			L	L	L	L		
	Hx tube wall heat transfer (condensation)	M	H						L	M	M	L	H	M
	Hx tube flow resistance				M	M			L	L	L	L		
	Hx feed line flow resistance				M	M								
	ECT pool circulation (3D effect)								L	M	M	M		
	ECT heat transfer (convective/ boiling)	L	M		L	L			L	M	L/M	L/M	L	L
	Loop natural circulation	M	H						L	M	M	L	H	M
PSIS	CMT Injection flow (mixture level change)	L	L				H	H	L	L	L	L	L	M
	CMT Boron injection	L	H						L	L	L	L	M	M
	CMT Direct condensation						L	M	L	L	L	L		
	CMT Wall heat transfer (condensation)						L	M	L	L	L	L		
	CMT Thermal stratification						L	M	L	L	L	L		
	SIT Injection flow (mixture level change)		L			M		M			H	H		
	SIT Boron injection		L								L	L		L
	SIT Direct condensation w/air		L			L		L			M	L		
	SIT Wall heat transfer		L			L		L			M	M		
	SIT Thermal stratification		L			L		L			M	L		
	PBL Wall heat transfer (condensation)						L	M			M	L	M	M
	SIL Direct condensation							L			L	L	L	M
	Loop Recirculation flow						M	L	L	M	M	L		
ADS	Discharge (Critical) flow							H		H	M	L		L
CVCS	Charging / letdown flow			L										
Containment	Back pressure								L	L	L	L		

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