Sensitivity Study with PSA Branch Probability for Ex-vessel Debris Coolability in OPR-1000

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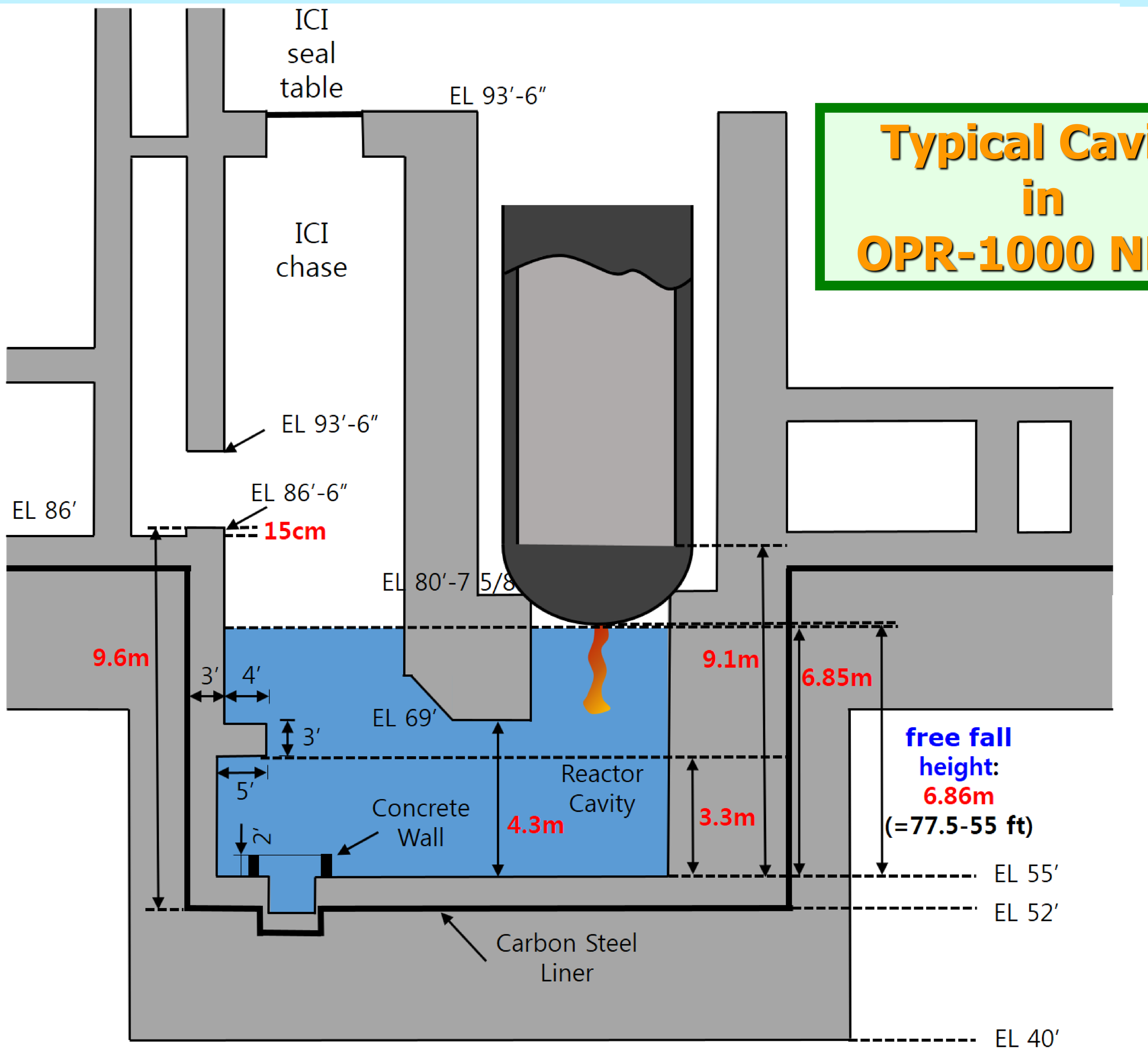
INTRODUCTION

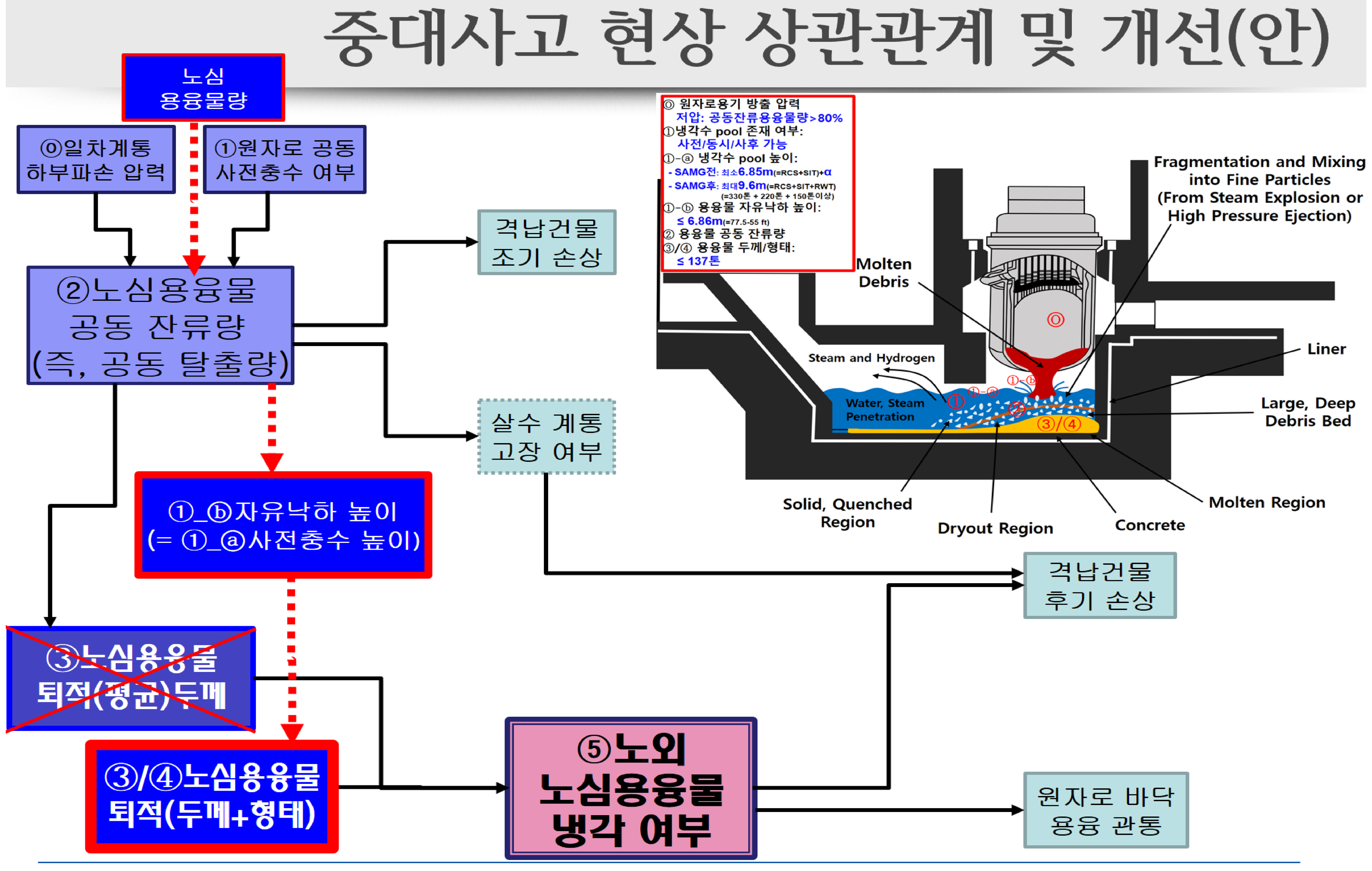
- Ex-vessel debris coolability (EDC) and stabilization under severe accident conditions is one of the important phenomena closely associated with molten core concrete interaction (MCCI) and then containment integrity issues
- As an effort to apply the research achievements to the practical improvement of the current SAMG, sensitivity analyses for the BMT factors are performed in the PSA viewpoint by changing EDC branch Probabilities in OPR-1000 plants
  - The strategy of pre-flooding into the reactor cavity is adopted in the SAMG (Severe Accident Management Guidance) of most operating Korean PWRs
  - KAERI has been performing the EDC research for this situation in an experimental (DEFCON) and a modeling (COLAS[1]) ways

[1] KAERI, "Development of ex-vessel particular debris bed coolability analysis model and coolability analysis report," KAERI/TR-8310/2020 (2020)

Typical Cavity in OPR-1000 NPPs



Major Factors for EDC in Level-2 PSA



EDC & BMT Basis Model (in Level-2 PSA)

"BMT"DET for CET top heading

AMOUNT OF CORIUM EJECTED OUT OF CAVITY	DEPTH OF DEBRIS POOL	COOLING WATER FOR DEBRIS IN THE CAVITY	DEBRIS COOLABILITY IN THE REACTOR CAVITY	CONTAINMENT BASEMAT MELTTHROUGH	SEQ #
CRM-EJECT	DB-DEPTH	CVT-WATER	EXVCOOL	BMT-MELT	

In the DET, the following 5 factors (as headings or top events) are modeled for the basis case in Hanul 3/4 OPR-1000 plant)

① CRM-EJECT: amount of corium ejected out of cavity (= opposite amount of cavity residue corium after reactor vessel bottom failure)
② DB-DEPTH: depth (= thickness) of debris pool or layer (= cake layer + particle debris bed)
③ CVT-WATER: existence of cavity water enough for 3-day (Level-2 PSA mission period) lasting cooling
④ EXVCOOL: EDC probability in the cavity
⑤ BMT-MELT: BMT probability in the cavity

BMT ("BMT-MELT") Branch Probability

CRM-EJECT	DB-DEPTH	CVT-WATER	EXVCOOL	BMT Probability	Tec. Basis
HIGH	-	-	-	Cooled	
MEDIUM	SHALLOW	YES		Cooled	
MEDIUM	SHALLOW	NO	NOT COOLED	P(INTACT) = 0.95 P(MELTHROU) = 0.05	Internal Cal.
MEDIUM	DEEP	YES	COOLED	Cooled	
MEDIUM	DEEP	YES	NOT COOLED	P(INTACT) = 0.95 P(MELTHROU) = 0.05	NUREG/CR-4551
MEDIUM	DEEP	NO	NOT COOLED	P(INTACT) = 0.9 P(MELTHROU) = 0.1	Internal Cal. (NUREG/CR-4551: 0.2)
LOW	SHALLOW	YES	COOLED	Cooled	
LOW	SHALLOW	NO	NOT COOLED	P(INTACT) = 0.95 P(MELTHROU) = 0.05	Internal Cal.
LOW	DEEP	YES	COOLED	Cooled	
LOW	DEEP	YES	NOT COOLED	P(INTACT) = 0.75 P(MELTHROU) = 0.25	NUREG/CR-4551
LOW	DEEP	NO	NOT COOLED	P(INTACT) = 0.6 P(MELTHROU) = 0.4	NUREG/CR-4551

<Base value for Branch Probability>

CRM-EJECT
- 'HIGH' (<60% (mean=50%)
- 'MEDIUM' (60%-80% (mean=70%)
- 'LOW' (>80%(mean=90%))

DB-DEPTH (thickest debris thickness)
- "VERY SHALLOW" (<10cm)
- "SHALLOW" (10~25cm)
- "DEEP" (>25cm)

CVT-WATER
- 'YES' (wet for 3 days)
- 'NO' (dry or depleted before 3 days)

DB-DEPTH	CVT-WATER	EDC
VERY SHALLOW	YES	Cooled
VERY SHALLOW	NO	P(COOLED) = 0.9 P(NOT COOLED) = 0.1
SHALLOW	YES	Cooled
SHALLOW	NO	Not Cooled
DEEP	YES	P(COOLED) = 0.5 P(NOT COOLED) = 0.5
DEEP	NO	Not Cooled

EDC ("EXVCOOL") Branch Probability

In Korean PSA, BMT importance is 35~60% for dry cavity while ~10% for wet cavity
- It is essential both to always supply water and to make the corium layer spread evenly

If cumulative debris in flooded cavity is thick, EDC is quite uncertain (P=0.5)
- According to SA code calculations, BMT (90cm penetration for 3 days into the accident) in dry & flooded cavity for thick and large-mass debris is likely to occur, but uncertain

Sensitivity Case Definition

The changes are added to the prior case, in an accumulating manner, like (1) the blue part is applied to Case-S1, (2) the blue and pink parts are applied to Case-S2, and (3) the blue, pink and green parts are applied to Case-S3

Case-S1
- It is based on the experimental observation that EDC varies depending on the inclination angle at the edge of debris bed having a cone
- (when 100% of the core melt is discharged into the cavity) the maximum angle was 20˚, and the maximum EDC was estimated at the angle between 10 ˚ and 20 ˚

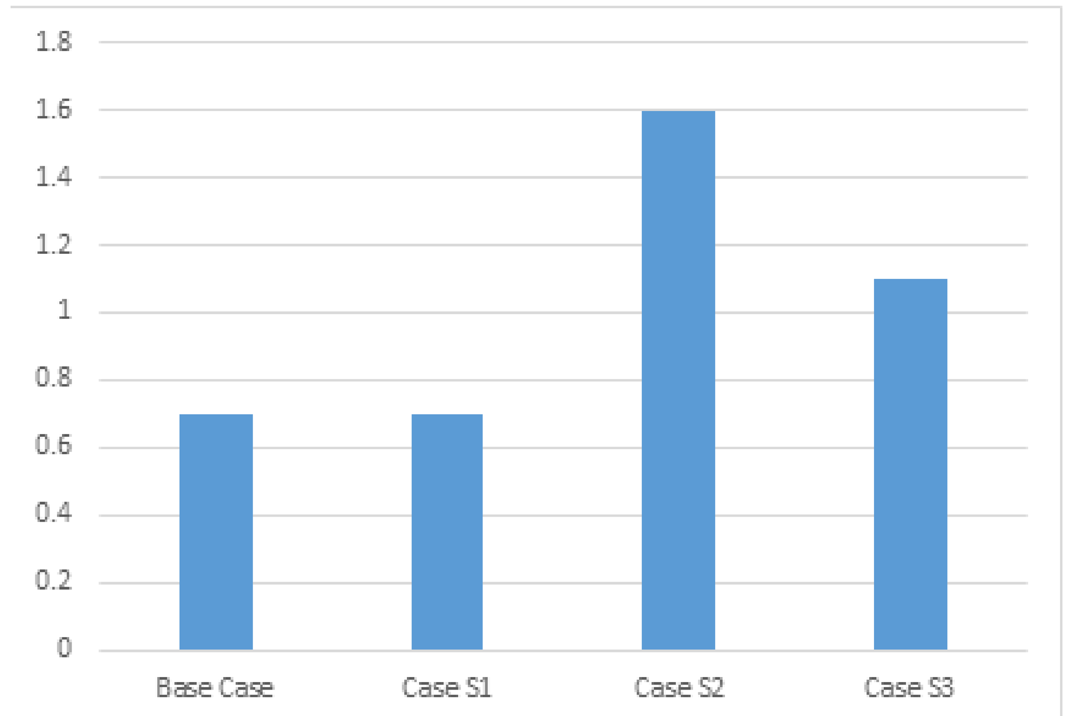
Case-S2
- It is mainly based on DEFCON experimental observations with the COLAS evaluation that the debris porosity is 0.5 (draft value at this stage)
- In addition to this, a half of core support structures is added to the basis composition of core melt

Case-S3
- It is mainly based on the model evaluation that temporary flooded cavity (with expected dryout within 3 days due to injection using only SIT water without RWST water) has better coolability compared with dry cavity
- In OPR-1000 plants, cavity flooding is possible with the injection of coolant from two safety measures, the passive one using SIT (Safety Injection Tank) and the active one using RWST (Refueling Water Storage Tank)

Changes in Branch Probability for Case-S1(blue)/S2(pink)/S3(green)

CRM-EJECT	CAV-WATER	DB-DEPTH		DB-SHAPE		EDC Not cooled	BMT
		SHALLOW	0.9			0.0	0.0
HIGH (>40%) (~50%)	YES (wet ≥3day)	DEEP	0.1	ANGLE-L (<10°)	0.6	0.3	0.01
				ANGLE-M (10~20°)	0.3	0.2	
				ANGLE-H (>20°)	0.1	0.4	
	TEMP (wet <3day)	SHALLOW	1.0	ANGLE-L	0.6	0.4	0.05
				ANGLE-M	0.3	0.3	
				ANGLE-H	0.1	0.6	
	NO (dry)	Very SHALLOW (<10cm)	0.1			0.1	0.0
		SHALLOW	0.9			1.0	0.05
MEDIUM (20-40%) (~30%)	YES	DEEP (>25cm)	1.0	ANGLE-L	0.6	0.3	0.1
				ANGLE-M	0.3	0.2	
				ANGLE-H	0.1	0.4	
	TEMP	SHALLOW (10-25cm)	0.9	ANGLE-L	0.6	0.4	0.05
				ANGLE-M	0.3	0.3	
				ANGLE-H	0.1	0.6	
		DEEP	0.1	ANGLE-L	0.6	0.3	0.1
				ANGLE-M	0.3	0.2	
				ANGLE-H	0.1	0.4	
	NO	SHALLOW	1.0			1.0	0.05
LOW (<20%) (~10%)	YES	DEEP	1.0	ANGLE-L	0.6	0.3	0.1
				ANGLE-M	0.3	0.2	
				ANGLE-H	0.1	0.4	
	TEMP	DEEP	1.0	ANGLE-L	0.6	0.3	0.2
				ANGLE-M	0.3	0.2	
				ANGLE-H	0.1	0.4	
	NO	SHALLOW	0.95			1.0	0.05

"BMT" Sensitivity Result



CONCLUSIONS

- BMT impacts are evaluated by changing EDC branch Probabilities in the Level-2 PSA (Probabilistic Safety Assessment) for Korean standard OPR-1000 plants
  - The core debris layer cooling properties may vary depending on the inclination angle and porosity of the debris layer deposited on the bottom of the reactor cavity, whose effects were not considered in the existing PSA
- The present results show that a negatively affecting porosity thickness appeared to have more impact than a positively affecting inclination angle
  - The increase in the thickness of the debris layer deteriorates the cooling property of the debris layer and increases the BMT probability
  - The inclination angle improves the cooling property of the debris layer and reduces the BMT
- This study is for the cavity that was previously submerged to a sufficient depth (before corium relocation into cavity)
  - The cooling characteristics for the cavity that was not submerged, which must have a greater effect on BMT, require a separate research