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Phenomena Identification and Ranking Tables for Inter-System Loss of Coolant Accident

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1. Introduction

An inter-system loss of coolant accident (ISLOCA) denotes the accident where the primary coolant ejected to the auxiliary building bypassing the containment through the systems penetrating the containment wall. The ISLOCA under the severe accident results in the release of the fission product to the environment directly without aids of containment, therefore, it is important scenario in terms of the radiological consequence even though the probability of the event occurrence is extremely low. US Nuclear Regulatory Committee (USNRC) performed analyses for the ISLOCA for their nuclear power plant (NPP), to estimate the radiological consequences to public [1].

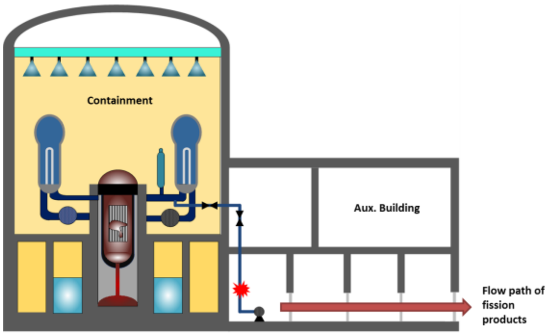

Fig.1. Schematic of ISLOCA

It is difficult to evaluate the releasing amounts of radioactive materials to the environment quantitatively under the ISLOCA because a variety of phenomena are involved such as radioactive aerosol generation, deposition, transportation, scrubbing, chemical reaction, etc. To develop suitable modellings and to estimate the radiological consequence on the ISLOCA, the related phenomena should be identified and ranked.

2. Methods and Results

A shutdown cooling system (SCS) of APR1400 as an example of inter-system has the largest pipe sizes of 16 inch and 18 inch among the systems connected to the primary cooling system and penetrating the containment. The SCS consists of varies pipe sizes, lengths, elevations and the components such as elbows or reducers. The SCS penetrates the containment and connected to the SCS pump room which is located at the 2nd basement (B2). The break point can be assumed as the weakest point of the system, which was the reducer near the SCS pump.

Auxiliary building has several floors started 2nd basement (B2) and has the door connected to the environment at the ground floor. Each floors are connected through the stairway and the elevation hall, and there are a lot of compartments and rooms at each floors. The one whole floor was assumed as a one big volume with floor, ceiling and outer wall Since the internal walls and the structures of the auxiliary building is overly complicated and the connection between the compartments depends on the opening of the doors. These surfaces and connections are highly related to the radioactive material depositions.

When the SCS pipe ruptures at the outside of the containment, it acts as a large break loss of coolant accident (LBLOCA) which causes a loss of primary coolant in the reactor system. The RCP trips by the accident and the main feed water (MFW) is also cut. In actual reactor protection system, the loss of coolant accident causes the rapid decreases of the pressure in the primary system, then the reactor trips by the low pressurizer pressure trip. After the SITs are exhausted and the core become dry, then the fuels and the internal structures starts to melt and then finally the RPV fails. Under the ISLOCA, the radioactive materials release from hot fuels and transport through the SCS pipe to the auxiliary building and finally to the environment. Some rooms in the auxiliary building can be flooded by the RCS coolant though break point of SCS pipe.

For identification and ranking, the phenomena related on the ISLOCA were identified and ranked separately for different sections such as in-pipe, wet auxiliary building (nearby break point), and dry auxiliary building (far break point).

The ranking of the phenomena were made for three different categories: (1) Impact on the radioactive material decontamination in the each section during a prototypic ISLOCA severe accident; (2) Availability of experimental data applicable to ISLOCA severe accident conditions to describe the phenomenon; (3) Availability of codes / models to describe the phenomenon under the conditions of ISLOCA severe accidents with the sufficient accuracy.

The ranking for all the categories was made using a three level scale: low (L), medium (M) and high (H). The criteria for the ranking are shown in Tables I.

There were a total of six experts who served on the panel and gave rankings for each phenomenon. In the ranking tables in Table II, the distribution of their rankings is represented by an L/M/H followed by the number of people who gave that ranking.

Table I: Phenomena Importance Ranking Scale

Rank	Definition	Application Outcomes
High (H)	Phenomenon has a controlling impact on the fission product decontamination in the each section during a prototypic ISLOCA severe accident	Experimental simulation and analytical modeling with a high degree of accuracy is critical
Medium (M)	Phenomenon has a moderate impact on the fission product decontamination in the each section during a prototypic ISLOCA severe accident	Experimental simulation and/or analytical modeling with a moderate degree of accuracy
Low (L)	Phenomenon has a minimal impact on the fission product decontamination in the each section during a prototypic ISLOCA severe accident	Modeling must be present to preserve functional dependencies

Table II: PIRT table for ISLOCA

No.	Phenomenon	Description	In pipe (SCS)	Aux. Dry	Aux Flooded	Exp. data	Models
1	Nucleation	Homogeneous, heterogeneous, and ion-induced	M5 H1	L6	L6	M6	M6
2	Gravitational settling	Settling of large particles by gravitation	L6	H6	L6	H6	H6
3	Inertial impaction	Impaction of large particles on surfaces at high velocity when flow changes direction	H6	L5 M1	M5 L1	M4 H2	M4 H2
4	Retention by droplets	Particle capture by droplets formed from water surface subjected to a jet	N/A	N/A	M5 L1	L3 M3	L3 M3
5	Bubble bursting and droplet formation	NC gas bubbles bursting on the water surface and creating droplets	N/A	N/A	M5 L1	M1 L1	M1 L1
6	Re-entrainment	For boiling pools, mechanical droplet formation and suspension into the gas phase at pool surface and at steam-water interface of bubbles	N/A	N/A	M6	M6	M6
7	Resuspension	Mechanical re-mobilization of single particles or deposit layers due to high turbulent forces or mechanical effects (erosion)	H1 M5	L6	N/A	M6	M6
8	Revaporization	Release of deposited fission products to gas phase due to increase in temperature	L6	M1 L5	N/A	M6	M6
9	Revolatilization	Evolution of gas/vapour species from deposits esp. iodine and caesium compounds due to chemical reactions / change of speciation	M4 L1	M4 L1	N/A	M4	M4
10	Turbulent deposition	Deposition due to turbulent eddies in a flow with a high Reynolds number	H6	L6	N/A	M6	M6
11	Thermophoresis	Migration of particles in thermal gradient to cold surfaces	M4 L2	M5 H1	L6	H6	H6
12	Diffusiophoresis	Deposition of particles due to steam condensation	L6	M5 L1	L2 M3	H6	H6
13	Diffusion	Brownian motion of small particles (in bubbles)	L6	M2 L4	M2 L4	H6	H6
14	Bounce	Re-bound of particles from a surface when the impaction velocity exceeds v_{crit}	M2 L4	L6	N/A	M6	M6
15	Fragmentation	Break-up of particles due to turbulent or mechanical forces, e.g., impaction	L6	L6	N/A	L6	L6
16	Coagulation and agglomeration	Growth of particles by collisions with other particles	L6	H1 M5	L6	H6	H6
17	Aqueous-phase iodine chemistry	Radiolytical formation of gaseous iodine species and transfer to the gas/vapour phase in bubbles (boiling pools) and pool surface	N/A	N/A	H4	M3 H1	M3 H1
17_1	Gas phase iodine chemistry		M4	L4	N/A	M3 H1	M3 H1

Table II: PIRT table for ISLOCA (continued)

No.	Phenomenon	Description	In pipe (SCS)	Aux. Dry	Aux Flooded	Exp. data	Models
18	Condensation	Condensation of fission product vapors on surfaces	L6	M3 L3	L6	H6	H6
19	Vapor deposition by chemisorption	Ab/adsorption of fission product vapors onto surfaces	L5	M4 L1	M1 L4	M5	M5

3. Conclusions

To develop suitable modellings and to estimate the radiological consequence on the ISLOCA, the related phenomena were identified and ranked. For identification and ranking, the phenomena related on the ISLOCA were identified and ranked separately for different sections such as in-pipe, wet auxiliary building (nearby break point), and dry auxiliary building (far break point). The ranking of the phenomena were made for three different categories: (1) Impact on the radioactive material decontamination in the each section during a prototypic ISLOCA severe accident; (2) Availability of experimental data applicable to ISLOCA severe accident conditions to describe the phenomenon; (3) Availability of codes / models to describe the phenomenon under the conditions of ISLOCA severe accidents with the sufficient accuracy.

The important phenomena were selected as inertial impaction, turbulent deposition of aerosol in pipe, and gravitational settling in dry auxiliary building, and aqueous-phase iodine chemistry in flooded auxiliary building.

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