Decontamination Factor Evaluation of Containment Pressure and Radioactivity Suppression System(CPRSS) for SMR

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1. Introduction

The CPRSS(Containment Pressure and Radioactivity Suppression System) is proposed as a part of the PCCS to replace the containment spray system as shown in Figure 1[1], the CPRSS shall have safety functions of 1) suppression of the increase of pressure and temperature (P/T) in the reactor containment area following accidents such as loss of coolant accident (LOCA) and main steam line break (MSLB), and 2) removal of the radioactive fission products from the reactor containment area. The system keeps the reactor containment area P/T from exceeding the design P/T with sufficient margin during 72 hours without AC power sources or operator actions. The reactor containment area in the SMART is divided into a Lower Containment Area (LCA) and an Upper Containment Area (UCA) with the boundary of the CPRSS lid. The CPRSS is comprised of CPRSS lid, pressure relief lines (PRLs) and PRL-spargers, an IRWST, radioactive material transport lines (RTLs) and RTL-spargers, two radioactive material removal tanks (RRTs), CPRSS Heat Removal System (CHRS) as a subsystem of the CPRSS, and instruments. The CHRS consists of four mechanically independent trains. The fission products released from a reactor core goes through the RRT via IRWST. Iodine is dissolved and retained in the RRT by preventing re-volitalization because the water pH of RRT is contained between 7.0 and 9.5. In this study, iodine behavior analysis and DF(Decontamination Factor) calculation were conducted using code in SMR with CPRSS.

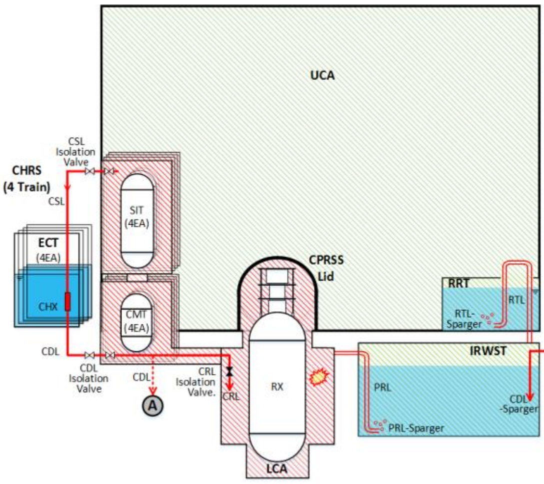

Fig. 1 Containment Pressure and Radioactivity Suppression System

2. Iodine behavior in water pool

In the evaluation of a LOCA, radioiodine in its various forms is the fission product of primary concern. Chemical forms of radioiodine released from RCS to containment are particulate iodine, elemental iodine, organic iodide by Reg. Guide 1.195.

The radioiodine released from a reactor core into the LCA is removed by pool scrubbing effect of the IRWST and RRT. To enhance this iodine retention capacity of the pool, the RRT solution is adjusted to an alkaline pH that promotes iodine hydrolysis, in which iodine is converted to non-volatile forms. The main aqueous phenomena that would influence the volatile iodine production in containment under accident conditions are schematized in Figure 2. Aqueous iodine reactions are the main source of gaseous iodine in containment together with the initial release from the RCS (Reactor Coolant System). Because the relatively large concentrations of both iodine and radiolytically-produced reactive species, the aqueous phase provides optimum conditions for the conversion of non-volatile iodine species to volatile iodine species, where volatile iodine species include molecular iodine (I2) and organic iodides (denoted by RI), and non-volatile iodine species (e.g. I-, HOI, I3− , IO3−). The volatile species formed in the aqueous phase could then be transferred to the gas phase at prevailing conditions. Thus, the rates of volatile I_2 and RI production/destruction in the aqueous phase are crucial parameters in determining gaseous iodine concentration. Gas-liquid interface mass transfer of iodine is described according to the two-film theory. At the interface, the species are considered to be at the equilibrium. The equilibrium value corresponds to the Henry's constant or more commonly used the partition coefficient (H) which is the ratio between the gas concentration and the liquid concentration at the interface.

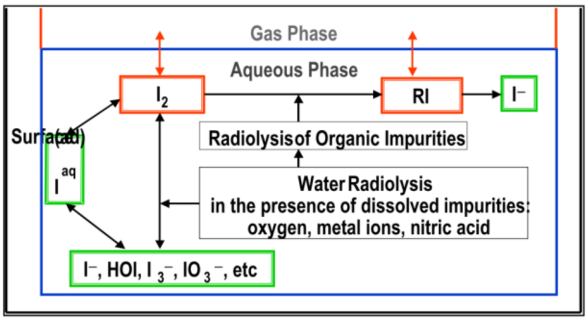

Fig. 2 Aqueous phenomena [2]

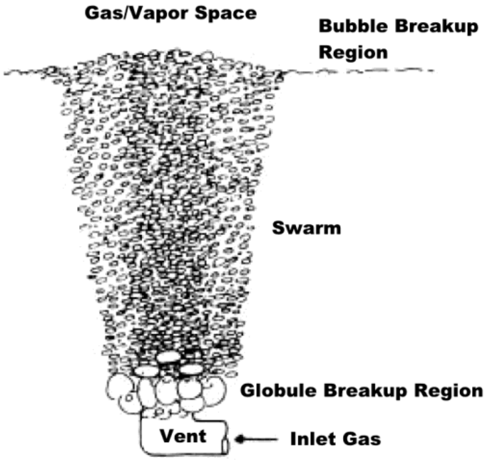

Fig. 3 Schematic bubble swarm rising of water pool [3]

3. Analysis Method and Results

When gas is injected from a vent into a water pool, large gas bubbles (globule) are formed initially and then broken into many small bubbles (swarm) as shown in Figure 3. While the bubbles rise up under gravity to reach the gas-vapor space, the aerosols within the bubbles are removed at the gas-liquid interface. When an aerosol particle reaches the gas-liquid interface by theses mechanisms, it is trapped in the liquid by surface tension and van der Waals forces. In the SPARCcode, the decontamination factor (DF) of aerosols is calculated in two regions: (1) vent exit (i.e. gas injection) and (2) swarm rise (i.e. bubble rising) regions.[4] The total DF is obtained by a product of the values calculated in those regions. Details on evaluation of the DF for particulate iodine in the RRT based on the methodology implemented in the PIAERO (Pool scrubbing Interpretation on AEROsol decontamination) computational code [5], which is developed by KAERI on the basis of the methodologies embedded in the SPARC code.

Table 1shows the main input parameters used for particulate iodine removal analysis. The analysis is performed for ten (10) intervals in consideration of RRT conditions by accident progression, which is tabulated in Table 2.

Table. 1 Input parameters for particulate iodine removal analysis in the RRT

Variable		Value
Pool Property	Depth [m]	5.0
	Temperature [℃]	50
	Surface pressure [bar]	1.12 to 1.34
Jet Property	Type	Horizontal Vent
	Nozzle diameter [cm]	0.8
	Jet temperature [℃]	50
	Jet pressure [bar]	1.67 to 1.91
	Jet steam mole fraction	0.0 to 0.757
	Volumetric flow rate [cm^3/sec]	2.93x10^4 to 3.37x10^7
Aerosol Characteristics	Density [kg/m^3]	4500
	Diameter [cm]	2.3x10^{-4}

Table. 2 Analysis results for particulate iodine removal in RRT

No.	Time (s)	DF		
		Vent Exit	Swarm Rise	Total
1	0~50	1.16767	100.0	116.767
2	50~80	1.13708	1141.1	1297.50
3	80~100	15.7257	300.7	4728.93
4	100~120	39.054	100.0	3905.40
5	120~150	25.9833	100.0	2598.33
6	150~300	13.727	100.0	1372.70
7	300~500	8.04064	100.0	804.064
8	500~700	5.52732	100.0	552.732
9	700~259200	3.89515	100.0	389.515
10	259200~864000	1.36606	445.9	609.142

4. Conclusions

In this study, the decontamination factor and iodine behavior analysis in the CPRSS applied to small modular reactor were performed by PIAERO code. It was confirmed that decontamination factor in RRT exceeds at least 100 by bubble rising modeling (swarm rise) in the pool.

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