Containment Performance Evaluation of a Sodium Fire Event Due to Air Ingress into the Cover Gas Region of the Reactor Vessel in the PGSFR

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1. Introduction

The PGSFR(Prototype Generation IV Sodium Cooled Fast Reactor) has been developing in the Korea Atomic Energy Research Institute(KAERI). Comparing with the light water reactor, sodium as a reactor coolant violently reacts with oxygen in the containment atmosphere. Due to this chemical reaction, heat generated from the combustion heat increases the temperature and pressure in the containment atmosphere. The structural integrity of the containment building which is a final radiological defense barrier is threaten. A sodium fire event in the containment due to air ingress into the cover gas region in the reactor vessel is classified as one of the design basis events in the PGSFR. This event comes from a leak or crack on the reactor upper closure header surface. It accompanys an event of the radiological fission products release to the inside the containment.

In this paper, evaluation for the sodium fire and radiological influence due to air ingress into the cover gas region of the reactor vessel is described. To evaluate this event, the CONTAIN-LMR[1], MACCS-II[2] and OR-IGEN-II[3] codes are used.

2. Analysis Methods

The evaluation for the integrity of the containment is performed because it is an important barrier to prevent the release of the radiological fission products to the outside of the containment. In determining the initial conditions of the event, conservative assumptions are applied to retain the safety and design margin. The evaluated results will be fed back to the design of the containment building and internal components. The input data for the evaluation are based on the pre-design data[4].

The event scenario is as follows. 1) A leak or crack is occurred on the reactor upper closure header surface. 2) Due to pressure difference, the cover gas inside of the reactor vessel is released into the containment atmosphere. 3) And, oxygen inside the containment building is penetrated through the leak or crack into the cover gas region in the reactor vessel. 4) The inflowing oxygen reacts with sodium on the hot pool surface in the reactor vessel. The sodium pool fire proceed until the oxygen is completely consumed. As the burning rate between the oxygen and sodium is decreased, the severity of the sodium fire is gradually mitigated.

2.1 Assumptions for Calculation

In calculation of the inventory of the radiological fission products generated from the core, conservative assumptions are applied to the ORIGEN-II code input. Taking into account the uncertainties, 110% core power, end of cycle and maximum burn-up of the fuel are assumed for the input.

The inventories calculated from ORIGEN-II are used as an input for the CONTAIN-LMR which calculates the release fraction of the fission products to the outside of the containment. Table 1 represents the assumed release fraction of the fission products from the reactor vessel to the inside of the containment through the leak or crack. Also, it calculates the temperature and pressure in the containment atmosphere during the sodium fire. For a conservative performance evaluation for this event, a few more assumptions are applied. 1) The sodium participating into the combustion reaction is completely consumed to produce the sodium monoxide (Na_2O) as a reaction product. It generates higher reaction heat than the sodium peroxide(Na_2O_2). 2) The total heat generated from the combustion reaction is released into the atmosphere, not the inside of the sodium pool.

Table 1: Assumed Released Fraction of the Fission Products

	TID-14844 (1962)	SNR 300** (Na 500 ℃)	EFR*	MONJU**	PRISM	4S (Assumed 1% fuel failure)	KALIMER 600 (2005)	**PGSFR**
Noble Gases (Xe, Kr)	100%	100%	100%	100%	100%	0.01%	100%	**100%**
Halogens (I, Br)	50%	50%	10%	10%	0.1%	0.01%	10%	**10%**
Alkali Metals (Cs, Rb)	1%	50%	10%	10%	0.1%	0.01%	10%	**10%**
Sr, Ba rare earths	1%	1.7%	-	-	0.01%	0.01%	1%	**1%**

* : non energetic CDA
** : energetic CDA

From the CONTAIN-LMR calculation, the release rate of the fission products to the outside of the containment is provided for an input to MACCS-II. It calculates the radiological dose in the EAB and LPZ which are specified in the 10CFR100. The gas release rate from the containment atmosphere to the outside of the containment is assumed to 1% of the containment volume per day at the containment design pressure. Based on the other reactor data, the values of the EAB and LPZ in the PGSFR are assumed to the 300 [m] and 4,000 [m], respectively.

Figure 1 illustrated a nodalization to evaluate the containment event using CONTAIN-LMR in the PGSFR. The containment is divided into 3 cells and 1 cell. The 3 cells are composed of internal structures such as the wall, the ceiling and the floor. The flow path areas between the cells 1 and 2, 2 and 3, 1 and 3 are assumed to be 0.75 [m^2], 1.5 [m^2] and 3.0 [m^2], respectively in the 3 cells containment. In figure, the C4 represents the atmosphere outside of the containment boundary. If the event occurred, the radiological fission products inside of the reactor are released to the C1 region.

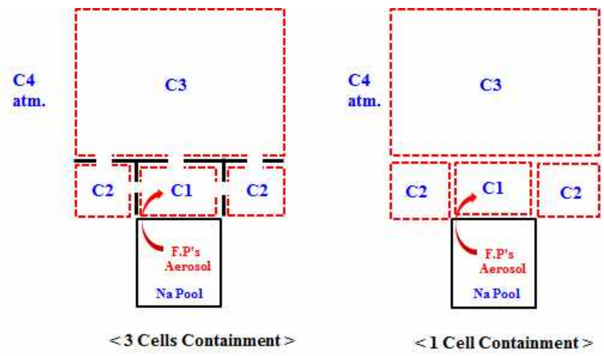

Fig. 1. CONTAIN-LMR Code Nodalization

2.2 Calculation Results

The pool fire event which occurred on the hot pool surface in the reactor vessel is analyzed with the CONTAIN-LMR code. Figure 2 shows the calculated results of both the oxygen consumption and Na combustion rates on the hot pool surface in the reactor vessel. The reaction rate soars up in the early times, and slows down for the initial 30 minutes. Because a sufficient oxygen inventory within the cell caused, the initial reaction rates to increase so rapidly. From the result, the reaction rate between the oxygen and sodium is increased with the size of the flow path area. As the amount of the oxygen transferred through the flow path area is decreased, reaction rate is gradually decreased. From the perspective of the thermal hydraulic, the 1 cell containment represents the most conservative result. It means that the oxygen inside of the containment can be sufficiently transported to the sodium pool surface.

Figure 3 represents the results of the oxygen inventory variation in the C3 cell. As the reaction rate between oxygen and Na are increased, the inventory of the limited oxygen in the containment is gradually decreased. The inventory of the oxygen in the containment is inversely proportional to the sodium burning rate.

Figure 4 compares the temperature results in the C3 cell atmosphere. The temperature in the 1 cell containment is much higher than those of the others cases. Temperature in C3 is approximately reached to 280 ºC for one hour. It could threaten the integrity of the internal structures and components in the containment. Because thermal radiation term between the structures such as the wall, the floor and ceiling and the cell atmosphere, is not taken into account in this calculation, the atmosphere temperatures is calculated at a higher value.

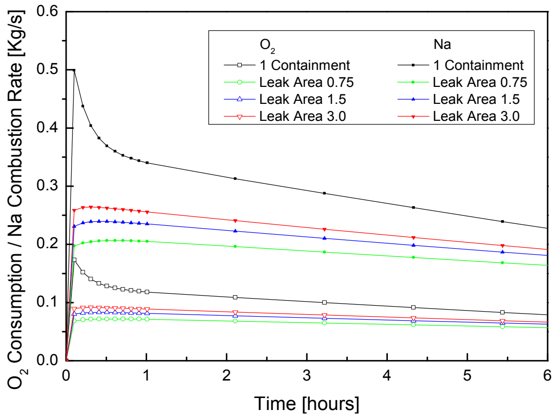

Fig. 2. Oxygen consumption and Na combustion rate on the surface of the sodium pool with the lapse of time.

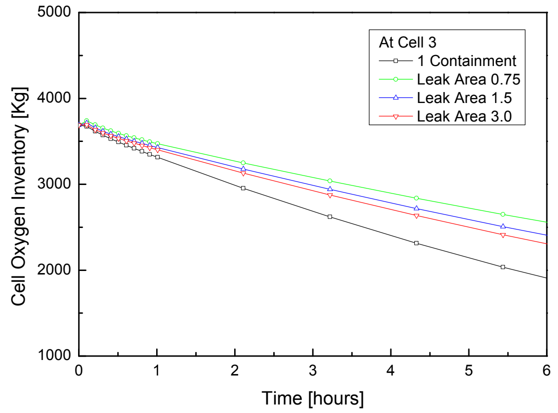

Fig. 3. Oxygen inventory variation in the Cell 3 with the lapse of time.

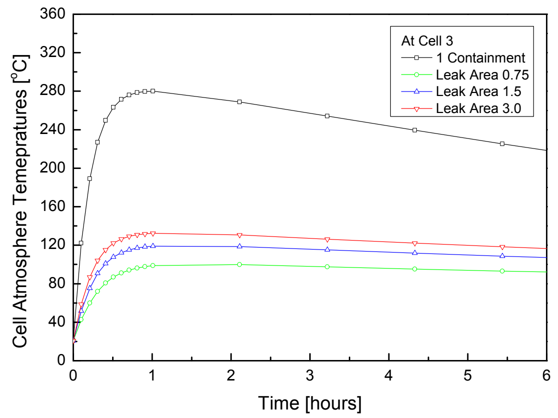

Fig. 4. Cell Atmosphere Temperature with the lapse of time.

Figure 5 presents the results of pressure in the C3 atmosphere. The pressure in the 1 cell containment is much higher than the others cases. The pressure in the containment is proportional to the temperature. The maximum pressure in C3 is approximately reached to the 0.185 MPa for one hour. Table 2 summarizes the radiological dose for the EAB and LPZ is calculated from the MACCS-II code. For design basis events, the acceptance criteria in the EAB and LPZ boundary are 10% of specified values in the 10CFR100. From the calculation result, the estimated doses at the EAB and LPZ for this event are satisfied with the acceptance criteria.

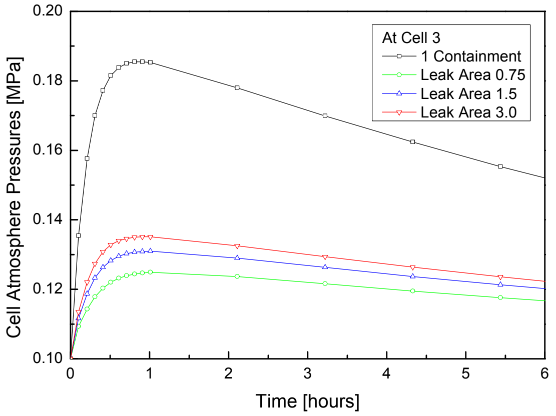

Fig. 5. Cell Atmosphere Temperature with the lapse of time.

Table 2: Dose Results from MACCS-II Code

Organ	10% of 10CFR100 (rem)	3 Comp Leak area 0.75		3 Comp Leak area 1.5		3 Comp Leak area 3.0	
		EAB	LPZ	EAB	LPZ	EAB	LPZ
Whole body	2.5	0.258	0.00392	0.289	0.00438	0.310	0.00469
Red Marrow	15	0.126	0.00168	0.141	0.00189	0.151	0.00202
Lungs	4.7	1.09	0.0214	1.23	0.0240	1.31	0.0257
Thyroid	30	0.581	0.00118	0.652	0.00133	0.0698	0.00142

3. Conclusions

For the sodium pool fire event in the containment, the performance evaluation and radiological influence are carried out. In the thermal hydraulic aspects, the 1 cell containment yields the most conservative result. In this event, the maximum temperature and pressure in the containment are calculated 0.185 MPa, 280.0 ºC, respectively. The radiological dose at the EAB and LPZ are below the acceptance criteria specified in the 10CFR100.

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