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A compartment design insight of potential sodium fire using SOFIRE II

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1. Introduction

A Sodium cooled Fast Reactor (SFR) is a fast neutron reactor cooled by molten metallic sodium. Since the sodium as a coolant in SFR has potential sodium fire risks when sodium leak occurs in the compartment where the sodium is contained, it should take account of reducing the impact of the sodium fire in designing the compartment in view point of pressure and temperature for enhancing the safety of SFR. This paper presents the evaluation and design insight for the pressure and temperature behavior in a compartment atmosphere during postulated sodium fire using SOFIRE-II code.

2. Case Study

In SFR, the maximum temperature of the sodium system is approximately 550°C when the reactor is operating and a significant margin with respect to the boiling point of sodium (approximately 900°C).

There are three types of sodium fire: pool fire, spray fire and mixed fire as shown in Figure 1. The pool fire is only considered in this analysis for the compartment where the safety grade and double wall pipe is applied. The SOFIRE II with one cell in Figure 2 is used for a sodium pool fire resulting from the postulated spilled sodium in the compartment floor.

The purpose of this study is to evaluate pressure and temperature in the compartment atmosphere and produce temperature gradients of heat structures for sodium fire due to sodium contained pipe failures with regard to parameter studies such as sodium initial temperature, spilled sodium mass, burnable floor area, free volume of compartment and oxygen weight percent as shown in the Table 1.

3. Modeling

SOFIRE II assumes that the sodium mass/volume collects upon the floor instantaneously to calculate the depth of sodium in consideration of floor area and initial temperature in spite of mostly time dependent leakage. It requires an initial temperature for the spilled sodium, thus, the temperature is assumed to be equal to the high temperatures conservatively. A sodium volume discharged onto the floor is determined according to the sodium density of its initial temperature.

The free volume taken up by the sodium system inside of compartment is not subtracted from the compartment volume. This is a conservative assumption in term of the amount of sodium that can be burned, although the heat up of the compartment gas atmosphere and potentially the gas pressure rise might be underestimated.

The sodium layer in the SOFIRE II divides the sodium pool into five axial layers of which the surface layer reacts with oxygen from the overlying gas atmosphere and transfers heat by natural convection (including heat generation from the sodium-oxygen reaction) and thermal radiation to the overlying gas atmosphere. In the present calculation, the layer thicknesses are defined to be identical. Thermal conduction is calculated between the five layers. Convection within the sodium pool is neglected. This may be expected to be a reasonable approximation given the high sodium thermal conductivity and the fact that a configuration in which the sodium temperature is highest at the upper surface and lowest at the lower surfaces should be a thermally stable configuration.

The sodium-to-oxygen burning ratio is set to 2.88 for the formation of sodium oxide, Na_2O, as the reaction product. The input variable for thermal radiation from the pool upper surface to the overlying gas atmosphere is set equal to unity and the variable for thermal radiation from the pool upper surface to the walls is set equal to zero.

SOFIRE II models a steel liner on the floor and walls of the compartment to prevent the sodium-concrete interaction directly. The liner thickness is assumed equal to 6.35 mm (0.25 in); the liner is described with the thermos-physical and transport properties for steel provided in the code. A heat transfer is considered between the floor liner and the underlying concrete floor.

4. Evaluation Results

Several parameters related to the results of sodium fire are evaluated according to the Table 1. The calculated results of basis case are presented in Figure 3 and Figure 4. Figure 3 shows the pressure and temperature of compartment including heat sink temperature gradient of the floor and wall concrete. Figure 4 shows the gas masses including oxygen mass in the compartment. It also shows the burned mass of oxygen and sodium related to the time dependent.

Figure 5 through Figure 9 show the parametric analysis results. The atmosphere temperature increases as the spilled sodium temperature increases (Figure 5). The temperature of compartment is proportional to the increase in the sodium initial temperature, free volume and oxygen weight percent as shown in Figures 5 ~ 7, respectively. On the sodium mass side, which is theoretically 2.88 times the oxygen masses contained in the free volume, can be combustible but the peak temperature result is shown in the around 60% of combustible sodium mass in Figure 8. It was also found that the peak temperature decreased, or at least by more than the sodium mass producing it. In the case of the floor area of combustion with sodium, the peak temperature appears to be between 120 % and 125 % of the basis area of the compartment; in this respect, the temperature trends are shown in Figure 9 and It has been shown that when the combustion area is larger or smaller than the basic area, the peak temperature is reduced.

5. Conclusion

A critical review of literature relevant to sodium pool fires has been carried out with the objectives of case studies for sodium pool fire. The code was applied to get the insight of compartment design in consideration of a sodium pool fire following a postulated sodium pipe failure and the subsequent release of sodium onto the floor of the steel-lined compartment. The insulation material such as MgO gravel, Aluminum-silica (Cerablanket) or lightweight (insulating) concrete as appropriately are inserted between steel liner and structural concrete in compliance with ACI Code requirements which can protect the structural concrete against high thermal degradation.

REFERENCES

[1] P. Beiriger, J. Hopenfeld, M. Silberberg, R. P. Johnson, L. Baurmash, and R. L. Koontz, “SOFIRE II User Report,” AI-AEC-13055, LMFBR SAFETY, UC-79p, Atomics International Division, Rockwell International, Canoga Park, CA March 30, 1973.

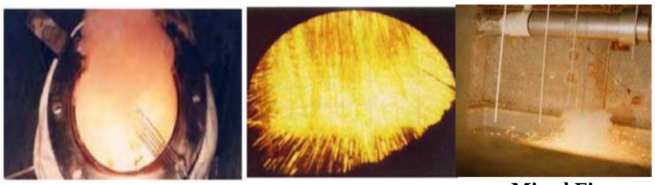
[2] James J. Sienicki and Anton Moisseytsev, “Sodium Pool Fire Phenomena, Sodium Pool Fire Modeling in SOFIRE II, and SOFIRE II Calculations for the AFR-100”, ANL-ARC-250, Argonne National Laboratory, September 24, 2012.

Table 1 Case Study for sodium pool fire

	Base	Case studies on each parameter change							
Na T(℃)	350	200	250	300	400	450	500	550	600
Vol(m^3)	3,600	5,400	4,680	3,960	3,240	2,880	2,160	1,800	1,080
O_2(wt%)	23.14	34.71	30.08	25.45	20.83	18.51	13.88	11.57	6.94
Na M(T)	13	19.5	16.9	14.3	11.7	10.4	7.8	6.5	3.9
Area(m^2)	230	345	299	253	207	184	138	115	69

Table 2 Peak Temperatures depending on parameters

	Base	Case studies on each parameter change							
Na Temp.	271.3	244.5	253.0	261.9	281.2	291.5	302.3	313.6	325.3
Volume	271.3	277.9	277.0	274.3	268.9	264.9	253.2	245.1	222.4
Oxygen	271.3	412.0	354.3	298.2	245.4	220.4	174.5	152.8	119.3
Na Mass	271.3	262.5	265.7	269.3	273.6	276.0	281.6	284.8	292.4
Floor Area	271.3	274.0	274.6	273.2	268.5	264.3	250.8	240.5	205.8



Pool Fire **Spray Fire** **Mixed Fire**

Figure 1 Sodium Fire Types

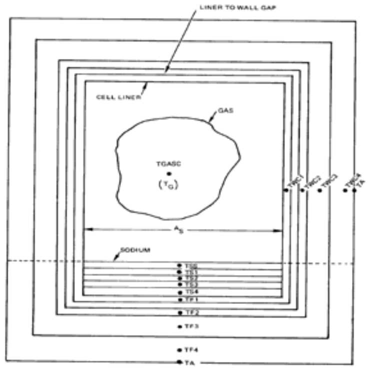


Figure 2 One Cell Geometry

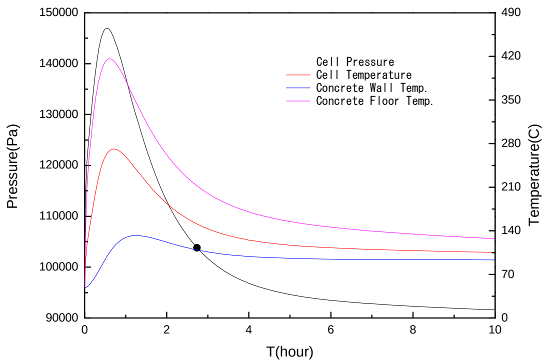


Figure 3 Compartment Pressure and Temperatures

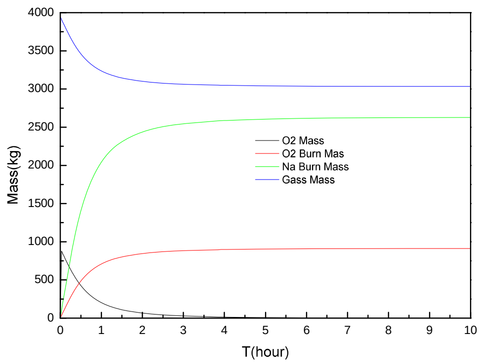


Figure 4 Gases and Sodium Masses in the Compartment

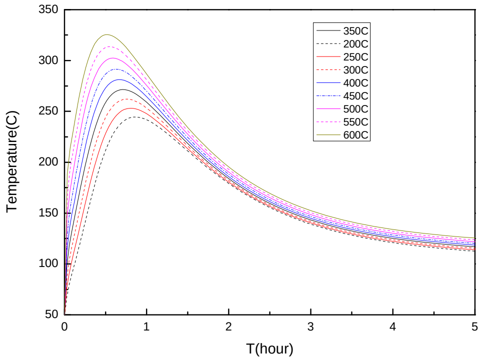


Figure 5 Compartment Temperatures on Sodium Temperature

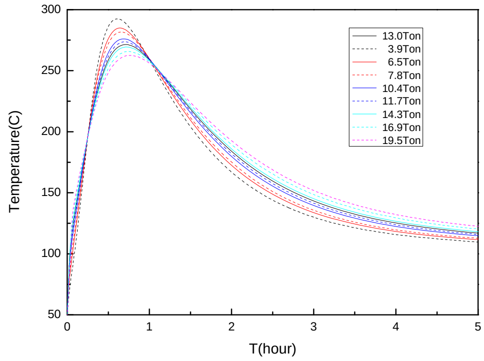


Figure 8 Compartment Temperatures on Sodium Mass

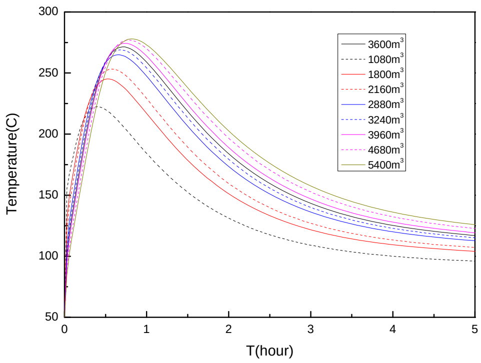


Figure 6 Compartment Temperatures on Free Volume

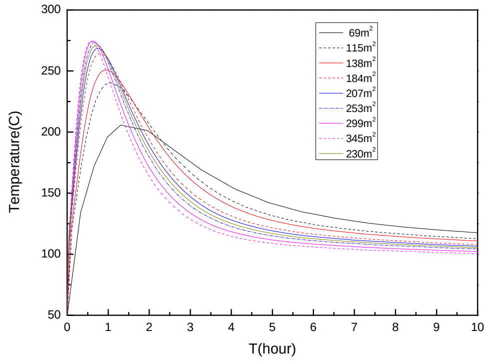


Figure 9 Compartment Temperatures on Pool Area

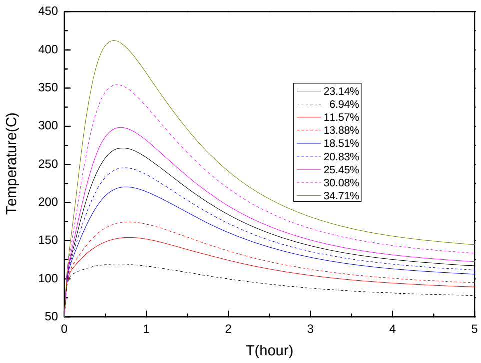


Figure 7 Compartment Temperatures on O_2 Percent