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A minimization of sodium fire risk using drain line in SFR

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1. Introduction

The SFR (Sodium cooled Fast Reactor) is a fast neutron reactor, i.e. it operates without a moderator. The core is cooled by molten metal, sodium (Na). Compared with thermal-spectrum neutrons, fast-spectrum neutrons more efficiently convert natural uranium (uranium-238), a fertile material, into plutonium, a fissile material, which means that the SFR could be operated in breeder mode, or conversely in burner mode for increased plutonium consumption. It can also transmute the very-long-lived actinides (americium, curium and neptunium).

Due to the use of the sodium coolant in SFR, we have to consider the potential sodium fire risk when the sodium leaks in the air where the sodium system is contained. Therefore it takes account of challenging the sodium fire risk to design the SFR Plant.

This paper presents the method of a minimization of sodium fire risk using drain pipe on the top of floor, which is classified as a design basis accident (DBA) to be considered in accordance with the requirements of the SFR.

2. Sodium Fire Risk Analyses and Results

This section provides information about the analyses performed that provide a DBA in the steam generator room (SG room) in auxiliary building of PGSFR (Fig. 1) due to sodium leak, including computer code and methods, key assumptions, and the results of the analysis.

2.1 Computer Code

The CONTAIN LMR/1B-Mod. 1 was used for these analyses. This code is a special version of the CONTAIN computer code intended for the application to the liquid metal reactor (LMR) using sodium coolant. The code was developed by applying LMR-specific updates to an official light water reactor (LWR) version of the CONTAIN 1.11 [1,2,3].

2.2 Analysis Model

There are three (3) kinds of sodium fires as shown in Fig. 2 due to type of a sodium leak from the sodium systems such as IHTS (Intermediate Heat Transfer System), DHRS (Decay Heat Removal System) and sodium transportation systems.

The sodium fire in the SG room is modeled as one node volume with heat structures of 4 walls, a roof and a floor in PSFGR [4]. The SG room's geometry in Table I is a rectangular shape and the floor is modeled as a lower-cell related to sodium burning area, as shown below in Fig. 3.

- Pool layer : sodium burning area (pool)
- Intermediate layer : liner plate
- Intermediate layer : insulating material if needs
- Concrete layer : floor concrete with 40 nodes

The material properties as shown in Table II were used for the analysis of CONTAIN-LMR.

The amount of sodium source for sodium fire is 609 kg which is leaked from failure of IHTS pipe in the SG room considering the engineering safety features actuation, and it was assumed to be temporary leaked at the beginning of analysis.

In case that a minimizing of sodium fire risk is reducing the burnable sodium amount using the drain pipe line with 5 cm of inner diameter on the floor, moves into the inert condition.

In case that the floor temperature can be higher than the requirement in Table III during accident condition, we have to consider the protection method for floor concrete by inserting the insulating material in Table II.

2.3 Analysis Results

From the results of analysis in Figs. 4 and 5, the maximum atmosphere pressure and temperature resulting from the sodium fire with 609 kg of sodium burned were 0.1307 Mpa and 145.3℃ respectively, and the maximum atmosphere pressure and temperature for the change of drain design were 0.1055 Mpa and 54.1℃, which were summarized in Table IV. However, it is shown in Fig. 6 that the floor surface temperature is within the temperature limits requirements given in Table III, ACI-349 requirements. Therefore, there was no need to consider additional measures whether using the drain method or not.

To minimize the sodium fire risk using drain pipe, it was assumed that the leaked sodium drained into the tank or sub-compartment of the inert condition where is filled with argon and is no longer burned.

The temporary leaked of sodium, 609 kg, took 460 seconds to burn out. But in case of design change to drain, sodium fire was maintained for 57 seconds, burned sodium is 56.8 kg and the remains (552.2 kg) moved through the drain pipe as shown in Fig. 7 and are summarized in Table V.

From the results, the atmosphere conditions and floor temperature can be reduced using drain pipe.

3. Conclusions

In this study, the analyses of the sodium fire risk were performed on the assumption that the sodium coolant on the sodium cooled fast reactor (SFR) was temporarily leaked due to the pipe failure of sodium systems.

In order to reduce the risk of sodium fire, sodium leak should be prevented first, leaked sodium should be minimized if the prevention is failed, and the amount of sodium fire that is minimized should also be combined with oxygen, thus participating in the sodium fire should also minimize the amount of oxygen or sodium.

In order to minimize the amount of sodium participating in the sodium fire, the drain pipe was installed on the floor, which can be drained into the inert conditions of tank or sub-compartment.

The analyses showed that sodium drain method through the installation of drain pipe can effectively reduce atmosphere temperature and pressure inside the compartment due to sodium fire, and also reduce the temperature of the floor structure.

Table I: SG Room Geometry

Description	SG Room	Remark
Free Volume(m^3)	5,744.654	
Height(m)	25.988	
Floor Area(m^2)	221.050	Celling area
Wall Area(m^2)	428.4901 376.5141	
Pressure(Pa)	101,352.9	
Temperature(℃)	40	
Floor Concrete(m)	2	
Floor Liner Plate(m)	0.006	

Table II: Concrete Thermal Property

Description	Light Weight Insulating Concrete*	Structure Concrete
Density(kg/m^3)	1,041.2	2,242.6
Compressive strength (Mpa)	6.2	27.6 ~ 41.4
Thickness(cm)	3 ~	45.7 ~
Thermal Conductivity (W/mK)	0.692 (310.92 K) 0.363 (477.64 K)	1.5923
Specific Heat (J/Kg-K)	1,674.72 (310.92 K) 1,088.57 (477.64 K)	879.2

* Thermal Property of Light Weight Insulating Concrete from Clinch River PSAR (Table 15.6.1.4-2)

Table III: Concrete Temperature Requirement in ACI-349

Description	Temperature Limit	Remark
Normal Operation or any other long-term period	150°F (65.5℃)	
During an accident or for any other short-term interruption	350°F (176.6℃) 650°F (343.3℃) for fluid jets local area	

Table IV: Atmosphere Conditions

Description	Atmosphere Temperature	Atmosphere Pressure
No Drain	145.3℃ @ 460 sec	0.1307 Mpa @ 460 sec
With Drain (Diameter =5 cm)	54.1℃ @ 220 sec	0.1055 Mpa @ 167 sec

Table V: Sodium Mass Distribution during Sodium Fire

Description	Burnt Sodium	Drained Sodium
No Drain	609 kg for 460 sec	0.0 kg
With Drain (Diameter =5 cm)	56.8 kg For 57 sec	552.2 kg

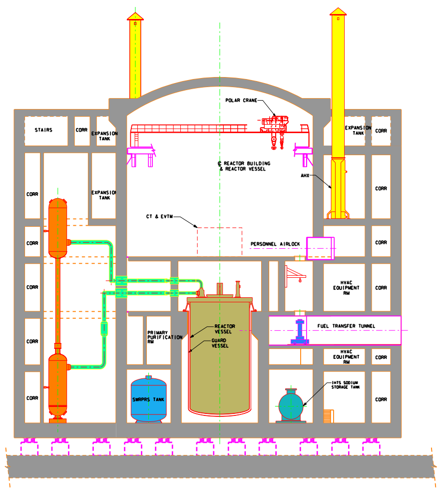
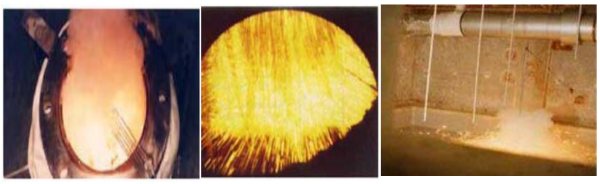


Fig. 1. PGSFR Nuclear Island



Pool Fire Spray Fire Mixed Fire

Fig. 2. Sodium Fire Types

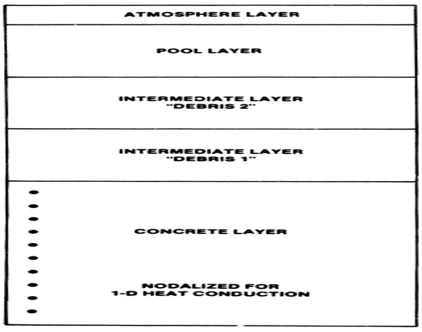


Fig. 3. CONTAIN-LMR lower-cell's Model

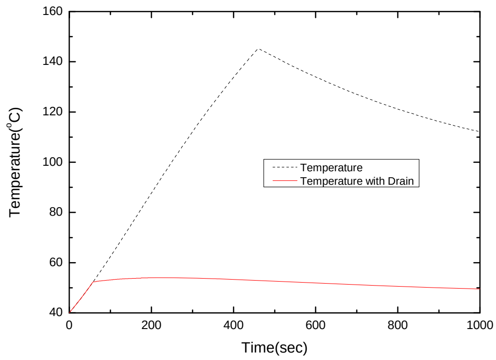


Fig. 4. SG room Atmosphere Temperatures in the SG Room

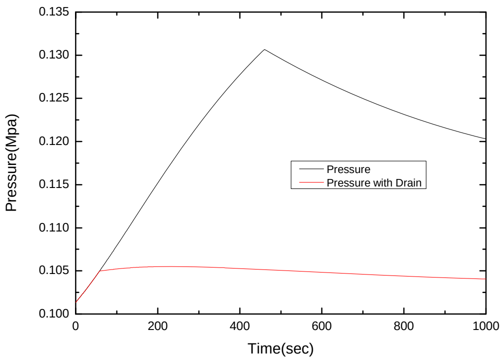


Fig. 5. SG room Atmosphere Pressures in the SG Room

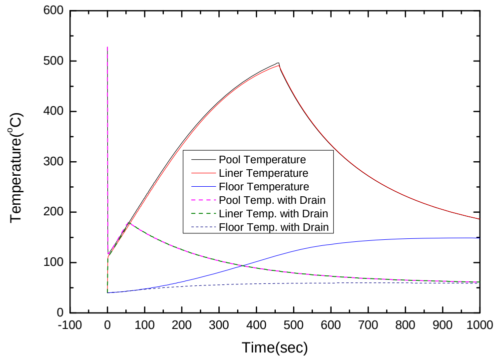


Fig. 6. Sodium & Floor Temperatures in the SG room

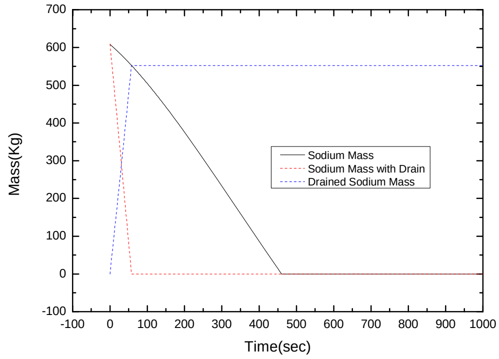


Fig. 7. Sodium Mass Distribution in the SG room

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