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Structural Assessment of Zero-power Research Reactor based on Parameter Analyses under Postulated Oil Fire

Jae-Min Jyung[a] and Yoon-Suk Chang[a*]
[a]*Department of Nuclear Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

The fire hazard analyses have been performed in Nuclear Power Plants (NPPs) according to IAEA Specific Safety Guide (No.SSG-25) and several national standards [1, 2]. Particularly, these researches have been introduced in huge commercial NPPs. In the recent, the relevant studies are necessary to take safe measures in zero-power research reactor.

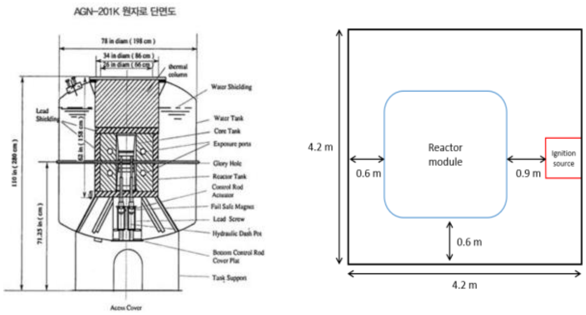
In NPPs, the ignition sources are various according to each place/space and consists of electricity, oil, pumps, batteries, and so on [3]. Thus, hazard analyses are necessary under diverse fire and conditions. Especially, the heat release rate of oil fire is higher than those of others.

The objective of this study is to implement integrity assessment of zero-power research reactor based on parameter analyses under postulated oil fire. The eight postulated fire scenarios were assumed and structural evaluations have been carried out using Finite Element Analysis (FEA). Subsequently, the maximum von-Mises stress results were compared with damage criteria, of which details and key findings are discussed.

2. Analysis methods and conditions

2.1 Fire scenarios

The zero-power research reactor has licensed power of 10 W. The reactor module is located in room of which size is 4.2 m x 4.2 m x 3.2 m. Fig. 1(a) depicts the reactor module and the distance between ignition source and target is 0.9 m in Fig. 1(b). In this research, the reactor module and the room were simplified due to efficient numerical simulation.



(a) Reactor module [4] (b) Ignition source

Fig. 1. Schematic of zero-power research reactor module and ignition source

The postulated fire scenarios are categorized with area, height of ignition source, and ventilation condition in Table I. Actually, the oil is not located in the room, however, it was assumed to analyze the high heat release rate fire.

Table I: Postulated fire scenarios and relevant parameters

Case	Area (m^2)	Height (m)	Ventilation (m^3/s)
1	0.5	0.5	0.67
2	0.5	0.5	0.33
3	0.5	0.1	0.67
4	0.5	0.1	0.33
5	0.1	0.5	0.67
6	0.1	0.5	0.33
7	0.1	0.1	0.67
8	0.1	0.1	0.33

2.2 Analyses conditions and models

The heat release rate of oil fire was derived by Eq. (1) in NUREG-1805 [5].

$$\dot{Q} = \dot{m}\Delta H_{c,eff} A_f \left(1 - e^{-k\beta D}\right) \quad (1)$$

In Eq. (1), $\dot{Q}$ is heat release rate of oil fire (kW), $\dot{m}$ is burning or mass loss rate per unit area per unit time (kg/m^2-sec), $\Delta H_{c,eff}$ is effective heat of combustion (kJ/kg), A_f is horizontal burning area of the fuel (m^2), $k\beta$ is empirical constant (m^{-1}), and D is diameter of burning area (m). In these analyses, it was 516kW when the fire area was 0.5 m^2 for more conservative assessment. The fire suppression system was also excluded and the initial temperature of room was defined to 25°C. It was set to operators' reaction time as 300 sec [6].

The material properties of the reactor module were SS304 regarding change of temperature [7]. The Computational Fluid Dynamics (CFD) analyses were carried out with Smagorinsky turbulence model employed in Fire Dynamics Simulator (FDS). The temperature was calculated by using fire parameters. Meanwhile, the bottom of the reactor module was fully fixed. In the subsequent, the structural values were evaluated by Analysis System (ANSYS) Mechanical and the values were compared with yield strength of the reactor module.

The analysis model in FDS was constructed by Eq. (2) referred to NUREG-1934 [3].

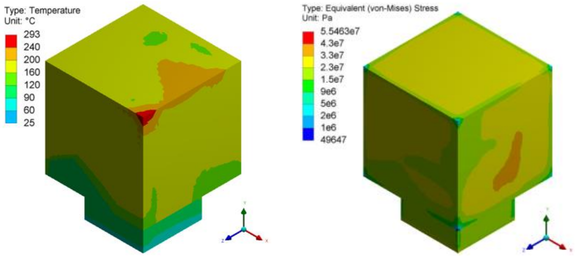
$$D^* = \left(\frac{\dot{Q}}{\rho_\infty C_P T_\infty \sqrt{g}}\right)^{\frac{2}{5}} \qquad (2)$$

The D^* is fire's characteristic diameter, ρ_∞ is ambient density of air (kg/m^3), C_P is specific heat of air (kJ/kg/°C), and g is acceleration of gravity (m/s^2) in Eq. (2). The number of grid was 56,448 through grid sensitivity analysis in FDS. Meanwhile, the analysis model in ANSYS was used by fine mesh which was 309,841 nodes and 73,216 elements.

3. Analysis results

3.1 Structural integrity assessment

The temperature and stress values were numerically estimated. Among cases, the maximum temperature was roughly 293 °C at the upper corner of the reactor module in Case 8. In view of von-Mises stress, the maximum value was also approximately 56 MPa at bottom of the reactor module in Case 4. It was 1.2 times higher than those in Case 8. Fig. 2 shows the temperature and von-Mises stress distribution in Cases 4 and 8. As Comparing with damage criteria, the reactor module sustained integrity in all of cases.



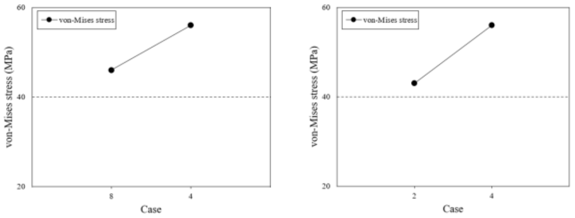
(a) Temperature distribution (Case 8)

(b) von-Mises stress distribution (Case 4)

Fig. 2. Temperature and von-Mises stress distribution in Cases 4 and 8

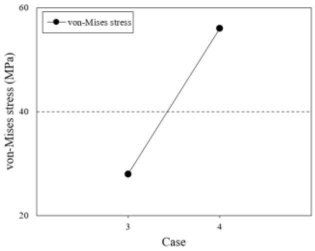
3.2 Parameter analyses

A parametric study was carried out by reflecting fire area, height, and ventilation conditions. Because the von-Mises stress result was maximum in Case 4, those in the case were contrasted with other cases. As results, each parameter was identified in Fig. 3. The ventilation condition was the most effective of parameters.



(a) Area

(b) Height



(c) Ventilation

Fig. 3. Parameter studies results

4. Conclusions

In this research, the structural integrity assessment of the zero-power research reactor was conducted under postulated oil fire, and then, the parameter analyses were performed. The conclusions of this analyses are as follows:

(1) Because distance between ignition source and target was close each other, the maximum von-Mises stress was calculated at the bottom of the reactor module in Case 4. The reactor module also sustained integrity in all of cases.

(2) Among fire parameters, the ventilation condition was more effective than fire area and height under considered fire scenarios.

(3) Further scenarios taking into account various ignition sources and fire parameters are being numerically examined.

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