Preliminary Structural Analysis of a Reactor Module under 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

In the recent, the importance of diverse hazard assessment has been increased more and more as a part of safe design and operation of nuclear structures and facilities. Particularly, fire analyses have been carried out according to strengthened IAEA guideline and national legislation in commercial nuclear power plants [1, 2]. In research reactors, the relevant analyses should be implemented.

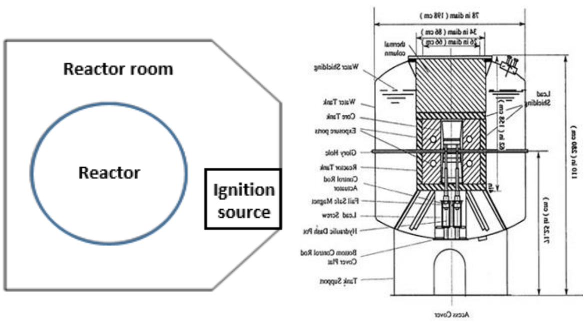
There are various causes of the fire such as oil, electrical, batteries and others. Especially, the oil fire has the highest heat release rate among ignition sources. For this reason, it is necessary to evaluate integrity assessment against oil fire accidents.

The objective of this study is to perform preliminary structural analysis against oil fire in research reactor. Three postulated fire scenarios were implemented and numerically calculated with Smagorinsky turbulence model [3]. In the subsequent, the maximum von-Mises stress of the reactor module was compared with the damage criteria, of which details and key findings will be discussed.

2. Analysis method

2.1 Fire scenarios

The size of reactor room is 4.2 m x 4.2 m x 3.0 m. The research reactor module operates a power of 10 W and is located in reactor room as shown in Figure 1(a) [4]. In fact, there is no oil in the reactor room, however, it was assumed to perform oil fire hazard assessment in this study. Figure 1 represents three postulated oil fire scenarios were divided based on fire area and ventilation conditions [5]. In these scenarios, the ignition source was unconfined oil in floor and the target was the reactor module.



(a) Reactor room (b) Reactor module [4]

Fig. 1. Schematic of a part of research reactor

Table I: Assumed fire scenarios

Scenario	Fire area (m^2)	Ventilation (m^3/s) [5]
A	1	No ventilation
B	4	No ventilation
C	1	0.67

The Figure 1(b) shows a part of research reactor. There are many components and internals in the reactor module. In this study, reactor tank, water shielding tank, upper shielding material, and reactor support were simplified. The reactor consists of SS304 and the material properties were applied according to temperature [5].

2.2 Analysis model and conditions

The heat release rate of ignition source was 4934 kW in NUREG-1934 report [3]. The Fire Dynamics Simulator (FDS) were used to calculate the heat release rate considering ventilation condition. The Computational Fluid Dynamics (CFD) was performed on Smagorinsky turbulence model by ANSYS CFX and the stress values were evaluated by ANSYS Mechanical. The figure 2 represents the analysis model in ANSYS, and the table II summarizes the number of mesh in numerical evaluation.

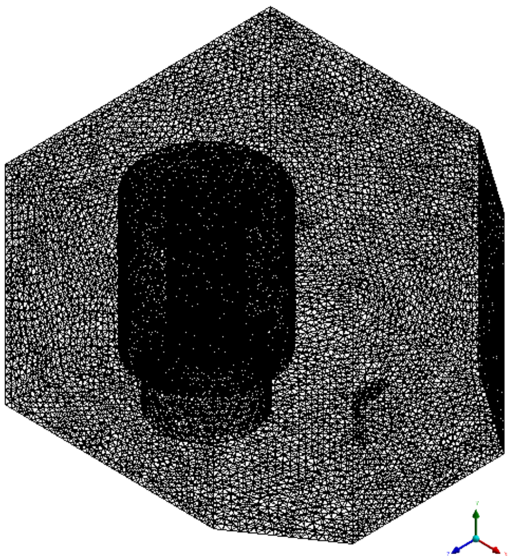


Fig. 2. Analysis model

It was assumed as operators' reaction time (300 sec), which is generally considered in fire suppression. When fire breaks out, the operators put out the fire within 300 sec. The initial temperature was set to 25 °C. The damage criterion was yield strength of the reactor comparing with the maximum von-Mises stress. Any other fire protection systems were excluded due to more conservative analysis.

Table II: Mesh information used in analysis

Identification	Number of mesh
Air	98,758
Water	5,800
Upper shielding material	17,616
Water shielding tank	61,440
Reactor support	18,374
Total	201,988

3. Analysis results

3.1 Heat release rate

Figure 3 represents the heat release rate calculated by considering ventilation condition and the differences were identified. As results, in no ventilation condition (Scenario A), the heat release rate of the fire represents sharp drop soon after the beginning of the fire (38 sec), which assumed that there was insufficient air like oxygen in the compartment to maintain the fire [3]. Meanwhile, the heat release rate applying ventilation conditions were sustained by operators' reaction time because of supplying sufficient air.

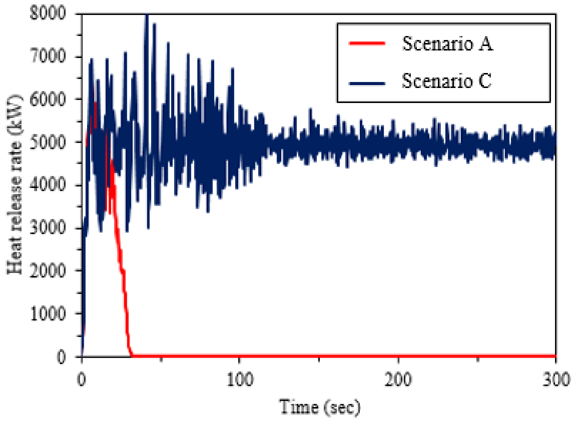
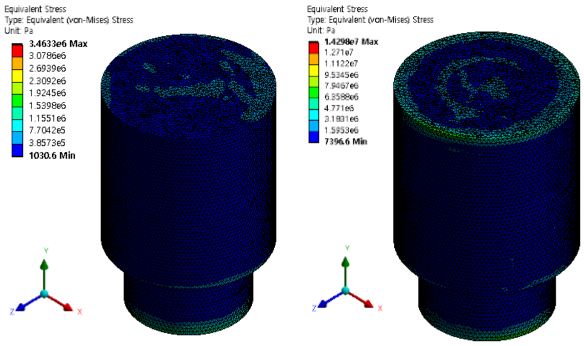


Fig. 3. FDS results according to ventilation conditions

3.2 Integrity assessment

The von-Mises stress of the reactor module was evaluated and those calculated in bottom of the reactor in all of scenarios. In view of fire area, the maximum von-Mises stress in scenario B were 1.5 times higher than those in scenario A. Meanwhile, in view of ventilation condition, the maximum von-Mises stress in scenario C were 4.1 times higher than those in scenario A. Figure 4 shows the distribution of maximum von-Mises stress results in fire scenarios A and C.



(a) Scenario A (b) Scenario C

Fig. 4. ANSYS results dependent on fire scenarios

4. Conclusions

In this research, the preliminary structural analysis against oil fire of reactor module were implemented with three postulated fire scenarios. Subsequently, the maximum von-Mises stress of the reactor was compared with the damage criteria and the conclusions of this study are as follows:

(1) Among fire scenarios, the ventilation condition was more effective parameter than the fire area of ignition source due to heat release rate histories.

(2) As results of the stress values by structural analysis, the reactor module maintained integrity under all of fire scenarios.

(3) Further validation studies and thermal-structural coupled analyses for more various scenarios based on fire area of ignition sources and ventilation condition will be carried out.

ACKNOWLEGMENTS

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (No. 2017M2B2B1072806).

REFERENCES

[1] IAEA Safety Standards Series, Periodic Safety Review (PSR) for nuclear power plants, IAEA Specific Safety Guide No. SSG-25, IAEA, 2013.
[2] NSSC, Regulation Notice of the Nuclear Safety and Security Commission, In Korean, 2018.
[3] USNRC and EPRI, Nuclear power plant fire modeling analysis guidelines, Second edition, NUREG-1934 final report, EPRI 1023259, 2012.
[4] Kyung Hee Univ., Education center information about AGN-201K (Cited August. 18, 2021), http://rrec.khu.ac.kr.
[5] M. H. Jee, C. K. Moon, H. T. Kim, Performance-based fire fighting strategies for confined fire zones in nuclear power plants, Progress in Nuclear Energy 62, pp.16-25, 2013.
[6] EPRI, Materials Reliability Program: Development of material constitutive model for irradiated austenitic stainless steels, MRP-135, Revision 2 final report, 2019.