Preliminary Review of SFUEL code for simulating the severe accident from the spent fuel pool under the complete drainage condition

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1. Introduction

This paper shows the results of the review on 'SFUEL' code, which was developed by SNL for simulating the severe accident of spent fuel pool under the complete drainage condition [1]. The purpose of this review is to get an insight to develop a parametric fast running tool for simulating a severe accident of the spent fuel pool. From this review, it showed that air flow patterns in the channel can have a crucial effect on the overall thermal behaviors including a heat transfer coefficient, the air oxidation from spent fuel pool accident during the complete drainage condition. But the embedded method to find out the natural circulation of hot air through the channel showed an instability sometimes and had a tendency of divergence according to their initial input values for the mass flow rate in the channel. More stable method to get the air flows in the channel needs to be developed for the fast running tool.

2. Methods and Results

2.1 Backgrounds

Storage of used fuel is normally under water for at least 5 years and then often in dry storage. However, in these days, spent fuel pool are increasing its stored quantity and storage density due to the discharged spent fuels have been only kept and stored every years without any efforts for an extension of storage capacity or a final disposal. This growing storage density requires more packed configuration of spent fuel arrangements in the spent fuel pool.

Therefore, it grow to increase the concerns on the safety for the spent fuel facility regardless of its type such as a dry or a wet. To evaluate the safety of such facility, especially, from the severe accident, it needs to define the scope of postulated accident from the spent fuel pool.

From this review study on the SFUEL code, the scope of postulated accident was only limited to a complete drainage accident. Of course, the possibility of occurrence of this complete drainage accident may be extremely very low (~1.0E-6/yr) but its consequences are expected to be quite high.

It is because that the totally exposed fuel can be heated up by strong exothermic oxidation reaction from zircaloy cladding by air. And also the released fission product aerosol from the damaged fuel rod such as a rupture of cladding or a melting of cladding can be more easily transported to the environment because there are no removal by a scrubbing from the pool.

To facilitate the assessment of the safety and a conceptual understanding for design on the spent fuel pool under the above mentioned dry condition, it is necessary to use a parametric tool. The purpose of developing a tool is to predict the maximum possible fuel rod temperature and the amount of fission product for the possible release to the environment under only this dry condition with simple and fast running mode.

From SFUEL code, it showed that the fuel rod temperature may be reached at some steady level depending on the heat balance among the system in the spent fuel facility. This heat balance can be established among the decay heat generation, exothermic oxidation heat generation and various heat transfer mechanisms such as natural convection, radiation and convection and conduction heat transfer among the core and surrounding structures.

However, the primary purpose of this review is to get an insights for the information on the air flows in the channel such as the existing amount of oxygen and the direction of flows depending on the location in the dry channel with a simple and a fast mode. Also this fast running tool will focus on the prediction of fuel rod steady peak temperature up to the cladding rupture time, not on the continuing severe fuel damage phenomena.

2.2 Nodalization of the spent fuel pool

Configuration of spent fuel pool is large rectangular space that fuel bundles are placed vertically in the space. The fuel rod bundles are arranged with adequate spacing to prevent from reaching criticality and to keep them cooling. The region where the fuel bundles are arranged were divided into several annular ring circles. These annular ring consist of fuel bundles, rack, narrow space between each rack, bottom space above the bottom floor in spent fuel pool. Each ring has its own history of decay heat.

The open space above the pool was lumped together as a large containment region. Special components that was considered were two support plates, which has an open-hole to flow the fluid vertical direction regardless of their directions. Figure 2.1 shows the concept of nodalization for the overall spent fuel pool building.

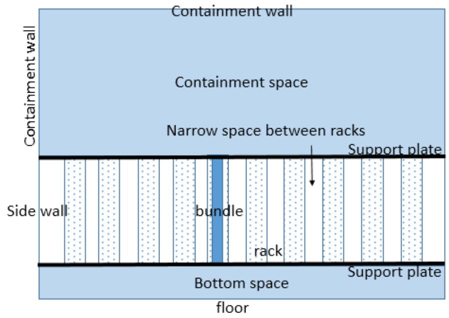

Fig. 2.1 Nodalization of spent fuel pool building

2.3 Natural convection of air in the pool region

Buoyancy driven hot air flow through the pool region was considered. The heat transfer coefficients and amount of oxygen available for the oxidation were derived based on these air flow patterns. This air flow through the bundles, narrow space between racks and the bottom space above the floor may have two direction such as downward, upward or forward, backward depending on the pressures at the boundaries. These boundaries are the upper part of fuel bundles (i.e, containment) and horizontal space above the bottom floor. Figure 2.2 shows the typical flow patterns modeled in SFUEL code.

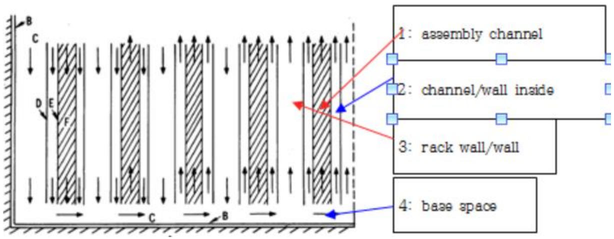

Figure 2.2 typical flow pattern in the pool region

2.4 Exothermic air oxidation

In SFUEL code, the air oxidation phenomena was calculated with two different model. This first model is the rate limited model that the rate of reaction is assumed to obey the parabolic rate law. The second one is the diffusion limited, which is occurred when oxygen is unable to diffuse through nitrogen to the zircaloy surface at fast enough rate to sustain the kinetic reaction.

Consequently, final oxidation reaction use the values, which shows the maximum value between the two models. However, in other code such as MELCOR, the air oxidation was modeled with the pre and the post oxidation phases, respectively. It is estimated that this method is more proper to simulate the air oxidation [2].

Table2.1 shows the coefficients for the correlation on the oxidation of zircaloy by air versus fuel temperature.

Table 2.1 Correlation for zircaloy oxidation by air

Temperature range [K]	C_1 [(mg Zr/cm^2)^{2}*s^{-1}]	C_2 (=E_a/R) [k]
T < 1193	9340	13760
1193≤ T < 1429	4.68E+8	26670
1429 ≤ T	5.04E+5	14630
$RATEK \equiv C_1 e^{-C_2/T}$	$RCN^2 = RCT_o^2 + RATEK * \Delta t$	Divide by $(\rho_{zr})^2$

2.5 Results on the fuel rod temperature from SFUEL

Figure 2.3 shows the fuel rod temperatures from the middle (1.8m) to the top (3.6m) in axial direction from the SFUEL code.

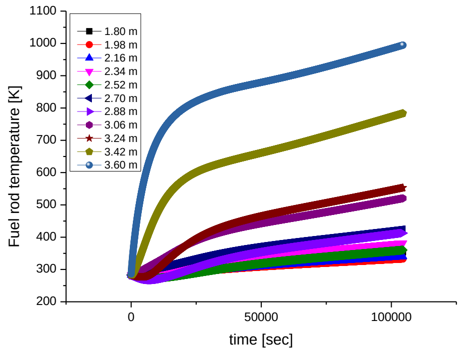

Fig. 2.3. Fuel rod temperatures in the first ring

3. Conclusions

From this review on SFUEL code, the following insight to develop a parametric fast running tool for simulating a severe accident of the spent fuel pool could be obtained.

The model to get the distribution of air flows in the channel can have a crucial effect on the overall thermal behaviors including the heat transfer coefficients, the air oxidation from the spent fuel accident during the complete drainage condition. In SFUEL code, 'modified newton raphson method' was applied to get the information on the air flows in the channel but it shows instability sometimes. More stable method to get the air flows in the channel needs to be developed for the fast running tool.

REFERENCES

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[2] L.L. Humphries et al., "MELCOR Computer Code Mannuals vol.1: Primer and Users' Guide Version 2.2.14959," SNL, Albuquerque, NM 87185-0748, SAND2019-12536 O, 2019