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Preliminary Evaluation of Structural Effect on Extended-term Cooling Capability of On-demand Flooding Safety System Using MARS-KS

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1. Introduction

According to net-zero policy and increasing energy consumption, global competition of small modular reactor (SMR) development has been intensified. Although the SMR is well-known to achieve advanced safety, adequate safety systems are still required for preventing core damage. Furthermore, for public acceptance and ultimate safety without any external response, many safety concepts which secure indefinite grace period have been proposed.

Among them, the NuScale safety concept shows outstanding passivity and simplification while indefinite cooling capability is secured [1]. However, permanently submerged condition of the reactor modules causes several disadvantages such as radioactivation of emergency coolant, difficult maintenance, and larger heat loss during normal operation. In addition, to achieve indefinite grace period adopting higher-powered reactor models, an additional strategy was required. To improve both extended-term safety with higher reactor power and operator's convenience, an on-demand flooding safety system (OFSS) adopting an advanced modularized configuration in the plant building was developed [2].

In the previous studies, the long- (~3 days) and extended-term (> 3days) cooling capability of the OFSS was confirmed [2,3]. In particular, the air-cooled condenser installed on the ceiling re-collect and re-supply the evaporated steam of emergency coolant. However, effects of the structures on heat transfer and mass transfer were neglected and condensate stagnation in the plant building was assumed as adopting re-collection ratio.

Thus, in this study, we investigated the effect of structures in the plant building through numerical analysis. The MARS-KS model was modified adopting additional hydrodynamic volumes and heat structures which represent structures in the plant building.

2. Numerical model

Figure 1 shows the configuration of the OFSS in the plant building. During an accident, the passive residual heat removal system (PRHRS) and emergency core cooling system (ECCS) operate as the PRHRS valve and flooding valve open. The evaporated steam is condensed and re-collected into the common pool. Subsequently, the emergency coolant continues to be available longer. Although the space was illustrated to be vacant, many structural obstacles such as foothold, pillars, pipes, and frames are expected to be installed as shown in Fig. 2.

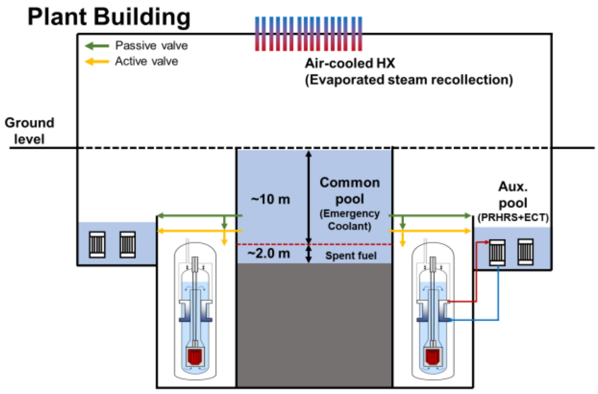

Figure 1. Cross-sectional configuration of the OFSS in the plant building.

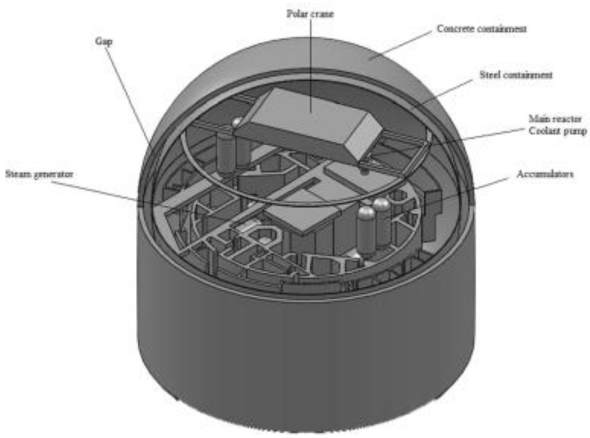

Figure 2. Structures in the VVER-1000 containment [4].

To investigate extended-term cooling capability for the period exceeding 3 days, the simplified models were utilized as shown in Fig. 3. The heat structures installed in the reactor module cavity were set to generate decay heat of 6 reactor modules whose thermal powers are 330 MWt. Three input models were compared to confirm the effect of the structures. Figure 3(a) shows the case without condenser. The evaporated steam is released into the atmosphere. Figure 3(b) shows the case with air-cooled condenser but without structures in the plant building. The steam is confined and condensed in the plant building. However, the structural effect is still excluded. Figure 3(c) shows the case with condenser and structural obstacles in the plant building. To represent the structures, additional volumes and heat structures were modelled. 3 additional volumes were set as 100 m^3.

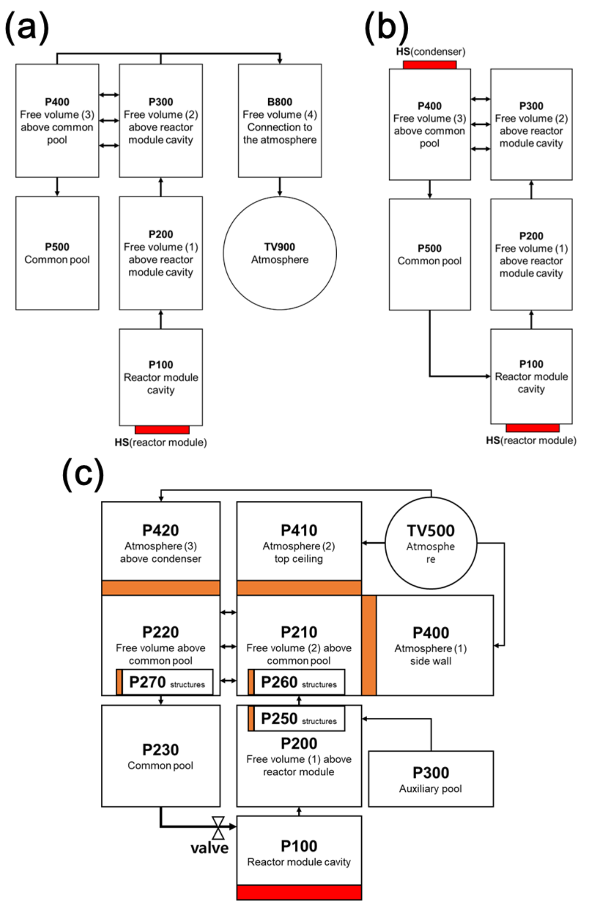

Figure 3. Nodalizations of MARS-KS input models (a) without condenser, (b), with condenser without structures, (c) with condenser and structures.

3. Results and Discussion

Even without re-collection strategy, the depletion time of emergency coolant in the reactor module cavity was evaluated as 38.6 days as shown in Fig. 4. However, the time is expected to be shorter in the practical deployment as the heat structure of the reactor in the simplified models were installed at the bottom of the reactor module cavity. In addition, to achieve initial purpose, the indefinite grace period, the additional strategy is still required. By adopting the condenser and re-collection strategy, the available emergency coolant maintained to be 98% of initial volume as shown in Fig. 5. Figure 5 shows the water level with structural obstacles in the plant building. While partial volume of condensate was stagnated in the additional volumes, most emergency coolant was re-supplied into the reactor module cavity. Thus, the re-collection strategy is expected to be effective even considering the structure effect.

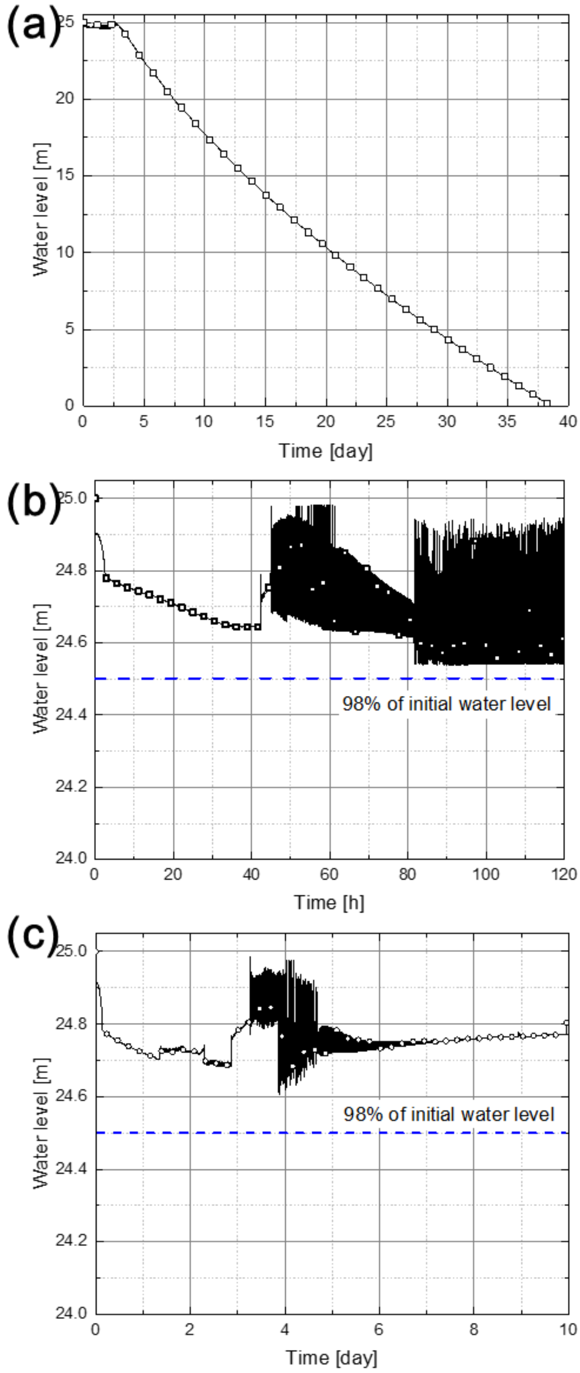

Figure 4. Water level in the reactor module cavity by using OFSS (a) without air-cooled condenser and structural effects, (b) with air-cooled condenser without structural effects, (c) with air-cooled condenser and structural effects.

From the current results as shown in Figs. 4(b) and 4(c), significant fluctuations were observed. The variations can be attributed to several factors such as numerical oscillations resulting from void fraction gradients and two-phase flow phenomena effects.

Considering that an accurate calculation of the collapsed water level requires an additional evaluation, the post-processing method will be improved as future work [5].

4. Summary and conclusion

In this study, the effect of the structural obstacles in the plant building was investigated through numerical analyses using MARS-KS code. The structures were expected to cause advert condensate stagnation in the plant building. Nonetheless, sufficient emergency coolant was expected to be re-collected with the total stagnation volumes of 300 m^3. In other words, the re-collection strategy using the OFSS is still effective to secure indefinite cooling capability even considering structures in the plant building. However, parametric study is needed because the variables were not obtained from specific design.

Acknowledgements

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