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Evaluating the Effectiveness of Alternate Entry Condition into the Severe Accident Management Guidance

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1. Introduction

The onset of core damage is considered to be a core (fuel rod cladding) condition at the time when the core exit temperature reaches the value prescribed for transition to Severe Accident Management Guidance (SAMG), which is 1200 °F. However, during a shutdown state, the core exit thermocouples measurements are unavailable after lifting reactor vessel head. Thus, an alternate means to detect the onset of core damage is necessary to cover all plant operating states. In order for that, a Computational Aid (CA), "Radiation Level as a Functional of Time after Shutdown," has been developed [1].

The upper containment radiation instrumentation is a gross gamma monitor, and has a reliable instrumentation range during severe accidents. It can be used for detecting onset of core damage. Thus, the radiation level can be used as alternative means of the entry condition into the SAMG.

In this study, the effectiveness of the CA as an alternate means is evaluated quantitatively by utilizing the Modular Accident Analysis Program (MAAP) 5 computer code [2] including the MAAP5-DOSE module, which can analyze the radiation level inside the containment.

2. Evaluation of the Effectiveness of the CA

2.1 Description of the Alternate Entry Condition

The relation between cladding failure percentage and the core exit temperature has been known. In order to use the containment radiation level as an alternate means to detect the onset of core damage, it is necessary to identify the relation between the percentage of cladding failures and the core exit temperature entry condition. Normally, if more than 10% thermocouples are indicating the core exit temperature as higher than 1200 °F, it is considered to as the inadequate core cooling. Based on this consideration, a value of 10% failed cladding is recommended for SAMG approaches which use the core exit temperature setpoint of 1200 °F for the SAMG transition criterion.

Figure 1 provides an example to determine the present core damage condition. If the intersecting point of the radiation level and time after shutdown is in the "No core damage" region, as the condition that below a 10% cladding failure, it is not necessary to conduct the accident management in accordance with the SAMG. Whereas, if this intersecting point is in the "Possible Core Damage" region, as the expected condition that the fission products leak out by rapid failure of fuel cladding, it is required to conduct the accident management in accordance with the SAMG.

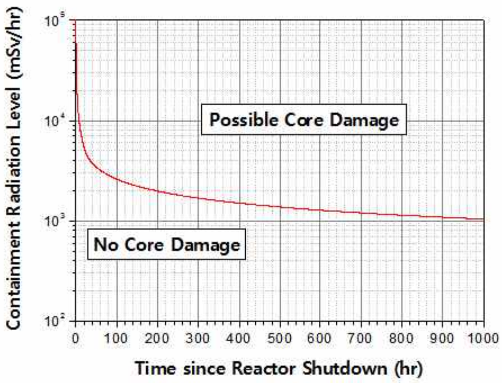

Fig. 1. Radiation level as function of time after reactor shutdown.

2.2 Modeling for Analysis using MAAP5 Code

The MAAP5 code is a useful tool for analyzing the consequences of a wide range of postulated plant transients and severe accidents. Thermal hydraulic behavior of the core and core exit region can be reasonably well analyzed by utilizing the MAAP5 code. In addition, the MAAP5 code can analyze the radiation level inside the containment with the MAAP5-DOSE module. Therefore, the MAAP5 code is utilized to evaluate the effectiveness of the CA as an alternate means by comparing between the core exit temperature and the dose rate inside in the containment.

The MAAP5-DOSE module utilized in this study is composed of five sub-nodes; two steam generator compartment, upper compartment, containment dome, and annular compartment. Because the interested radiation monitor is located in upper compartment, the dose point to calculate the dose rate is determined as the upper compartment.

For the analyses, the station blackout (SBO) is chosen as initial event during a refueling operation. Two scenarios are considered for the sensitivity cases; one is started at 150 hr after shutdown (CASE A) and the other is started at 500 hr after shutdown (CASE B). The differences between two cases are the timing of fuel extraction and reloading operation.

2.3 Results of Analyses

The effectiveness has been investigated by comparing the SAMG entry timings determined by the core exit thermocouples measurement and the radiation monitoring (the CA). If the time difference is small, it can be concluded that the CA has the effectiveness.

The results of the analyses are illustrated from Fig. 2 to Fig. 5. As shown in Fig. 2, the time that the core exit temperature exceeds 1200 °F in Case A is 44747 sec (745.8 min) after the initial event. If the core exit thermocouples are available, the operator can identify the onset of core damage at this time and may start to use the SAMG. If the core exit thermocouples are not available, the onset of core damage should be indicated by Fig 1. The radiation level which indicate "Possible Core Damage" region at 150 hr after reactor shutdown is about 2000 mSv/hr. And, the time that the containment radiation level exceeds 2000 mSv/hr in Case A is 45131 sec (752.2 min) after the initial event as shown in Fig 3. In this case, the operator can identify the onset of core damage at this time. The time interval between two means to indicate the onset of core damage is 6.4 min in Case A.

In Case B, the time that the core exit temperature exceeds 1200 °F is 75475 sec (1257.9 min), and the time that the containment radiation level exceeds 1200 mSv/hr (500 hr after reactor shutdown) is 76258 sec (1271.0 min) as shown in Fig 4 and Fig. 5. The time interval is 13.1 min in Case B.

Since the radioactivity of the fission product in the core and the decay heat decreases with the passing of time, the heat-up rate of the core also decreases as shown in Fig. 2 and Fig. 4. Thus, the time interval in Case B is longer than that in Case A.

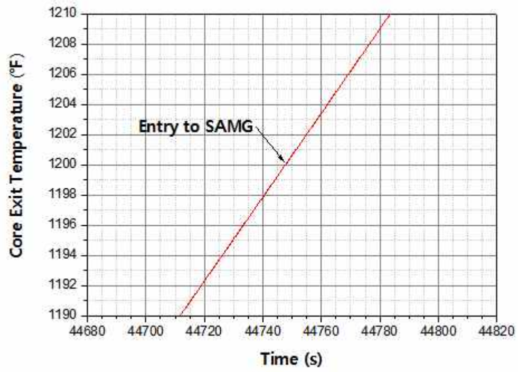

Fig. 2. Core exit temperature in Case A.

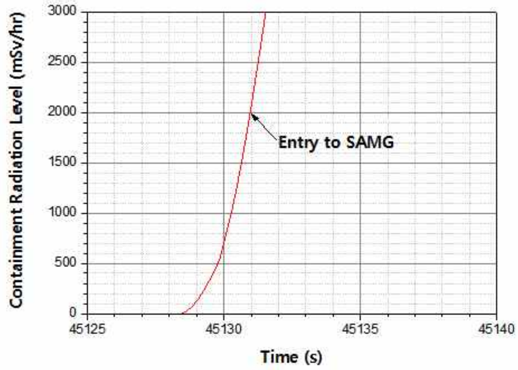

Fig. 3. Containment radiation level in Case A.

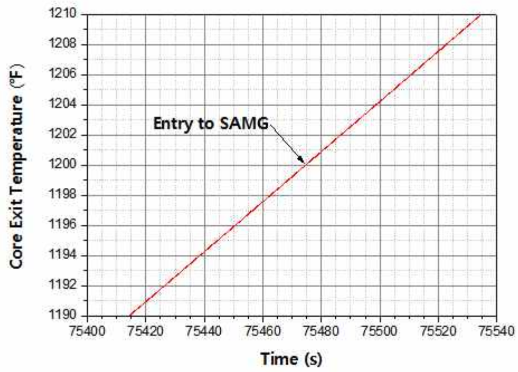

Fig. 4. Core exit temperature in Case B.

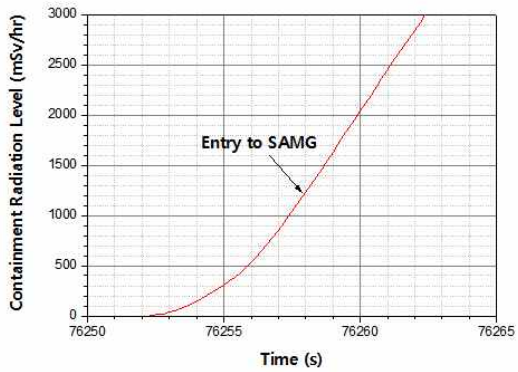

Fig. 5. Containment radiation level in Case B.

3. Conclusions

The effectiveness of the CA has been investigated by utilizing the MAAP5 code including the MAAP5-DOSE. It has been shown that the SAMG entry timings determined by using the core exit thermocouple measurements and by the radiation monitoring with the CA would not be differentiated. The time difference estimates entering SAMG would be less 15 min which would not influence the operator action significantly. Therefore, it can be concluded that the CA, "Radiation Level as a Functional of Time after Shutdown," is effective as an alternate means when the core exit thermocouples measurements are unavailable.

REFERENCES

[1] "Generic Severe Accident Management Guidance for the Advanced Power Reactor 1400 MW," Korea Hydro & Nuclear Power Company, Ltd., 2012.
[2] "Modular Accident Analysis Program (MAAP 5) Version 5.0.3 - Windows," Electric Power Research Institute, August 2014.