Development of MAAP5.0.3 Dose Model for Radiation Environment Effect Analysis

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1. Introduction

After the Fukushima accident, the importance of the severe accident management guideline (SAMG) has been greatly magnified. In Korea, the SAMG for all nuclear plant had been already developed against the accidents during full power operation mode. And, after the Fukushima accident, the SAMG for low power and shutdown mode is being developed including the strategies to mitigate the accident in the spent fuel pool. In addition to this, the revision of the existing SAMG by considering the actual effectiveness is being progressed.

To establish the effective SAMG strategies against the severe accident, the operability of the mitigation facilities and the accessibility to them is mostly important. So, the equipment survivability assessment under the severe accident conditions should be performed.

For the environmental conditions such as the pressure and temperature, they can be calculated using MAAP (Modular Accident Analysis Program) code. However, since MAAP itself cannot calculate the radiation DOSE, MAAP5 DOSE model should be developed in order to calculate the DOSE rate during the severe accidents.

In this study, we developed the MAAP5 DOSE model for spent fuel pool of OPR1000 type NPP and calculated the DOSE to assess the survivability of the facilities in spent fuel pool and fuel handling region.

2. Methods and Results

2.1 The characteristics of MAAP DOSE module

Originally, the MAAP DOSE module is the separated independent code from MAAP. However, in the MAAP5 code, the DOSE module is integrated to the MAAP code to function as a DOSE model under the control of the MAAP code. The integrated MAAP5 code, functioning as a single code, provides an extra capability to calculate the radiation dose simultaneously with the progression of an accident. The calculation of DOSE module is independently performed except the interface for fission products information with MAAP even though it is performed in the MAAP code frame. The interface between the MAAP and DOSE module is shown in Fig. 1.

The purpose of MAAP5 DOSE module is to calculate the radioactivity, dose rates, and doses in the containment and auxiliary building node specified in MAAP code. In addition to these, the dose rates and doses at off-site locations specified by the atmospheric dilution factor (χ/Q) from the release point can be calculated.

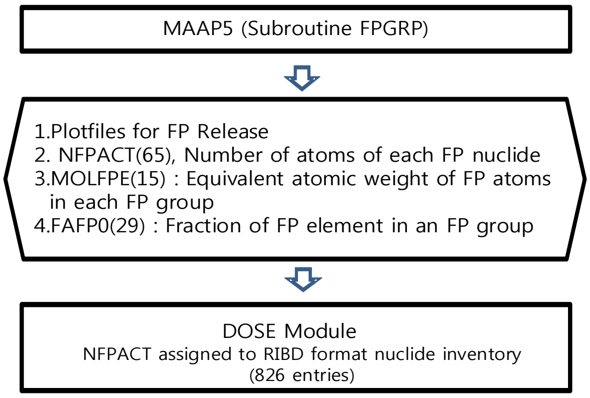

Fig. 1. Interface between MAAP and DOSE Module

Generally, the MAAP DOSE module calculates the dose for the anteroposterior of adult human applying the dose conversion factor based on the energy strength. However, in case of dose calculation for the facilities or equipments, the dose conversion factor should not be considered. So, it is appropriate that the method compensating the 0.533 as the dose conversion factor for 0.1 Mev is used.

2.2 Dose calculation model

The dose calculation model in MAAP5 has two options: the AST-based dose model (MAAP-AST) and the point-kernel-based dose model (MAAP4-DOSE).

MAAP-AST model was developed for the design basis alternate source term application. So, The AST-based dose model conforms to U.S. NRC Regulatory Guide 1.183 on the Alternative radiological Source Terms (AST) for evaluating design basis accidents at nuclear power reactors

The point-kernel method is typically used in radiation shielding calculations that consider both material attenuation and geometric attenuation. This method as implemented in the code can calculate dose contribution from an adjacent room through the concrete wall which can be significant during severe accidents. The dose conversion method used in the code conforms to the ANSI/ANS-6.1.1-1991 standard which is based on ICRP-1987.

In case of AST-based dose model, the concentration has the same value for the whole corresponding area with one source, but in the point-kernel method, the concentration has the different value according to the measurement location. In addition to this, the point-kernel method does not calculate the dose if the radiation should have to penetrate more than one wall from the source to the dose point.

So, it is judged that the point-kernel method is more proper than MAAP-AST model for dose calculation during the severe accident since it is known that the MAAP-AST model produced the less conservative value than that of point-kernel method.

2.3 Dose Model parameter development

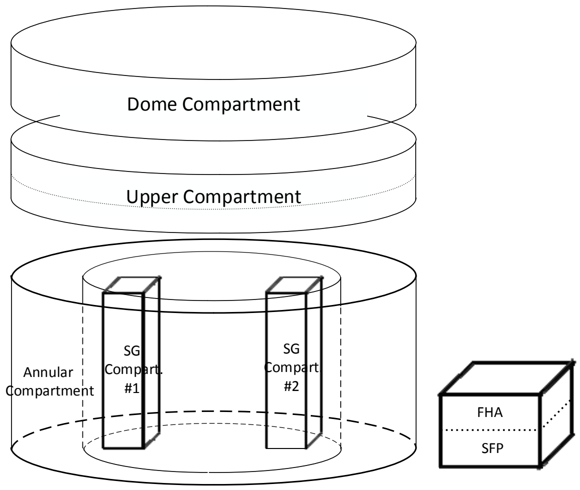

Fig 2. MAAP DOSE Compartment Nodalization

Figure 2 shows the nodalization for dose calculation in MAAP DOSE module. In the MAAP DOSE module, there are 3 types of geometry for nodalization such as rectangular box, cylinder, and annular cylinder. So, we nodalized the containment into 5 nodes and the spent fuel building into 2 nodes as shown in Figure 2. In the MAAP code for severe accident phenomena analysis, the spent fuel building is nodalized into 1 node. However, in the DOSE module to calculate the dose, the spent fuel building is divided into 2 nodes, spent fuel pool (SFP) and fuel handling area (FHA).

2.4 Accident Scenario and Initial Condition

In order to calculate the dose in SFP and FHA, the loss of SFP cooling accident without any recovery actions is considered for the SFP of OPR1000 type NPP.

For the condition of SFP, the general assumptions in order to assess the severe accident phenomena in the typical SFP are used. It is assumed that the whole core is transferred in the SFP for refueling, the refueling interval is approximately 18 months and that the one-third of the fuel assemblies in the entire core is replaced at each refueling. Also, it is assumed that 10 cycles fuel assembly are accumulated in the SFP. And, first fuel assembly group consists with three type of batch. It is assumed that the one cycle outage length is 1 month (30 days). We use the 30 channels model which modeled the 12 spent fuel racks. The entire fuel assemblies are classified into 12 groups. In these 12 groups, there are 3 groups of fuel assemblies transferred into SFP for refueling and the cooling time for these 3 groups is assumed to be 150 hours.

The enrichment of the whole spent fuel is assumed to be 4.2w/o ^{235}U conservatively. And the fraction of elemental iodine and organic iodine is assumed to be 4.85% and 0.15% respectively

The total mass of fission products elemental group in the entire spent fuel pool at time zero, the fraction of decay power in each MAAP fission product group, and the fraction of decay power in each MAAP fission product group are determined by the results of OrigenArp 5.1.01 code calculation.

2.5 Analysis Results

The representative major event occurrence time for loss of SFP cooling accident is summarized in Table 1.

Table 1. Major Accident Progression

Fuel Assembly Uncover (S)	SFP Dryout (S)	BMT (S)
228630 (64h)	290618 (81h)	598000 (166h)

Figure 3 shows the change of total external dose (DDE) according to the accident progression. As expected, the DDE is started to increase after the fuel is uncovered.

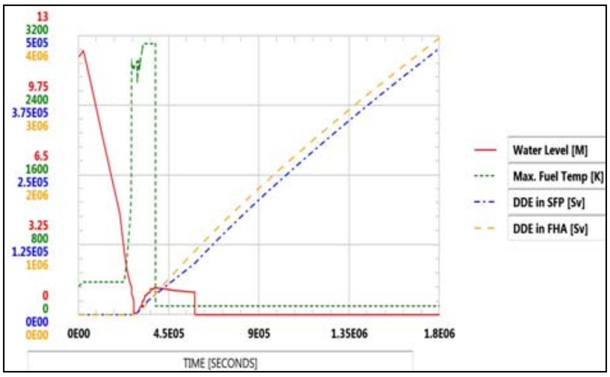

Fig. 3. The change of DDE according to the Accident Progression

Figure 4 shows the change of total external dose rate (RDDE) according to the accident progression. In this figure, it is known that the dose rate in the SFP is much larger than that in the FHA. This is important because there are few facilities in the SFP. Figure 5 shows the comparison of the change for DDE and RDDR.

Until now, there is no international or domestic criterion for radiation dose from the view point of equipment survivability. So, it is the typical method to apply the criterion for the equipment qualification (EQ).

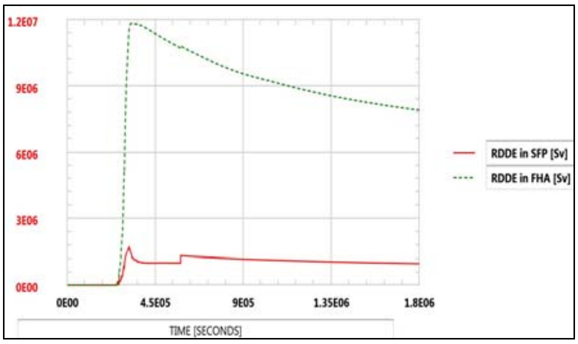

Fig 4. The change of RDDE

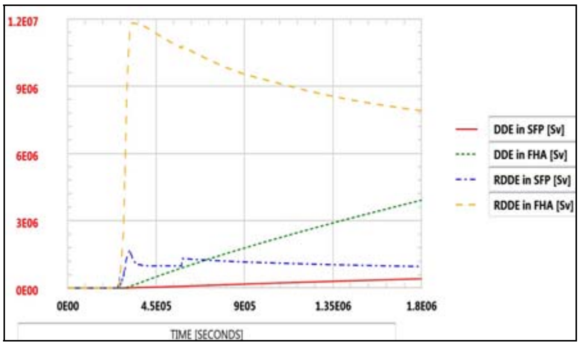

Fig 5. The Comparison of DDE and RDDE

In the EQ condition, the dose rate is limited as 4 Sv for FHA which is the criteria for DBA like the damage of new fuel. So, this criterion is not appropriate for the severe accident case. Also, the dose rate in SFP is limited as 4E9 Sv. This criterion is not also appropriate because it is too much high.

The dose rate criterion of EQ condition inside the containment is limited as 2E6 Sv. So, it is judged to be reasonable that this criterion should be used for SFP and FHA. According to the analysis result, the RDDE in FHA is exceeded this criterion at approximately 77 hr after the initiation of accident. And the DDE in FHA is exceeded this criterion at approximately 272 hr after the initiation of accident.

3. Conclusions

Until now, there are so many uncertainties in the analysis for radiation effect during the severe accident. However, in terms of the establishment of the severe accident management strategy, quantitative analysis in order to find the general trend for radiation increase during the severe accident is useful.

For the radiation environmental effect analysis, the previous studies are mainly focused inside the containment. However, after the Fukushima accident, the severe accident phenomena in the SFP have been the great issues in the nuclear industry including Korea.

So, in this study, the dose rate for spent fuel building when the severe accident happens in the SFP is calculated using MAAP5 DOSE.

As expected, the dose rate is increased right after the spent fuel is partially uncovered. However, the amount of dose is less significant since the rate of temperature increase is much faster than the rate of dose increase. In other words, it can be judged that the most important environmental factor for equipment survivability during the severe accident in the SFP is not the radiation dose but also the temperature.

Up to now, there are so many uncertainties in MAAP5 DOSE model and the parameters. So, the more sensitivity study should be needed for more detailed and appropriate analysis.

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