Supercritical Kinetic Analysis of Accumulated Fuel Debris in the Fukushima-Daiichi NPS

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INTRODUCTION

Criticality safety is an important issue in safely decommissioning the Fukushima-Daiichi Nuclear Power Station (NPS). It is necessary not only to prevent a criticality of fuel debris in the core during the fuel debris reloading process, but also to estimate the released energy and expected radiation dose in a re-criticality accident in order to establish safety measures for workers. Especially in the case of a prompt supercritical condition, the transient is so fast that it is difficult to take any action at all after the detection of the criticality. It is essential to estimate the energy and the dose in advance and with the highest possible accuracy in order to establish the measures to be taken. Point-kinetic analysis may not serve this purpose if the fuel debris is large and/or if some fuel debris is coupled weakly from the viewpoint of neutron transportation. Therefore, space-dependent and time-dependent neutron transport analysis is necessary to estimate the radiation dose. The MIK code was developed for a space-dependent neutron transport kinetic analysis based on the integral kinetic model [1][2], and some preliminary analyses have been carried out for some ideal geometries [3][4]. The purpose of the present study was to show the applicability of a MIK code based on the integral kinetic model to an analysis of practical fuel debris geometry in which fuel debris accumulates at the bottom of a reactor.

ANALYSIS CONDITIONS AND METHODS

Fig. 1 shows the geometry of the fuel debris in the present analysis. There is a flat cylinder of consolidated fuel debris on the concrete floor. Fragmented fuel debris particles in the shape of a cone are found on the consolidated debris in light water. Table I shows the parameters of the geometry of each region. The composition of the fuel debris in the present analysis was 53% UO₂, 11% Zr, 10% ZrO₂, 11% Fe and 15% other minor elements (Cr, Ni, Si, etc.). Uranium enrichment was set at 5%.

The effective multiplication factor of the system is obtained by continuous energy Monte Carlo code MVP2.0 [5] and the JENDL-4.0 nuclear data library. Several parameters for the MIK code analysis were also obtained through analyses by MVP2.0. In this analysis, the fuel debris is divided into three regions, as shown in Fig. 2. The kinetic analysis was performed by setting the effective multiplication factor at unity with very low power in the initial condition and inserting stepwise excess reactivity at time 0. The reactivity feedback of the fuel debris by the Doppler effect and by temperature increase is taken into account during the transient. It is assumed that there is no heat transfer from the fuel debris to the water during the transient. The MIK code treats prompt neutrons only. Thus, excess reactivity in the present analysis means excess reactivity above the prompt critical condition.

RESULTS AND DISCUSSION

The effective multiplication factor obtained by the MVP calculation was 1.0141 (1 sigma = 0.01%). The kinetic analysis was performed by MIK code, inserting the stepwise reactivity. Fig. 3 shows changes in the fission rate and temperature of each region. The figure shows that the power of Region 1 increases after the reactivity insertion and then decreases rapidly. The power of Region 2 is not as high as that of Region 1 but is still significant, and its peak is slightly delayed compared to that of Region 1. The power of Region 3 is so small compared to that of the other two regions that it can be considered negligible. The total energy released was 533MJ in Region 1, 54MJ in Region 2, and 3 MJ in Region 3. This means that Region 1 is the dominant region in the estimation of radiation dose, but that it is necessary to take into account the effect of the fission in Region 2 in calculating radiation dose. It is also necessary to take into account the shielding effect of Regions 1 and 3 in the estimation of the radiation dose of Region 2. The fission power ratio among regions can be different in different geometries; therefore, a space-dependent kinetic calculation is needed for this kind of geometry. The current MIK code can treat Doppler feedback only. It will be possible to perform more detailed analyses when other feedback effects are included.

CONCLUSIONS

We carried out a space-dependent kinetic analysis of fragmented debris particles that accumulated on consolidated fuel debris in light water. Our results showed that the space-dependent analysis code MIK can provide information about the released energy in each fuel debris region. This provides useful information for the exact estimation of radiation dose in the event of a re-criticality accident. More detailed analyses are needed for fuel debris with various geometries and various compositions.
REFERENCES


TABLE I. Geometry of fuel debris.

<table>
<thead>
<tr>
<th>Region</th>
<th>Volume of the region</th>
<th>Fuel debris particle radius</th>
<th>Volume packing fraction of the particles</th>
<th>Horizontal angle of the cone</th>
<th>Height of the cone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conical fragmented fuel debris region</td>
<td>4.7x10^5 cm^3</td>
<td>0.1 cm</td>
<td>0.6</td>
<td>30°</td>
<td>53.0 cm</td>
</tr>
<tr>
<td>Cylindrical solid fuel debris region</td>
<td>5 cm</td>
<td>150 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindrical concrete region</td>
<td>30 cm</td>
<td>180 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindrical light water region</td>
<td>30 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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