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THESIS OUTLINE

Supercritical transient analysis in possible fuel debris systems at Fukushima Daiichi NPS by multi-region approach based on integral kinetic model

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In this study, supercritical transient analyses in various fuel debris systems - from rather ideal to more practical yet hypothetical - possible at the Fukushima Daiichi NPS (1FNPS) were performed using the integral kinetic model based approaches (IKM-based approaches).

Chapter 1. Introduction

As a consequence of the Great East Japan Earthquake and tsunami, the reactor cores in Units 1-3 of the Fukushima Daiichi Nuclear Power Station (1FNPS) were damaged resulting in a formation of fuel debris. The effort to decommission the 1FNPS has started shortly after the accident and is expected to take further 30-40 years until the completion. One major part of decommissioning is a fuel debris retrieval from the damaged reactors. Currently, the full or partial submersion method is preferred for the retrieval, however, there is a risk of criticality accident due to the presence of water in the submersion method. From the viewpoint of safety, depending on the criticality control strategy to be chosen, the fuel debris retrieval strategy must make sure that fuel debris does not become critical in any scenario during the retrieval, or the risk must be evaluated beforehand for possible accident and its mitigation method must be determined. In either case, criticality analysis for fuel debris system in various scenarios is expected to be performed to support the decision making. Transient analysis is crucial for an evaluation of a consequence of possible criticality accident in terms of power, energy release, and dose. However, so far there has been no study on transient behavior in any fuel debris system.

In this study, the IKM-based approaches, which are relatively new space/region-dependent method based on neutron transport method, were used for transient analysis. In addition, the one-point kinetics model (PKM), which is well known conventional method, was used as a comparison in several cases.

The main purpose of this study was to establish the IKM-based approaches as an applicable method to transient analysis in various fuel debris systems possible at the 1FNPS. In the current study, an adiabatic (i.e., no heat transfer) supercritical transient following a step-wise reactivity insertion was considered in all systems.

Chapter 2. Transient analysis in simple coupled fuel debris system by integral kinetic model based approach

This chapter introduced the IKM-based approach, which describes a space/region-dependent fission rate in a system with arbitrary complex geometry utilizing Monte Carlo neutron transport method, in detail including the method to obtain the kinetic parameters and the feedback modeling.

The IKM-based approach was applied to supercritical transient with Doppler feedback in simple two-region coupled fuel debris systems for the first time as a demonstration of its applicability to fuel debris. Several coupled fuel debris systems were made by changing the distance between the regions. As a result, region-wise fission rate profile, energy release, and temperature were obtained. The results also showed the important effect of the surrounding debris on the consequence of transient excursion. For example, energy release in the two-region systems were about 74-90% higher than that in the single-region system under the same reactivity insertion.

Chapter 3. Comparative analysis between integral kinetic model based approach and one-point kinetics model

The purpose of the study in this chapter was to investigate the applicability of the IKM-based approach and the PKM to supercritical transient with Doppler feedback in systems with generic geometric feature of symmetry and asymmetry. In specific, the IKM-based approach and PKM were applied to supercritical transient in simple two-region fuel

debris systems of symmetric and asymmetric geometry. Several coupled fuel debris systems were made by changing the distance between the regions.

It was found that the PKM overestimated the fission rate profile and energy release as compared to the IKM-based approach. The overestimation was much profound, i.e. about 12-34%, in the asymmetric systems. The reason of this overestimation was found to be due to the feedback modeling in the PKM. The results of the analyses in this chapter suggested that the PKM overestimates energy release compared to the IKM-based approach especially in asymmetric systems if correction is not made for a feedback modeling in the PKM. In general, the study in this chapter confirmed the applicability of the IKM-based approach to supercritical transient with Doppler feedback in simple coupled fuel debris systems with generic geometric feature of symmetry and asymmetry.

Chapter 4. Improved integral kinetic model based approach

In this chapter, the improved integral kinetic model based approach (improved IKM-based approach) was introduced in detail. The improved IKM-based approach has been developed in this study by making the new method to calculate the kinetic parameters and functions using Monte Carlo method and by extending the feedback modeling capability considerably to treat multiple regions.

The improved IKM-based approach was verified and validated by means of Godiva experiment. The verification results showed that the improved IKM-based approach works well with different combinations of regions and is in acceptable agreement with the PKM when the feedback is ignored. On the other hand, in the validation calculation, the thermal expansion feedback, which is a major feedback in Godiva, was considered. The validation results were in reasonable agreement with the experimental results in the burst range caused by the prompt neutrons. The tail part of the experimental result caused by the short-lived delayed neutron precursors was not reproduced by the simulation because the treatment of the delayed neutrons has not been implemented yet in the improved IKM-based approach.

Chapter 5. Transient analysis in hypothetical fuel debris systems by improved integral kinetic model based approach

The purpose of the analysis in this chapter was to confirm the applicability of the improved IKM-based approach to supercritical transient with Doppler feedback in more practical yet hypothetical fuel debris systems possible at the 1FNPS, and to investigate the effect of several variables on the consequence of transient excursion. The hypothetical system was based on the scenario, in which small fuel debris particles fall and pile on some consolidated fuel debris inside light water leading to criticality accident.

The angle of repose of fragmented conical debris, height of consolidated cylindrical debris, and enrichment of ^{235}U were systematically changed to investigate their effect on the consequence of the supercritical transient excursion. As a result, region-wise power, energy release, and temperature were obtained for each system. Also, it was found that, in the range of these variables considered in this study, the enrichment of ^{235}U has the highest impact on the consequence of the transient excursion in terms total energy release while next parameter with the highest impact was the angle of repose of fragmented conical debris.

As a quick comparison to the improved IKM-based approach, simple Nordheim-Fuchs model in the framework of the PKM was also applied to these systems. The results in terms of total energy release by two methods were compared. It was found that Nordheim-Fuchs model overestimated total energy release in all systems by about 20-290%, except for two systems, in which consolidated debris is absent. The reasons of the overestimation and underestimation were discussed.

Chapter 6. Conclusions

In this chapter, the results of this study were summarized. In general, this study established the IKM-based approaches as a useful tool for supercritical transient analysis in fuel debris systems. In addition to this, suggestions for future studies on transient analysis for fuel debris and on further development of the improved IKM-based approach were briefly discussed.