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Article / Book Information

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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

The Fukushima Daiichi NPS (1FNPS) was severely damaged due to the Great East Japan Earthquake and resulting tsunami. Specifically, the reactor cores of Units 1-3 experienced a meltdown to varying extent, resulting in the formation of fuel debris. Shortly after the accident, an effort to safely decommission the damaged reactors has started and is expected to take about 30-40 years. One major part of the overall decommissioning is a fuel debris retrieval from the damaged reactors. Currently, several candidate methods, namely full or partial submersion and dry, are being considered for the fuel debris retrieval with the submersion method as a preferred method. However, there is possibility of criticality accident in fuel debris due to the presence of water in case of the submersion method. Analyzing the possible criticality accident by an appropriate method is crucial for a risk estimation and safety measures, which are essential parts of safe decommissioning and safety of workers, should the submersion method be selected.

In this study, the multi-region approach based on the integral kinetic model (IKM), which is neutron transport theory based space- and time-dependent transient methodology, was utilized. The IKM defines region- and time-dependent fission rate during a transient in fissile system of arbitrary geometry. Key kinetic parameters and functions of the given system for the IKM can be obtained with Monte Carlo transport method, which provides the IKM a necessary geometrical flexibility.

The purpose of this study was to establish the IKM-based approaches as an applicable method to transient analysis in various fuel debris systems – from rather ideal to more practical yet hypothetical – 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.

First, the IKM-based approach was applied to the supercritical transient with Doppler broadening feedback in simple coupled fuel debris systems of two-regions for the first time. Several weakly coupled systems were made by changing the distance between the regions. As a result, region-wise power profile, energy release, and temperature change were obtained for each system. The obtained energy release in two-region systems was about 74-90% higher than that in single-region system under the same reactivity insertion condition. This analysis confirmed the applicability of the IKM-based approach in simple coupled fuel debris system for the first time.

Secondly, the IKM-based approach was compared with the one-point kinetics model (PKM), which is rather conventional well known method. In specific, the both models were applied to supercritical transient with Doppler feedback in simple two-region fuel debris systems with generic geometric features of symmetry and asymmetry. Various amounts of reactivity were inserted by changing the distance between the regions. The results showed that the PKM overestimated the power and energy release compared to the IKM-based approach, especially in the asymmetric systems. For example, the PKM gave about 12-34% higher energy release than the IKM-based approach in the asymmetric systems. The reason of the overestimation was an assumption of uniform temperature distribution in whole system in the PKM. This analysis suggested that IKM-based approach is inherently better than the PKM in terms of feedback modeling. In general, this analysis confirmed the applicability of the IKM-based approach in simple fuel debris systems with generic geometric features of symmetry and asymmetry.

Third, the existing IKM-based approach was improved with the development of the new method to calculate the kinetic parameters and functions necessary for the IKM using Monte Carlo transport method, and with the considerable extension of the feedback capability. The improved IKM-based approach was attempted to be validated by the Godiva experiment. The simulation considering the thermal expansion feedback gave the results that are in reasonably good agreement with the experimental results in the prompt burst range caused by the prompt neutrons. The tail part of the experimental result that was caused by short-lived delayed neutron precursors was not reproduced in the simulation because currently the effect of delayed neutrons has not been implemented yet in the improved IKM-based approach.

Finally, the improved IKM-based approach was applied to supercritical transient with Doppler feedback in more practical fuel debris systems in terms of geometry and composition compared to the previous fuel debris systems. In specific, the systems, in which small fuel debris particles fall down on top of some consolidated fuel debris inside of light water making a supercritical system, were considered. Various amounts of excess reactivity were considered by changing the height of consolidated debris region, angle of repose of fragmented conical debris region, and enrichment of ^{235}U. The results showed that power and energy release increased as the height, angle of repose, and enrichment increased. Within the considered ranges of these three variables, the enrichment was found to be the most influential variable on the consequence of the supercritical transient excursion in these systems followed generally by the angle of repose. In addition, simple Nordheim-Fuchs model in the framework of the PKM was utilized to estimate total energy release, and the obtained results were compared with that by the improved IKM-based approach. The comparison showed that in most of the systems Nordheim-Fuchs model overestimated the energy release by about 20-290%. These analyses confirmed the applicability of the improved IKM-based approach to supercritical transient in more practical yet hypothetical fuel debris systems with rather complicated geometry.

In general, this study established the IKM-based approaches as an applicable method to transient analysis in various fuel debris systems possible at the 1FNPS.