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Direction of Near-Term Research to Support Regulations in the Field of LOCA

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1. Introduction

Korea Institute of Nuclear Safety (KINS), as a regulator of nuclear power plants, has carried out regulatory research to ensure the validity and reliability of its regulations and to confirm the resolution of the existing and new safety issues, especially in the field of loss-of-coolant-accident (LOCA). With the recent re-planning of Korea Foundation of Nuclear Safety (KOFONS)-sponsored safety researches, it has been required to establish a research plan that can focus on a specific subject and produce a specific result rather than on a wide range of fields as in the past. Accordingly, the main direction of the safety analysis auditing system research was determined to focus on the development of regulatory technology taking into account the fuel burnup effect, and the near-term research direction in the LOCA field was established to realize it specifically [1]. Although it is still true that research is needed on a number of issues, including detailed phenomena of LOCA, its best estimate (BE) calculation, uncertainty assessment, and the performance of new and passive devices, it is very difficult to find a comprehensive research theme to consider them as detailed items. These traditional research items will be optionally considered under the top tiered topic ‘consideration of the high burnup effect’.

The present paper discusses the direction of near-term research in LOCA field derived through the results and insights of the researches so far.

2. Insights from the Previous Research

In the KINS's regulatory research from 2012 to 2017, studies have been carried out to reflect new safety features and new safety standards in the current regulatory framework [2]. The new safety features here meant facilities such as safety injection tanks (SIT) equipped with fluidic device (FD), Emergency Core Cooling System (ECCS) core barrel duct (ECBD), and passive auxiliary feedwater system (PAFS), and the focus of the study was to assess how the design employed them would affect the progression of LOCA. In addition, the new safety standards meant the revision of the ECCS performance rule and the Reactivity Initiating Accident (RIA) rule reflecting the effects of burnup, and the research sought to establish the regulatory auditing technology by understanding the technical basis of the regulations and evaluating the phenomena occurring under actual high burnup conditions.

In the post-2018 research direction, as the construction plan of the new nuclear power plants became uncertain due to the de-nuclear stream in Korea, the portion of the new facility was reduced and the items required for strengthening safety standards became the main focus. To effectively consider the interaction between fuel and system under LOCA condition, a code has been developed by integrating FRAPTRAN code calculating the fuel rod behavior and MARS code calculating the system thermal-hydraulic response [3]. Validation effort for the integrated code has been performed for the experiments from HALDEN and LOFT. Also the fuel specific phenomena such as Fuel Fragmentation Relocation and Dispersal (FFRD) which should be considered for the effect of burnup have been studied since 2018. Additionally, research on development of regulatory auditing analysis methodology using the integrated code has been conducted for large break LOCA and some of the Non-LOCA events. Specific and important research items were as follows:

a. Maintenance and improvement of the integrated code
b. Validation of the integrated code
c. Fuel relocation model and implementation
d. Flow blockage model and validation
e. Multi-layer model and implementation
f. Prediction of rupture fraction in full core
g. Mobility of fragmented fuel particles
h. BE Plus Uncertainty of LBLOCA in actual plants
i. Generation of fuel burnup history in full core
j. Others

Those detailed research items were designed to complete the regulatory auditing technology to ensure that the licensee’s analysis of design basis accidents adequately address the effects of fuel burnup in the future regulations on this issue. From the results of the research, it was evaluated that the study of each item has been conducted properly in a given environment and generally achieved close to its specific objective. However, in the course of the study, further study was found to be necessary to achieve the actual research objective as follows [3]:

a. Modeling scheme to simulate the multiple fuel rods under different power peaking and burnup level for use of the integrated code
b. Multi-dimensional thermal-hydraulic capability incorporating the effect of the fuel rods of different characteristics

c. Analytical capability to properly reflect the effects of flow blockage due to the fuel behavior with various characteristics under LOCA environment
d. Determination of uncertainty parameters for the fuel burnup and multi-dimensional nature using the integrated code

In addition to these four items, many of the basic research needs were derived, such as the establishment of experimental database, the supportive use of detailed computational fluid dynamics analysis technology. They should be optionally included in the development of specific research plans in addition to the above four important items.

3. Direction and Specific Contents

The direction and its details of the four research needs derived above are as follows.

3.1 Multiple Fuel Rods Modeling

The FRAPTRAN code embedded in the current integrated code performs the calculation of the single fuel rod. This problem can make it difficult to obtain the core-wide flow path deformation due to swell and rupture of various fuel rods within the core. Currently, a method of linking the FRAPTRAN code to the MARS code by dynamic link library method is proposed, but there is room for improvement in terms of calculation speed, etc.

Another problem is the process of creating inputs of multiple fuel rods from the entire core fuel cycle data, which are to be used both in MARS code and FRAPTRAN code. This requires a program toolkit that processes and organizes a massive data into inputs, including information on dimensions of fuel rods, material properties, and gaps depending on the burnup state.

3.2 Multi-dimensional Thermal-hydraulics

It is known that the deformation of the flow path caused by swell and rupture of the fuel rods induced by LOCA may cause a redistribution of the flow in the core, affecting core reflood. If the core is modeled as a single hydraulic channel, it can only see the average flow of the core as a whole, making it difficult to identify the effect of the flow redistribution. Fig.1 shows an example of the calculation result of a reflood test from Slab Core Test Facility (SCTF) [4]. As shown in the figure, multi-dimensional pattern in flow and liquid distribution were found in the core and upper plenum during reflood phase. To see the effect of the distribution of burnup and power in the core on the flow redistribution and the combined effect on the safety parameters, a three-dimensional hydraulic channel model based on the actual core nuclear design is required.

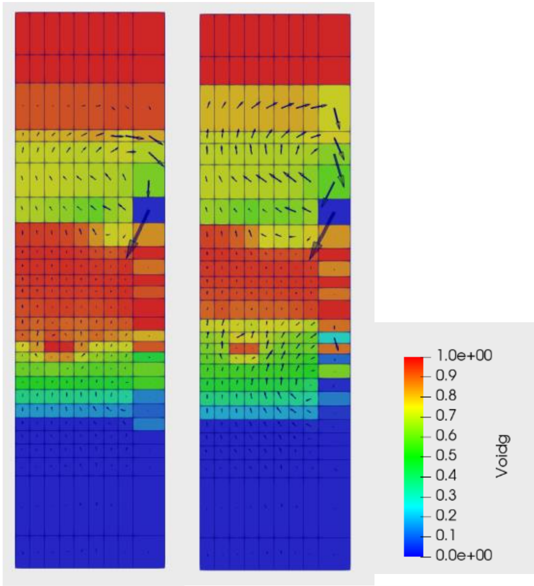

Fig. 1. Example of multi-dimensional flow pattern in a reflood test of SCTF.

This item requires a specific process, 'mapping' in which the certain group of the fuel assemblies comprising the actual core is converted to a specified hydraulic channel on either rectangular or cylindrical coordinates, and important data such as flow area, volumes, and powers and burnup levels of the group of fuel assemblies, etc. should be mapped into the values suitable for that channel. Fig. 2 shows an example of the multi-dimensional modeling of one quarter of the core of OPR1000. A scheme of 4 rings in radial direction and 3 sectors in azimuthal direction was adopted in this figure. To get a reliable modeling scheme, an extensive study of the noding sensitivity is requested. Validation of the multi-dimensional modeling using the available experimental data is one of the important issues in thermal-hydraulic field.

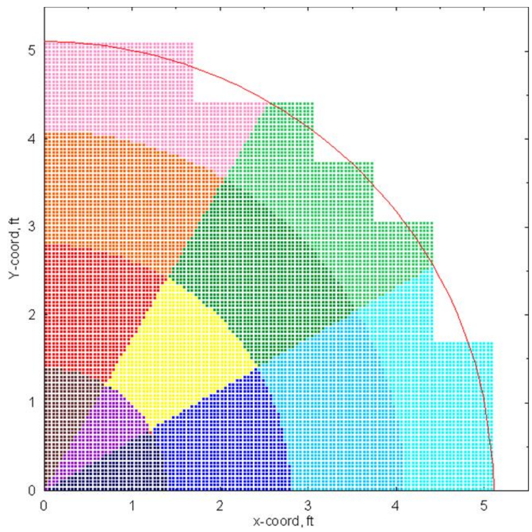

Fig. 2. Scheme of multi-dimension modeling of core

3.3 Flow Blockage Model

Flow blockage is generated by the swell and rupture of fuel rod and is expressed as the sum of the deformation of the fuel rods located in a hydraulic channel. Effect of flow blockage may have an effect on reflood PCT through its mechanism including reduction of flow area and volume, increase of heat transfer area and change in heat transfer coefficient, etc. And flow pattern around the blocked nodes can be changed as shown in the Fig.1. In the previous study, the reduction of flow area was modeled by use of valve component in MARS code and the additional K-factors were introduced to consider the effect of flow blockage, which led to a conservative prediction of reflood peak cladding temperature (PCT) and quenching time [5]. However, comprehensive evaluation of the various effects mentioned above requires code and modeling to consider all phenomena related to flow blockages. Currently, the effect on geometric change was not considered in the MARS code and an effort to improve this feature is undergoing.

3.4 Uncertainty Parameters and Treatment

Since numerous parameters will contribute to the calculation of LBLOCA, which reflects the conditions of fuel burnup, defining the uncertainties of those parameters and evaluating their overall impact on the final safety criteria will be the final goal of this research program. Since the current MARS-FRAPTRAN integrated code is driven by each input, it is important to reflect the uncertainty of each parameter without duplication to be appropriate for each input of each code. Research so far has defined parameters having a large impact that are applied to each code.

For the parameters or models which cannot be treated by the input, a special treatment may be required. Typical examples are the uncertainties which may come from the grouping of the fuel assemblies for multi-dimensional noding of the core, the selection of multiple fuel rods and the related modeling. We need to find a reasonable answer to how to evaluate those uncertainties.

In addition, it is necessary to consider any phenomena that have the lowest probability of occurrence if their effects are significant, for example the relocation of nuclear fuel pellets.

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4. Conclusions

The present paper discussed the direction of near-term research in LOCA field derived through the results and insights of the researches so far. Four important research items were derived (1) multiple fuel rod modeling, (2) multi-dimensional thermal-hydraulics, (3) flow blockage model, and (4) uncertainty parameters and teatment. The rationale and details for these four research items were also presented. In addition to those four research needs, LOCA phenomena including traditional experimental database and the associated analyses should be considered in the specific research plans.

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