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Analysis of IFA650.9 using MARS-KS coupled with SCDAP

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1. Introduction

In order to model the fuel behavior during design basis accidents and design extension conditions, the fuel accident code, SCDAP [1], has been integrated into MARS-KS [2]. In the coupled code, a fuel rod of interest is modeled by using SCDAP features and other hydraulic components and heat structures are simulated within the capability of MARS-KS. By using the interchanged variables, such as fluid temperature, from the connected hydraulic components, the coupled code calculates condition of the fuel rod, based on property information from MATPRO [3]. In turn, by applying the calculated condition into the hydraulic components, the behavior of the fuel rod is implemented. As a part of validation, an assessment has been performed against IFA-650.9 experiment conducted at Halden reactor [4]. By comparing calculated cladding temperature against the experimental data, the behavior of the fuel rod, implemented from the coupled SCDAP code, has been assessed.

2. Description of Experiment and Model

2.1 Overview of IFA-650.9 experiment

The IFA-650.9 experiment was proceeded by following five steps, using a high burnup fuel rod. At first phase, the test channel was pressurized to 70 atm under forced circulation conditions within the forced flow loop (blue line), as depicted in Fig.1. And then, heater power was imposed for adiabatic condition of the fuel channel. At second phase, forced convection was ceased, and then natural circulation condition was maintained. At third phase, LOCA experiment was started by opening blowdown valve, and the coolant in the test channel was immediately removed through the blowdown line. After then, at fourth phase, deformation of the fuel rod was induced due to heat up, and relocation of the fuel pellet was occurred with the fuel rupture. After the fuel burst, spray injection was started as the cladding temperature was reached at 1217K. Finally, at fifth phase, the test was terminated by removing system power with scram.

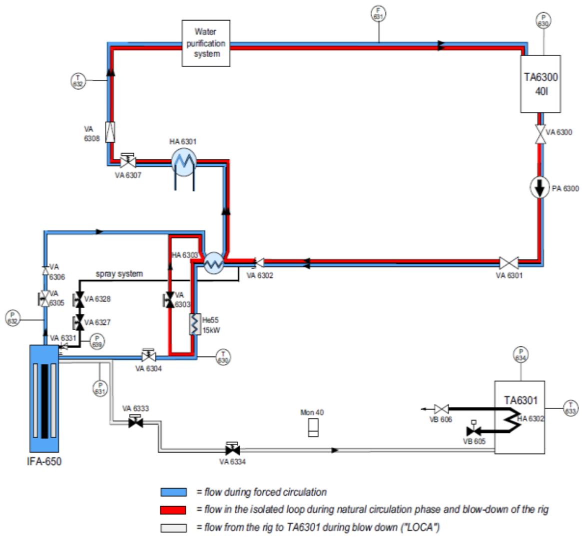

Fig. 1. System scheme of IFA-650.9 experiment [4]

2.2 Model for IFA-650.9

As depicted in Fig.2, the test vessel includes two independent flow channels, and they are modeled by using pipe component. One of them is enclosed by the heater, where the fuel rod is located, and the other is a surrounding channel outside the heater. The fuel rod is modeled by using fuel rod component of SCDAP input, and initial conditions for the fuel rod are given by using calculated data from FRAPCON-4.0 patch 1 [5]. In the case of the heater, it is modeled by using the heat structure component. The spray junction is connected to the fuel channel, and it operates as the cladding temperature exceeds 1217K. Pipelines out of the test vessel are modeled by giving same length and elevation, using the pipe component. Time dependent components are connected to the pipelines with valve components, in order to give boundary conditions before the blowdown phase. They maintain the system pressure condition at 70 atm, and, just before starting the blowdown phase, they are isolated by closing the valves. By opening the blowdown valve, the blowdown calculation of interest in this study is initiated.

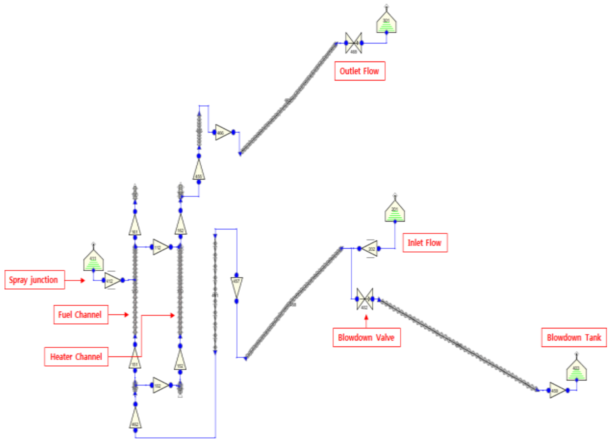

Fig. 2. Nodalization of test section for the assessment of IFA-650.9 experiment

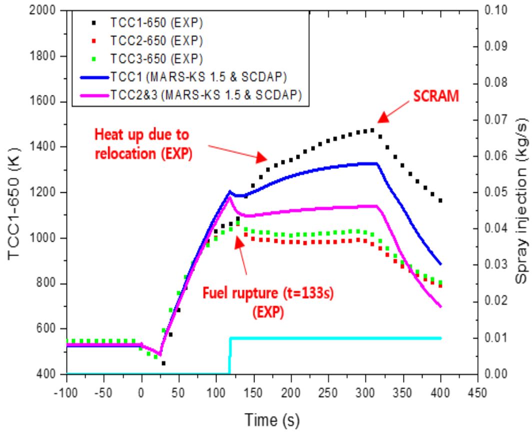

Fig. 3. Calculated fuel behavior of MARS-KS1.5&SCDAP against IFA-650.9 experimental results

3. Results

Transient calculation has been conducted during 400 sec. Behavior of the fuel rod has been compared with the experiment by plotting the cladding temperature, as depicted in Fig.3. Chronology of transient calculation is listed and compared with the experiment in Table I. Before ballooning of the fuel rod, the results indicate that the cladding temperature increases due to the loss of heat sink, since the coolant in the test vessel is immediately removed after the blowdown initiation. The increasing behavior of the cladding temperature is quite analogous to the experiment. However, as the ballooning occurs, the cladding temperature in the experiment changes with slow heat up. This is because transferred heat flux gets reduced as heat transfer area of the fuel rod increases. Meanwhile, the coupled code predicts the fuel rupture, immediately induced by the ballooning of the fuel rod. Therefore, there is no changing phenomenon to the cladding temperature, and this is considered as the limitation of the SCDAP code. By the way, after the fuel rupture, the fuel relocation occurs in the experiment. Then, the cladding temperature at low position (colored by black) increases due to the relocation of the fuel pellet from above section. However, in the case of code calculation, there is no additional heat up of the cladding at the low position (colored by blue), even though the code predicts the fuel rupture. This is because the SCDAP code implements the fuel relocation only in the case of meltdown of the fuel rod, and this is also regarded as the limitation of the code. In turn, heat up of the fuel rod is quenched with the spray injection, and the cladding temperature successfully decreases as the power is removed with SCRAM.

Table I: Chronology of event during code calculation against IFA-650.9 experimental data.

Event	Time (s) [EXP]	Time (s) [CAL]	Remark
Blowdown	0.0	0.0	Open blowdown valve
Fuel rupture	133.0	94.85	-
Spray injection	149.0	117.89	Cladding temperature > 1217 K
Heater reduction	169.0	129.85	35sec after the cladding burst
SCRAM	314	314.0	System power removed

4. Conclusions

As a part of validation of MARS-KS1.5 coupled with the SCDAP code, an assessment has been performed against IFA-650.9 experiment. The results have been compared against the experimental data, by plotting cladding temperature. Although several limitations have been captured, calculated results could have been described physically. Especially before the fuel rupture occurs, heat up of the cladding has been predicted quite well against the experimental data. However, even though there have been temperature changes in the experiment due to the ballooning, the code predicts no temperature changes, accompanying the immediate fuel rupture due to the ballooning. Even more, after the fuel rupture, there have been no further temperature changes, whereas the experiment has been shown the increase of the cladding temperature at the lower position due to the fuel relocation. This is because the SCDAP code models the fuel relocation only in the case of meltdown condition of the fuel rod. It has been considered that these features are of the limitation of the code capability, and further improvement seems to be necessary, but that is beyond the scope of this study.

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