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# Research and Activities of OECD/NEA Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF) Project

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## 1. Introduction

Severe accident occurred on March 11, 2011 in Fukushima Daiichi nuclear power station. It is expected that core melt down occurred in unit 1, 2, and 3. Japanese government has been trying to recover the damages and established the road map on the removal of fuel debris in the plants [1]. Some severe accident analyses codes have been developed since TMI-2 accident, such as MELCOR, MAAP, SAMPSON and so on. Nowadays, severe accident code also has been developing in KAERI. The severe accident codes were used to analysis the Fukushima Daiichi accident and give valuable information. In addition, the insufficient part of the code could be revised by comparing the calculation result with the measured data. In this circumstance, working plans have been set up to conduct a Benchmark Study of the Accident progression for the Fukushima Daiichi nuclear power plant(BSAF) units 1-3 with the members of the OECD/NEA. The BSAF project was launched in November 2012 with the fifteen organizations of eight countries (France, Germany, Korea, Russia, Spain, Switzerland, the United States, and Japan).

The objectives of the project are: [2]

- to analyze the Fukushima accident progression.
- to raise the understanding of severe accident(SA) phenomena.
- to contribute the improvement of methods and models of SA code.
- to contribute the status of debris distribution to a future debris removal plan.

BSAF phase 2 also has been implemented from April, 2015 and it will be continued to March, 2018. It is more focused on the fission product behavior and source term estimation in phase 2.

In this paper, KAERI's research activities in BSAF are presented and fission product models which need to be improving are discussed.

## 2. Activities in KAERI

KAERI has been participated in the BSAF project, and working on unit 1 and 2 using MELCOR 1.8.6 as an analysis code [3,4]. Plant modeling method and boundary conditions are described in this section, and calculation results are presented briefly.

### *2.1 Plant Model*

The type of Fukushima nuclear power plant is Boiling Water Reactor(BWR) and it consists of reactor pressure vessel(RPV), primary containment vessel(PCV), and reactor building(RB) as shown in Fig. 1. The main difference between pressurized water reactor(PWR) and BWR plant is that water boiling is allowed in the core of BWR [5]. The modeling of RPV was conducted by dividing it into several volumes, downcomer, lower plenum, core, bypass, shroud dome, steam separator, dryer and steam dome. In addition, jet pump and recirculation loop in downcomer were also considered. The PCV contains drywell, vent leg and wetwell. In order to simulate the fission product behavior accurately, each volume was divided into several parts. For instance, the wetwell was divided into 2 parts in axial direction and 8 parts in azimuthal direction. RB was also modeled considering the geometry of the plant. Heat structures which can simulate fission product aerosol deposition were modeled in each volume. The geometrical dimensions of plant in unit 2 are generally larger than unit 1, and it was originated from the difference of operating power of unit 1 and 2, 1380.0 and 2381.0 MWth, respectively.

Difference between unit 1 and 2 is also existed in safety system. Unit 1 has an isolation condenser to remove decay heat in coolant. On the other hand, reactor core isolation cooling(RCIC) system is equipped

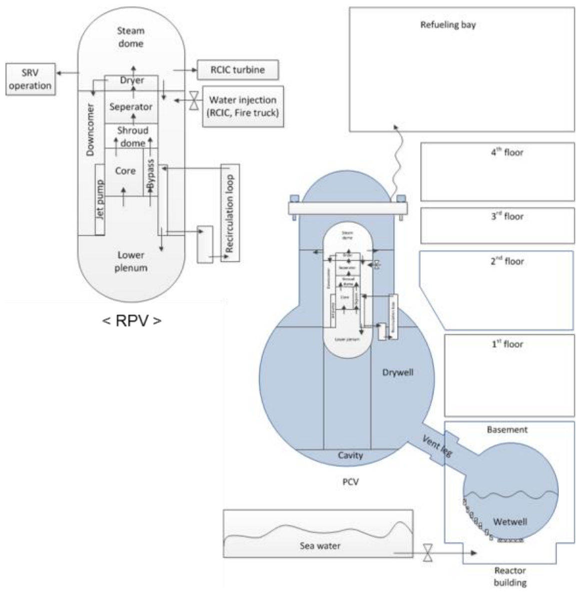


Fig. 1 Nodalization of Fukushima power plant

Table 1 Chronological calculation event of unit 1 and 2

| | Event | Time (hr) | |
|---|---|---|---|
| | | Unit 1 | Unit 2 |
| 1 | Earthquake time | 0.0 | |
| 2 | Scram time | 0.0 | |
| 3 | MSIV closure time | 0.0 | |
| 4 | Activation and termination of IC, RCIC, HPCI, spray | 0.096 | 0.0667 |
| 5 | Tsunami arrival time | 0.667 | |
| 6 | First occurrence of water level at TAF | 2.418 | 75.83 |
| 7 | Onset of hydrogen generation | 4.362 | 77.36 |
| 8 | First fuel clad failure time | 4.441 | 77.49 |
| 9 | First control blade melting/liquefaction time | 6.028 | 77.78 |
| 10 | First fuel rod failure time (melting or collapse) | 7.076 | 80.16 |
| 11 | First UO2 relocation to lower head | 7.076 | 80.16 |
| 12 | First lower core plate failure time | 7.075 | 80.16 |
| 13 | First and subsequent RPV pressure boundary failure (MSL, gaskets, tip probe) | 5.723 | |
| 14 | Time of vessel water dryout in lower head | 12.215 | |
| 15 | Time of lower head failure and mode of failure | 15.411 | |
| 16 | Time of initiation of MCCI | 19.694 | |
| 17 | Time of termination of MCCI (if appropriate) | | |
| 18 | Time of containment failures or self-venting and mode (e.g. Drywell head flanges) | 19.762 | |
| 19 | Time of operator WW and DW containment venting | 23.76 | 87.5 |
| 20 | Time of fresh or sea water injection to RPV and termination of inject ion | 15.000 | 77.13 |

in unit 2.

Operation of safety relief valve(SRV) was modeled before and after tsunami by applying different pressure criterion.

Operational events conducted by operator manually, such as valve open/close, were also considered in the calculation.

Boundary conditions such as alternative water injection flow rate were determined by referring to the given data from OECD/NEA BSAF project.

### *2.2 Calculation Result*

The calculation was conducted within the first 1 week of the Fukushima Daiichi Accident in March 2011. A few measured data are available during the first 1 week, such as RPV and PCV pressure, water level in RPV, and it was compared with the calculation result. Details were not presented in the paper, but generally the calculation results show good agreement with the measured data.

The calculation results of unit 1, 2 were summarized in Table 1. In the case of unit 1, there was no available cooling system, it was directly related with the early vessel failure. On the other hand, the operation of RCIC system had been removed the decay heat during about

Table 2 Calculation group in BSAF 2

| UNIT 1 | UNIT 2 | UNIT 3 |
|---|---|---|
| IAE, JAEA(Japan)<br>IRSN(France)<br>CIEMAT(Spain)<br>IBRAE(Russia)<br>KAERI(Korea) | VTT(Finland)<br>NRA, IAE,<br>CRIEPI(Japan)<br>GRS(Germany)<br>KAERI(Korea) | NRA, IAE,<br>CRIEPI(Japan)<br>PSI(Swizertland)<br>SNL(USA) |

Table 3 Future work of other institutes

| Institute | Future work |
|---|---|
| IRSN | Sensitivity analysis on iodine surfaces |
| JAEA | Sensitivity on water injection rate with THALES2/KICHE |
| CIEMAT | Effect of cavity meltspreading and pool scrubbing |
| IBRAE | Model the under-shield plug region (H2 and FP collection) |
| VTT | 3 axial nodalizations of wetwell |
| NRA | MCCI estimation for long term calculation |
| PSI | Focus on suppression chamber scrubbing capacity |
| SNL | RCIC turbine model<br>Model improvement (resuspension, spreading model..) |

72 hours. Thus fuel damage was smaller than unit 1 and vessel failure was not detected in unit 2.

### 3. Activities in other participants

Other participants also performed the calculation, and the results were presented in the BSAF PRG meeting periodically. Each institute has been working on the one or two of the unit 1-3, and it was indicated in Table 2. The research activities of other institutes were summarized in Table 3.

From the calculation results, necessity of model improvement in the code is confirmed. In the view of the fission product release, it is important to understand the pool scrubbing mechanism. Most of released fission products are expected to trap in the water of wetwell. Thus the scrubbing efficiency could affect the amount of released fission product into the environment. Realistic MCCI model is also necessary to estimate the amount of generated aerosol accurately.

### 4. Conclusions

The phase 2 project implementation period is 3 years from April 2015 to March 2018. The main topic of the BSAF 2 is the fission product behavior in the Fukushima nuclear power plant. In the process of calculation, it is important to know the insufficient models in the code. Furthermore, the model would be applied to the KAERI's severe accident code after making up for the insufficient part.

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