Establishment of coupling structure in CAISER code for an integrated severe accident simulation of CANDU reactor

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1. Introduction

Along with the severe accident legislation in 2016, the criterion of Cs release is definitely defined and the power plant operator has submitted the AMP (Accident Management Plan) report to a regulatory body, in which the accident mitigation ability of all the operating NPP has been evaluated by checking whether the criterion is satisfied in severe accident condition.

The criterion in the legislation, which is the probability of the events in which the amount of Cs release exceeds 100TBq should be less than 10^{-6}, needs to a detailed severe accident analysis. However, ISAAC code used in the AMP analysis has a limitation in the accuracy because of its fast-running code characteristics using simplified modeling.

Because of the necessity for the detailed simulation of CANDU reactor under severe accident condition, KAERI has been developing the detailed severe accident analysis code, CAISER (Candu Advanced Integrated SEveRe accident code) from 2015 with 5-year plan [1].

During the first 3 years of the project, the core module has been developed. The core module of CAISER consists of two representative modules, which are a fuel channel module and a calandria tank module. While a fuel channel module treats a fuel rod degradation in a representative fuel channel, a calandria tank module simulates the overall core degradation which is happening in a calandria tank, including a fuel channel failure, a debris bed formation, a moderator water evaporation, a corium pool formation and finally a calandria tank failure.

2. Design of coupling structure of CAISER

2.1 Coupling with MARS code

Since it is a challenging task to develop an integrated severe accident code within 5 years, some modules has utilized the existing available one, while the core module of code has been modeled in detail.

For the simulation of thermal hydraulics in RCS (Reactor Coolant System), MARS code [2] has been utilized since the CANDU specific features has already reflected on MARS cod, such as a stratified flow in a horizontal fuel channel. For the coupled calculation with CAISER code, the thermal hydraulic information has been transferred from MARs to CAISER, while the transient information of solid components, such as fuel rod melt/relocation, a fuel channel failure, has been transferred from CAISER to MARS, including the convective heat transfer rate. In the coupled calculation, the overall time step is designed to be controlled by MARS code.

2.2 Coupling with CONTAIN code

For the analysis of severe accident progression in a containment, CONTAIN code [3] has been utilized, which has been developed in Sandia National Laboratory of U.S. It is a kind of standalone running code for the severe accident simulation in a containment. The information of severe accident progression in a core is given by a boundary condition in input file. The information includes a calandria tank failure time, a corium discharge flow rate & temperature from a calandria tank, a liquid/vapor flow rate & temperature from RCS (or calandria tank), a fission product release rate from core.

The CONTAIN code can simulate the most of severe accident progression happening in a containment, including a MCCI (Molten Corium Concrete Interaction), hydrogen distribution and explosion, hydrogen elimination by using PARs (Passive Autocatalytic Recombiner), a fission product release from MCCI, all kinds of thermal hydraulic behavior such as a convection and condensation.

For the coupled calculation with CAISER, the above listed information related to a corium, a fission product and thermal hydraulics are given from CAISER to CONTAIN. While, the containment pressure is given from CONTAIN to calculate the corium discharge flow rate in CAISER.

While some of transfer variables in a coupled calculation of CONTAIN are calculated by CAISER, others are calculated by MARS. For example, the thermal hydraulic information in RCS are calculated by MARS, while the corium mass and temperature are calculated by CAISER. The generation of fission product is calculated by CAISER, and it is transferred to CONTAIN through RCS modeled by MARS. In CAISER, the generation of fission products are calculated with categorized 7 groups which are in gas and aerosol types. The gas type of fission product is transferred to RCS and released to containment through a valve, while the aerosol type of fission product is remained in a corium and released to containment together with a corium discharge.

For the purpose of a design basis accident analysis, MARS had been coupled with CONTAIN in the previous works [4]. Hence, the thermal hydraulic information has already been coupled between MARS and CONTAIN. In the MARS-CONTAIN coupling, CONTAIN was made as a type of DLL (Dynamic Link Library) and it is called from MARS. In a same way, in the MARS-CAISER coupling, CAISER code has been made as DLL and it is called from MARS. Hence, in the coupled calculation among CAISER, MARS and CONTAIN codes, CAISER and CONTAIN are made as DLL. And then, MARS is designed to call these DLL files in the transient coupled calculation.

As remarked previously, CAISER has been coupled with MARS for the core region of CANDU reactor. Several variables from CAISER, such as corium mass and temperature, is necessary to communicate CONTAIN. However, it is more efficient to use the current coupled structure in the communication of variables. That is, instead of communicating directly between CAISER and CONTAIN, it is better to use MARS as an intermediate transfer stage. Hence, the corium mass and temperature are transferred to MARS and finally sends to CONTAIN.

Since the severe accident progression in containment tends to occur in a long term, the transient time step in CONTAIN may have a large difference with that of MARS. In order to reduce a computing time, the transfer variables communicate between MARS and CONTAIN based on the time step of CONTAIN. The variables from MARS are integrated during the time step of CONTAIN before it sends to CONTAIN.

3. Preliminary test for the integrated severe accident code

3.1 Definition of concept problem

For the purpose of checking whether a coupling process has been implemented as intended, a preliminary test has conducted with a concept problem having a relatively simple node structure. In a concept problem, 6 channels are modeled with horizontal pipes and it is connected with a vertical feeder pipe as shown in Fig. 1. As a severe accident simulation, LOCA by a feeder pipe break is assumed to occur at 50 sec. Reactor power has initially 200MW and it sharply decreases to the decay power level with a system pressure decrease from 7MPa to 0.1MP after a feeder pipe break.

Along with MARS input, CAISER has divided a core having 380 fuel channels with 6 zones. Each zone contains a similar number of fuel channel. In each zone, the representative fuel channel is considered with a fine mesh of 3 by 5 to analyze the fuel rod degradation inside a fuel channel.

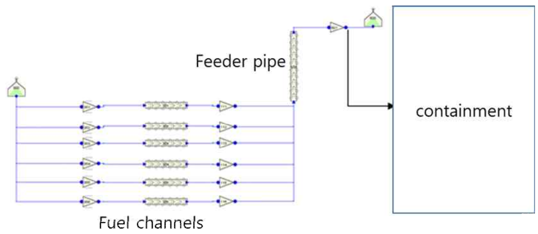

Fig.1 Node structure of concept problem

CONTAIN is simulated with 3 cells. Cell 1 is environment, and cell 2 is a cavity cell to which a corium is discharged, cell 3 is a remained containment volume to which a steam and water are discharged from a feeder pipe and a valve. Fission product is discharged in a type of gas and aerosol. A gas fission product is discharged together with a steam/water mixture to cell 3, while an aerosol fission product is discharged together with a corium to cell 2.

3.2 Computational results of concept problem

In order to save a computing time, a fuel channel failure and a vessel failure is made to occur earlier than it really is. Computation has been conducted stably with 0.1 time steps. The computing time was 10 times faster than a real time.

Figure 2 shows the corium mass inside a calandria tank calculated by CAISER. A corium mass starts to accumulate because of a fuel channel failure at about 2,500 sec. And, it starts to steeply decrease due to a calandria tank failure at about 7,500sec. It is noted that the exact failure time has no meaning in this conceptual problem, while it aims to check a mass transfer from a calandria tank of CAISER to a cavity of CONTAIN. It is shown from a CONTAIN result in Fig. 3 that the decreased mass of 60,000kg in a calandria tank is transferred to a cavity of containment about 7,500 sec in a form of oxidic and metallic component. A oxidic corium mass is shown to increase sharply about 12,500 sec because of MCCI, while a pool mass starts to decrease from 12,500 sec because of water evaporation.

Figure 4 shows a fission product mass of the first group (a noble gas, NG) of 7 groups, calculated by CAISER. The mass of noble gas contained in a fuel rod is shown to decrease sharply because of a fission product release, while a noble gas in a gas type increases, satisfying a mass conservation. Note that a noble gas mass in Fig.4 shows the mass change by fission product release in a core without reflecting a mass transfer from CAISER to CONTAIN, while it is considered separately.

Figure 5 shows a fission product in a gas type in a containment, calculated by CONTAIN. After a fission product release happens in a core, the fission product mass of gas type becomes to transfer to a containment through a safety valve. Hence, the noble gas mass in a gas type in CONTAIN is shown to increase which corresponds to the noble gas mass in CAISER in Fig. 4.

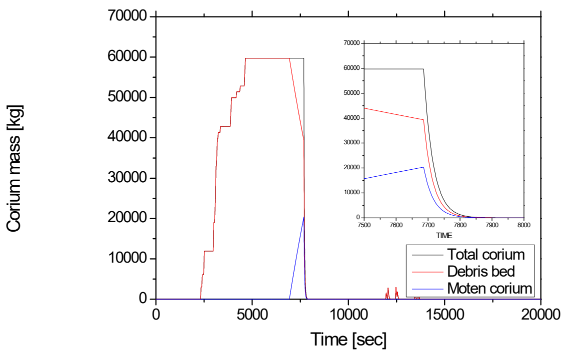

Fig.2 Corium mass in a calandria tank

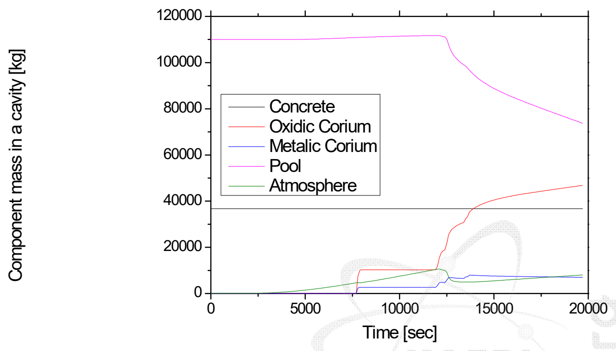

Fig. 3 Component mass in a cavity of containment

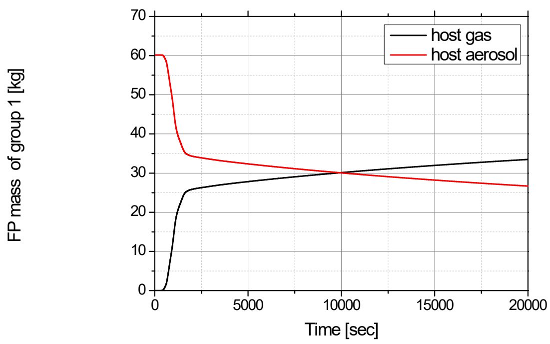

Fig. 4 Fission product mass of group #1

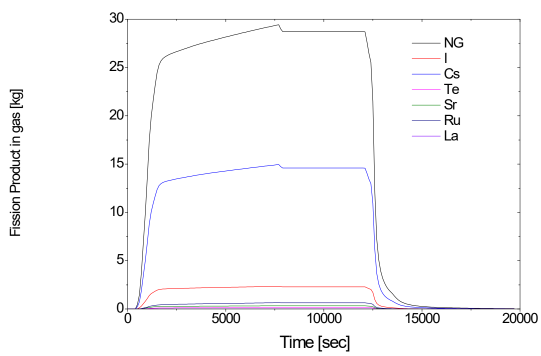

Fig. 5 Fission product mass of gas type in a containment

4. Conclusion

Because of the necessity for detailed simulations of CANDU reactor under severe accident condition, CAISER code has been developed. For the purpose of integrated simulation of CANDU reactor plant, the core module has been coupled with MARS and CONTAIN codes, which are for a themal hydraulics simulation in RCS and a containment analysis, respectively. In a coupled calculation among CAISER, MARS and CONTAIN, the transferring variables are defined and the strategy of coupling has been setup. The validity for the coupling process has been evaluated by solving a conceptual problem. A corium mass discharge due to a calandria tank in CAISER is confirmed to be in line with the corium mass increase in a cavity of containment, calculated by CONTAIN. The fission product release in a core is also shown to be in line with the mass increase in cell 3 of containment. Based on the established coupling strategy established by this study, a coupled, integrated simulation for a CANDU plant is scheduled in the next step.

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