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SPACE code ECCX Component Model and Comparisons with RELAP5/Mod 3.3 Code Predictions

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1. Introduction

During the loss of coolant accident, especially when the break is considered a large break, in the nuclear power plant system, an emergency core cooling (ECC) injection is activated once the pressure has decreased sufficiently. The ECCS provides the process of the re-establishment of liquid/fuel contact by refilling, reflooding and quenching of the heated fuel rod cladding. The performance of the ECC injection at its initial stage is affected by the process of mixing of a jet of a cold water injected into a two-phase and the resulting steam condensation that follows. SPACE code incorporates a special component ECCX to account for the mixing and condensation phenomena near the ECC injection. This paper outlines the implemented models and assessment results of the ECCX component.

2. Model Improvements

2.1 Flow regimes

Due to the special geometrical configuration of ECC injection the normal flow regime map incorporated in SPACE code is not relevant to the ECC mixing region. A special regime map is, therefore, devised for the ECCX component. The regime map is modeled based on the experimental observation [1](See Fig. 1).

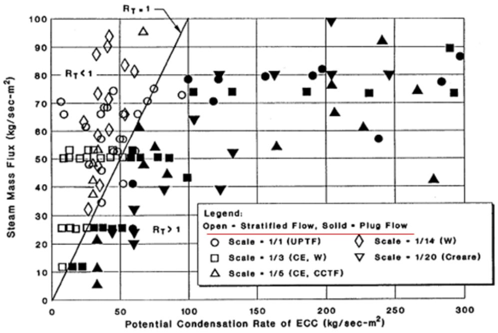

Fig. 1. Flow regimes distribution

In Fig. 1, R_T is a thermodynamic ratio defined as

$$R_T = \frac{W(ECC)(H_f - H_{ECC})/H_{fg}}{W_{steam}(in)} \qquad \text{(Eq. 1)},$$

where $W(ECC)$ and $W_{steam}(in)$ are the total ECC mass flow rate and steam mass flow rate from the core side, respectively. H_f , H_{ECC} , and H_{fg} are the enthalpies of the saturated liquid, ECC injection, and latent heat, respectively. The thermodynamic ratio R_T, therefore, represents the ratio of the potential condensation to the incoming steam amount. When R_T is greater than 1, the ECC injection rate combined with its degree of subcooling is large enough to induce a considerable condensation for the incoming steam. It is, however, noted that the value of R_T does not account for the degree of superheat in the incoming steam (W_{steam}(in)).

The experimental observation suggested a clear separation of the two regions divided by the R_T value of 1. When the R_T is over 1, a plug flow regime was observed, whereas when R_T is under 1 stratified wavy regimes were dominant flow structures. The current SPACE code adopts this observation when determining the flow regimes.

2.2 Heat Transfer Coefficients

Once the flow regime is determined, the interfacial area concentration and heat transfer coefficients are modeled accordingly. A similar modeling method as RELAP5 is employed for this purpose. The interface is assumed to be at saturation temperature corresponding to the vapor pressure. In condensation of saturated steam, there is almost no temperature difference between vapor and the interface, whereas there is a very high rate of heat transfer from the steam to the interface through the mass transfer. For this reason heat transfer coefficient of a very high value of 10^7 w/m^3K is assigned for the heat transfer from vapor to the interface.

For the liquid/interface, the following correlation is used both for the wavy and plug regimes.

$$Nu = 0.0344\,(\mathrm{Re})_g^{0.58}(\mathrm{Re})_f^{042}(\mathrm{Pr})_f^{0.33} \qquad \text{(Eq. 2)}$$

The interface concentrations for the wavy and plug regimes are determined in the similar methods used in RELAP5/MOD3.3 [2].

3. Results

The most significant thermal/hydraulic phenomenon would be the condensation of the steam introduced into the ECCX component from the reactor core region, by the relatively cold ECC injection water. The liquid fractions, therefore, are compared this those predicted by RELAP5/MOD3.3.

The following typical configuration is considered for this purpose.

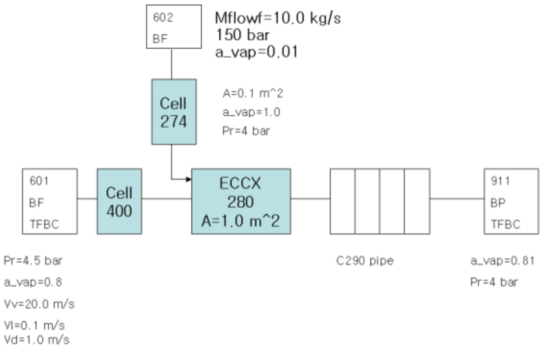

Fig. 2. ECCX Component Assessment Scheme

As seen in Fig. 2, the ECC water is injected in the ECCX component 280 via Cell 274. The steam coming from the reactor core is simulated with TFBC 601 which is connected with the cell 400 to the ECCX component.

Fig. 3 compares the liquid fraction in the ECCX component during the ECC injection. The ECC injection rate is also shown in this figure. The maximum injection rate of 750 kg/sec shown in this figure is based on the typical value observed from the LBLOCA simulation for the APR1400 plant. As seen in this figure, RELAP5 simulation is showing quite oscillatory behavior starting even before the real injected is initiated. The oscillation is continued to the end of the injection. SAPCE code, however, is comparatively showing a much smoother change in the liquid fraction. The liquid fraction in SPACE code is also found more sensitive to the injection rate.

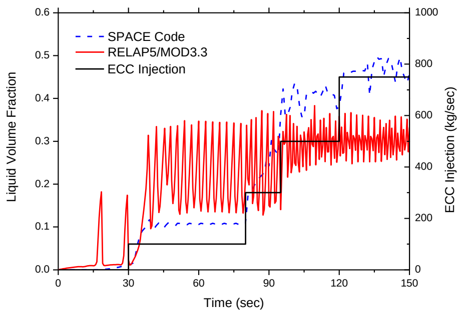

Fig. 3. Liquid fraction comparison in the ECCX component for SPACE code and RELAP5/Mod3.3

The SPACE code ECCX component result is compared with the prediction when a BRANCH component is used instead, in Fig. 4. As expected, the ECCX component predicts the liquid volume fraction a little higher than the BRACH.

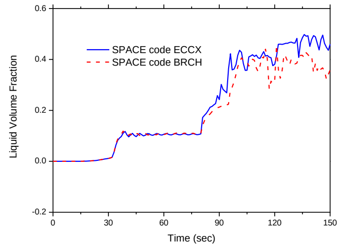

Fig. 4. The liquid volume fraction prediction by SPACE code ECCX and BRANCH components

Finally, for the SPACE ECCX component is tested for the lowered injection rate expected during the small break LOCA accident. Fig. 5 depicts the injection rate (max. 20 kg/sec) and the corresponding liquid volume fraction predicted by the ECCX component.

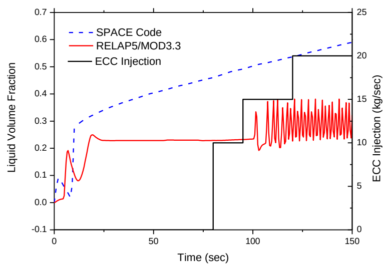

Fig. 5. Liquid volume fraction for the ECCX component during the small break LOCA

4. Conclusions

A ECCX model is implemented in the SPACE code. The thermodynamic ratio is used to determine the flow regimes, either wavy regime or plug regime. Once the flow regime is determined, the corresponding interfacial concentration and the heat transfer coefficient are modeled in the similar way as RELAP5/MOD3.3. For the assessment of the implemented model, test calculations were performed and the results were compared with those predicted by RELAP5/MOD.3.3 code.

While, the absolute model validation against the experimental observation was not performed due to the lack of the relevant data, the comparisons with RELAP5 results suggest the satisfactory implementation of the model. The flow regimes model, however, may need a further improvement, especially considering the static characteristics of the experimental data.

REFERENCES

[1] US NRC, Reactor Safety Issues Resolved by the 2D/2D Program, NUREG/IA-0127, 1993

[2] SCINTECH, Inc., RELAP5/MOD3 Code Manual, Volume I: Code Structure, System Models, and Solution Methods, 1998