Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Investigation of ECC Delivery in UPTF Test Using CUPID-RV Code

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1. Introduction

Fluid flow analysis in nuclear society has been mainly focused on investigating the safety in nuclear reactors. For decades, one-dimensional approaches such as RELAP5 [1], MARS etc. have been developed to deal with the accidental conditions of reactor cooling system. They are successfully designed to put up with the severe numerical hardships in high heat flux conditions, severe phase transition, and sudden significant pressure drop over 150 bars etc. so that those codes are still applying to assessing the license in regulatory organizations.

With the need of the multidimensional thermal hydraulic knowledge in nuclear safety issues, the CUPID code [2] has been being developed in Korea Atomic Energy Research Institute (KAERI). It has been verified with many numerical benchmark problems and validated against the experimental tests in three dimensions. CUPID analyzed components in reactor systems for the design performance and presented the multidimensional perspectives.

The latest version of CUPID for reactor vessels (CUPID-RV) includes the safety-related models and correlations and deals with the LOCA problems, such as reflooding and ECC delivery phenomena. The models for LOCA analysis were brought from MARS vertical flow regime.

In this study, ECC delivery issue in UPTF tests isanalyzed by using CUPID-RV. The difference in pressure drop between model and correlations has been tested. Then, the possibility of the combination in CMFD and 1-D safety analysis models in LOCA analysis is investigated.

2. Methods and Results

In this section CUPID reactor vessel module and the validation results are described. The reactor vessel module includes a reactor core bundle module including reflooding model and downcomer CFD module.

2.1 Governing Equations in CUPID code

A set of two-fluid conservation equations [3], which is used in nuclear system analysis code, is adopted to establish CUPID-RV module.

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \nabla \cdot (\alpha_k \rho_k \vec{u}_k) = \Gamma_{v/c} + \Gamma_{wall} \quad (1)$$

$$\frac{\partial}{\partial t}(\alpha_k \rho_k \vec{u}_k) + \nabla \cdot (\alpha_k \rho_k \vec{u}_k \vec{u}_k) = -\alpha_k \nabla P + \nabla \cdot (\alpha_k \mu_{k,eff} \nabla \vec{u}_k) + \alpha_k \rho_k \vec{g} + \vec{M}_k^{mass} + \vec{M}_k^{drag} + \vec{M}_k^{VM} + \vec{M}_k^{WF} \quad (2)$$

$$\frac{\partial(\alpha_k \rho_k e_k)}{\partial t} + \nabla \cdot (\alpha_k \rho_k e_k \vec{u}_k) = -P\frac{\partial \alpha_k}{\partial t} - P\nabla \cdot (\alpha_k \vec{u}_k) + \nabla(\alpha_k \vec{q}_k) + \frac{P_s}{P} H_{ik}\left[T^s(P_s) - T_k\right] + \Gamma_v h_k^* - \left(\frac{P - P_s}{P}\right) H_{gf}(T_g - T_l) + q''_{k-p} A_{k-p} \quad (3)$$

$$\rho_p \frac{\partial T_p}{\partial t} = k \nabla T_p + S_p \quad (4)$$

2.1 Analysis Using the UPTF Tests

The simulation of UPTF 201/III [4], in which 493, 487, 489 kg/s ECC flows for 1, 2, 3 cold legs, 102 kg/s steam flow, and 942 kg/s ECC delivery flows were measured as shown in Fig. 6, was conducted to validate downcomer analysis capability of CUPID-RV. Initially, topology-based interfacial drag is used, but it turned out to provide much high drag coefficient and the ECC delivery is underestimated. The interfacial drag was replaced with the one based on traditional flow regime map, and then, the ECC delivery and downcomer pressure become similar to MARS calculation results. The slight difference of ECC delivery mass flow rate seems to be induced by the discrepancy in downcomer flow regime between CUPID-RV and MARS. It must be noted that the interfacial drag model was implemented only for vertical flow regime in CUPID-RV.

Table 1. Test cases

Test / Phase	Steam injection (kg/s)	Steam temp. (K)	ECC flow in cold legs			ECC subcooling (K)	ECC delivery (kg/s)	Pressure in D/C (kPa)
			1 (kg/s)	2 (kg/s)	3 (kg/s)			
201/III	102	455.2	493	487	489	12	942	414
203/IV	51	461.2	493	485	487	2	1031	337
200/I	104	471.2	494	0	0	20	5	451
201/I	102	468.2	0	487	490	10	861	330
202/II	128	463.2	0	486	491	11	714	416
200/III	102	467.2	735	0	0	22	6	498
203/III	71	464.2	737	0	733	9	823	398
203/I	69	471.2	735	0	0	13	95	401
200/II	54	469.2	736	30	0	7	351	330
203/II	30	468.2	737	0	0	0	519	286

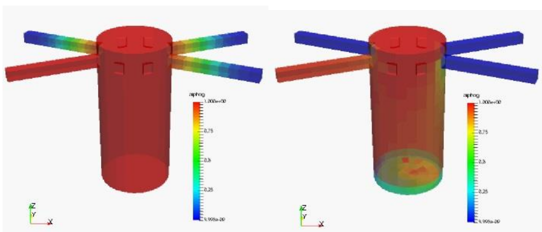

Fig. 1. UPTF analysis result for case1.

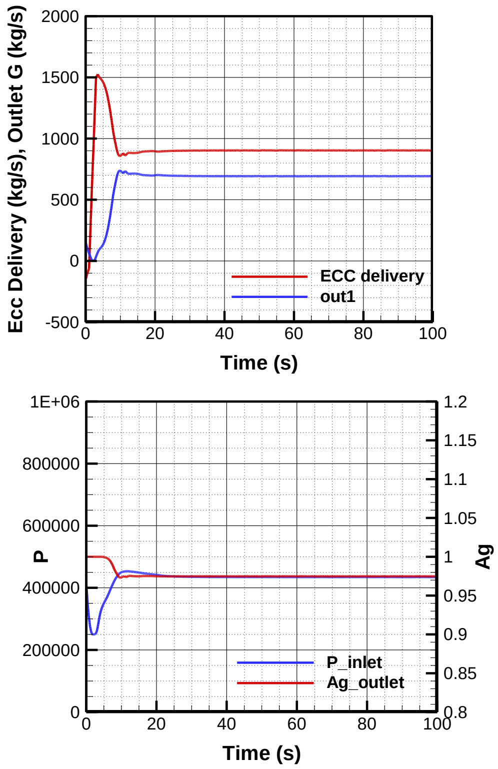

Fig. 2. ECC delivery and downcomer pressure transient.

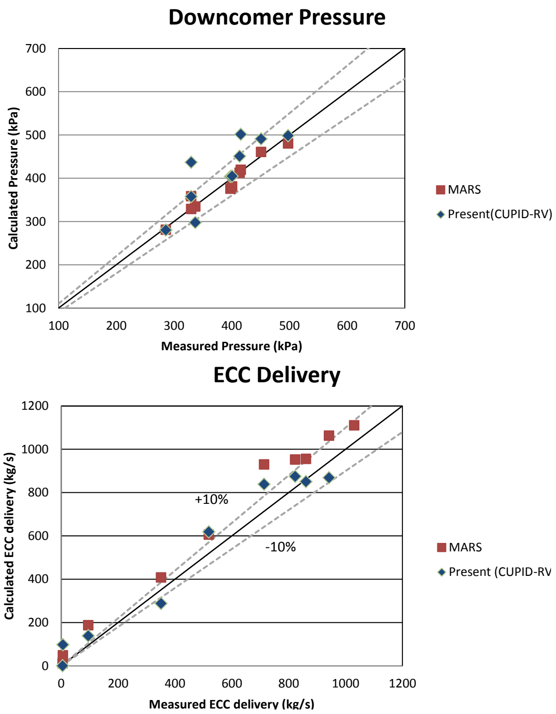

Fig. 3. ECC delivery and downcomer pressure for all cases.

3. Conclusions

In this paper, the recent development and validation of CUPID reactor vessel module, CUPID-RV, is tested with the ECC delivery issue. The capability of the CUPID-RV models is investigated. The issue in the combination of CMFD models and 1-D safety code models are investigated.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) and the Korea Foundation of Nuclear Safety (KoFONS) grant funded by the Korean government (MSIP & NSSC) (Nuclear Research and Development Program: 2017M2A8A4015005 & 2017M2A8A2055743, Nuclear Safety Research Center Program: 1305011).

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