PIRT and Development of Cooling Models for Reactor Building and Pool of Research Reactors

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1. Introduction

The thermal hydraulic analysis of a research reactor building becomes much more important during long-term cooling stage in loss of normal electric power if the building is designed as containment to fulfill the enhanced regulation requirements of radiological consequence.

Since the existing containment analysis computer codes are oriented to the condition and validated for nuclear power plants, it is necessary that a computer code adequate for the research reactors is developed.

The purpose of this paper is to identify the thermal hydraulic phenomena during the long-term cooling of a research reactor and to select the appropriate analysis models and to use it as the basic data for the development of a computer code for reactor building and pool cooling analysis.

This paper consists of three steps, and a description of each step is as follows:

- PIRT for identification of thermal-hydrodynamic phenomena during long-term cooling of research reactors
- Literature review and selection of analysis models for the thermal hydraulic phenomena determined by PIRT
- Development of the code structure and algorithm of a computer code for cooling analysis of reactor buildings and pool

2. PIRT for Long-Term Cooling Analysis

In general, the research reactor core maintains stable conditions after the loss of electric power because the large amounts of water in pool play a role as an ultimate heat sink. However, if the electric power is not restored for a long time, the containment air pressure will rise and integrity of containment will be threatened because of evaporation of pool water. To prevent this situation, the Containment Air Cooling System (CACS) for cooling the containment air and steam, Long-term Pool Cooling System (LTPCS) for pool cooling, Containment Filtered Venting System (CFVS) for discharging the pressure and Emergency Water Supply System for additional water supply to the pool are installed. The long-term cooling scenario was defined according to the operation of these four systems. The thermal hydrodynamic phenomena occurring in each long-term cooling scenario are summarized and classified according to their importance and knowledge level. The evaluation criteria of safety for rating importance level are pressure of containment, temperature and water level of pool. The result of importance and knowledge levels is shown in Table 1.

The thermal hydrodynamic phenomena to be investigated for the development of computer code were selected according to the knowledge and importance level. The selected phenomena are listed below.

- Evaporation and natural convection on the pool surface,
- Condensation and convection on the wall
- Condensation and convection in fan cooler

Table l. PIRT results of long term cooling

Component	Phenomena	Lv[1)]	Lv[2)]
Containment inner space	State	H	H
	Natural circulation	L	L
Containment Wall	Conduction heat transfer	M	H
	Natural convection heat transfer at horizontal wall	M	H
	Natural convection heat transfer at vertical wall	H	H
	Natural convection mass transfer at horizontal wall and condensation	M	M
	Natural convection mass transfer at vertical wall and condensation	H	H
	Radiation heat transfer	L	L
	Containment leakage	M	M
CACS	Forced convection heat transfer	H	H
	Forced convection mass transfer	H	H
CFVS	Relief valve characteristic	H	M
	Air Filtering	L	M
LTPCS	Heat removal	H	H
Inner Pool	Natural circulation	L	L
	Stratification	L	M
	State	H	H
Pool Surface	Natural convection heat transfer	H	H
	Natural convection mass transfer and evaporation	H	M
	Radiation	L	L
	Boiling	M	M
Wall	Conduction	L	H
Core(Fuel)	Reactivity Feedback	L	H
	Decay heat	H	H
	Natural convection	L	H

1) Importance Level
2) Knowledge Level

3. Literature Review and Selection of Analysis Models

3.1 Evaporation model

The evaporation models on the surface of the pool can be divided into two kinds of correlations based on Dalton law, and heat and mass transfer analogy. The form of correlations based on Dalton law is Eq. (1). Brady[1], Boelter[2] and Pauker[3] are representative researcher. The correlations based on Dalton law are good in the low temperature region. And these correlations are confirmed in case of low evaporation rate in the high temperature region.

$$\dot{m}_{evp} = C(e_s - e_a)^n \quad (1)$$

On the contrary, it is confirmed that the correlations based on heat and mass transfer analogy are relatively accurate even in the high temperature region. The forms of correlations based on heat and mass transfer analogy are Eq. (2), (3). Eq. (2) was suggested by Chilton and Bird and Eq. (3) was suggested by Coiler and Stephan. The representative researchers of these correlations are Ryan[4], Shah[5], Hugo[6] and Wang[7].

$$\dot{m}_{evp} = K\frac{(\omega_s - \omega_a)}{1-\omega_s} \quad (2)$$

$$\dot{m}_{evp} = Kln\left(\frac{\omega_{a,nc}}{\omega_{s.nc}}\right) \quad (3)$$

3.2 Condensation model

The condensation models on the wall are separated by experiment-based correlations and correlations based on heat and mass transfer analogy. The representative researchers of experimental correlation are Uchida[8], Dehbi[9], Kataoka[10] and Liu[11]. It is confirmed by experiment that Uchida correlation (Eq. (4)), which used in the licensing process and many of existing system codes, gives conservative results.

$$h_{Uchida} = 380(\eta)^{-0.7} \quad (4)$$

Coiler and Thome[12] method (Eq. (5)) is the most common heat and mass transfer analogy model which has been adopted many of containment analysis codes such as CONTEMPT, CONTAIN. The other correlations using heat and mass transfer analogy show similar results in most cases[12-17] and it is confirmed that they are relatively accurate compared with the experimental results. In addition, the wavy interphase effect developed by S.K.Park[16] can be used in high condensation with a wavy condensate film for accurate calculation.

$$j_{cond} = K_v\rho_v \ln\left[\frac{1-C_{v,i}}{1-C_{v,b}}\right] \quad (5)$$

3.3 Fan cooler model

The models for fan coolers used in the existing system codes have been investigated. We select simple heat removal models, the MARCH model that follows the characteristics of the Zion plant fan cooler, and the Mechanistic model that calculates heat removal rate and condensation rate through iterative calculation using information on heat exchanger, flow rate and etc.

3.4 Natural convection heat transfer model

Finally, since the natural convection heat transfer models have already been sufficiently validated in the existing system codes such as GOTHIC and CONTEMPT, they are selected. The form of convection heat transfer model is Eq. (6)

$$Nu = CRa^n \quad (6)$$

4. Code structure and algorithm

Based on the PIRT and selected models, code structure, calculation algorithm and detailed functions are set up for the code development. The schematic of calculation region and major thermal hydraulic phenomena is shown in Fig. 1. This code applies a compartment model that calculates containment and pools on one cell, respectively. This method is also applied in TRACE and CONTEMPT codes. The thermodynamic state is the same in each cell and the internal flow of each region is not considered. Therefore, the mass and energy conservation is only considered in each cell.

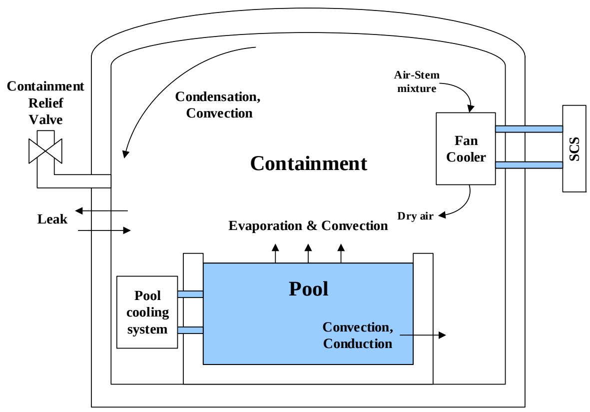

Fig. 1. Schematic of calculation region and phenomena

The computer code consists of several modules for input/output, solving governing equations, calculation of heat and mass transfer coefficient, component model, property, core decay heat, heat structure, and trip control. The link between each module and calculation logic is shown in Fig. 2. Each module is configured to set the initial value through user input and to perform the calculation using the Euler forward method every time increment.

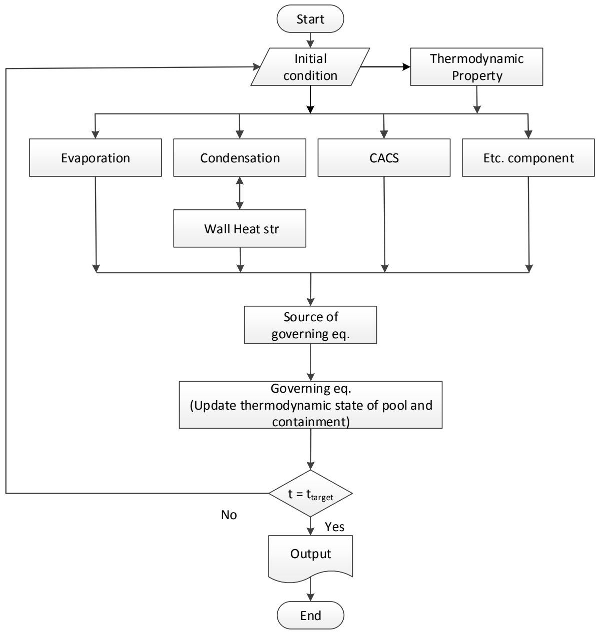

Fig. 2. Structure and logic of code

5. Conclusions

The work for a cooling analysis code development of the research reactor building and pool during the long-term cooling has been performed. First, the PIRT analysis was carried out to identify the major thermal hydraulic phenomena during the long-term cooling. Second, a literature survey was conducted to develop appropriate models for the identified phenomena. Finally, the code structure and algorithm was established.

Acknowledgement

This work was funded by the Korea government (MSIT: Ministry of Science and ICT).

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