Influence of T-H model's uncertainty on natural circulation

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Abstract: Passive system operation based on natural circulation is widely used in new generation nuclear power plant. However several uncertainty factors will affect the system operation reliability, as well as the accident development, and the T-H model's uncertainty induced by fitting of heat and mass transfer correlations is one of such important factors. Passive containment cooling system(PCCS) is novelly used in AP1000, by which the residual heat is removed by natural circulations in the steel vessel and in the air channel outside the vessel. In this paper we analyze the effect of the uncertainties of heat and mass transfer correlations on the containment state with the accident development after main steam line break(SLB), which is one of the accidents threatening the containment integrity. Since the peak value of pressure in the steel vessel is the criterion for the system function, so a group of values of such parameter are gained under different correlations' uncertainties based on the Thermal-Hydraulic model which simulates the system behavior. Based on the results it can be concluded that the T-H model's uncertainty may have comparable important influence on the system operation, which should be considered in the system reliability model accompanied with the accident development.

Keywords: Natural circulation, T-H model's uncertainty, Accident development, Passive containment cooling system

I. INTRODUCTION

Passive system operation based on natural circulation is widely used in new generation nuclear power plant (Ref.1) to improve the safety especially under outside disasters such as earthquake, tidal wave and so on, because of its simple structure and less need of human intervention. However several uncertainty factors will affect the system operation reliability (Ref.2 and 3), as well as the accident development, and the T-H model's uncertainty induced by fitting of heat and mass transfer correlations is one of such important factors (Ref.4). Passive containment cooling system(PCCS) is novelly used in AP1000 (Ref.5), by which the residual heat is removed by natural circulations in the steel vessel and in the air channel outside the vessel. In this paper we analyze the effect of the uncertainties of heat and mass transfer correlations on the containment state with the accident development after main steam line break(SLB), which is one of the accidents threatening the containment integrity. Since the peak value of pressure in the steel vessel is the criterion for the system function, so a group of values of such parameter are gained under different correlations' uncertainties based on the Thermal-Hydraulic model which simulates the system behavior after the accidents.

II. SYSTEM DESCRIPTION

Passive containment cooling system(PCCS) (Ref.5) is one of the important safety systems in AP1000 design, whose function is to transfer the heat produced in the containment to the atmosphere based on the natural circulations in and outside the steel vessel. When the steam is injected into the vessel after accidents such as LOCA and SLB, it will be cooled and condensed and the heat will be transferred to the environment through the vessel, the flowchart of the system is shown in Fig.1 (Ref.5)

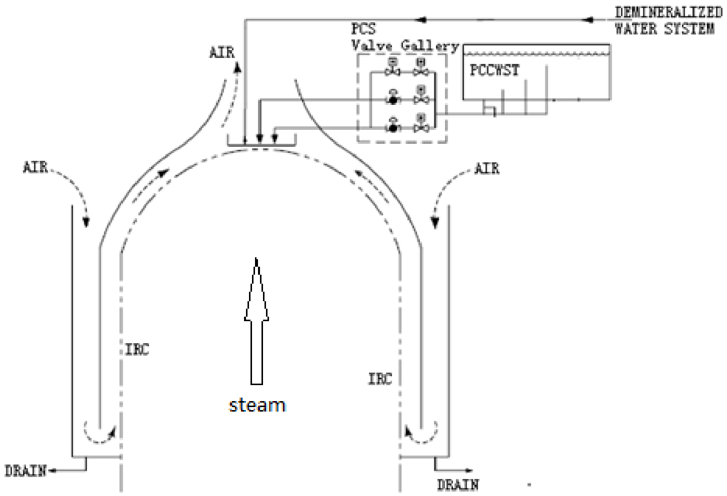


Fig.1 System flowchart of PCCS

III. UNCERTAINTY MODEL

The correlations of heat and mass transfer are gained based on the experiments (Ref.6):

$$G = k_G \cdot M_A \cdot (p_{Ai} - p_{AG}) \tag{1}$$

$$Q = \alpha \cdot A \cdot \Delta t \tag{2}$$

Here G -- the condensing or evaporating mass flux
k_G -- the mass transfer coefficient
M_A --the molecular weight of gas A
p_{Ai} , p_{AG} -- the partial pressure of gas A at the interface and at the bulk gas mixture respectively
Q -- the heat transfer amount
α -- the heat transfer coefficient
A -- the heat transfer area
Δt -- temperature difference between the surface of the steel vessel and the flux

In formula (1) and (2) the mass transfer coefficient (k_G) and the heat transfer coefficient (α) should be summarized by the experimental data, and the other parameters are characteristic dimensional parameters, physical parameters or parameters which can be gained from the experiment directly.

$$\alpha = Nu \cdot \lambda / L \tag{3}$$

$$k_G = Sh \bullet (D_v P)/(RTp_{BM} L) \tag{4}$$

$$p_{BM} = (p_{AG} - p_{Ai})/\ln[(P - p_{Ai})/(P - p_{AG})] \tag{5}$$

$$Sh = Nu/(\Pr/Sc)^n \tag{6}$$

Here Nu --Nusselt number

Sh--Sherwood number
λ -- heat conductivity coefficient
L-- the characteristic dimensional parameter
Dv-- diffusion coefficient
P-- total pressure
R-- gas constant
T-- temperature
p_{AG} -- steam partial pressure in the vessel
p_{Ai} -- steam partial pressure at the film

So *Nu* and *Sh* can be fitted based on the experimental data, then we can get α and k_G. When the correlations for *Nu* and *Sh* are fitted, their uncertainty model can be established. The experimental values of such two numbers (Nu_e, Sh_e) can be gained from the experimental data, while the theory values can be gotten from the correlations (Nu_c, Sh_c). Then the distribution of the ratio（Nu_e/Nu_c),（Sh_e/Sh_c) can describe the uncertainty of the heat and mass transfer models.

IV. RESULTS

IV.A. Uncertainty of Nu model

In this paper we focus on the effect of T-H model's uncertainty which induced by the heat and mass transfer correlations, that is, the experience formulae of *Nu* and *Sh* Number, furthermore the *Sh* is related to *Nu* (See formula (6)), so influence of *Nu* model on the system reliability is analyzed here, the ratio of （Nu_e/Nu_c) is according to a normal distribution, as shown in Fig.2(Ref.4).

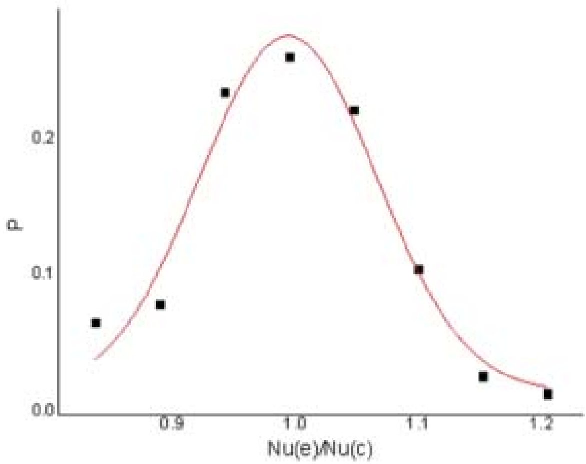
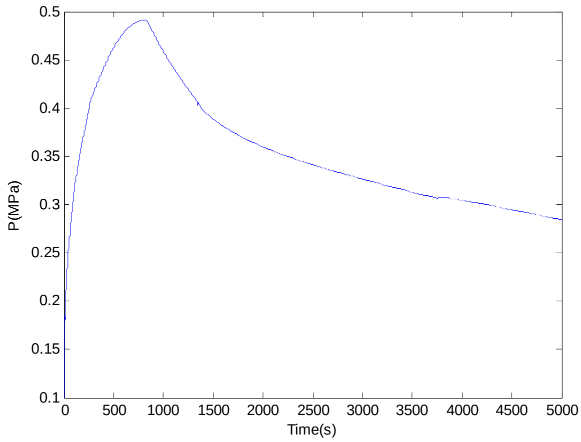


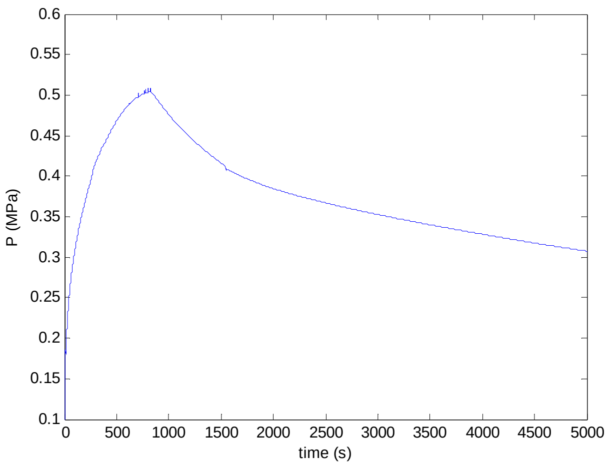
Fig.2 Uncertainty of Nu model

IV.B. Reliability of PCCS after SLB based on Nu uncertainty

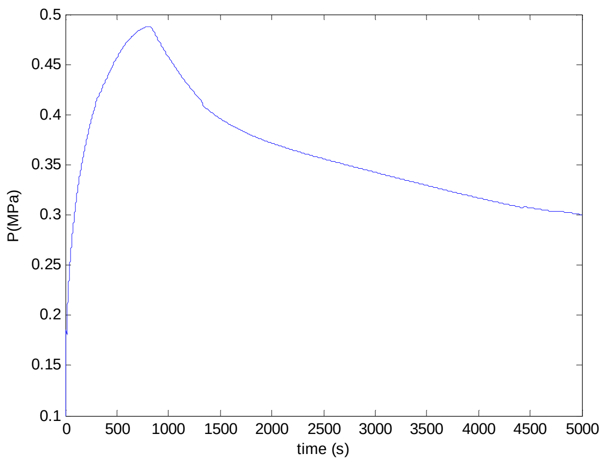
Here we analyze the system reliability after SLB accident based on *Nu* uncertainty shown in Fig.2. The total pressure in the containment should be kept below 0.5 MPa, so the pressure distributions under design condition are given in Fig.3, the distribution in Fig.3(a) is the result of not considering the uncertainty of *Nu*, while the distributions in Fig.3(b) and (c) are the results of considering the uncertainty of $Nu_e/Nu_c=0.9$ and $Nu_e/Nu_c=1.1$.



(a) Nue/Nuc=1



(b) Nue/Nuc=0.9



(c) Nue/Nuc=1.1
Fig.3 pressure distribution in the containment

From the results it can be seen that the uncertainty of *Nu* correlation has important effect on the system behavior and the peak pressure in the containment exceeds the threshold value (*0.5MPa*) when $Nu_e/Nu_c=0.9$. Since the *Nu* number will influence the heat and mass transfer processes, the *Nu* is higher, the processes are stronger, so the pressure is lower. The probability of

$Nu_e/Nu_c=0.9$ or lower is about 0.08 based on Fig.2, which is much higher than the device fault probability and should be considered in the system reliability model.

V. CONCLUSIONS

The uncertainty of heat and mass correlations may have important effect on the system reliability, while the physical process failure is an integrated result of model uncertainty and parameter uncertainty (e.g. air temperature, power,...), which will be analyzed in the future.

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