The Effect of Air Temperature Probability Distribution Form on the System Reliability of PCCS in AP1000

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Abstract: Passive Containment Cooling System (PCCS) in AP1000 is a typical passive safety system, which operates based on natural circulation and atmosphere is the cold source. Air temperature is one of the key parameters influencing the system operation, and its probabilistic density distribution is gotten by fitting based on historical data. Normal distribution or Bi-normal distribution are always used for air temperature, since the values of air temperature will concentrate around a value for most of the time in a year if the plant site is in a tropical region, while the values of air temperature can have two peak values if the plant site is in an area with apparent four seasons. However, the variance of the distribution may have important effect on the result of system reliability evaluation, because the probability of system failure is so low that the temperature values are quite high in such cases and such values are in the tail of the distribution. In this paper, the probabilistic density distribution is fitted for a certain month, the different distribution forms are used and the effect on the system reliability evaluation is analyzed.

Keywords: System Safety Reliability, Air Temperature, Probability Distribution Form.

1. INTRODUCTION

Passive system is widely used in new generation reactor design to improve the safety of nuclear power plant, and functional failure of passive system (i.e., the system fails to implement its safety function since the system operational condition deviates from the design condition.) should be considered in Probabilistic Safety Analysis (PSA) [1,2] since the system operates based on natural circulation. Passive Containment Cooling System (PCCS) in AP1000 nuclear power plant [3,4] is a typical passive safety system, and atmosphere is used as the heat sink, so air temperature has important influence[5,6] on the system operation. However, system failure always occurs at the air temperature with very high value, because of the large system safety margin in design.

For the air temperature probabilistic density curve, Normal (for torrid areas or semi- torrid areas) or Bi-Normal (for area with apparent for seasons) curve are always fitted based on historical data. Since the probability of air temperature for failure case is very low and at the tail of the probabilistic curve, so the variance may have important effect on the system physical failure evaluation.

2. SYSTEM DESCRIPTION

Passive Containment Cooling System (PCCS) in AP1000 nuclear power plant is a typical passive safety system, the heat produced in the containment is transferred to the atmosphere through the natural circulations inside and outside the steel vessel, as shown in FIGURE 1[3].

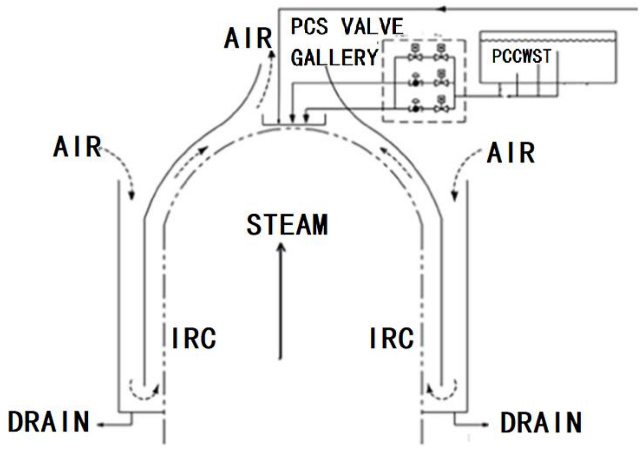


FIGURE 1: PCCS SYSTEM

The Thermal-Hydraulic (T-H) model[7] is established based on lumped parameter method to describe the T-H behavior of the system, including the natural circulation and steam condensation inside the steel vessel, heat conduction through the steel wall and the natural circulation outside the steel vessel. The T-H model has dozens of input parameters including enviromental parameters, operation parameters and construction parameters, and the output is the curve of pressure in the containment varying with the time. The system failure can be judged if the peak value of pressure in the containment exceed 0.5 MPa, that is,

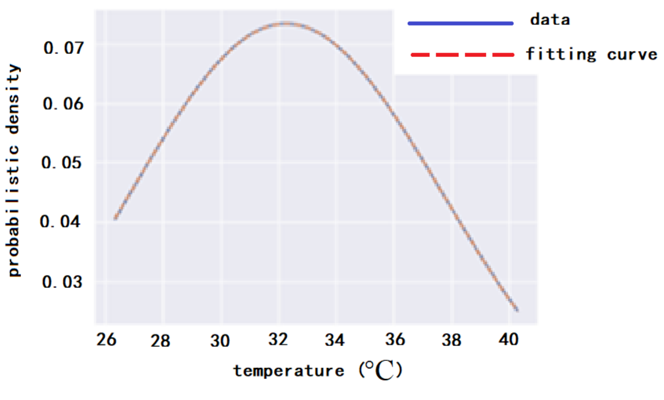
$$P_{containment} > 0.5\ MPa \tag{1}$$

Based on the sensitivity analysis, air temperature, air pressure and uncertainty of the steam mass flow are screened as the key inputs affecting the peak value of pressure in the containment.

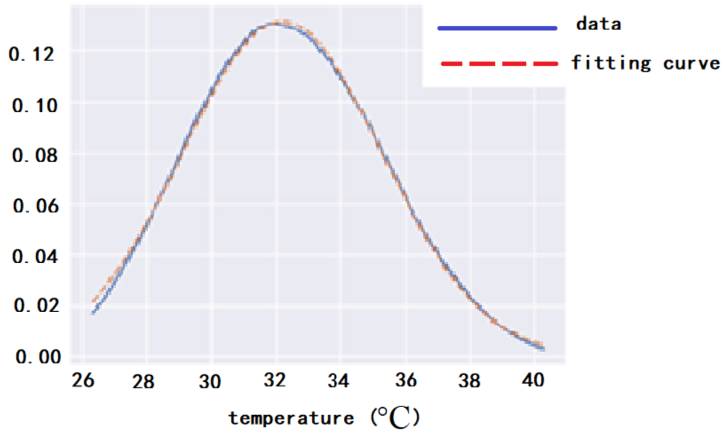
3. CASE STUDY

3.1. Air Temperature Distribution

Air temperature is one of the key inputs to influence the system T-H behavior, and the system always has high safety margin and the failure cases can occur when air temperature has quite high values whose probabilities are so low that at the tail of the probabilistic density curve. Then the variance of the distribution curve may have important effect on the results. In order to decrease the effect of uncertainty in air temperature distribution curve induced by the seasonal variations, we sample the month firstly and then sample the air temperature based on the distribution curve for the certain month[7]. However, the samples of extreme high temperature inducing system failure are few and their probabilities are gained from extrapolation, so different extrapolation methods may affect the results. Here, two probabilistic density curves of one month shown in FIGURE 2 (a) and (b) are used to analyze the system physical process failure probability of PCCS.



(a)



(b)
FIGURE 2. Air Temperature Curves

3.2. Results based on Different Air Temperature Distributions

The system physical process failure probabilities are evaluated based on the curves in FIGURE 2 (a) and (b), and air pressure and steam mass flow uncertainty are shown in Table 1, the design values are used for other inputs of the T-H model, and the results are shown in Table 2.

Table 1. Distribution of Key Inputs

Parameters	Distribution	Interval	Source
Air pressure	Uniform	[0.09MPa,0.11 MPa]	Historical data
Air temperature	Shown as FIGURE 2 (a) and (b)		Centered
Steam mass flow uncertainty	Uniform	[1,1.02]	Measuring error

Table 2. Results

Air Temperature Distribution	System Physical Process Failure Probability
FIGURE 2 (a)	$1.8 * 10^{-3}$
FIGURE 2 (b)	$< 1* 10^{-4}$

The system physical process failure probability based on the air temperature distribution in FIGURE 2 (b) is smaller than that based on air temperature distribution in FIGURE 2 (a) by at least one order of magnitude. From FIGURE 2 we can see that mean values of two distributions in (a) and (b) are almost the same, and the variance in distribution of (b) is smaller than that of (a). The values of air temperature in failure cases are very high and at the tail of the curve, so the probabilities of such values are much lower based on FIGURE 2 (b) than on FIGURE 2 (a).

4. CONCLUSION

Air temperature is one of the key factors to influence the passive containment cooling system operation, and the values in failure cases are always in the tail of the distribution curve, so the variance can have important on result of the system physical process failure probability evaluation. Since such high values of air temperature are too high to get their probabilities from the historical data directly, extrapolation method is used, different extrapolation methods have less effect on the mean values but important effect on the variance.

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