M02/3

An Estimation of Uncertainties in Containment P/T Analysis Using CONTEMPT/LT Code

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ABSTRACT

In a nuclear power plant, the containment design pressure and temperature (P/T) have been established based on the unrealistic conservatism with suffering from a drawback in the economics. Thus, it is necessary that the the uncertainties of design P/T values have to be well defined through an extensive uncertainty analysis with plant-specific input data and or models used in the computer code. This study is to estimate plant-specific uncertainties of containment design P/T using the Monte Carlo method in KNU3. 3 plant parameters and Uchida heat transfer coefficient are selected to be treated statistically after the sensitivity study. The Monte Carlo analysis has performed based on the response surface method with the CONTEMPT/LT code and Latin Hypercube sampling technique. Finally, the design values based on 95%/95% probability are compared with worst estimated values to assess the design margin.

1. Introduction

In a nuclear power plant, the containment vessel is the last barrier to protect the public from radiation hazards during certain postulated accidents. Thus, the containment design pressure and temperature (P/T) have been established based on the conservatism, i.e. the worst initial operating and environmental conditions. Moreover, the CONTEMPT/LT code which is a lumped zero dimensional code is still the only available licensing code. This method is ready to suffer from a drawback in the economical point of view. Thus, the uncertainties of design P/T values have to be well defined with an extensive uncertainty analysis with plant-specific input data, assumptions or models used in the analysis code to quantify the design margin. Also this internally secured margin than worst estimated value may show the good evidence that there is little undue risk to the public against the severe accident in the existing plants.

This study is to estimate plant-specific uncertainties of containment design pressure and temperature using the Monte Carlo method for important parameters in Kori-Unit 3 nuclear power plant. 3 plant parameters and Uchida heat transfer coefficient model have been selected to be treated statisti- cally after the sensitivity study. The selected plant parameters are containment inside humidity and temperature and outside temperature. The probability distributions of those plant parameters are obtained from the weather history of site and the operating history for last 3 years. Also, the uncertainty of Uchida heat transfer coefficient model is calculated from existing experimental data. The other parameters, which the statistical treatment is difficult for or are insensitive to the results, remain to limiting values.

In order to perform the Monte Carlo analysis, we adopt the response surface model using the CONTEMPT/LT code and Latin Hypercube sampling technique. Finally, the analysis has been implemented for the main steamline break (MSLB) accident, which is the design-base accident for the plant. The resultant design values based on 95%/95% probability are compared with the worst estimated values to assess the design margin improvment. The results from this study are also expected to provide various important informations to the Individual Plant Evaluation for severe accidents.

2. The Methodology of Analysis

In this study, the Monte Carlo analysis has been performed to estimate the uncertainties of containment design pressure and temperature for the MSLB accident which is the design-base accident of Kori-Unit 3 nuclear power plant. This analysis adopts the response surface model using the CONTEMPT/LT code and Latin-Hypercube Sampling(LHS) technique.

2.1. CONTEMPT-LT Code

The CONTEMPT-LT code is a computer program to describe the thermal hydraulic behavior of reactor containment during postulate accident conditions. This code is used to analyze the transient behavior of PWR, BWR, and related eexperiments. This code was licenced by NRC as a containment analysis code with conservative thermal-hydraulic models. In this code, the lumped zero dimensional model is applied to four types of compartments and several heat transfer coefficients are used to the wall heat transfer description as user option. In this study, PWR drywell compartment was modeled and Uchida heat transfer coefficient was used for the MSLB accident analysis.

2.2. Monte Carlo Simulation

The Monte Carlo method is widely used to obtain the randomly sampled data combinations based on distribution functions of each input variables. And using these combinations of input values, computer calculations are carried out and are repeated until the resonable distribution for calculated results are obtained. However, such procedure using the sophisticated design code requires too much efforts and costs. Therefore, in this study, the response surface method is used as shown in the following section.

2.2.1. The Response Surface Method

The response surface model(RSM) is used to obtain a simplified equation for the complex system calculation by making the approximate functional form between input variables and desired output parameter. Suppose that output variable is a function of input variables as follows;

$$y = f(x_1, x_2, x_3, \ldots, x_k) \tag{1}$$

where, x_i = input variable

If the correlation between the input variables are linear or nearly linear in the range of input variable changes, the first order regression model like Eq.(2) can be used. If not, the second order regression or the higher order regression model like Eq. (3) shoud be used.

$$y = a_0 + \sum_{i=1}^{k} a_i x_i \tag{2}$$

$$y = a_0 + \sum_{i=1}^{k} a_i x_j + \sum_{i=1}^{k}\sum_{j=1}^{k} a_{ij} x_{ij} \qquad (3)$$

The polynomial coefficients in the above equations will be determined from leat-square fitting with results of the system code, CONTEMPT/LT, which are calculated with input data set chosen by the experimental design.

2.2.2. Experimental Design

In order to obtain the reliable response surface, a lot of test runs with appropriate input data are required and also the cases must be chosen carefully so that all the proposed dependencies in the fit are accurately determined. In such purpose, some sampling thchniques were developed as like MN factorial design or central composite design. Among them, in this study the central composite design method was employed due to compactness and suitability for the second-order fit. This method is two-level, full-factoial design and thus samples five points for each input variables, $-\alpha$, -1, 0, 1, α . These poiunts are factorial points, central point, and axial points as combination of (-1,1), (0,0), ($-\alpha$, α), respectively. Thus, the total number of experiments is 2^k+2k+1, where the number of variables to be considered.

From these points, a matrix which are used to calculate the coefficients of the second order regression model can be formed. This matrix is called "experimental design". From this matrix, the following equation can be obtained as,

$$Y = AX + E \qquad (4)$$

where Y is response vector. X and A are input variable and coefficient vector of RSM, respectively. And e represents the error vector.

In obtaining the above equation, vector, A, is calculated by least-square method to minimize error, E, as follows;

$$A = (X^TX)^{-1}(X^TY) \qquad (5)$$

Then the second order regression model like Eq.(3) can be constructed, which have small errors in all range.

2.2.3. Monte Carlo Analysis

From the response surface obtained above and the marginal probability distributions of each independent variable, the Monte Carlo analysis is carried out. This simulation can be broadly defined as the use of repeated computer trials or experiments to draw influences on a parameter or random variable and obtain the aggregate effect of the uncertainties. In Monte Carlo method, it is very important to develope an effective sampling technique in view of accuracy and conputating time. Among well-known sampling techniques as like Crude Monte Carlo(CMC), Factorial Stratified Sampling(FSS) and Latin-Hypercube Sampling(LHS), CMC is simple but there is a possibility that all trials would use data point clustered in a particular region of the sample space unless the number of trials is sufficiently large. In FSS, the combined sample space is partitioned to insure that points are chosen in each quadrant. In LHS, each marginal distribution is partitioned to insure that points are chosen from each part of the marginal distribution. The superiority of each technique depends to a large extent on the behavior of the output function, the range of the variables, the sample size and the aspects of the parameter distribution that are to be estimated.

In this study, the Latin-Hypercube Sampling method was used due to good results even with less trials compared to other techniques. The calculational precedure with those models is illustrated in Fig. 2.

3. Plant Analysis and Results

3.1 Problem Description

The MSLB accident, which belongs to the DBA in a nuclear power plant, is the most restrictive pipe break from the standpoint of containment pressure concurrent with a failure of one emergency diesel. This pipe break release tremendous mass and energy in the form of steam from the secondary loop to inside of containment and increases the containment pressure and temperature. Thus, if the containment is not designed properly or the safety system is not adequately operated, the integrity of containment would be threatened. The sequence of this accident is analyzed with the CONTEMPT/LT code described previously in the conservative design under the worst environmental and operational conditions and assumptions listed in the Final Safety Analysis Report of the plant.

For Kori-Unit 3, the resultant pressure and temperature profiles during the accident with such conservative calculation are shown in Figs. 2 and 3. The peak P/T are calculated as 55.51 psia and 376.126 °F. However, this approach is so conservative that this study uses the more realistic and plant-specific data and treats their uncertainties statistically.

3.1. Parameter Sensitivity Analysis and Variable Selection

Before performing the Monte Carlo simulation, the sensitivity study was carried out to choose sensitive input parameters and models to results and treat them stochastically. The results for 20% change(10%) from the base calculation value are shown in table 1 and selected input parameters are 3 environemntal input parameters and 1 model; inside temperature, inside relative humidity, outside temperature and Uchida heat transfer coefficient. Even though the effects of volumetric heat capacity and containment free volume were large, these parameters were rejected in this study because their distributions were difficult to obtain. Also the containment inside pressure was excluded due to its negligible uncertainty in the plant data. The containtment inside humidity was considered even its small effect because it had some sensitivity in LOCA analysis. Among various heat transfer coefficient options, the Uchida heat transfer coefficient was selected because FSAR recommanded to use the coefficient in MSLB analysis. All other parameters remain to limiting values.

Now, in order to obtain the probability distributions for those variables, about 100 points for each of 3 plant parameters, CIH, CIT and COT were obtained daily and seasonally from the plant operating history and weather history of site for last three years. Also, the distribution of Uchida heat transfer coefficient uncertainties were obtained from the comparison to 47 data generated by 3 existing experiments. Those distributions were fitted to the normal distribution and, thier means and standard deviations were shown in Table 2.

3.2 Monte Carlo Simulation

Using the central composite design method, a calculation matrix has established as shown in Table 3. From this matrix, 25 calculations using the CONTEMPT/LT code were implemented to obtain polynomial coefficients in the response surfaces, Eq.(3) for the containment peak pressure and temperature. The least-square fitted results are shown in Table 4. Also the accuracy of RSM are shown in Table 3. The maximum deviation from CONTEMPT/LT calculations is 6% and the standard deviations for P/T are 0.6 psia and 2.96 °F, respectively.

Finally, using those response surfaces and 3000 input sets sampled by LHS, the Monte Carlo simulations were performed and the output distributions for containment P/T are depicted in Figs. 4 and 5, respectively. As shown in those figures, the peak pressure distribution has 45.22 and 0.71 psia of mean and standard deviation, respectively. And for the peak temperature distribution, the mean and standard deviation are 342.47 and 4.17 °F, respectively. Thus the resultant design values based on 95%/95% probability and combined with RSM model uncertainties are 47.76 psia and 355.39 °F for pressure and temperature, respectively. Compared to the conservative calculations described in Sec. 3.1, it has revealed that the design margin would be increased with amount of 7.75 psia and 20.63 °F for P/T respectively according to this approach.

4. Discussion and Conclusions

This study is to estimate the design containment pressure and temperature with not the conventional worst-estimate method using convervative input data and models but the statistical method using the plant-specific data and combining thier uncertainties. In order to perform this calculations, the response surface model and Monte Carlo method using Latin-Hypercube sampling technique have been adopted.

In the sensitivity study, the containment inside temperature was most sensitive to the peak temperature. The Uchida wall heat transfer coefficient has been so sensitive and conservative that more accurate correlation would be required for the best-estimate evaluation. The final results of this study show that the design margin can be increased by amounts of 7.75 psia and 20.63 oF for the peak pressure and temperature, respectively by the stochastical approach. In future, for more accurate evaluation, it is recommended that the best-estimate code should be developed and thus the code uncertainty from the comparison between the code and integral-effect test should be combined.

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Table 1. Sensitivity Test Result

Parameter	Nominal Input	del P	del T
Inside Pressure	14.7(psia)	3.84	6.94
Inside Temperature	120 °F	2.06	13.46
Inside Relative Humidity (CIH)	0.7	-0.09	-0.11
Heat Transfer Coefficient(HTC)	Uchida HTC	-5.43	-5.40
Outside Temperature (COT)	92 °F	0.9	2.05
Thermal Conductivity	-	-1.72	-1.78
Volumetric Heat Capacity	-	-3.50	-4.46
Containment Free Volume	2.15+6	-3.53	-0.20
Spray Efficiency	1.0	-1.54	0

Table 2. Input Distribution

Vaiables	Function	Mean	σ
HTC	Normal	1.36	0.20
CIH	Normal	0.35	0.14
CIT	Normal	83.12	7.92
COT	Normal	66.51	13.60

Table 3. Experimental Design

RUN	HTC	CIH	CIT	COT	LT CODE		RSM		ERROR	
					P	T	P	T	P	T
1	-1	-1	-1	-1	49.552	346.50	48.838	345.39	-0.714	-1.11
2	-1	-1	-1	1	49.682	348.18	49.054	346.29	-0.628	-1.89
3	-1	-1	1	-1	52.605	364.32	51.834	362.55	-0.771	-1.78
4	-1	-1	1	1	52.888	365.32	52.126	363.83	-0.762	-1.49
5	-1	1	-1	-1	49.463	348.21	48.730	346.08	-0.733	-2.12
6	-1	1	-1	1	49.590	347.13	48.953	346.28	-0.637	-0.85
7	-1	1	1	-1	52.320	363.61	51.561	362.10	-0.759	-1.51
8	-1	1	1	1	52.604	364.58	51.861	362.70	-0.743	-1.88
9	1	-1	-1	-1	37.616	320.75	37.930	321.37	0.314	0.62
10	1	-1	-1	1	37.768	321.04	38.091	321.96	0.323	0.92
11	1	-1	1	-1	40.320	337.04	40.524	337.31	0.204	0.27
12	1	-1	1	1	40.456	337.42	40.762	338.28	0.306	0.87
13	1	1	-1	-1	37.495	321.08	37.821	321.99	0.326	0.91
14	1	1	-1	1	37.648	321.37	37.990	321.88	0.342	0.51
15	1	1	1	-1	40.050	336.17	40.251	336.80	0.201	0.63
16	1	1	1	1	40.216	336.55	40.497	337.08	0.281	0.53
17	0	0	0	0	43.819	339.45	44.268	340.52	0.449	1.08
18	$-\alpha$	0	0	0	61.470	379.08	62.584	381.55	1.110	2.46
19	α	0	0	0	35.086	320.15	32.938	315.35	-2.150	-4.80
20	0	$-\alpha$	0	0	44.036	339.52	44.499	340.46	0.463	0.94
21	0	α	0	0	43.678	338.92	44.138	339.96	0.460	1.04
22	0	0	$-\alpha$	0	41.461	326.29	41.726	326.87	0.265	0.57
23	0	0	α	0	46.715	358.37	47.293	359.60	0.578	1.23
24	0	0	0	$-\alpha$	43.770	339.22	44.967	341.76	1.200	2.54
25	0	0	0	α	43.902	339.63	44.976	341.96	1.070	2.33

Where $1 = 2\sigma$
$\alpha = 3\sigma$

Table 4. Response Surface Model

COEFFI.	P	T	COEFFI.	P	T
a0	.58648+02	.35449+03	a23	-.17661-01	-.12159+00
a1	-.11947+02	-.25496+02	a24	.46835-03	-.44816-01
a2	.39052+00	.15215+02	a31	.00000+00	.00000+00
a3	.73287-01	.15745+00	a32	.00000+00	.00000+00
a4	-.93164-01	-.16555+00	a33	.24578-03	.27597-02
a11	.83457-01	-.75791-01	a34	.48064-04	.24288-03
a12	-.10163-02	-.27947+00	a41	.00000+00	.00000+00
a13	-.15781-01	-.47836-01	a42	.00000+00	.00000+00
a14	-.12821-02	-.72734-02	a43	.00000+00	.00000+00
a21	.00000+00	.00000+00	a44	.71640-03	.13744-02
a22	.60672+00	-.36999+01			

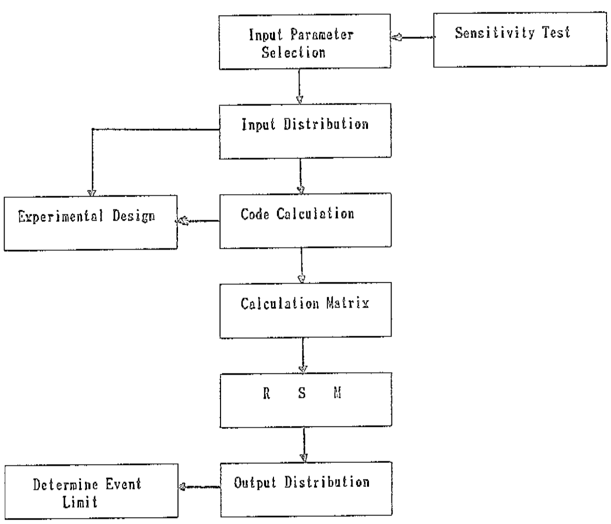

Figure 1. Working Flow Chart

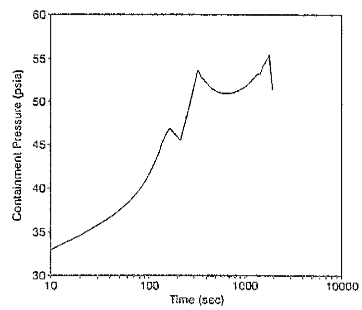

Figure 2. The Containment Pressure Calculated by The CONTEMPT/LT Code during MSLB in Kori-Unit 3

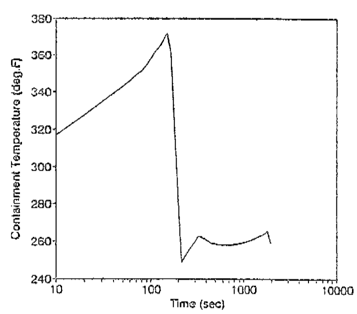

Figure 3. The Containment Temperature Calculated by The CONTEMPT/LT Code during MSLB in Kori-Unit 3

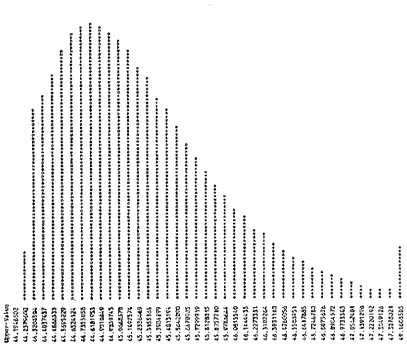

Figure 4. Containment Peak Pressure Distribution in Monte Carlo Simulation

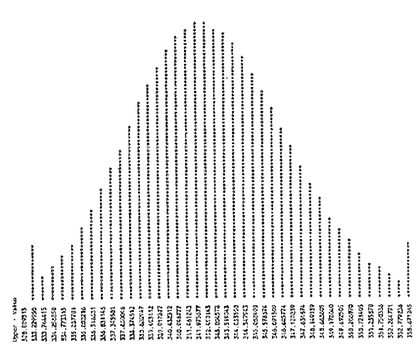

Figure 5. Containment Peak Temperature Distribution in Monte Carlo Simulation