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Uncertainty Calculations for NEPTUN Reflood Test

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1. Introduction

The nuclear plant licensing procedure has traditionally been employing so-called Evaluation Model thermal/ hydraulic analyses for the design basis accidents analyses. The evaluation method, however, is considered to be too conservative, resulting in unrealistic predictions in many applications with little information about the physical process during an accident. This is due to the very conservative models selections intended to envelop the related uncertainty. On the other hand, the best-estimate approach is required to specify a range of prediction based on the analysis of the uncertain parameters used in the calculations. In this study, the uncertainty analyses based on the Wilks' formula and extensive number of calculations are performed using MARS code [1]. The NEPTUN Reflood test 5052 is selected as a target problem.

2. Methods

2.1 NEPTUN Tests

NEPTUN facility is a half height 37 rod bundle (33 heater rods and 4 guide tubes) facility for core boil-off and forced bottom reflooding experiments. The power distributions are cosine shape with a peaking factor of 1.58 axially and uniform in the radial direction. The pressure, rod surface and fluid temperatures are recorded for 8 locations along the channel. The reflood velocity as well as exit steam flow is also monitored throughout the test. Among the 40 tests performed, the test 5052 which has a medium reflood velocity is chosen for the analysis. The rod temperature is raised by the 2.45 kW heater, and the reflood is initiated when the desired heater temperature is reached.

2.2 NEPTUN Modeling using MARS

The NEPTUN test section is modeled with one dimensional 18 hydraulic volume, by noting that the radial distribution is uniform. The base experimental conditions are:

- pressure	4.1 bar
- Reflood velocity	2.5 cm/sec
- Reflood subcooling	78 K
- Single Rod Power	2.45kW
- Max. Rod Temperature	795.5 ^{o}C

The inputs for the MARS code is prepared such that the reflooding is initiated when the maximum rod surface temperature reaches 795.5 ^{o}C.

2.3 Wilks' Formula

If we perform N calculations, the confidence level β is defined for upper tolerance limit by [2,3]

$$\beta = 1 - \binom{n}{0}\alpha^{N}(1-\alpha)^{0} - \binom{n}{1}\alpha^{N-1}(1-\alpha)^{1} - \ldots - \binom{N}{r-1}\alpha^{N-(r-1)}(1-\alpha)^{r-1} \quad (1)$$

For $r=1$, we get $N=59$ to have $\alpha = 0.95$ and $\beta = 0.95$. The values for N are 93, and 124 for $r=2$ and 3, respectively, with same values of α and β. The formula tells that if we perform 59 calculations, the highest outcome is within the upper 5% range with 95% confidence. The theory would be applied to locate the 95% boundary range, with the 95% confidence.

2.4 A extended number of calculations (Monte Carlo)

Another way to find the 95% tolerance limit would be to perform a extended number of calculations by varying the uncertain parameter over the reasonable range. The range would be $[-2\sigma, 2\sigma]$ if a specific parameter is expected to show normal distribution. The number of occurrence needs to be selected accordingly. The number of calculation might be determined by tracing the variance of results of importance.

3. Results

3.1 Base Calculation Results

The MARS code results for the base input deck is as shown in Figure 1. As in the experimental data, the temperature at level 4 is found to show a maximum value. Although the experimental data show the earlier quenching behavior, the peak rod surface temperatures are seen to have good agreement with the measured values.

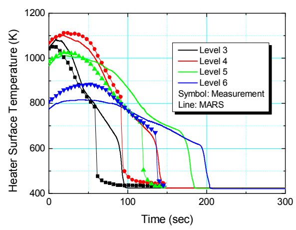


Figure 1. Base Deck Results

3.2 Uncertainty Parameter Selection

The uncertainty parameter range for the Wilks' formula and Monte Carlo calculations are selected by the following method. As a first step, the parameters of importance are selected based on the CSAU LBLOCA

PIRT results [4]. The parameters with importance of 7 or higher are selected. Even though, the loss of fluid test includes a several *phenomena*, the fuel and core would be appropriate in the NEPTUN test. Moreover, since the properties of the main fuel materials (Inconel600, copper, Al_2O_3) are not expected to have such an uncertainty range enough to significantly affect the result, compared to others, only the core phenomena are chosen to be varied.

Two major areas for the core phenomena would be the model uncertainty in the MARS code and measured data uncertainty. For the MARS code models, which are basically RELAP5/MOD3 models, the relevant models are reflood heat transfer model coefficients. The uncertain model parameters are listed in Table 1 with their uncertainty range.

Table 1. Uncertain Model Parameters

Parameter description		Dist.	2σ
Single Phase Liquid	D-Boelter	N.	±20%
CHF	AECL CHF	N.	±74%
Transition Boiling	Transition	N.	±30%
Film Boling HT	Film boiling	N.	±36%
Single phase Vapor	D-Boelter	N.	±20%
Nuclear Boiling	Chen	N.	±23.2%

N: normal

The standard deviations are based on the RELAP5 models and correlation manual [5].

For the test data, the detailed quantification of uncertainty is not reported. Therefore, the estimated uncertainty is used [6] for this purpose. Among them the relevant uncertain parameters are shown in Table 2.

Table 2. Uncertain Test Measurements

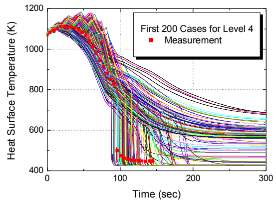
Parameter description	Dist.	2σ
Flooding water mass flow	N.	±53%
Flooding water temperature	N.	±0.5 °C
Rod Power	N.	±1.8%

N: normal

The whole uncertainty range is, therefore, comprised of 9 parameters from both models and measurement uncertainties. A total of 10,000 cases has been selected based on the aforementioned parameter ranges. The model uncertainty is *dialed* for the MARS code through the newly added input provision.

4. Results

The 10,000 calculations were performed to find the range of rod surface temperature variation, based on the uncertain parameters described in section 3.2. Figure 2 shows the calculated rod surface temperature variations at level 4 where the maximum values are observed, along with the measured data. The calculation results of the first 200 cases are employed for this purpose. As seen in this figure, the measure data are completely enveloped by the simulation results. It is interesting to note that even the earlier quenching behavior is covered by the code results. The jagged temperature variation observed at the top of the figure is believed to stem from the abrupt change in heat transfer coefficient near the flow regime boundary. The stiff change, which does not occur during the ordinary analysis, is quite normal behavior coming from the artificial amplication of heat transfer coefficients.



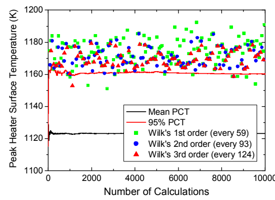


Figure 2. Rod Temp. (Level4) Figure 3. 10,000 cases

The figure 3 shows, for the highest rod surface temperature at level 4, a mean value, 95% bounding value and wilks' formula bounds, based on the 10,000 cases run. Every 59 case is examined, for instance for the 1st order, to apply Wilks' method. It is seen that the 1st or 2nd Wilks' formula show rather too wide variation from the *real* 95% bounding by the Monte Carlo method.

5. Summary

In this study, an uncertainty study has been performed for the NETUN reflood test. By performing 10,000 calculations based on the variation of MARS model parameters and measured data, the Wilks' method is compared with the true 95% bounding value predicted by Monte Carlo simulation. The uncertainty band by the Wilks' formula, compared with the real 95% bounding value, is found to be too broad, especially in the case of 1st order. The 2nd or 3rd order would be more appropriate for the practical applications.

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