Uncertainty Analysis for PGSFR Under ULOF Transient

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1. Introduction

A Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) is a 150-MWe pool-type fast reactor designed using U-TRU-Zr metal fuel. There are several Design Extension Condition (DEC) events of PGSFR, such as unprotected transient over power (UTOP), unprotected loss of flow (ULOF), unprotected loss of heat sink (ULOHS), large partial subassembly blockage, large steam generator tube rupture (SGTR), large sodium leak and station black out (SBO). In this research, the ULOF accident was selected as the target scenario for the best estimate uncertainty analysis.

One of the main concerns regarding the reliability and robustness of the simulation codes is estimating the uncertainty in code prediction. The quality of the prediction will eventually impact reactor safety through the introduction of the safety margins on the reactor design to ensure a proper operation. The best estimate plus uncertainty (BEPU) analysis [1], [2] adopted for uncertainty quantification of the code predictions has been performed through a statistical approach where the figure of merit (FOM) is evaluated multiple times by using several combinations of parameters that are randomly generated according to their distributions. The statistical approach of uncertainty quantification is known to be very powerful for estimating response distributions, but sometimes inapplicable owing to demanding calculation requirements. In this research, Wilks' formula [3] was used to estimate the 95% probability value of the FOM from a limited number of code calculations.

2. Description of the actual work

The objective of the global uncertainty analysis is to evaluate all the safety parameters of the system in the combined phase space formed by the parameters and dependent variables. The methods for uncertainty analysis are based on statistical or deterministic procedures. Deterministic methods are used for linear systems while statistical methods are used for nonlinear systems. The deterministic approach of the uncertainty propagation utilizes the Taylor series expansion of the response around the nominal parameter values. The various moments of the random variables can be obtained by integrating the Taylor series expansion of the random variables over the unknown joint probability distribution for the parameters. The statistical approach of the uncertainty propagation is based on sampling variables from the possible values of the parameters. More specifically, sampling-based uncertainty propagation involves the following steps:

1. Determine important or the most influential parameters. Define the subjective distributions for characterizing the uncertain parameters.

2. Use the distributions to generate multiple samples.

3. Use each parameter sample to perform model calculations that then generate response distributions

4. Perform an uncertainty analysis based on the response distributions obtained in Step 3

The FOM includes all parameters used to judge the relative importance of the phenomena. ULOF means the loss of core cooling capability owing to pumping failure of the primary pump and no leaking coolant unlike pressurized water-cooled reactor (PWR). Based on expert opinions, the FOM for the ULOF of the PGSFR is selected to be the fuel solidus temperature (1250 ℃), clad temperature (1075 ℃), and sodium boiling temperature. In the case of the sodium boiling temperature, the thermal margin of vaporization, which is the difference between saturation temperature and coolant temperature at the channel exit of hot pin, was considered and the saturation temperature was determined to be approximately 900 ℃

3. Result

Figure 1 shows the coolant temperatures for the ULOF obtained using the MARS-LMR by completing the uncertainty propagation for 124 samples of the parameters. Note that the analysis was performed for the 3 FOM: fuel centerline temperature, clad temperature, and coolant temperature, however calculation result for only coolant temperature was presented here due to the space limitation. Wilks' formula was used for the BEPU evaluation, where the simulation models credit the third largest value from the 124 code calculations to satisfy the 95%/95% criterion. The maximum values for each sample calculation are presented in Figures 2. It was observed that the third largest value of the maximum fuel centerline, cladding and coolant temperatures for the ULOF are 1190 K, 1184.3 K, and 1170.5 K, respectively. Thus it was concluded that the thermal margin of the PGSFR for the ULOF does not exceed the safety acceptance criteria.

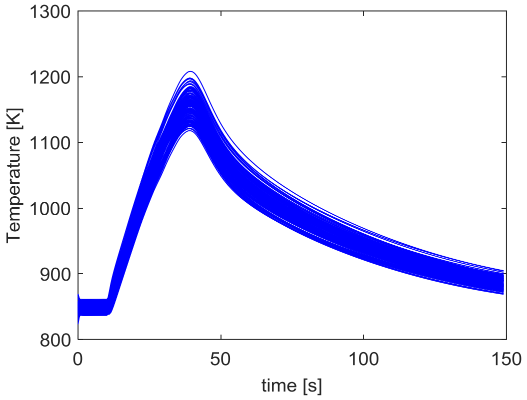

Figure 1. Coolant temperature distributions obtained by propagating parameter uncertainties.

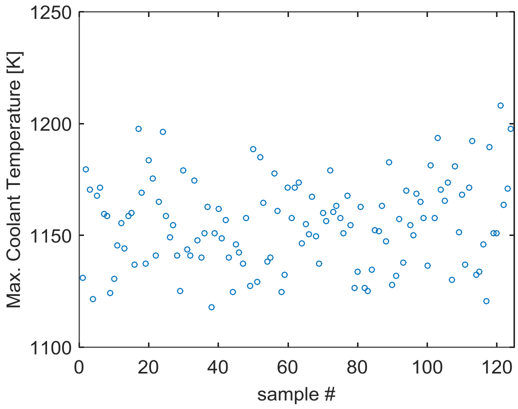

Figure 2. Maximum coolant temperatures for the 124 samples

4. Conclusion

The uncertainty propagation was performed by mapping the uncertainty bands of the model parameters through the MARS-LMR to determine the distributions for the fuel centerline, cladding, and coolant temperatures for the ULOF. The results indicate that the temperatures do not exceed the safety limit.

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