Assessment of Uncertainty in Full Core Reactor Physics Calculations Using Statistical Methods

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Summary

The best estimate method of safety analysis involves choosing a realistic set of input parameters for a proposed safety case and evaluating the uncertainty in the results. Determining the uncertainty in code outputs remains a challenge and is the subject of a benchmarking exercise proposed by the Organization for Economic Cooperation and Development. The work proposed in this paper will contribute to this benchmark by assessing the uncertainty in a depletion calculation of the final nuclide concentrations for an experiment performed in the Fukushima-2 reactor. This will be done using lattice transport code DRAGON and a tool known as DINOSAUR.

1. Introduction

Traditionally, conservative assumptions have been used in safety calculations to ensure the margins to operating limits are not overestimated. In this approach, input parameters for a given safety case are set to values which reflect the worst case scenario and if the output results are acceptable, it is deemed that the real results would be of an equal or lower severity. The problem with this method is that it is not known how conservative the results really are. An alternative is to do a best estimate calculation in which realistic values are input for a given scenario and the uncertainty in the results is assessed. This provides a much better understanding of the true margins to operating limits but comes at the cost of having to determine the uncertainty in the simulation results.

Reactor physics calculations involve numerous inputs and the codes used for these calculations contain simplifications, all of which contribute to the uncertainty in the final results. The Organization for Economic Cooperation and Development (OECD) has initiated a benchmarking exercise to assess the uncertainty that arises in various stages of reactor physics calculations. This benchmark is divided into three phases, each of which contains three or four exercises. The goal of this work will be to contribute to the second exercise of the second phase: Time-dependent neutronics. Specifically, an experiment performed in the Fukushima-2 reactor will be modeled and the uncertainty will be assessed and compared with the experimental results.

A popular method of computing the uncertainty in the results of a code is the random sampling method. A set of input parameters is first defined for a given scenario and a calculation is performed. The uncertainty in the input parameters is then used to create a probability distribution about the initial set of inputs for each parameter. A new set of input parameters is generated by sampling from these distributions and these are used to perform another calculation. This is repeated until a sufficient number of output values have been collected and the distribution of these outputs is used to statistically define an uncertainty range [1]. Note that some input parameters depend on the value of others, and this covariance must also be taken into account when sampling to produce a new set in inputs [2].

2. Proposed Work and Methodology

The OECD has recently (as of March 30 2011) sent out the test cases that are to be analyzed as part of the second phase of their benchmarking exercise. The focus of this work will be the second exercise of Phase II concerning the time dependant depletion of assemblies. The experimental results come from the Fukushima-2 reactor and are in the form of final nuclide concentrations in the fuel [3]. The goal of this work will be to model the reactor and predict the final nuclide concentrations, as well as the uncertainty in these results to see if they bound those found in the experiment. This will be performed using the École Polytechnique de Montréal's lattice physics transport code DRAGON in conjunction with a program developed by M. Ball of McMaster University for perturbing cross section libraries known as DINOSAUR [2].

2.1 Validation of DRAGON and DINOSAUR for Uncertainty Propagation Calculations

DRAGON is a versatile transport code which is capable of modelling a number of various fuel types and geometries. The software comes with several example cases of different fuel geometries including those seen in BWRs, PWRs, and CANDU. DINOSAUR is a tool developed at McMaster University which is capable of modifying the 69-group IAEA WIMS-D4 cross section library read by DRAGON. Note that the library is independent of the input case and thus DINOSAUR can be used for any fuel type or geometry.

2.2 DRAGON Modelling of Fukushima-2 Fuel Geometry

The first step will be to create a three dimensional model in DRAGON of the fuel assembly for the Fukushima 2 reactor. The fuel assembly consists of a 7x7 grid and is depicted in Figure 1. Each numbered rod contains a unique enrichment, gadolinium concentration, and density. A burnup calculation over 1400 days at the specified power of 32 MW will then be performed and the final nuclide concentrations will be extracted at specified points along the assembly. All geometry data and initial conditions are provided by the OECD [3].

+	1	2	3	4	5	6	7
1	4	3	3	2	2	2	3
2	3	2	1	1	1	1	2
3	3	1	5A	1	1	5A	1
4	2	1	1	1	1	1	1
5	2	1	1	1	6A	1	1
6	2	1	5A	1	1	1	2
7	3	2	1	1	1	2	2

Figure 1 Diagram of a Peach Bottom 2 Fuel Assembly [3]

2.3 Perturbation of DRAGON Model Using DINOSAUR

Once the base case has been run, the DINOSAUR program will be used to perturb the cross section library used by DRAGON. It does this by sampling from distributions for each cross section parameter, taking into account any covariance between these values. The uncertainty and covariance information are taken from the 69GROUPV6REC database which is a 69-group extrapolation of the 44-group Oak Ridge National Laboratory database 44GROUPV6REC [2]. The result is a new set of cross sections which are used to perform the burnup calculation again. The nuclide concentrations are then found at specific points along the fuel assembly. This process will be repeated until a sufficient number of results exist to achieve the desired confidence in the output uncertainty. The number of trials required to achieve a particular confidence in the results can be calculated using Wilks' formula [2][4].

2.4 Processing of Results and Comparison with Experimental Values

The final step will be to calculate the standard deviation in the output distribution for each nuclide concentration. The calculated uncertainty range for each nuclide will then be compared with the experimental results to see whether or not they bound them.

3. Conclusion

The proposed work will result in a best estimate calculation with uncertainty of the final nuclide concentration at specific points in the fuel assemblies of an experiment performed in the Fukushima-2 PB-2 BWR. The nuclide concentrations calculated by the model will then be compared with those found in the experiment to see if they are within the predicted error. This will be done by creating a three dimensional model in DRAGON of the PB-2 fuel assembly used in the experiment and perturbing the cross section library using DINOSAUR. This work is proposed as a response to the Uncertainty Analysis in Modeling (UAM) benchmarking exercise proposed by the OECD and will contribute to the development of best estimate modeling for nuclear reactor safety analysis.

4. References

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