Computational Physics and Engineering Division

Sensitivity and Uncertainty Analysis Applied to Range of Applicability Determination

B. L. Broadhead, C. M. Hopper and C. V. Parks

Oak Ridge National Laboratory,*
P. O. Box 2008,
Oak Ridge, TN 37831-6370
(423) 576-4476
bub@ornl.gov

Submitted to the
American Nuclear Society
1999 Winter Meeting and Embedded Topical Meetings,
November 14B18, 1999,
Long Beach, California

---

*Managed by Lockheed Martin Energy Research Corporation under contract DE-AC05-96OR22464 for the U.S. Department of Energy.

Sensitivity and Uncertainty Analysis Applied to Range of Applicability Determination

B. L. Broadhead, C. M. Hopper, and C. V. Parks
Oak Ridge National Laboratory,*
P. O. Box 2008,
Oak Ridge, TN 37831-6370
(423) 576-4476
bub@ornl.gov

Sensitivity and uncertainty (S/U) analysis and the subsequent application of generalized-linear-least-squares methods (GLLSM) were developed in the 1970s for application to primarily fast reactor studies.[1] Recently, interest in the United States has increased in the use of the S/U and GLLSM techniques for the validation of data used in a criticality safety analysis. As a result, both the U.S. Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) have initiated programs to apply these techniques to their respective criticality safety application areas. This paper will review the current status of this work.

The application of S/U techniques allows for a formal determination of the applicability of each of the critical benchmarks in a given set to an application area under consideration. The NRC-sponsored portion of this work developed techniques that can be utilized in a formal determination of applicability using integral parameters based on differences in sensitivity profiles between systems (D) and the correlation coefficients between systems (c_k). These D values are defined below:

$$D_n = \sum_{i=1}^{g} \left| S_{nai} - S_{nei} \right| \quad D_c = \sum_{i=1}^{g} \left| S_{cai} - S_{cei} \right| \quad D_s = \sum_{i=1}^{g} \left| S_{sai} - S_{sei} \right| \quad ,$$

*Managed by Lockheed Martin Energy Research Corporation under contract DE-AC05-96OR22464 for the U.S. Department of Energy.

where S is the sensitivity of k_{eff} for the application, a, or experimental configuration, e, to the capture and scattering cross sections, or to nu-bar (c, s, or n, respectively) for energy group i. These parameters have proven useful not only as formal determinations of critical benchmark data applicability, but additionally as trending parameters in the traditional criticality safety data validation approach.

The objectives of both the NRC and DOE phases of this work are both the development of the procedures and the analysis of certain specific application areas, along with the release of the resulting tools for general use. Prototypic sensitivity/uncertainty analysis tools have been developed to facilitate these types of analyses.

(1) SEN1, a one-dimensional (1-D) sensitivity analysis tool based on the XSDRNPM discrete-ordinates transport code. This sensitivity module has been developed and placed into a SCALE system format. Plans are to include these capabilities in the next major release of SCALE.[2] SEN2 is a prototypic two-dimensional (2-D) sensitivity analysis tool used in-house at ORNL and is based on the DORT[3] 2-D discrete-ordinates transport code.

(2) SAMS, a three-dimensional (3-D) Monte Carlo sensitivity analysis tool based on the KENO V.a code.[2] SAMS is a postprocessor module that retrieves forward and adjoint fluxes from a KENO V.a execution and produces sensitivity information in much the same manner as the SEN1 and SEN2 modules.

(3) CANDD and GLLSM are two postprocessing codes that produce the c_k and D parameters and prepare inputs for the FORSS generalized-linear-least-squares code, respectively.

This summary presents an illustrative application of both the S/U and GLLSM procedures to the validation of criticality safety studies for facilities processing uranium fuels with enrichments greater than 5 wt %, where much of the critical experiment data correspond to lower than 5-wt % enrichments. The use of S/U and GLLSM methods in validation studies was demonstrated by performing a validation of a hypothetical set of application scenarios, which consist of 14 systems, each having $U(11)O_2$ fuel with H/X values varying from 0 to 1000. The 11-wt % enrichment was chosen so the entire range of moderations, including dry, could be studied. The benchmark set consisted of 102 criticals, which are described in Ref. 4. The data validation included traditional trending analyses with EALF and H/X, trending analysis with the D and c_k parameters, and finally the full GLLSM approach. These trending analyses used the USLSTATS[5] procedure to predict the bias and its uncertainty based on trending the calculated k_{eff} values for all of the benchmarks with EALF, H/X, D and c_k. The GLLSM results are detailed in Ref. 4.

The results of applying the various techniques to 4 of the 14 application cases are given in Table 1. The comparisons among the various trending techniques were quite interesting in that they give very different answers, depending on the particular system being analyzed. The predicted biases for various systems were in some cases up to a factor of 8 different between the various trending techniques. These differences arise due to the presence of multiple systems that have similar H/X and EALF values, but the S/U methods indicate they have significant differences. Further details on these differences and guidance on the usage of the various trending techniques will be given in the presentation.

Table 1. Comparison of predicted) k bias and its standard deviation[a] for various procedures

Procedure	H/X = 0		H/X = 3		H/X = 40		H/X = 500	
	Bias (%)	Std. dev. (%)	Bias (%)	Std. dev. (%)	Bias (%)	Std. dev. (%)	Bias (%)	Std. dev. (%)
EALF	0.32	0.74	0.45	0.74	0.46	0.74	0.46	0.74
H/X	0.49	0.77	0.49	0.77	0.47	0.77	0.31	0.77
D_{sum}	-	-	1.26	0.76	0.66	0.78	0.28	0.78
c_k	1.28	0.73	1.40	0.69	0.69	0.76	0.39	0.78
GLLSM	2.56	0.38	1.30	0.33	0.77	0.40	0.63	0.37

[a]For all but GLLSM, the standard deviations correspond to the Apooled standard deviation@ as specified in Ref. 5, because this definition was judged to best match that provided by GLLSM.

REFERENCES

1. J. L. Lucius, C. R. Weisbin, J. H. Marable, J. D. Drischler, R. Q. Wright, and J. E. White, *A Users Manual for the FORSS Sensitivity and Uncertainty Analysis Code System*, ORNL-5316, Union Carbide Corporation, Oak Ridge National Laboratory, January 1981.

2. *SCALE - A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), March 1995. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-545.

3. W. A. Rhodes, and R. L. Childs, *An Updated Version of the DOT 4 One- and Two-Dimensional Neutron/Photon Transport Code*, ORNL-5851, Union Carbide Corporation, Oak Ridge National Laboratory, 1982.

4. B. L. Broadhead, C. M. Hopper, and C. V. Parks, ASensitivity and Uncertainty Analyses Applied to Criticality Validation, Volume 2: Illustrative Applications and Initial Guidance,@ NUREG/CR-5593, Vol. 2 (ORNL/TM-13692/V2), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, 1999.

5. J. J. Lichtenwalter, S. M. Bowman, M. D. DeHart, and C. M. Hopper, *Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages*, Appendix C, AUser's Manual for *USLSTATS* V1.0,@ pp. 339B344, NUREG/CR-6361 (ORNL/TM-13211), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, March 1997.