Sandia National Laboratories

Energy, Climate & Infrastructure Security

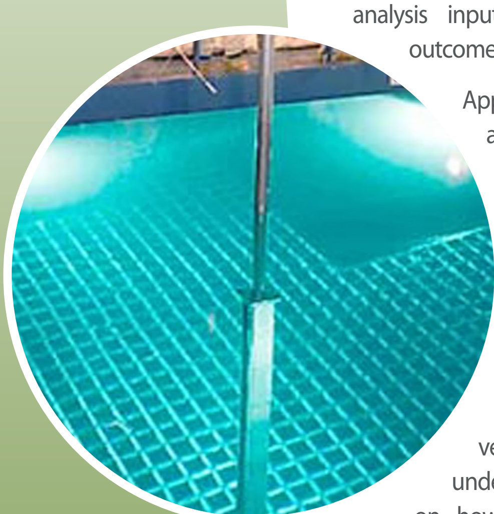
Uncertainty and Sensitivity Analysis

Assessing the uncertainty present in any complex problem is an essential part of its analysis and is often required by major U.S. and international regulatory agencies.

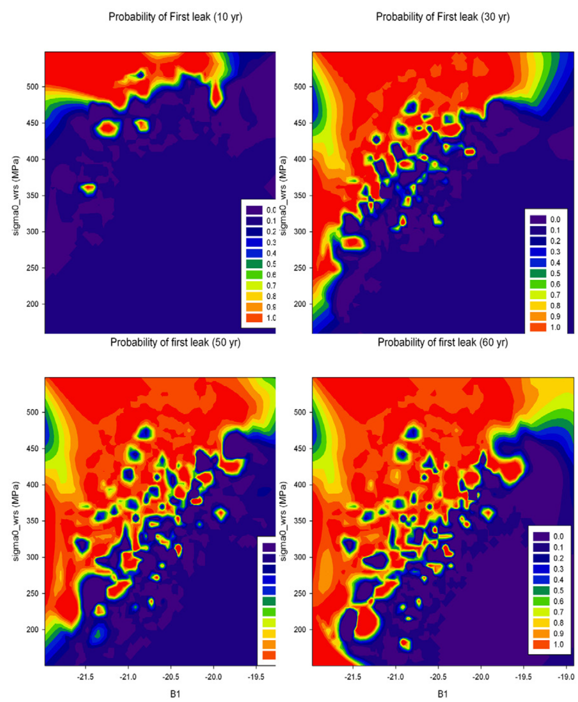
Uncertainty in Complex Systems

Important questions must be answered about the nature, quality, and significance of calculated results. Uncertainty and sensitivity analysis are central to answering such questions. The objective of uncertainty analysis is to determine the uncertainty in analysis outcomes that results from uncertainty in analysis inputs. The objective of sensitivity analysis is to determine the effects of the uncertainty in individual analysis inputs on the uncertainty in analysis outcomes.

Appropriately designed uncertainty and sensitivity analyses are essential to enhancing the usefulness and credibility of risk and safety analyses by providing an unbiased representation and assessment of the relationships between the uncertainty in individual analysis inputs and the uncertainty in analysis outcomes. Such analyses support verification and validation of the model under consideration and provide guidance on how to appropriately invest additional resources to carry out experimental work or detailed studies to reduce the uncertainty in important inputs, thus reducing the uncertainty in analysis outcomes.



Uncertainty analysis provides verification and validation of models used to evaluate nuclear power plant components such as the spent fuel pools (shown above).



Contour plots for the parameter sensitivity in the probability of occurrence of the first crack in pressurizer surge nozzles in the primary water piping for a commercial boiling water nuclear reactor

Analyzing the Effects in a Systematic Way

When viewed at a high level, most uncertainty and sensitivity analyses involve five components:

- Definition of probability distributions to characterize the uncertainty in analysis inputs
- Generation of a sample from the probability distributions for the uncertain analysis inputs
- Propagation of the generated sample through the model under consideration to produce a mapping between values for uncertain analysis inputs and corresponding analysis outcomes
- Organization and display of the probabilistically-based uncertainty in the generated analysis outcomes
- Exploration of the generated mapping between analysis inputs and analysis outcomes with a variety of procedures to obtain sensitivity analysis results

Sandia National Laboratories pioneered the development and implementation of techniques for use in the five preceding areas. Sandia's expertise in the design and implementation of uncertainty analyses for complex systems has successfully played a central role in many applications supporting nuclear reactor safety analysis, severe consequence analyses, and nuclear fuel cycle programs including storage, transportation, and disposal. Sandia maintains world-class computing facilities and supporting software for uncertainty and sensitivity analysis utilizing advanced approaches such as evidence theory and probability theory. Further, Sandia personnel are experts in effectively using these resources.

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U.S. DEPARTMENT OF ENERGY

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Building Confidence in High Fidelity Analyses

At a time when great value and trust is placed in computational analyses, future computational analysis that supports an important societal decision may not be accepted as being complete without an adequate assessment of the uncertainties present in its results. This importance is now recognized in many regulatory requirements including assessment of the risk from commercial nuclear power and throughout the nuclear fuel cycle. Uncertainty analyses are used as critical input to probabilistic risk assessments, which use a systematic process to identify possible points of vulnerability within a complex system (such as a nuclear power plant) before an incident or emergency situation occurs.

Similarly, uncertainty and sensitivity analysis informs performance assessments, which support radioactive waste repository licensing applications. Critical analyses support the National Nuclear Security Administration's mandate for the quantification of margins and uncertainties (QMU) in assessments of the safety and reliability of the U.S. nuclear stockpile. Serving as a cornerstone of risk-informed regulation and decision-making, these analyses play an ever-increasing role in shaping the future of nuclear and non-nuclear risk analyses.

Sandia's uncertainty and sensitivity analyses were critical to permitting the U.S. Department of Energy Waste Isolation Pilot Plant repository shown here.

Publications

Example Sandia references related to uncertainty analysis, sensitivity analysis, and the analysis of complex systems:

(2012). State-of-the-art reactor consequence analyses project (NUREG/CR-7110). Albuquerque, NM: Sandia National Laboratories.

Bonano, E. J. et. al. (2011). Performance assessment at Sandia National Laboratories (SAND2011-Unknown). Albuquerque, NM: Sandia National Laboratories.

Mattie, P. D., Sallaberry, C. J., Helton, J. C., & Kalinich, D. A. (2010). Development, analysis, and evaluation of a commercial software framework for the study of extremely low probability of rupture (xLPR) events at nuclear power plants (SAND2010-8480). Albuquerque, NM: Sandia National Laboratories.

Helton, J. C. (2009). Conceptual and computational basis for the quantification of margins and uncertainty (SAND2009-3055). Albuquerque, NM: Sandia National Laboratories.

(2008). Total system performance assessment model/ analysis for the license application (MDL-WIS-PA -000005 Rev. 00, AD 01). Las Vegas, NV: U.S. Department of Energy Office of Civilian Radioactive Waste Management.

Helton, J. C., Johnson, J. D., Sallaberry, C. J., & Storlie, C. B. (2006). Survey of samplingbased methods for uncertainty and sensitivity analysis (SAND2006-2901). Albuquerque, NM: Sandia National Laboratories.

Helton, J. C. & Davis, F. J. (2002). Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems (SAND2002-0417). Albuquerque, NM: Sandia National Laboratories.

Special Journal Issues

Journal issues guest edited by Sandians containing results from analyses related to uncertainty analysis, sensitivity analysis and the analysis of complex systems:

Helton, J. C., & Pilch, M. (Eds.). (2011). Special Issue: Quantification of Margins and Uncertainty. Reliability Engineering and System Safety, 96(9), 959-1256.

Helton, J. C., Cooke, R. M., McKay, M.D., & Saltelli, A. (Eds.). (2006). Special Issue: The Fourth International Conference on Sensitivity Analysis of Model Output (SAMO 2004). Reliability Engineering and System Safety, 91(10-11), 1105-1472.

Helton, J. C., & Oberkampf, W. L. (Eds.). (2004). Special Issue: Alternative Representations of Epistemic Uncertainty. Reliability Engineering and System Safety, 85(1-3), 1-376.

Helton, J. C., & Marietta, M. G. (Eds.). (2000). Special Issue: The 1996 Performance Assessment for the Waste Isolation Pilot Plant. Reliability Engineering and System Safety, 69(1-3), 1-451.

Helton, J. C., & Anderson, D. R. (Eds.). (1999). Special Issue: Performance Assessment for Radioactive Waste Disposal. Risk Analysis, 19(5).

Helton, J. C., & Burmaster, D. E. (Eds.). (1996). Special Issue: Treatment of Aleatory and Epistemic Uncertainty. Reliability Engineering and System Safety, 54(2-3), 91-257.

Helton, J. C., & Breeding, R. J. (Eds.). (1992). Special Issue: The NUREG-1150 Probabilistic Risk Assessments. Nuclear Engineering and Design, 135(1), 1-137.

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