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Prototypical Sensitivity and Uncertainty Analysis Codes for Criticality Safety with the SCALE Code System

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PROTOTYPICAL SENSITIVITY AND UNCERTAINTY ANALYSIS CODES FOR CRITICALITY SAFETY WITH THE SCALE CODE SYSTEM

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Two prototypical sensitivity analysis sequences for criticality safety have recently been developed for the SCALE[1] code system at the Oak Ridge National Laboratory (ORNL). The motivation for developing both of these sequences was the need for modern tools that could be used to produce the sensitivity data necessary for the integral parameter techniques described in the previous papers in this session. Both of these sequences are applications of the first-order linear perturbation theory as described in the previous paper. The SEN1[2] sequence involves one-dimensional (1-D) deterministic neutron transport calculations using XSDRNPM. The SEN3[3] sequence involves three-dimensional (3-D) Monte Carlo neutron transport calculations using KENO V.a. Each of these sequences and the types of results they produce will be described in subsequent sections.

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SEN1 Sequence

Using the SCALE philosophy and/or protocol as a guide, a 1-D sensitivity sequence, SEN1, was produced. It generates sensitivity coefficients which represent the percent change in the system k_{eff} for a one percent cross-section value change in a given energy group for each reaction type and isotope of interest (nuclide-reaction pair). This sequence performs standard resonance processing tasks (BONAMI and NITAWL modules), then determines (using 1-D transport theory) the forward and adjoint angular fluxes and flux moments needed for sensitivity coefficient generation. The radiation transport solver utilized was the XSDRNPM code, which is used extensively within the SCALE system. The sequence then calls modules VIP1D,[2] and LAKE,[2] which compute the sensitivity coefficients and estimates the uncertainty in the system k_{eff} value, respectively.

The user input to SEN1 is very similar to the user input of the shielding module, SAS1, except that, since k_{eff} sensitivities do not require a source input, a fixed source is not required. The input contains the standard composition description that is common to all SCALE modules, followed by a simple geometry model for the problem. SEN1 uses any of the types of resonance shielding calculations available in SCALE including INFHOMMEDIUM, LATTICECELL and MULTIREGION. For the first option, no resonance shielding is performed; the second technique treats resonance-shielding effects in lattice-pin geometry cases; the third technique gives the user more flexibility in defining the geometry in which the resonance calculations are performed. The SEN1X sequence calculates cell weighted cross section with XSDRNPM prior to performing the 1-D criticality calculations. The SEN1 sequence is near production level and should be included in the SCALE 5 release.

SEN3 Sequence

The SEN3 sequence implements sensitivity analysis techniques, similar to those used by SEN1, for 3-D Monte Carlo calculations. The input for SEN3 is very similar to the CSAS25 sequence of SCALE commonly used for criticality safety analysis. SEN3 performs resonance-shielding calculations using the same options as SEN1. Forward and adjoint angular neutron fluxes are obtained from an enhanced version of KENO V.a that uses a novel approach to produce the flux components necessary for sensitivity analysis. Once the fluxes are obtained, the SAMS module produces flux moments through a spherical harmonics expansion of the angular fluxes and calculates the sensitivity coefficients from this data and the problem dependent cross section data. The SAMS module also calculates the uncertainty in the sensitivity coefficients due to the Monte Carlo uncertainties.

The SEN3 sequence is not yet at the near-production level of the SEN1. SEN3 has been used internally at ORNL, but there are some shortcomings that must be addressed prior to public release. First, adjoint solutions using multi-group Monte Carlo techniques are not as easily obtained as the forward solutions. Some finesse on the part of the user is required for certain classes of problems. Second, large computational regions are not well suited for angular flux calculations because of the large variation in the flux solution that may exist across the region. Some sub-division of the typical Monte Carlo geometry is often necessary to obtain the most accurate sensitivity solution. Once guidances and/or automated techniques to address these issues have been developed, this sequence may be available for public release.

Sensitivity Data

The standard output files from both SEN1 and SEN3 contain sensitivities presented as a total sensitivity which is integrated over all cross-section energies for a particular reaction type

of an isotope. These are presented on a region-dependent basis and well as region-integrated, which provides a single sensitivity coefficient for each reaction of a particular isotope integrated over the entire system. Each code also generates a text file containing the sensitivity "profiles" in which the relative change in k_{eff} is displayed for each reaction type of each isotope for each energy group. Sensitivities are generated for a wide variety of nuclear reactions including scattering, fission, capture, absorption, $\bar{\nu}$ (the average number of neutrons emitted per fission), χ (the fission spectrum) and the total of all reactions.

SEN1 and SEN3 produce this sensitivity data for each nuclide-reaction pair for which cross-section data is available. These files can be stored and used in subsequent integral parameter or cross section covariance analyses using the techniques described in other papers in this session.

Plotting routines have been developed to read the energy-dependent sensitivity data files and produce two-dimensional plots for visualizing the data. The SENPLT code plots the data generated from SEN1, and the SAMSPLOT code plots the data generated from SEN3 with its associated uncertainties. An example plot from SEN3-SAMSPLOT is show in Figure 1.

Mathematical Verification of Sensitivity Codes

The sensitivity data generated from each of these codes has been mathematically verified by comparisons with direct calculations of the sensitivity data as well as with comparisons between the two codes. Favorable results have been demonstrated in other documents and will not be repeated here.[2,4] One concern that remains from this previously published work is the effect of the resonance shielding calculations on the calculation of the sensitivity coefficients. Work is currently underway to resolve this issue.

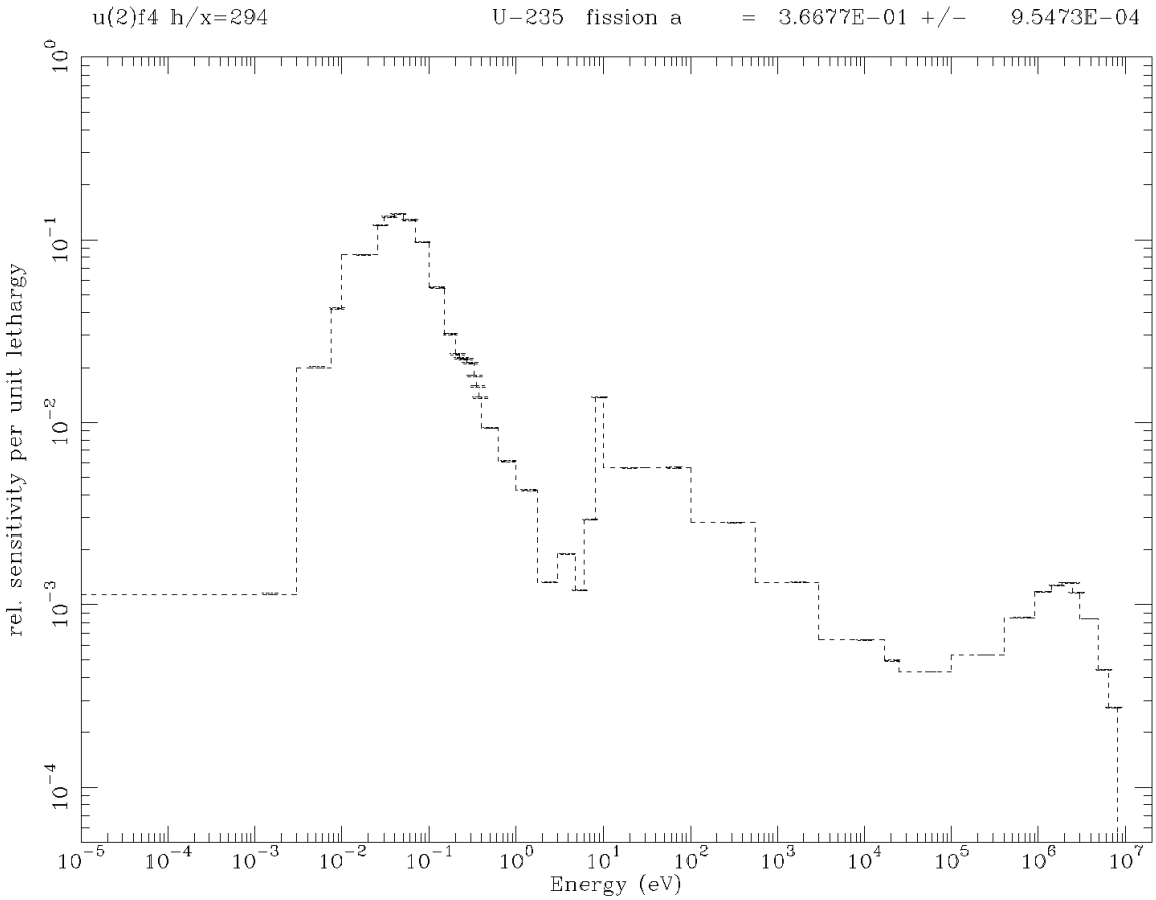

Figure 1. Example of SEN3-SAMSPLOT Energy-Dependent Sensitivity Profile

Integral Parameter Analysis

A new data processing code called CANDE was created to perform the integral parameter analyses using the sensitivity data created from the SEN1 and/or SEN3 sequences. The user of CANDE provides a list of applications, which will be compared to a list of experiments. The integral parameter values described in the previous two papers[5,6] are calculated for each application with comparisons against the entire experimental data set.

Conclusions

The SEN1 and SEN3 SCALE sequences provide powerful sensitivity analysis tools in the familiar SCALE format using established criticality safety codes. Each of these codes provides a source for the data necessary for the integral parameter and cross section covariance techniques. The CANDE code provides an automated method for interpreting and applying the sensitivity data in the integral parameter techniques.

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