Verification Methods for the SCALE Code System*

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The Standardized Computer Analysis for Licensing Evaluation (SCALE) code system developed at Oak Ridge National Laboratory (ORNL) provides a comprehensive, verified and validated, user-friendly tool set for criticality safety, reactor physics, radiation shielding, and sensitivity and uncertainty analysis. For over 30 years, regulators, licensees, and research institutions around the world have used SCALE for nuclear safety analysis and design. A substantial effort has been applied to the verification and validation of SCALE; however, this paper focuses only on the verification techniques used to ensure the quality of SCALE software.

SCALE 6.0 Overview

SCALE provides a "plug-and-play" framework with 76 computational modules, including three deterministic and three Monte Carlo radiation transport solvers that are selected based on the desired solution. SCALE's graphical user interfaces assist with accurate system modeling and convenient display of desired results. The latest version, SCALE 6.0, was released in early 2009. Some of the key capabilities of SCALE are described here.

The TRITON analysis sequences couple two-dimensional deterministic or three-dimension (3D) Monte Carlo transport with the ORIGEN depletion and decay module to provide powerful and flexible capabilities for lattice physics analysis and custom characterization of used fuel inventories for specific conditions, such as unique research reactor fuel. For SCALE 6.0, ORIGEN was updated with improved solution algorithms and extended data libraries, which now include 1946 nuclides: 129 actinides, 1119 fission products, and 698 structural activation materials. ORIGEN provides a complete and accurate prediction of isotopic concentrations, decay heat, and radiation spectra. For many common power reactor fuel types, used fuel characterization can be rapidly performed with the ORIGEN-ARP technology. The STARBUCS analysis sequence couples the ORIGEN-ARP technology with 3D Monte Carlo modeling to provide criticality analyses applicable to used fuel systems or packages that implement burnup credit.

For criticality safety analysis, SCALE 6.0 provides the well-validated KENO family of Monte Carlo neutron transport codes. The KENO codes provide rapid analysis using multigroup cross-section data prepared by other SCALE 6.0 modules based on the latest Evaluated Nuclear Data Files (e.g., ENDF/B-VII). Also new for SCALE 6.0, criticality safety analyses can be conducted using continuous-energy cross-section data from ENDF/B-VI.8 or ENDF/B-VII.0. SCALE also includes the TSUNAMI sensitivity and uncertainty analysis capabilities, which are especially useful for criticality code and data validation.

SCALE 6.0 provides advanced fixed-source Monte Carlo shielding and dose assessment capabilities with automated 3D variance reduction. The MAVRIC analysis sequence is based on the Monaco Monte Carlo code, which uses a generalized geometry package and multigroup coupled neutron-gamma cross-section data from ENDF/B-VI.8 or ENDF/B-VII.0. MAVRIC uses results from the new Denovo 3D discrete-ordinates transport code to determine effective variance reduction parameters specific to the problem solved; Monaco then uses the variance reduction parameters to quickly and accurately compute fluxes and dose rates at one or more detector locations for deep penetration problems, typical of those for heavily shielded packages and site boundary analyses.

SCALE 6.0 Verification Techniques

As a toolbox comprised of nearly 1,000,000 lines of code and 17 GB of nuclear data generated by 25 active developers, SCALE has components that range from state-of-the-art object-oriented code in C++ and Java, to modern Fortran 95 codes following modular design, to legacy Fortran codes with algorithms first developed in the 1960s. Although all SCALE modules are actively maintained and new features are continually being developed, a graded approach to verification must be employed to accommodate each type of capability.

SCALE is developed under a formal configuration management and quality assurance program. A GForge Advanced Server collaborative development environment system is used to track issues and interface with version control using Subversion. All updates to the production version of SCALE are conducted though a change control process that requires full documentation of the change, test cases that demonstrate the functionality of the change, and an independent review of the change prior to management approval and change implementation.

For the end user, a standard test suite is deployed for SCALE that tests a representative set of SCALE's capabilities. An expected set of solutions is also deployed along with scripts to simplify comparison of the user's results with the expected results.

With each modification to the production version of SCALE, the appropriate subset of end-user sample problems are run and the results verified on four platforms: 32- and 64-bit Linux, Windows, and Mac OS X.

For the more recently developed codes, modern programming practices are followed with unit test harnesses implemented during development, in addition to global testing at the program execution level. For codes with integrated unit testing, the occurrence of unexpected behavior is greatly reduced, and the SCALE team plans to integrate unit testing in legacy modules in the future.

For nuclear data testing, test suites of benchmark experiment models have been developed. Results are compared before and after updates are made to the nuclear data libraries to identify differences introduced by updates in the nuclear data libraries or by the processing codes used in their development. For example, for the SCALE neutron libraries, a test suite of 900 benchmarks is compared for each data library update.

Conclusion

SCALE 6.0 provides a comprehensive set of nuclear safety analysis and design tools. The verification and configuration management techniques employed by ORNL provide robust and reliable tools for the nuclear community.