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# SCALE CRITICALITY SAFETY VERIFICATION AND VALIDATION PACKAGE

S. M. Bowman, M. B. Emmett, and W. C. Jordan

Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, TN 37831-6370
(423) 574-4538



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S. M. Bowman, M. B. Emmett, and W. C. Jordan
Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, TN 37831-6370
(423) 574-5263

## INTRODUCTION

Verification and validation (V&V) are essential elements of software quality assurance (QA) for computer codes that are used for performing scientific calculations. V&V provides a means to ensure the reliability and accuracy of such software. As part of the SCALE QA and V&V plans, a general V&V package [1] for the SCALE [2] criticality safety codes has been assembled, tested and documented. The SCALE criticality safety V&V package is being made available to SCALE users through the Radiation Safety Information Computational Center (RSICC) to assist them in performing adequate V&V for their SCALE applications.

## VERIFICATION

Verification is intended to demonstrate that the software has been properly coded, installed, and performs the intended functions for a given set of input. The verification problems are divided into two categories: installation and functional. Installation problems are the standard sample problems distributed with the SCALE package. Functional verification problems test the functionality of the codes by solving problems that have known results. These problems include

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analytic problems for which the solutions are known and problems that test specific code capabilities for which there is a known response.

The functional verification problems include analytic problems for BONAMI that demonstrate that the code correctly performs the Bondarenko iteration and produces the correct cross sections. The NITAWL-II analytic problems verify the consistency of the infinite homogeneous media (0-D), slab (1-D), cylindrical (2-D), and spherical (3-D) options in the code. The KENO V.a functional verification problems consist of a series of hole intersection checks, start type checks, and geometric orientation verification cases.

## VALIDATION

Validation problems usually involve calculation of experiments. Validation is the process of demonstrating that the software predicts accurate results for the systems to which it is applied. The calculated results for systems with a known solution are used to establish the calculational bias. The establishment of the bias defines a range over which the result is acceptably correct. Experimental parameters and physical properties of these systems are used to determine the range of applicability of the validation and define the systems for which the bias applies. Validation is the responsibility of the code user and is specific to an intended application.

The validation set is comprised of approximately 600 critical experiment models collected from previous validations of KENO V.a using the CSAS25 criticality sequence. These validation experiments cover a broad range of systems and fissile material types. The results of the validation have been used to establish a bias for several classes of systems and to develop upper subcritical limits (USLs) of calculated $k_{eff}$ values. The critical experiment validation models were taken from three reports [3-5] that included validation of KENO V.a. The models were obtained from the authors of the reports and were used unaltered except for material specifications necessary for compatibility with the 44-group library and the current version of the SCALE Standard Composition Library. The models were organized to correspond to the organization in the original reports to allow easy cross referencing. A brief description is given for each group of models.

Models taken from Ref. 3 correspond to those described in Tables 1 through 6 of the reference report. The models include low-enriched $^{235}$U systems, primarily for homogeneous water-moderated single units and arrays of large units. Another set of models are arrays of large low-enriched uranium metal billets moderated and reflected by water. Highly enriched $^{235}$U systems and several $^{233}$U systems are also included. These critical experiments cover a broad range of geometry, fissile fuel mixture, moderator, and reflector combinations with a broad range of neutron spectra. These models validate $^{235}$U, $^{238}$U, water cross sections, and many materials of construction used in the critical systems.

Models taken from Ref. 4 correspond to those discussed in Appendices C, D, and E of the reference report. The models from Appendix C are for $^{233}$U systems. Included are $^{233}$U metal systems, water-moderated systems at various concentrations, and arrays of large units. The models from Appendix D are for highly enriched $^{235}$U systems. The models in Appendix D were primarily extracted from Tables 4 and 5 of Ref. 3. The selection process was intended to exclude highly thermal systems in order to validate harder thermal, epithermal, and fast systems. The models from Appendix E are for $^{239}$Pu systems. Systems with variable $^{240}$Pu content were analyzed as well as systems with a range of fissile material form, geometry and moderation level. Several arrays of large units were also included in the validation. These experiment models validate the codes and cross sections for harder spectra over a broad range of fissile materials and materials of construction.

Models taken from Ref. 5 correspond to those discussed in Tables 3 and 4 of the reference report. The first set of models are 1-D CSAS1X/XSDRNPM models, primarily of CSEWG fast and thermal benchmarks. The fast benchmarks include $^{233}U$, $^{235}U$, and $^{239}Pu$ systems in 1-D geometry representations in a variety of unreflected and water- and metal-reflected systems. Graphite-moderated systems and $UH_3$ systems have also been included. The thermal benchmarks include highly enriched $^{235}U$ water-moderated systems, low-enriched $^{235}U$ lattices, and water-moderated $^{239}Pu$ systems. The second set are 3-D KENOV.a models, primarily of low-enriched light-water-reactor (LWR) reactor lattices. These cases provide significant testing of the SCALE resonance cross-section processing methodology for heterogeneous systems. Both $UO_2$ and mixed-oxide (MOX) lattices have been included. Several fast-reactor MOX lattices and homogeneous $^{235}U$ systems were also included. These experiments are useful for validating the code and cross sections for analysis of LWR fresh and spent fuel storage and transportation packages.

## CONCLUSION

All of the V&V problems were originally run using the SCALE 27-group ENDF/B-IV cross-section library and SCALE-4.2. The SCALE V&V package distributed by RSICC contains results from the current version of SCALE using the 44-group ENDF/B-V cross-section library. The problem set can be analyzed with other cross-section libraries. The V&V package consists of the input and output files, the results of the calculations, and the utility codes used to process the output. The utility codes collect the relevant results into tabular form so that users can readily compare their results with those from ORNL.

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