## New Capabilities to Calculate Volumes of SCALE/KENO-VI Geometry Models

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### INTRODUCTION

The KENO V.a and KENO-VI three-dimensional (3-D) Monte Carlo criticality computer codes in the SCALE (Standardized Computer Analyses for Licensing Evaluation) [1] computer software system developed at Oak Ridge National Laboratory (ORNL) are widely used and accepted around the world for criticality safety analyses. The primary objective in the initial development and ongoing enhancements to SCALE is to provide easy-to-use calculational tools for performing accurate safety analyses of nuclear facilities and packages.

The SCALE KENO-VI program does not calculate volumes for model bodies by default. The reason is that the calculation of volumes in KENO-VI is more difficult than in KENO V.a due to the generalized geometry in KENO-VI that allows body intersections. Volumes are not needed for the calculation of k-effective, but they are necessary for the calculation of other parameters such as fluxes and fission densities. They are also required for TRITON6/KENO-VI fuel depletion calculations to correctly normalize the power densities.

The options for the calculation or input of volumes in KENO-VI have been improved for SCALE 5.1. In addition, the GeeWiz user interface [2] and KENO3D visualization tool [3] have been enhanced to calculate KENO-VI volumes analytically and write those volumes directly to a KENO-VI input file. This new feature is a significant capability that will prove useful for applications that use a KENO-VI (i.e., SCALE Generalized Geometry Package) model and require accurate volumes for model bodies.

### CALCULATING VOLUMES IN KENO-VI

KENO-VI offers two options for calculating the volumes; however, the methods used are statistical or an approximation, thus producing results that are imprecise and have an uncertainty associated with them. A third option allows users to specify the volumes in the KENO-VI input file.

The two volume-calculation options in KENO-VI are TRACE and RANDOM. The TRACE option performs a trapezoidal integration using ray tracing through the geometry. The RANDOM option performs a Monte Carlo integration by randomly selecting points throughout the geometry. Calculated volumes based on ray tracing have an order of error associated with them, while those calculated with the random method have an associated standard deviation. When volumes are calculated using either RANDOM or TRACE, the calculated volumes are written to a file so that the user can use them in other KENO-VI calculations that use the same geometry models. KENO-VI provides input parameters that allow the user to control the number of intervals used in the trapezoidal integration or the number of batches and points per batch to be used in the Monte Carlo integration, thus providing user control over the computational time and uncertainty associated with the calculated results.

### CALCULATING VOLUMES WITH KENO3D

KENO3D is a visualization tool that allows users to interactively view the components of their geometry model as it is constructed. Internally KENO3D uses constructive solid geometry to build the faceted or wireframe model bodies for display. KENO3D has the capability of calculating volumes of individual bodies. Previously, the volume calculation was used internally by KENO3D when performing Boolean operations (e.g., subtracting bodies and intersecting bodies). With the need for accurate volume calculations for KENO-VI geometry models, the volume calculation was extended to calculate the volumes for each media in the model and to write the volumes to a file that is formatted for reading by KENO-VI or GeeWiz.

The initial implementation of the KENO3D volume-calculation procedure proved to be resource intensive due to the number of intersections required to construct the model. To display KENO-VI geometry models, KENO3D performs analytic intersections on every model object several times. The accurate calculation of volumes requires accounting for all changes in volume due to Boolean operations. For one large model (i.e., a four-assembly shipping cask) with over 240,000 bodies, KENO3D required 30 minutes to complete the volume calculation without optimization.

Consequently, the calculation of volumes was optimized for models where all units and arrays are bounded by rectangular solids, such as the shipping cask model. If a unit or array is bounded by a rectangular solid, then each body can be tested to see if its bounding box intersects that of the rectangular solid. A box is specified by the Cartesian coordinates of two corners on the diagonal, going from most-positive X, Y, Z to most-negative X, Y, Z. For rectangular geometries, if the bounding boxes do not intersect, then the model bodies do not intersect. If the model bodies do not intersect, the volume of each object as constructed in its unit of origin is simply added to the accumulated volume for that media. Fig.1 shows an example of cylinders in an array with bounding boxes that do not intersect, while Fig. 2 shows an example of overlapping cylinders with intersecting bounding boxes.

The intersection of boxes is significantly faster than the intersection of bodies. For the truck cask model, execution time required to accurately calculate volumes was reduced from 30 minutes to less than 1 second by using the bounding box optimization. With rectangular geometries, when a unit or array bounding box does intersect an object's bounding box, the more-costly calculation using intersections is required for that object. In most practical applications, only a subset of object boundaries intersect unit or array bounds, therefore, execution time would still be reduced by box optimization.

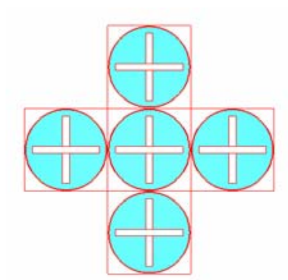

Fig. 1. Cylinders with nonintersecting bounding boxes.

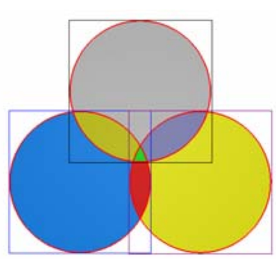

Fig. 2. Cylinders with intersecting bounding boxes.

For KENO-VI units and arrays that do not have a single rectangular body specified as the bound, the more-costly volume calculation is required.

## IMPLEMENTATION OF VOLUME CALCULATIONS IN GEEWIZ

Volumes can be calculated directly with KENO3D; however, as an aid to GeeWiz users, a volume-calculation capability was added to the GeeWiz Volume dialog form. If the user selects the "Keno3D Volumes" button, KENO3D will be executed to calculate volumes and create an ASCII volume file formatted for input into SCALE. Subsequently, if the user selects the "Attach Volumes" button, the volume data will be added directly to the media records in every region in the KENO-VI input file.

## COMPARISON OF VOLUME CALCULATION METHODS

Volume calculations were performed for two critical experiment models: 4 aqueous and 4 metal (4a–4m) cylinders (KENO V.a sample problem 12) [1] and a partially flooded triangular pitched array of 19 low-enriched-uranium metal cylindrical annuli billets (KENO V.a sample problem 33) [1]. The calculations were performed to compare the accuracy and computational time of the various available methods. The TRACE and RANDOM options in KENO-VI and KENO3D analytical calculations were compared with known volumes from KENO V.a.

The KENO-VI results are summarized in Fig. 3. For the RANDOM method cases, calculations were performed for 5, 50, 500, 5000, and 50,000 batches (1000 points per batch). Note that the calculation times are linear with respect to the total number of points. For the TRACE cases, a set of 5 cases were run for each model using $10^3$, $10^4$, $10^5$, $10^6$, and $10^7$ rays per case. Note that the run times and statistics are dependent on the chosen face. For these cases, the optimum setting for minimizing both error and run time appears to be 5000 batches for RANDOM and $10^6$ rays for TRACE. In comparison with the RANDOM and TRACE methods in KENO-VI, KENO3D calculated the volumes exactly in extremely short times (0.2 and 2.6 seconds, respectively) for these problems.

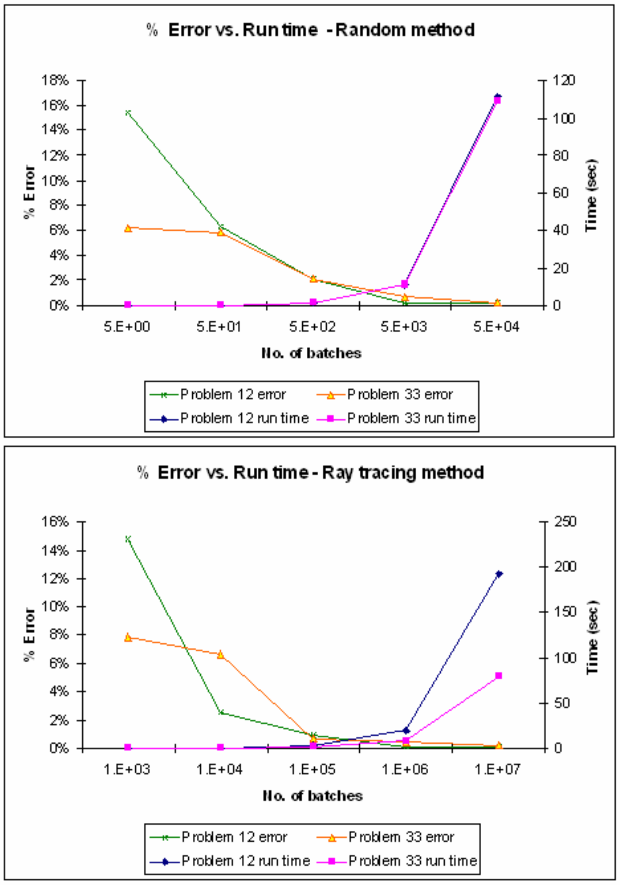


Fig. 3. Error vs. run time for RANDOM and TRACE methods.

## CONCLUSION

Volumes are necessary in KENO-VI for the calculation of quantities such as fluxes and fission densities. They are also required for TRITON6/KENO-VI fuel depletion calculations to correctly normalize the power densities. Although improvements have been made to the volume calculation options in KENO-VI, the GeeWiz user interface coupled with KENO3D provides users with an easy method for quick analytical calculations of KENO-VI volumes. GeeWiz/KENO3D writes the calculated volumes directly to a KENO-VI input file. The calculation of volumes for KENO-VI geometry models is a significant new capability that will prove useful for applications that use the KENO-VI geometry model but requires accurate volumes for model bodies. Integrating the KENO3D volume calculation procedure with GeeWiz allows the calculation and management of volume data in a user-friendly interactive computing environment.

## REFERENCES


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