June 23, 2006 **Summary**

Nuclear Science and Technology Division (94)

Advances in the KENO-VI Geometry Package

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For submission to the
American Nuclear Society
2006 Winter Meeting, "Ensuring the Future in Times of Change: Nonproliferation and Security"
November 12–16, 2006
Albuquerque, NM

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[1] Managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

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INTRODUCTION

With the release of version 5.1 of the SCALE system [1], many new features and capabilities are added that expand the types of problems that may be analyzed and the ease with which these problems can be modeled. Although initially designed as a criticality safety code, KENO-VI [2] is capable of static reactor analysis as part of TRITON6 [3], a depletion control module in SCALE 5.1 used for 3-dimensional (3-D) fuel burnup analysis. The ability to easily model an entire reactor core, including all non-regular-shaped components, makes KENO-VI a powerful tool for performing reactor analysis where burnup credit, flux profiles, or power densities are needed. Although many enhancements and improvements have been made to KENO-VI since its last release, this paper describes recent advancements in its geometry modeling capabilities.

GEOMETRY FEATURES

KENO-VI is a 3-D generalized geometry Monte Carlo code initially developed for criticality safety analysis. The ability to use holes and arrays in the geometry allows very complex problems to be constructed without having to explicitly specify every region in every location. A unit may be specified once and then used in multiple locations by placing that unit in holes and arrays. These holes and arrays may then be placed within other holes and arrays, a process referred to as "nesting." In SCALE 5 and earlier versions, certain restrictions had to be followed when using holes and arrays:

1. A hole may share surfaces with, but must not intersect, other holes or the boundary of the unit that contains the hole
2. A hole in a unit contained in an array may share a boundary with, but must not intersect, the array boundary
3. A higher-level array boundary may share a boundary with, but must not intersect, a nested array boundary.

Examples of violations of these restrictions are shown in Figs. 1, 2, and 3, respectively. Note that each of these examples could be modeled in KENO-VI with alternative methods that do not violate the restrictions.

These restrictions stem from the algorithm used to perform particle tracking through the geometry. The particle is tracked only to the level of the unit and array (if applicable) in which it is currently contained. If the particle is in a unit that contains a hole, it will continue its motion in the unit until it is either absorbed or crosses out of the unit. If the hole unit intersects the boundary of the unit that contains the hole, it is possible for the particle to leave the hole and not be in the unit that contains the hole, thus causing the particle to terminate (i.e., to be lost from the problem). Similarly, a particle in a nested array that intersects the boundary of the array in which it is nested may leave the nested array and not be in the higher-level array, thus causing the particle to terminate. In both situations, it is possible to calculate results that are higher or lower than expected with no error message. The magnitude and direction of the error in k_{eff} in such a case is dependent upon the problem geometry, materials, and model setup.

The updated version of KENO-VI in SCALE 5.1 has modifications to its tracking routines to address these problems. If the first or second of the restrictions is violated, KENO-VI terminates and writes an error message not only stating why the problem terminated but also providing the unit, location, and direction of the particle. The third restriction has been lifted in SCALE 5.1.

The lifting of the third restriction allows a problem that previously had a complex model to be set up much more simply. For example, see the one shown in Fig. 3, where a nested array boundary overlaps a higher-level array boundary. Since the previous version of the geometry package traced particles only in the current array level, it was required that the particle cross out of a lower-level array before crossing out of a higher-level array. This has been changed so that the particle is tracked in the current array level and all higher-level arrays either up to a hole or until it is no longer in an array. This allows the particle to determine the shortest distance to any array crossing and to possibly cross out of multiple arrays simultaneously.

Another example of a problem that can be modeled easily using the new geometry capabilities is a reactor composed of multiple fuel assemblies, each composed of multiple fuel pins, and control blades that move between the assemblies. Each fuel assembly may be set up as an array of fuel pins. The reactor is then set up as an array of fuel assemblies with a boundary that consists of the reactor vessel and the control blades. Figure 4 shows an example of this type of configuration. A particle in a fuel assembly crossing into a control blade crosses out of the fuel assembly array and the array of fuel bundles before crossing into a control blade.

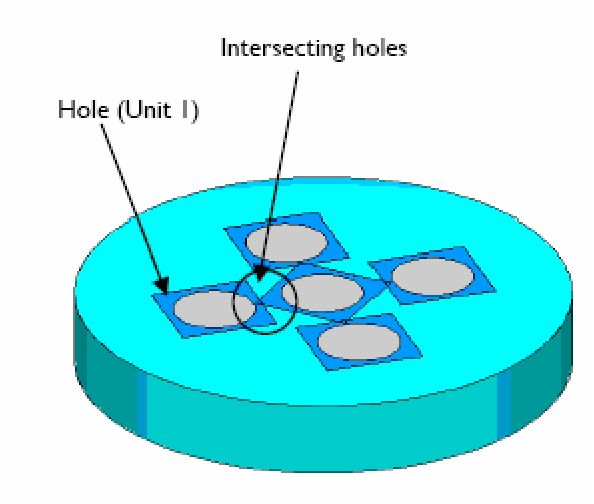

Fig. 1. Example of holes intersecting holes.

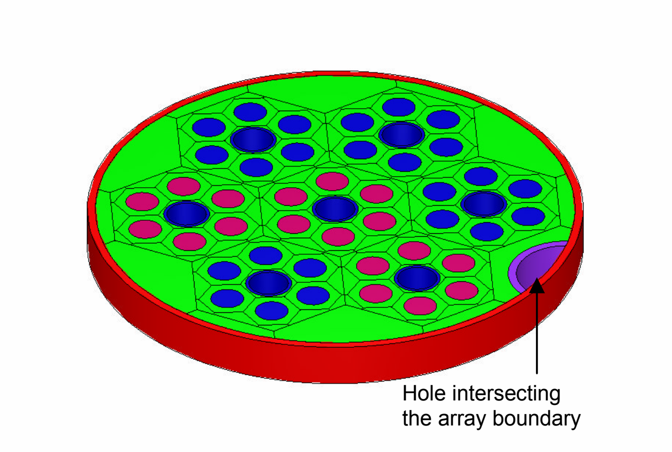

Fig. 2. Example of hole intersecting array boundary.

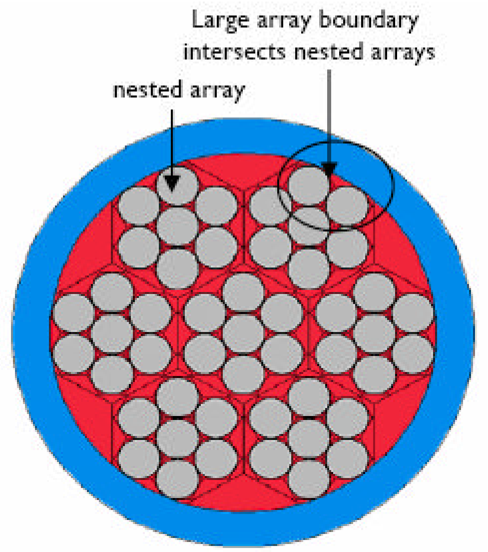

Fig. 3. Example of intersecting array boundaries.

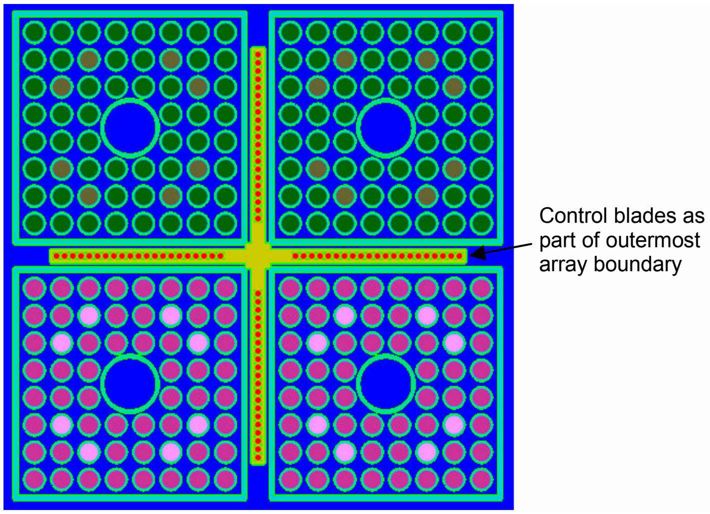

Fig. 4. BWR assemblies with control blades as part of the outer array boundary.

VOLUME CALCULATIONS

The latest release of KENO-VI also included a significant improvement in the way volumes are handled. In previous versions of KENO-VI, the volumes could either be read in from a volume file or calculated using random points or ray tracing and then written to a volume file for subsequent use. Volumes may still be read from a volume file; however, the format has been improved so that volumes are now input by unit and region, thus reducing the likelihood of error. Volumes may also be included using the keyword “vol=” following data on the MEDIA content record. This feature has been coupled with GeeWiz and KENO3D, which can calculate the volumes exactly and then write them in the input file. [4] If volumes are calculated, all volumes for the problem will automatically be written to a separate volume file. In addition to being used to calculate fission and flux densities in KENO-VI, accurate volumes are required for a new version of TRITON, TRITON6, which uses KENO-VI for depletion calculations.

In the latest version of KENO-VI, volumes are defaulted to -1.0 for any region where volumes are not set or calculated. This may result in negative fluxes or fission densities for a region. Negative values for fluxes and fission densities indicate that these are not true densities because appropriate volumes are not available. In order to get the correct fluxes and fission densities, the results need to be divided by the appropriate volume. If any flux or fission densities are negative, a warning message is printed at the end of the table stating this.

CONCLUSIONS

Significant improvements have been made to KENO-VI for the release of SCALE 5.1. The addition of more error checking, fixes for numerical problems that caused infinite loops, changes to volume data, lifting of previous restrictions, and many other changes have significantly improved the robustness and user friendliness of the code.

REFERENCES

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