SCALE 6 SIMULATION OF CRITICALITY ACCIDENT AND ALARM SYSTEM

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ABSTRACT

This research is on performing computational analysis of Criticality Accident Alarm System (CAAS). It is focused on the parts of the standard that are most applicable to calculating CAAS detector response and evaluating CAAS detector coverage. This is followed by a brief discussion of how CAAS detector response calculation differs from eigenvalue calculations that criticality safety practitioners perform regularly. This research provides computational example how to determine the minimum accident of concern according to ANSI/ANS-8.3-1997 (R2012), how to calculate the response of a CAAS detector due to a specific criticality accident, and how to evaluate the coverage of a CAAS detector for criticality accidents. These researches are solved applying SCALE 6, but the methodologies can be applied to other radiation transport codes with the similar capabilities, including deterministic codes.

ABSTRAK

Kajian ini adalah berkaitan dengan analisis berkomputer Sistem Penggera Kemalangan Kritikal. Ianya difokuskan di bahagian kebiasaaan yang kebanyakan dapat dikaitkan untuk mengira tindak balas pengesan CAAS dan menilai liputan pengesan CAAS. Ini diikuti oleh satu perbincangan ringkas bagaimana pengiraaan sambutan pengesan CAAS pengiraan berbeza dari pengiraan-pengiraan nilai Eigen yang boleh diaamalkan oleh pengelidik keselamatan kritikal. Penyelidikan ini menyediakan contoh pengiraan bagaimana untuk menentukan kemalangan minimum berdasarkan ANSI / ANS 8.3 1997, bagaimana untuk menghitung sambutan pengesan CAAS disebabkan kemalangan kegentingan khusus, dan bagaimana untuk menilai liputan pengesan CAAS untuk kemalangan-kemalangan kegentingan. Penyelidikan ini menggunakan SCALE 6, tetapi kaedah lain boleh digunakan ke atas kod pengangkutan sinaran lain kod dengan keupayaan serupa, termasuk kod-kod deterministik.

Keywords: criticality, alarm system, SCALE 6

INTRODUCTION

A new capability in SCALE allows users to quickly and easily model both the criticality and deep-penetration shielding portions of criticality accident alarm system (CAAS) problems in fully 3-D Monte Carlo. The SCALE CAAS capability uses both KENO-VI for simulating the criticality accident (to determine the fission distribution) and MAVRIC for radiation transport through thick shields using automated variance reduction. This paper demonstrates the CAAS capability with examples of calculating single detector responses and for calculating dose rates over large areas.

A wide variety of methods are currently in use to calculate the response of CAAS, with many drawbacks. Fast, approximate techniques typically model the criticality source as a point source and make use of one dimensional, point-kernel, or build-up factor approximations for estimating transport over long distances and through thick shielding. Multidimensional discrete ordinates methods have been widely used but require separate calculation of the critical system and the shielding systems as well as geometric approximations due to the orthogonal mesh.

Standard Monte Carlo codes using detailed models and detailed physics can simulate radiation transport more accurately than point-kernel or build-up factor codes but can suffer from the long run times required to calculate detector responses with reasonably low levels of stochastic uncertainty. This is especially true for simulating systems that require tallies at many points. Similarly, Monte Carlo codes can accurately model the complex geometry necessary for CAAS problems, but typical variance reduction techniques are tailored to criticality or shielding problems, and as a result, CAAS problems are broken into multiple steps which can be unnecessarily complicated.

SIMULATION

The CAAS capability in SCALE is a two-step approach using KENO-VI and MAVRIC. The first step is the determination of the source distribution, typically done with the CSAS6 (Criticality Safety Analysis Sequence) control sequence, which uses the KENO-VI functional module. Along with calculating the system keff, KENO-VI has been modified to accumulate the fission distribution over the nonskipped generations. This information is collected on a three-dimensional Cartesian mesh that overlays the physical geometry model and is saved as a Monaco mesh source.

The mesh source is then used in the second step as a source term in MAVRIC. The absolute source strength is set by the user based on the total number of fissions (based on the total power released) during the criticality excursion. Further neutron multiplication is prevented in the MAVRIC transport calculation. MAVRIC can be optimized to calculate one specific detector response at one location using CADIS or to calculate multiple responses/locations with roughly the same relative uncertainty using FW-CADIS. For calculating mesh tallies of fluxes or dose rates, MAVRIC also uses FW-CADIS to help balance the Monaco Monte Carlo calculation such that low flux voxels are computed with about the same relative uncertainty as high flux voxels.

With this two-step approach, users will have a great deal of flexibility in modeling CAAS problems. The CSAS6 step and the MAVRIC step could both use the same geometry and materials definitions or could include different levels of detail. For best results, a possible scheme would be to model the critical system geometry with only the closest surrounding materials but in fine detail. The transport geometry could leave out small details but would include the large building-level components. The fission source distribution from one CSAS6 calculation could be used in a number of different MAVRIC building/detector models, with each MAVRIC calculation optimized for a given type of detector. Figure 1 shows the generic flow of the simulation.

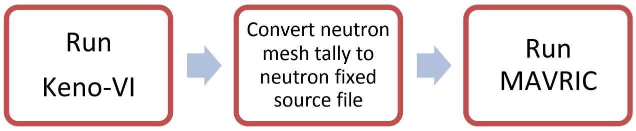

Figure 1. Simulation process flow

RESULTS AND DISCUSSIONS

Consider the following problem based on a critical assembly of Jezebel (PU-MET-FAST-001 [3]) in a simple block building, which is 1200 cm long, 600 cm wide, and 300 cm high above the ground. The exterior and interior walls are all made of a double layer of typical concrete blocks (total of 40 cm thick). The floor is made of poured concrete, extending 60 cm into the ground. The roof and the exterior door (120 cm wide and 210 cm tall) are made of 0.3175 cm thick steel. The center of Jezebel is 100 cm above the concrete floor of this building. This example uses one KENO-VI calculation to determine the fission distribution and three MAVRIC calculations to find (a) the total dose at the detectors in the lower level of the control room, (b) the total dose at the detectors in the upper level inside the experimental area, and (c) the total dose on a mesh covering the inside and the areas just outside the experimental bay.

KENO-VI was used to find the fission distribution on a 14 × 14 × 14 mesh covering a cube of 122.022 cm surrounding the fissionable material, which is shown in Figure 2. The fission spatial distributions are symmetrical. The value of keff has converged well, so the fission spatial distributions are symmetrical. Depending on the fineness of the grid resolution, the criticality calculation may need to be run longer than a typical k_{eff} calculation in order to reduce the statistical variation in the computed mesh source.

For the various MAVRIC transport calculations, the critical assembly model was added to a simple building model, see Figure 3. The fission mesh source is read by MAVRIC for both the spatial and energy distribution of the starting neutrons. Fission photons can also be added when importing a mesh source.

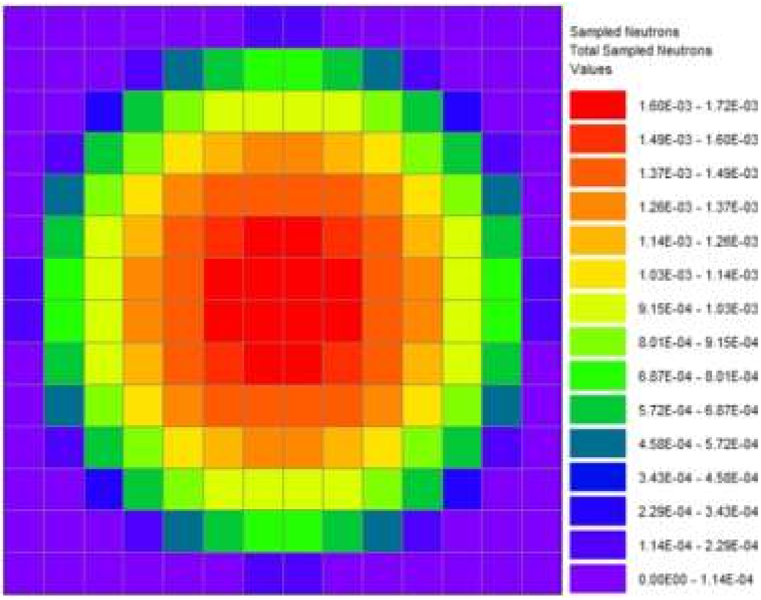

Figure 2. Fission spatial distribution from KENO-VI of the Jezebel

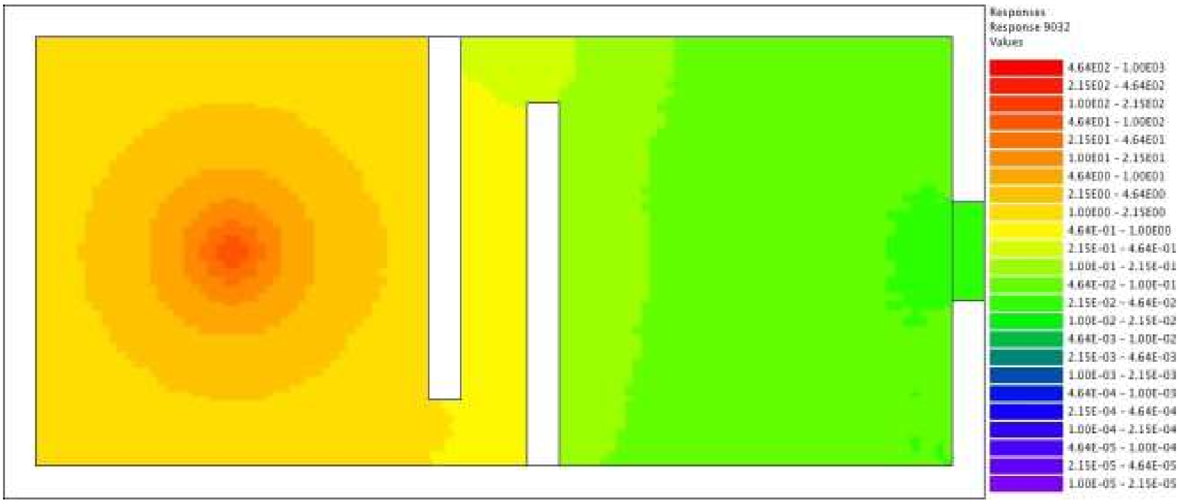

Figure 1. Top view of 2 simple rooms made of concrete blocks surrounding area where the criticality excursion occurs

CONCLUSION

As conclusion, the process of determining the minimum accident of concern has been discussed, which is followed by basic examples of how to calculate CAAS detector responses using the 3D Monte Carlo radiation transport capabilities of SCALE. Then, an example of how to calculate the coverage of a CAAS detector is provided. Finally, a strategy to determine the optimum placement of the minimum number of CAAS detectors is described. This strategy accounts for the number of credible accident locations relative to the number of potential CAAS detector locations, and recommends applying forward and adjoint transport simulations in different situations.

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