"Swapped Source": A Forward Calculation Technique to Help Establish the Worst-Case Accident Location for CAAS Detectors in Fixed Locations

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INTRODUCTION

Criticality Accident Alarm Systems (CAAS) must be able to detect the minimum accident of concern [1]. The CAAS analyst is frequently tasked to evaluate the ability of a small number of detectors in pre-determined locations to "see" the minimum accident wherever that accident might be located. The purpose of this work is to present an approach that allows the analyst to make an informed decision regarding selection of the worst-case accident location for a system of fixed detector locations.

DESCRIPTION OF THE WORK

CAAS analyses to demonstrate detection of the minimum accident of concern (MAC) typically evaluate the combined capability of a small number of fixed detector locations. The fixed detectors must be capable of detecting the MAC, and in most cases the accident location is not limited to a small number of locations. Fissile material frequently presents a non-trivial risk of a criticality accident in many fixed equipment systems as well as any location where portable containers could be located during movement or storage. This leads to an effectively infinite number of possible accident locations. Reference 2 provides a valuable resource to guide the analyst in completing evaluations for MAC detectability. That reference acknowledges the difficulty of determining the worst-case accident location. A variety of common methods to determine the worst-case accident location include:

- Review the fissile material operation and apply intuition/experience to determine the worst-case accident location.
- Perform separate forward dose calculations with a fixed detector and the source (accident) location varied on a grid that covers the full range of possible accident locations.
- Perform adjoint calculation(s) to establish the detector response map.

Analyst intuition and experience can reliably identify the worst-case location when the layout is simple (e.g. an accident that might occur behind a concrete wall in an otherwise empty room). However, most fissile material operations involve complex equipment and complicated structural layouts that require more than intuition to identify the worst-case accident location for detection.

When intuition is not enough, the analyst may be able to "map out" the detector response by performing many forward-simulations with the detector location(s) fixed and the hypothetical accident location varied from one calculation to the next. In this approach, the calculation results from a collective dose map that allows identification of the location that results in the lowest calculated dose rate at the detector. This process is time consuming, even for simple configurations, and is resource-prohibitive in most situations.

Reference 2 provides guidance for the use of deterministic and Monte Carlo codes to determine dose for a given fission source location and for application of adjoint calculations to determine detector response. The adjoint calculation uses an adjoint particle source at the detector location and transports them throughout the volume of interest (where the accident might possibly occur). The adjoint calculation provides the user with detector response to each accident location within the facility. The iso-dose map resulting from adjoint calculations provides detector response to each accident location within the volume of interest. The worst-case location for detection is the location that exhibits the lowest adjoint flux/dose.

This work presents a method that the authors refer to as "swapped-source" that can be applied in many circumstances to identify the worst-case accident location for detection using a single forward dose calculation. The swapped-source method involves dividing the fission source with equal probability among the fixed detector locations. In MCNP6 [3] this is accomplished with general source definition (*SDEF*) input.

Detector locations are entered directly into a *POS* variable distribution listing where each location is listed as source information (*SI*) input with equal probabilities entered for each location in the associated source probability (*SP*) input. The flux is tallied throughout the volume of interest with a superimposed mesh tally, such as the MCNP6 *TMESH* or *FMESH* tallies. The worst-case accident location will be the region with the lowest mesh tally result. This approach was developed based on the analogy of turning on the light switch in a room (each detector being envisioned as a bulb) and then searching the room for the region in darkest shadow. Figure 1 (copied for convenience from Figure 43 of Reference 2) provides the results of adjoint analyses performed in that reference to identify the number of detectors expected to activate based on three proposed detector locations. Accidents in the left half of the room (yellow and red areas) will alarm two detectors; accidents in the right half of the room (green areas) will alarm one detector; and accidents in the lower right corner of the room will not alarm any of the three detectors.

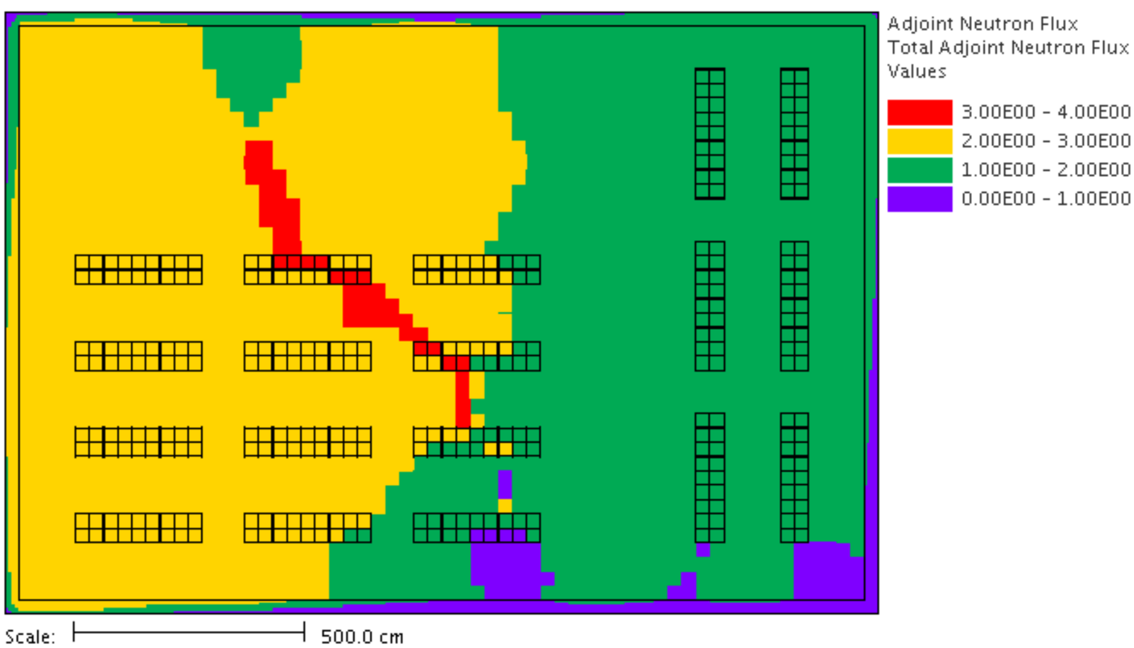

Figure 1. Reference 2 Map of Number of Detectors Activated in Hypothetical Vault Sample Case (Copied from Figure 43 of Reference 2).

RESULTS

The “swapped-source” method is illustrated here by applying it to a sample case from Reference 2. This allows the swapped-source method to be compared to the Reference 2 results shown in Figure 1. Case *srcA.inp* (and the associated *srcA.wwinp* weight window file) from Appendix A.20.b of Reference 2 was modified by changing the *SDEF* position to a distribution of source locations; each detector location included in an *SI* listing and each is given an effectively equal probability on the associated *SP* cards (0.333, 0.333 and 0.334, so the sum is equal to 1.0). In this case, *FMESH4* represents the neutron mesh tally, and the result is plotted at elevation z=100 cm (similar to the Figure 1 elevation). The results of the “swapped-source” mesh tally map are presented in Figure 2 and provide a good illustration of the performance of the method. It is clear that the worst-case accident location is in the bottom-right corner. A point-by-point comparison of the particular *FMESH* tally results in Figure 2 actually match the features of Figure 1 to a larger degree than the color-resolution applied in Figure 2 is capable of showing.

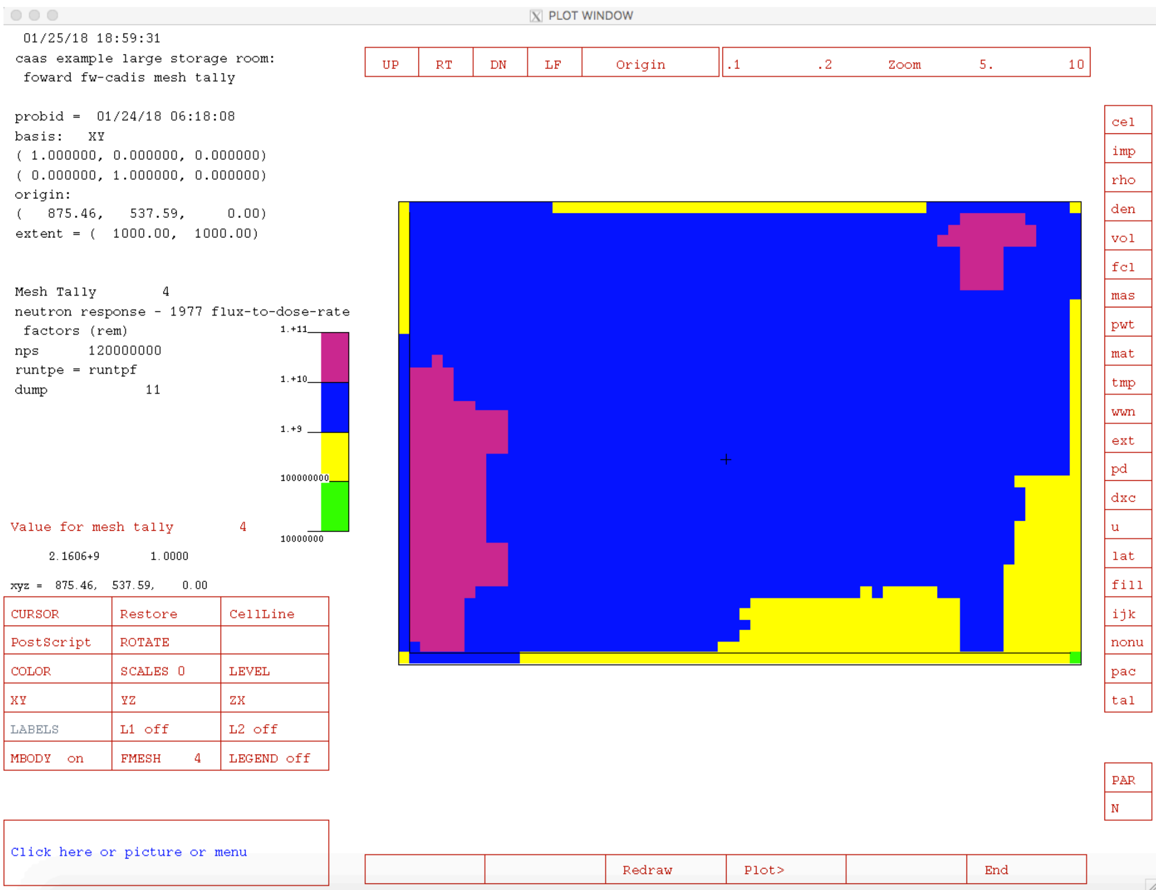

Figure 2. Swapped-Source Neutron Result of Modified srcA.inp Case.

The swapped-source method has limitations. Particle transport is not “reversible,” meaning that the transport of particles through an intervening material to a detector is not always the same magnitude when the detector and source locations are switched. For example, neutron transport through a concrete wall, and then a metal layer would be different if the material order were switched. The method is not intended as replacement for final, validated, calculations of detector dose but is presented as a semi-quantitative method to help the analyst determine the worst-case location for detection of the MAC. With that end-use it seems to be surprisingly robust to a wide range of material conditions and general structural and equipment layouts.

REFERENCES

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