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EFFECTIVE BIASING SCHEMES FOR DUCT STREAMING PROBLEMS

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The effective use of biasing for the Monte Carlo solution of a void streaming problem is essential to obtaining a reasonable result in a reasonable amount of time. Most general purpose Monte Carlo shielding codes allow for the user to select the particular biasing techniques best oriented to the particular problem of interest. The biasing strategy for void streaming problems many times differs from that of a deep penetration problem. The key in void streaming is to bias particles into the streaming path, whereas in deep penetration problems the biasing is aimed at forcing particles through the shield. Until recently, the biasing scheme in the SCALE SAS4 shielding module was considered inadequate for void streaming problems due to the assumed one-dimensional nature of the automated bias prescription. A modified approach to the automated biasing in SAS4 has allowed for significant gains to be realised in the use of the code for void streaming problems. This paper applies the modified SAS4 procedures to a spent fuel storage cask model with vent ports. The results of the SAS4 analysis are compared with those of the ADVANTG methodology, which is an accelerated version of MCNP. Various options available for the implementation of the SAS4 methodology are reviewed and recommendations offered.

INTRODUCTION

The quantification of surface and 2 m dose rates is a primary analysis step in the licensing activities for spent fuel transport and storage casks. The pertinent regulations are described in 10CFR71 and 10CFR72, respectively. These shielding applications require fairly sophisticated tools due to the deep penetration nature of the shield, typically both neutron and gamma components are important, and the large and geometrically complex nature of the source. The source for the calculations must be independently generated via a reactor fuel assembly depletion code, i.e. the SAS2 methodology in SCALE or by other means. The pin-by-pin modelling of the source geometry is typically not needed; however, the cavity basket geometry arrangement can still be quite complicated and margin can be gained by accurate modelling. The sheer size of the source volume can be an issue, in particular the height. The ~12 ft height of the active source region, along with a modified cosine axial shape, must be accurately treated in the biasing for meaningful results. The inclusion of vent cooling ports for storage casks further complicate the analyses since streaming can be an over-riding issue in many designs.

The Shielding Analysis Sequence #4 (SAS4) in the SCALE system[1] is specifically tailored to produce automated biasing for a class of deep penetration applications, in particular, coupled neutron–gamma shield analyses for transport and storage spent fuel casks. As such, the automated biasing is designed to separately force particles radially outward through the side shield or axially up or down through the lid or bottom shields. In addition, provision is made for the axial calculations to automatically bias the source location to take into account the large source height. However, the treatment of voiding streaming in the SAS4 program has always had a limitation, since the included automatic features are designed only for the deep penetration aspects of biasing. The one-dimensional (1-D) basis of the automatic biasing precludes the simultaneous biasing of both shield and void regions in the same vicinity.

Recently, a modified approach[2] to the automated biasing in SAS4 has allowed for significant gains to be realised in the use of the code for void streaming problems. This paper applies the modified SAS4 procedures to a spent fuel storage cask model with vent ports. The results of the SAS4 analysis are compared with those of the ADVANTG methodology[3], which is an accelerated version of MCNP. Various options available for the implementation of the SAS4 methodology are reviewed and recommendations offered.

DESCRIPTION OF AN APPROACH

The technique consists of a two-step procedure to increase the number of particles tracked though the void region:

(1) change the natural spatial distribution of the source to start a proportionally larger number of particles near the void location and
(2) change the standard source-plus-shield 1-D adjoint configuration to a source-plus-void geometry to be appropriate for particles that penetrate the void streaming geometry.

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For vent ports near the top or bottom of the cask, the first step above can be accomplished by performing an axial biasing calculation. The default axial calculation does spatial source location biasing such that the particles are preferentially biased towards the top or bottom of the source where the vent ports are typically located. Thus, an axial calculation should be performed even though the detector locations are on the cask side.

The second step is relatively straight-forward, but critical in the success of the technique. For the axial calculation, the 1-D adjoint model should begin as usual at the axial centreline of a symmetric model. (If vent ports are different for the top and the bottom, two different calculations are necessary, otherwise the bounding location should be selected.) The material in the source region should be smeared in the 1-D adjoint, even if an explicit geometry is modelled in the full 3-D calculation, and the remaining portions of the cask axial 1-D geometry should be modelled as void (mixture number 0). This technique should effectively bias particles out of the source region, and then let the particles travel through the penetration without any further biasing.

A total of six analysis approaches were attempted for a solution of this problem. These six procedures are included for completeness and comparison among the various approaches. A single best approach could have been surmised *a priori*, but this approach allows for the various techniques, successes and failures to be demonstrated.

Specific analysis approaches

The six approaches are as follows:

SAS4 radial standard biasing: radial biasing using standard SAS4 adjoint model. Source and radial shield models corresponded to axial centreline geometry.

SAS4 radial modified biasing: radial biasing used, but shield material was set to void, which corresponds to vent port.

SAS4 axial standard biasing: axial biasing using standard SAS4 adjoint model. Source and axial shield regions were specified, which correspond to cask centreline geometry.

SAS4 axial modified biasing: axial biasing with axial shield material set to void, which corresponds to vent port.

MCNP simple biasing: standard MCNP case with uniform importance, except the vent port

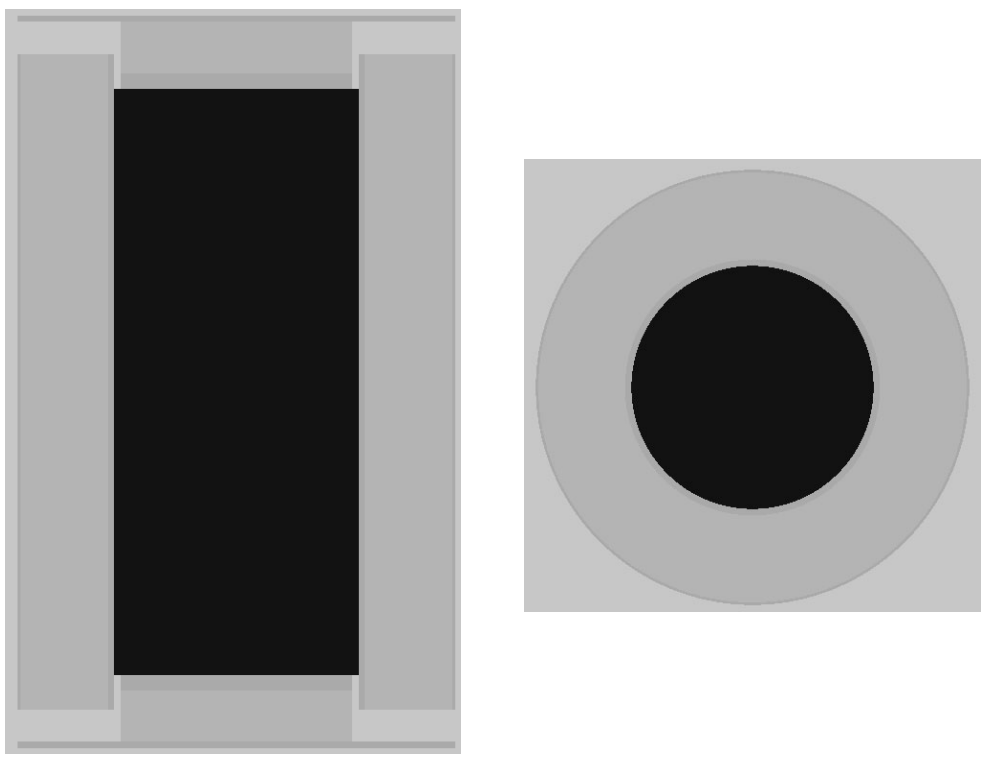

Figure 1. Geometry for example storage cask problem Illustrative Problem Description.

void regions. The vertical void was specified as a weight of 2.0 and the horizontal void as a weight of 4.0. All other regions have a weight of 1.0 assigned to them.

MCNP ADVANTG biasing: complete use of the ADVANTG method for automated biasing. ADVANTG automatically executes a three-dimensional TORT adjoint calculation and generates mesh-based weight window values for MCNP[4] execution.

The streaming of particles through the vent ports of storage casks can be easily demonstrated with a fairly simple cask model. This work has developed a standard model that is somewhat typical of many modern storage casks.

The plots shown in Figure 1 illustrate the simple geometric configurations that were used in this study. The black shading indicates the smeared source region, with the lighter shaded areas representing the stainless steel and concrete locations. The locations of the vent ports are clearly seen at the top and bottom of the cask geometry (the geometry is symmetric about the axial midplane) and are indicated by a lightest-grey shading. The desired location of the dose rate is at the outlet of the vent ports. For simplicity in modelling and analysis, these vent ports are assumed to completely encircle the top and bottom portions of the cask body.

RESULTS

The results of the various approaches are given in Table 1 and also in Figure 2. The difficulty encountered by SAS4 in the prediction of the dose rate at the vent port location is evident from these results. Only the axial-modified biasing scheme works to a satisfactory degree. Both the simple biasing and more advanced biasing in MCNP seem to work well for this demonstration problem. Completely unbiased solutions were not attempted for either the SAS4 or the MCNP methods. The traditional figure of merit (form) comprises of the best SAS4

Table 1. Comparison of dose results (mrem h^{-1}) for various biasing techniques.

Methods	10^5 Histories	10^6 Histories	10^7 Histories	10^8 Histories
SAS4 radial bias	40	53	123	160
SAS4 radial modified bias	1018	1705	4381	2056
SAS4 axial bias	1724	3789		18,041
SAS4 axial modified bias	1778	3270	2964	3170
MCNP simple bias	997	3279	2446	2919
MCNP Advantg bias	—	3100	2865	3086

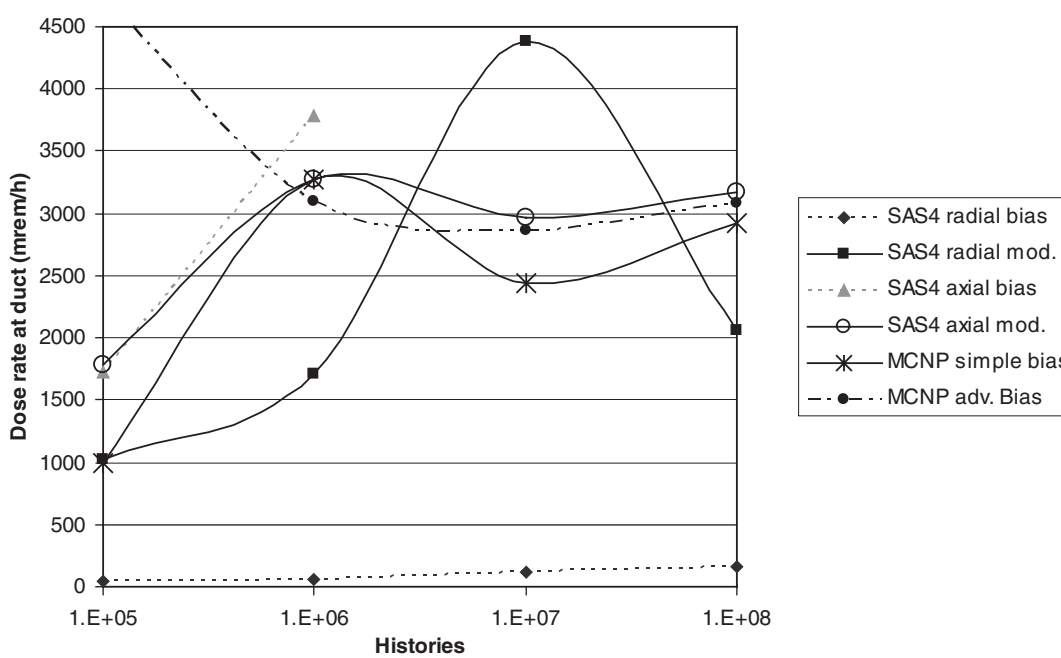

Figure 2. Convergence of biasing schemes for storage cask vent streaming problem.

Table 2. Comparison of efficiencies for various biasing techniques (based on 10^7 histories).

Methods	FOM	Gain relative to MCNP simple bias
SAS4 axial modified bias	23	58
MCNP simple bias	0.4	1
MCNP Advantg bias	4.0	10

approach with the two MCNP approach is shown in Table 2. The use of simple and ADVANTG-based biasing for MCNP is not intended as a formal comparison of these techniques, as the ADVANTG-based results were not fully optimised. They are only used to provide two independent biasing techniques to provide a benchmark for comparison of the various SAS4 techniques.

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