Effective Biasing Schemes for Duct Streaming Problems

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ABSTRACT

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 realized 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 transportation and storage casks. The pertinent regulations are described in 10 CFR 71 and 10 CFR 72, respectively. These shielding applications require quite 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 modeling 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 modeling. The sheer size of the source volume can be an issue, in particular the height. The roughly 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 complicates the analyses since streaming can be an overriding issue in many designs.

The Shielding Analysis Sequence #4 (SAS4) in the SCALE system is specifically tailored to produce automated biasing for a class of deep penetration applications, in particular, coupled neutron-gamma shield analyses for transportation 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 been a limitation, since the included automatic features are designed only for the deep penetration aspects of biasing. The one-dimensional basis of the automatic biasing precludes the simultaneous biasing of both shield and void regions in the same vicinity.

Recently, a modified approach to the automated biasing in SAS4 has allowed for significant gains to be realized 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.

Description of 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.

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 performs 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 to the success of the technique. For the axial calculation, the 1-D adjoint model should begin as usual at the axial centerline of a symmetric model. (If vent ports are different for top and 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 modeled in the full 3-D calculation. The remaining portions of the cask axial 1-D geometry should be modeled 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 solution of this problem. These six procedures are included for completeness and comparison of the various approaches. A single best approach could have been surmised *a priori*, but this approach allows for the successes and failures of various techniques to be demonstrated. 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 centerline 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 to correspond to cask centerline 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 for the vent port 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 assigned of 1.0.

MCNP ADVANTG biasing—full use of the ADVANTG method[3] for automated biasing. ADVANTG automatically executes a three-dimensional TORT adjoint calculation and generates mesh-based weight window values for MCNP execution.

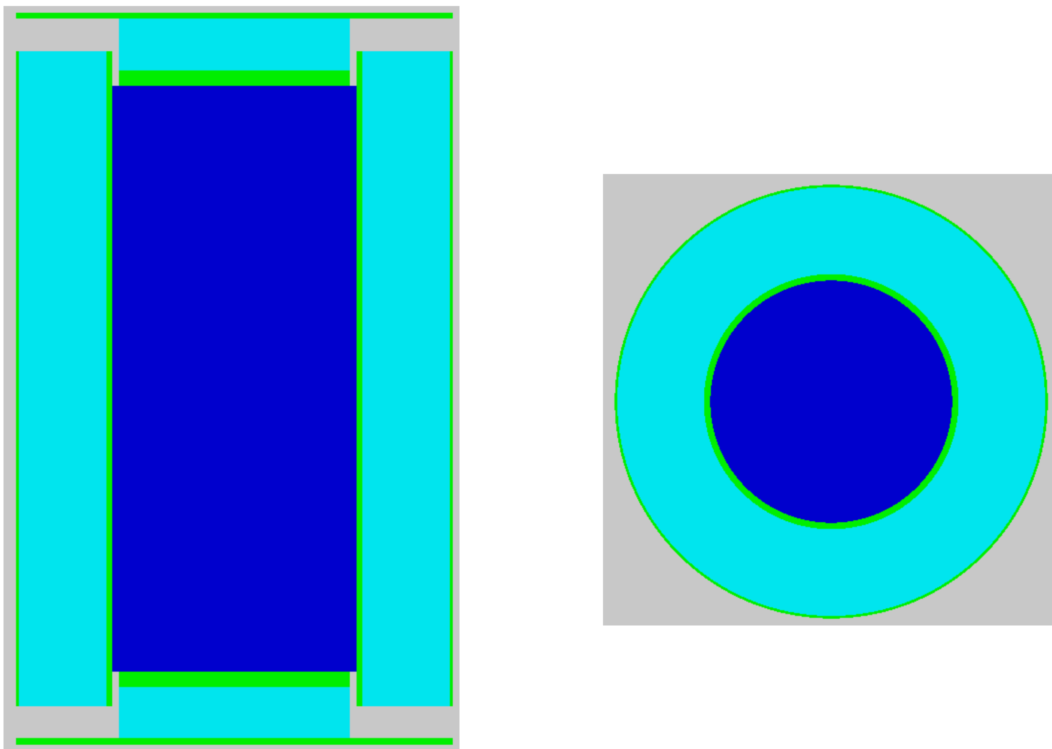

Fig 1: Geometric configuration for sample storage cask problem.

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 Fig. 1 illustrate the simple geometric configurations that were used in this study. The dark blue shading indicates the smeared source region, with the light green areas representing the stainless steel locations. The blue-green areas correspond to concrete shielding regions. 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 gray shading. The desired location of the dose rate is at the outlet of the vent ports. For simplicity in modeling 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 Fig. 2. The difficulty encountered by SAS4 in prediction of the dose rate at the vent port location is evident from these results. Of the SAS4 approaches, 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 MCNP methods. 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 optimized. They are used only to provide two independent biasing techniques to provide a benchmark for comparison of the various SAS4 techniques.

As a further comparison of the results of the various biasing techniques, the product of the percent standard deviations (%SD) and the computing times (in minutes) were determined for the last three methods shown in Table 1. These comparisons are shown in Table 2. It is clear from these results that the methods as outlined in this paper for SAS4 compare quite favorably with other biasing techniques for void streaming problems.

Table 1: Comparison of dose results (for various biasing techniques

Method	1.00E+05 Histories	1.00E+06 Histories	1.00E+07 Histories	1.00E+08 Histories
SAS4 radial bias	40	53	123	160
SAS4 radial mod.	1018	1705	4381	2056
SAS4 axial bias	1724	3789		18041
SAS4 axial mod.	1778	3270	2964	3170
MCNP simple bias	997	3279	2446	2919
MCNP adv. bias	-	3100	2865	3086

Table 2: Comparison of efficiencies for various biasing techniques (based on 1E7 histories)

Method	Product of %SD and time[a]	Ratio to minimum
SAS4 axial mod.	72	1
MCNP simple bias	1976	27
MCNP adv. bias	320	4

[a]Figure of merit.

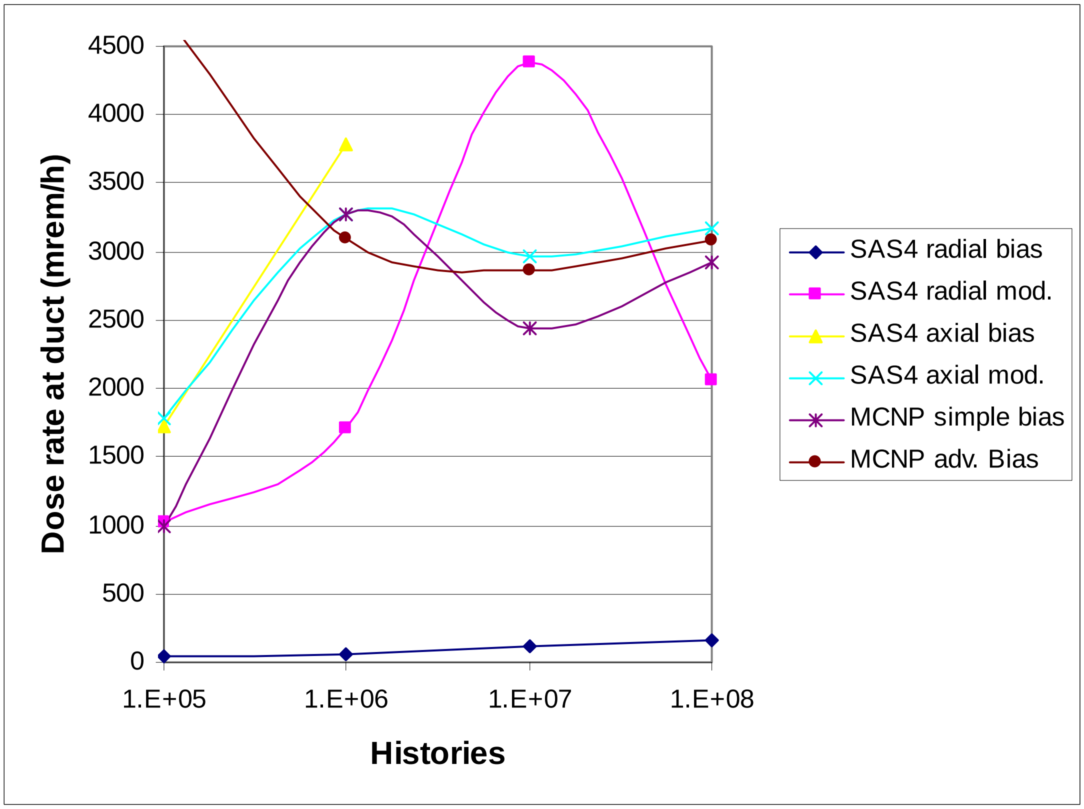

Figure 2: Convergence of biasing schemes for storage cask vent streaming problem.

References:

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