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An Assessment of the MCNP4C Weight Window

*Christopher N. Culbertson**
John S. Hendricks

**Graduate Research Assistant at Los Alamos. Purdue University, West Lafayette, IN 47907*

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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ABSTRACT (U)

A new, enhanced weight window generator suite has been developed for MCNP[1] version 4C. The new generator[2,3] correctly estimates importances in either a user-specified, geometry-independent, orthogonal grid or in MCNP geometric cells. The geometry-independent option alleviates the need to subdivide the MCNP cell geometry for variance reduction purposes. In addition, the new suite corrects several pathologies in the existing MCNP weight window generator. The new generator is applied in a set of five variance reduction problems. The improved generator is compared with the weight window generator applied in MCNP4B. The benefits of the new methodology are highlighted, along with a description of its limitations. We also provide recommendations for utilization of the weight window generator.

I. INTRODUCTION

A. Description of MCNP

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first-and second-degree surfaces and fourth-degree elliptical tori.

Pointwise cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF/B-VI) are accounted for. Thermal neutrons are described by both the free gas and $S(\alpha,\beta)$ models. For photons, the code takes account of incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation, and bremsstrahlung. A continuous slowing down model is used for electron transport that includes positrons, k x-rays, and bremsstrahlung, but it does not include external or self-induced fields.

Important standard features that make MCNP very versatile and easy to use include a powerful general source, criticality source, and surface source; both geometry and output tally plotters; a rich collection of variance reduction techniques; a flexible tally structure; and an extensive collection of cross-section data.

B. How to Use This Report

We envision three uses of this report.

First, as a validation document. This assessment validates the MCNP4C weight window generator. If you just want a document to prove it works, put this on your shelf and read no further.

Second, as a handbook for using weight windows in MCNP. See the guidelines for use, Section VII.

Third, for training in using MCNP in shielding problems. You should probably read the entire report and try the problems described with the proposed methodology.

C. Contents

The contents of this assessment report are:

1. Introduction
2. Variance Reduction and Weight Windows

   The weight window variance reduction technique and the weight window generator which computes weight window values is described.
3. Objectives

   This assessment of the MCNP4C weight windows was needed to verify that the new MCNP4C treatment of cell-based weight windows is as least as good as the MCNP4B treatment it replaced, to determine the worth of mesh-based windows relative to cell based windows, and to demonstrate to what degree the mesh-based windows reduce the need to subdivide problem geometries for variance reduction.
4. Methodology

   We describe our methodology for assessing the MCNP4C weight windows and weight window generator.
5. Model Descriptions

   The weight window assessment was done with five shielding problems. These were taken from the MCNP neutron[4] and photon[5] benchmark reports, the MCNP test set, and a sample problem for variance reduction.[6] All 5 problems have well-defined, highly optimized importance functions honed by experts but without the benefits of the new weight window generator.
6. Results

   Our data from the assessment of the MCNP4C weight windows and weight window generator is presented. We observe that the MCNP4C capabilities are generally superior to those of MCNP4B and that the new mesh generator can provide a superior importance function even when geometries are not subdivided for variance reduction.
7. Guidelines

   Our experience in using the MCNP4C weight windows and weight window generator has provided a recommended set of guidelines for their utilization.

8. Recommendations for Future MCNP Development

   Our experience with the MCNP4C windows indicates where future improvements in MCNP may be desirable.

9. Conclusions

II. VARIANCE REDUCTION AND WEIGHT WINDOWS

There are four classes of Monte Carlo variance reduction techniques that range from the trivial to the esoteric.

Truncation Methods are the simplest of variance reduction methods. They speed up calculations by truncating parts of phase space that do not contribute significantly to the solution. The simplest example is geometry truncation in which unimportant parts of the geometry are simply not modeled. Other truncation methods available in MCNP are energy cutoff and time cutoff.

Population Control Methods use particle splitting and Russian roulette to control the number of samples taken in various regions of phase space. In important regions many samples of low weight are tracked, while in unimportant regions few samples of high weight are tracked. A weight adjustment is made to ensure that the problem solution remains unbiased; that is, weight is preserved. Specific population control methods available in MCNP are geometry splitting and Russian roulette, energy splitting/roulette, weight cutoff, and weight windows.

Modified Sampling Methods alter the statistical sampling to better sample important regions of phase space. For any Monte Carlo event it is possible to sample from any arbitrary distribution rather than the physical probability as long as the particle weights are then adjusted to compensate. Thus, with modified sampling methods, sampling is done from distributions that send particles in desired directions or into other desired regions of phase space such as time or energy, or change the location or type of collisions. Modified sampling methods in MCNP include the exponential transform, implicit capture, forced collisions, source biasing, photon reaction biasing, and neutron-induced photon production biasing.

Partially-Deterministic Methods are the most complicated class of variance reduction methods. They circumvent the normal random walk process by using deterministic-like techniques, such as next event estimators, or by controlling of the random number sequence. In

MCNP these methods include point detectors, DXTRAN, and differential operator perturbations.

A. Weight Windows

The weight window is a space-energy-dependent splitting and Russian roulette technique. For each space-energy phase space cell, the user supplies a lower weight bound. The upper weight bound is a user-specified multiple of the lower weight bound. These weight bounds define a window of acceptable weights. If a particle is below the lower weight bound, Russian roulette is played, and the particle's weight is either increased to a value within the window or the particle is terminated. If a particle is above the upper weight bound, it is split so that all the split particles are within the window. No action is taken for particles within the window.

Three important weights define the weight window in a space-energy cell

1. W_L , the lower weight bound,
2. W_S , the survival weight for particles playing roulette, and
3. W_U , the upper weight bound.

The user specifies W_L for each space-energy cell on WWN cards. W_S and W_U are calculated using two problem-wide constants, C_S and C_U (entries on the WWP card), as $W_S = C_S W_L$ and $W_U = C_U W_L$. Thus, all cells have an upper weight bound C_U times the lower weight bound and a survival weight C_S times the lower weight bound.

Although the weight window can be effective when used alone, it was designed for use with other biasing techniques that introduce a large variation in particle weight. In particular, a particle may have several "unpreferred" samplings, each of which will cause the particle weight to be multiplied by a weight factor substantially larger than one. Any of these weight multiplications by itself is usually not serious, but the cumulative weight multiplications can seriously degrade calculational efficiency. Worse, the error estimates may be misleading until enough extremely high-weight particles have been sampled.

Although it is impossible to eliminate all pathologies in Monte Carlo calculations, a properly specified weight window goes far toward eliminating pathologically high-weight particles. As soon as the weight gets above the weight window, the particle is split and subsequent weight multiplications will thus be multiplying only a fraction of the particle's weight (before splitting). Thus, it is hard for the tally to be severely perturbed by a particle of extremely large weight. In addition, low-weight particles are rouletted, so time is not wasted following particles of insignificant weight.

One cannot ensure that every history contributes the same score (a zero variance solution), but by using a window inversely proportional to the importance, one can ensure that the mean score from any track in the problem be roughly constant. (A weight window generator exists to estimate these importance reciprocals.) In other words, the window is chosen so that the track weight times the mean score (for unit track weight) is approximately constant. Under these conditions, the variance is due mostly to the variation in the number of contributing tracks rather than the variation in track score.

Thus far, two things remain unspecified about the weight window: the constant of inverse proportionality and the width of the window. It has been observed empirically that an upper weight bound five times the lower weight bound works well, but the results are reasonably insensitive to this choice anyway. The constant of inverse proportionality is chosen so that the lower weight bound in some reference cell is chosen appropriately. In most instances the constant should be chosen so that the source particles start within the window.

B. Weight Window Generator

The generator is a method that automatically generates weight window importance functions. The task of choosing importances by guessing, intuition, experience, or trial and error is simplified and insight into the Monte Carlo calculation is provided. Although the window generator has proved very useful, two caveats are appropriate. The generator is by no means a panacea for all importance sampling problems and certainly is not a substitute for thinking on the user's part. In fact, in most instances, the user will have to decide when the generator's results look reasonable and when they do not. After these disclaimers, one might wonder what use to make of a generator that produces both good and bad results. To use the generator effectively, it is necessary to remember that the generated parameters are only statistical estimates and that these estimates can be subject to considerable error. Nonetheless, practical experience indicates that a user can learn to use the generator effectively to solve some very difficult transport problems. Note that this importance estimation scheme works regardless of what other variance reduction techniques are used in the calculation. We provide guidelines for using the weight window generator in Section VII.

1. Weight Window Generator Theory

The importance of a particle at a point P in phase space equals the expected score a unit weight particle will generate. Imagine dividing the phase space into a number of phase space "cells" or regions. The importance of a cell then can be defined as the expected score generated by a unit weight particle after entering the cell. Thus, with a little bookkeeping, the cell's importance can be estimated as

Importance (expected score) = total score because of particles entering the cell/total weight entering the cell

After the importances have been generated, MCNP assigns weight windows inversely proportional to the importances. Then MCNP supplies either card images or an auxiliary file of the weight windows for use in a subsequent calculation. The WWGE card defines the energy or time phase space division used to generate the weight windows. The constant of proportionality is specified on the WWG card.

2. Limitations of the Weight-Window Generator

The principal problem encountered when using the generator is bad estimates of the importance function because of the statistical nature of the generator. In particular, unless a phase space region is sampled adequately, there will be either no generator importance estimate or an unreliable one. The generator often needs a very crude importance guess just to get any tally; that is, the generator needs an initial importance function to estimate a (we hope) better one for subsequent calculations. Fortunately, in most problems the user can guess some crude importance function sufficient to get enough tallies for the generator to estimate a new set of weight windows. Because the weight windows are statistical, several iterations usually are required before the optimum importance function is found for a given tally. The first set of generated weight windows should be used in a subsequent calculation, which generates a better set of windows, etc. See the guidelines in Section VII.

In addition to iterating on the generated weight windows, the user must exercise some degree of judgment. Specifically, in a typical generator calculation, some generated windows will look suspicious and will have to be reset. In MCNP this task is simplified for cell-based weight windows by an algorithm that automatically scrutinizes importance functions, either input by the user or generated by a generator. By flagging the generated windows that are more than a factor of 4 different from those in adjacent cells, often it is easy to determine which generated weight windows are likely to be statistical flukes that should be revised before the next generator iteration. For example, suppose the lower weight bounds in adjacent cells were 0.5, 0.3, 0.9, 0.05, 0.03, 0.02, etc.; here the user would probably want to change the 0.9 to something like 0.1 to fit the pattern, reducing the 18:1 ratio between cells 3 and 4. The weight window generator also will fail when phase space is not sufficiently subdivided and no single set of weight window bounds is representative of the whole region. It is necessary to turn off the weight windows (by setting a lower bound of zero) or to further subdivide the geometry or energy or time phase space.

In MCNP4C mesh-based weight windows can be used to avoid modifying the geometry if the problem description is too coarse for cell-based weight windows. However, mesh-based weight windows have even more statistical fluctuations and are more difficult to adjust.

III. OBJECTIVES

There are many questions surrounding the new capabilities in MCNP4C. Whether MCNP4C generates and utilizes cell-based windows more or less efficiently than MCNP4B needs to be demonstrated. A thorough comparison of the mesh-based techniques to cell-based techniques is also desired. The addition of the weight window mesh introduced new parameters and techniques, which must be investigated as thoroughly as the application of the mesh. The location of coarse meshing and the number of fine gridding will influence the performance the mesh applying runs. Too coarse a mesh will produce a crude estimate of the importance function, whereas too fine a mesh will produce zero-windows due to insufficient sampling in addition to burdening the calculation. Finally, a primary purpose of mesh-based windows is to eliminate the tedious and error prone work of subdividing a geometry; we compare the performance of a simply defined problem using a mesh versus a fully divided problem using cell-based importances to assess whether subdivision of geometries is still required for variance reduction.

IV. METHODOLOGY

To assess the new weight window and weight window generator capabilities of MCNP we have chosen five test problems. These problems all required strongly geometric dependent importance functions, with cell-based importances or weight windows varying over several orders of magnitude. These problems also have expert-determined importance functions. Our comparisons of the new capabilities are to problems that were optimized by experts as much as possible before the new methods were available; they demonstrate the improvements over the best that could be done previously rather than some poor importance function where almost anything is better. The benchmark problems are described in Section V.

Each test was simplified to its basic elements, including the source definition, geometry, and the optimized tally. Five copies of the problem were then created. The first was altered to generate cell-based weight windows for execution in MCNP4C, whereas the second was altered to generate cell-based weight windows for execution in MCNP4B. The third copy was altered to produce mesh-based weight windows using the cell-based importances or weight windows provided in the original problem. It was assumed that an expert user generated these importances and that they reflect a greater degree of insight and experience than most users of the code possess. The fourth copy created mesh-based weight windows but used either one or zero (binary) values for the initial importances.

Most difficult variance reduction problems are set up using many more geometric cells than are needed to describe the physical geometry of the problem. Typically one mean free path of the transported particle is used as a standard unit of subdivision length to aid in numerical calculation of a smoothly varying importance function throughout the problem. This results in ten to one hundred times more MCNP cell descriptions than are necessary to fully describe the model. A driving force behind the inception of mesh-based weight windows was the elimination of this tedious and error-prone pursuit; the fifth copy was simplified to contain only as many cells as were reasonably necessary to describe the problem. This fifth copy created a mesh using binary-valued importances in these new cells.

The MCNP4C cell-based weight window enhancements were assessed on the basis of generation and utilization of weight windows. Using MCNP4C and MCNP4B on the first and second copies to first generate nearly converged sets of cell-based weight windows, the output weight windows are applied as input to both MCNP4B and MCNP4C, resulting in four total runs applying newly generated cell-based weight windows. The figures of merit are then compared. The mesh-based weight windows generated were applied with the aforementioned variations and the results were compared to the results of the cell-based techniques.

Applying weight-window based variance reduction techniques in MCNP must usually be done as an iterative process. A thoughtful balance must be kept between generating an adequately converged set of windows and not devoting too much computation time towards this end. A set of windows generated by a run with 0.1% error will perform better than a set generated from a run with 30% error, but there is no reason to apply the more converged set because a sufficient solution has already been determined. We recommend that 10-20% error on the window-generating run should provide the necessary balance. Another recommendation is to run until the slope in the tally statistical analysis is greater than 3.

Before the figures of merit are compared, however, a problem must be run long enough to meet several criteria indicating a converged solution. A run using an expert generated set of cell importances was run for 10^7 histories typically to obtain a solution for comparison.

Note: The available installation packages for MCNP4B and MCNP4C apply different *mcsetup.for* routines. This application results in slightly different optimization options, and therefore the codes are not truly comparable. A large performance variation was observed which was solely due to this compilation variation. The solution to this problem was to consistently apply the *mcsetup.for* from MCNP4C for both MCNP4B and MCNP4C installation procedures.

V. MODEL DESCRIPTIONS

Five problems were selected to test the new features of MCNP4C. The problems chosen were: the skyshine and air over ground problems from the photon benchmark set,[5] the fusion shielding from the neutron benchmark set,[4] the oil well logging problem from the MCNP test set, and a neutron problem taken from the introductory and advanced classes on MCNP offered by the X–CI group in X–Division at Los Alamos National Laboratory.[6]

A. Skyshine

The photon skyshine problem[5] is illustrated in Fig. 5.1. It consists of an infinitely opaque, open-top drum containing a cesium-137 point source resulting in a beam cone approximately 150° pointed skyward. The drum sets on 9 cm of dirt with a hemisphere of air 1.2 km in radius surrounding the drum above the dirt. The rest of the world is modeled as void. For this study, the ring detectors were removed from all locations except at 0.7 km from the source, which was the most difficult tally. Additionally, thick target bremsstrahlung was turned off using the *phys:p 2j 1* entry for efficiency. The exclusion of thick target bremsstrahlung treatment should not affect the relative performance when comparing importance functions. The base model input file used in all runs is appended as A1. The variations implemented on the base model to produce the runs in this assessment are detailed in A2 as obtained by the UNIX *diff* utility. The purpose of each of the runs listed in A2 is briefly described in table A3. Input for the simplified geometry is listed as A4. The complex description of the problem required 19 cells, whereas the simple model using mesh-based variance reduction required only 5.

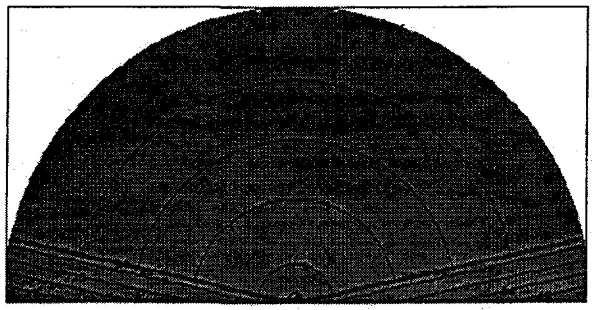

Fig. 5.1: Skyshine geometry plot from MCNP plotter.

B. Fusion Shielding

The seventh configuration of the fusion shielding iron benchmark problem[4] was chosen, with a 55.88-cm-thick shield wall. The problem consists of 14 MeV D-T fusion neutron source in a cement shield structure. An experimental shield configuration consisting of iron and borated polyethylene is placed between the beamline and an off-axis point detector. A stainless steel sheet is also used between the detector and the source. The cement walls of the experiment room are fully modeled, including three open doorways. Plots of the top view and side view are seen in Figs. 5.2 and 5.3. The base model used in all runs is appended as B1. The variations implemented on the base model to produce the runs in this assessment are detailed in B2 as obtained by the UNIX *diff* utility. The purpose of each of the runs listed in B2 is briefly described in table B3. Input for the simplified geometry is listed as B4. The complex description of the problem required 179 cells, whereas the simple model using mesh-based variance reduction required only 53.

C. Air Over Ground

The photon air-over-ground deep penetration problem[5] is illustrated in Fig. 5.4. A planar cobalt-60 source is distributed across a 1 km disc. Below the disc is soil; above, air. A detector at the center of the disc collects information on the modeled fallout dose levels. The base model used in all runs is appended as C1. The variations implemented on the base model to produce the runs in this assessment are detailed in C2 as obtained by the UNIX *diff* utility. The purpose of each of the runs listed in C2 is briefly described in Table C3. Input for the simplified geometry is listed as C4. The complex description of the problem required 122 cells, whereas the simple model using mesh-based variance reduction required only 4.

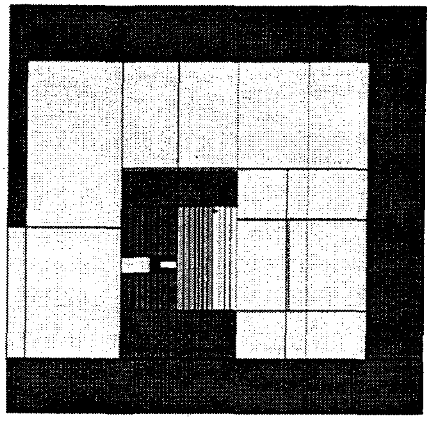

Fig. 5.2: Side view of the fusion problem geometry from MCNP plotter.

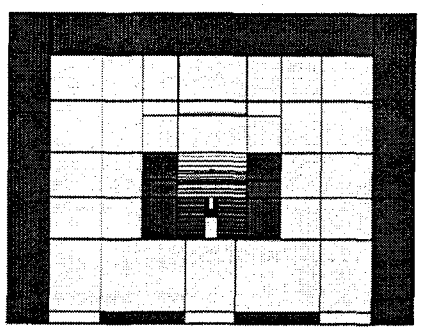

Fig. 5.3: Top view of the fusion problem geometry from MCNP plotter.

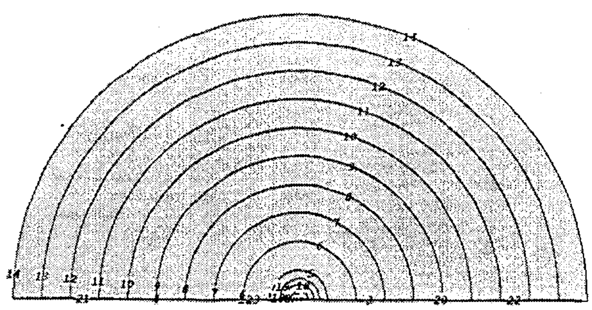

Fig. 5.4: Air over ground geometry plot from MCNP plotter

D. Oil Well Logging

The oil well logging problem is from the MCNP4B test set and is illustrated in Fig. 5.5. In this problem, near and far helium-3 detectors are modeled to detect a signal from a neutron source in an iron rod (sonde). This iron sonde is deployed down a cylindrical shaft filled with water and surrounded with limestone. The sonde is placed off-center of the well axis. The neutron source emits over a continuum up to 11 MeV and the tallies are binned into ten energy groups, allowing a spectrum to be analyzed. Only the far, optimized tally was retained in the model. The base model used in all runs is appended as D1. The variations implemented on the base model to produce the runs in this assessment are detailed in D2 as obtained by the UNIX *diff* utility. The purpose of each of the runs listed in D2 is briefly described in table D3. Input for the simplified geometry is listed as D4. The complex description of the problem required 231 cells, whereas the simple model using mesh-based variance reduction required only 7.

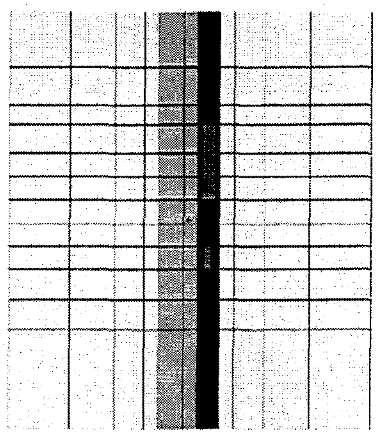

Fig. 5.5: Oil well logging problem geometry plot from MCNP plotter.

E. MCNP Class Variance Reduction Problem

The sample problem for variance reduction,[6] which is used in the MCNP introductory and advanced classes to illustrate a truly challenging variance reduction problem, is illustrated in Fig. 5.6. It consists of a 20-m-deep cylindrical well filled at the bottom with 180 cm of cement. A perfect absorber of zero importance surrounds the well, while a hundredth-density cement cell at the top of the well caps an intermediate region of void of unity importance. A detector outside the top of the well tallies neutrons introduced beneath the cement. The exponential transform, a DXTRAN sphere, forced collisions, and a point detector are all used.

The base model used in all runs is appended as E1. The variations implemented on the base model to produce the runs in this assessment are detailed in E2 as obtained by the UNIX *diff* utility. The purpose of each of the runs listed in E2 is briefly described in Table E3. Input for the simplified geometry is listed as E4. The complex description of the problem required 23 cells, whereas the simple model using mesh-based variance reduction required only 7.

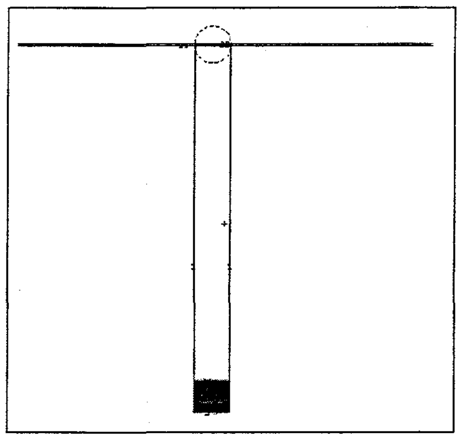

Fig. 5.6: Class variance reduction geometry plot from MCNP plotter.

VI. RESULTS

A. Window Utilization

1. Skyshine Problem.

Given identical input weight windows, MCNP4C utilizes weight windows as effectively as MCNP4B, as seen in the figure-of-merit comparison shown in Fig. 6.1a. The 4C runs performed 1% slower than the 4B runs, which is statistically insignificant.

Note that the run with windows generated and applied in 4C was performed using the *wwout/wwinp* feature. As MCNP4B does not allow automation of the weight window iteration process, the output weight windows were added by hand to the input files in the second generation for the other 3 runs.

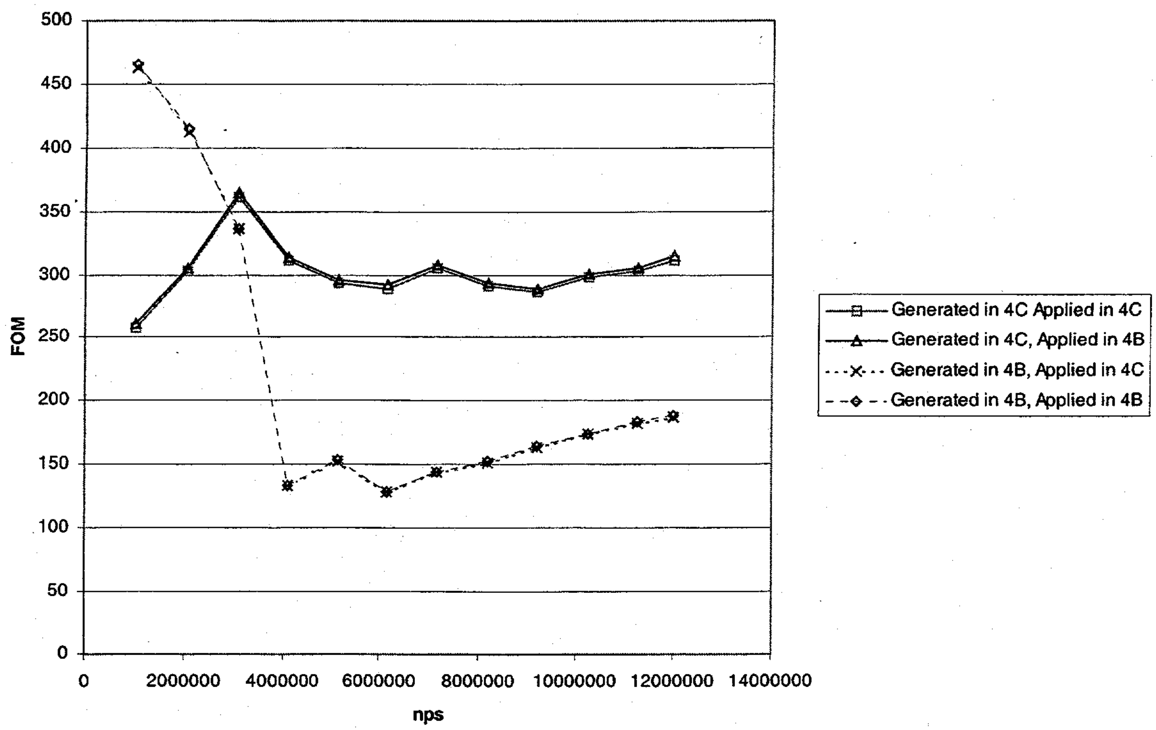

Fig. 6.1a: Skyshine problem.

2. *Fusion Problem*

Given identical input weight windows, MCNP4C utilized weight windows comparably or a little less effectively than MCNP4B. This is most easily observed in the figure-of-merit comparison shown in Fig. 6.1b. The results show a 6.5% improvement in 4B over 4C for the runs in which the windows were generated in 4C. The runs in which the weight windows were supplied by 4B indicate nearly identical performance between 4C and 4B.

3. *Air Over Ground Problem*

Given identical input weight windows, MCNP4C utilized weight windows slightly more effectively than MCNP4B. This is most easily observed in the figure-of-merit comparison shown in Fig. 6.1c . The results show a total of only 6% variation between all of the runs, but indicate higher performance when windows are run in 4C as opposed to 4B. Runs executed with 4C performed 5.5% higher than those executed with 4B when applying 4B generated windows. Runs executed with 4C performed 4.5% better than those executed with 4B when applying 4C windows. The poor convergence is due to the mismatch of weight windows and source spatial bias described later.

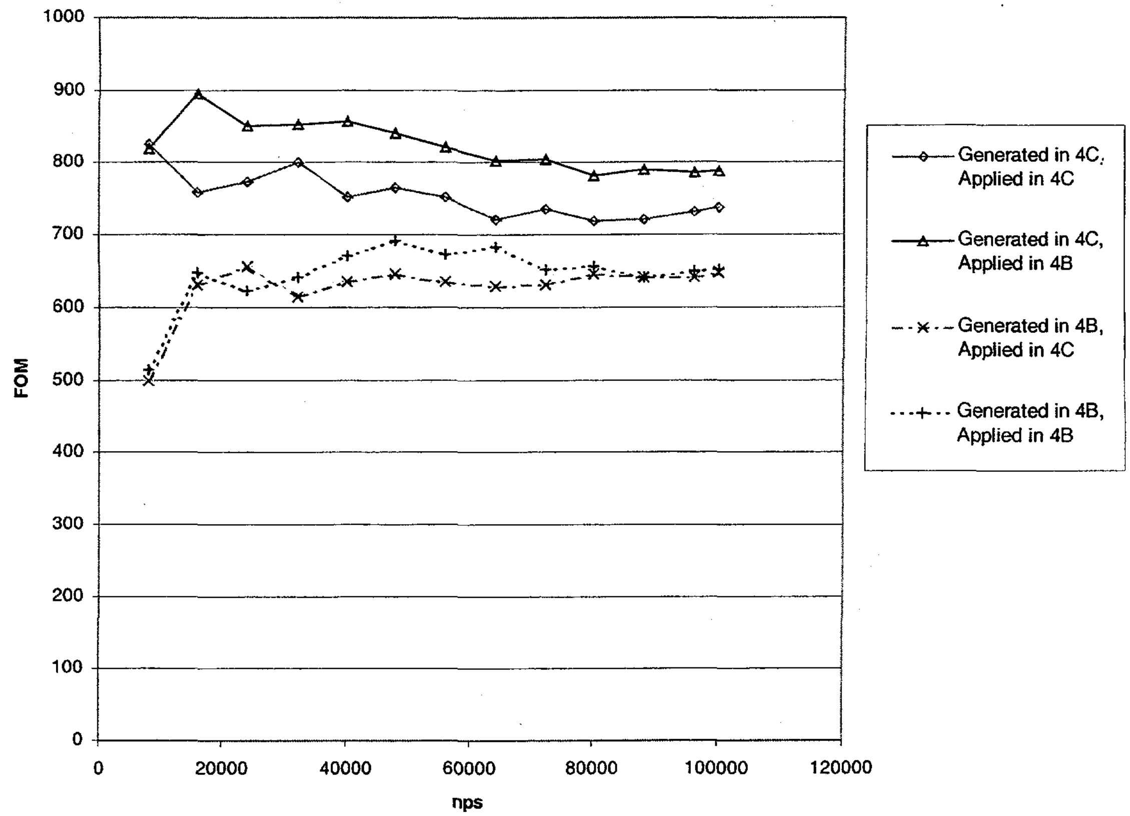

Fig. 6.1b: Fusion problem.

4. Class Variance Reduction Problem

Given identical input weight windows, MCNP4C utilized weight windows comparably to MCNP4B in this problem as can be observed in the figure-of-merit comparison shown in Fig. 6.1d. The final results showed a 1.5% performance improvement running in 4C compared to 4B when using 4C windows. A 1.3% improvement was observed when running in 4C compared to 4B when applying 4B windows.

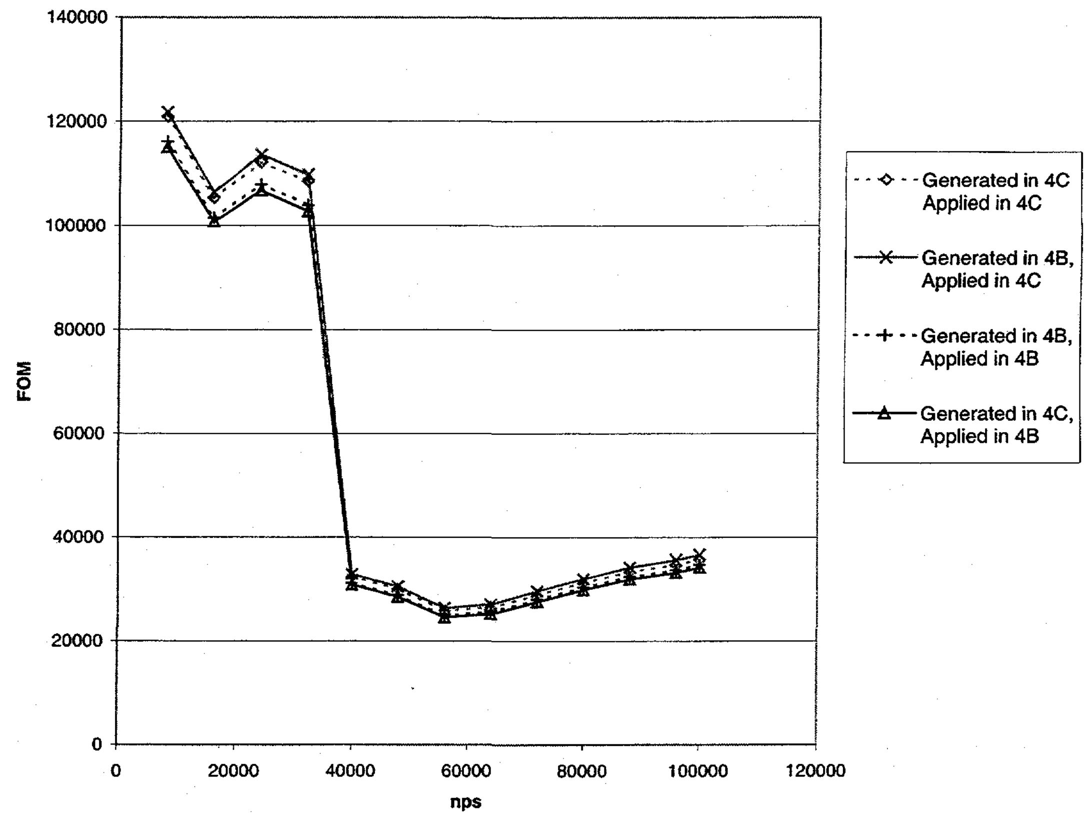

Fig. 6.1c: Air over ground problem.

<u>5. *Oil Well Problem*</u>

Given identical input weight windows, MCNP4C utilized weight windows more effectively than MCNP4B in this problem as is most easily observed in the figure-of-merit comparison shown in Fig. 6.1e. The results show an 11.8% improvement in 4C over 4B for the runs in which the windows were generated in 4C. The runs in which the weight windows were supplied by 4B indicate an 11.9% improvement in 4C over 4B.

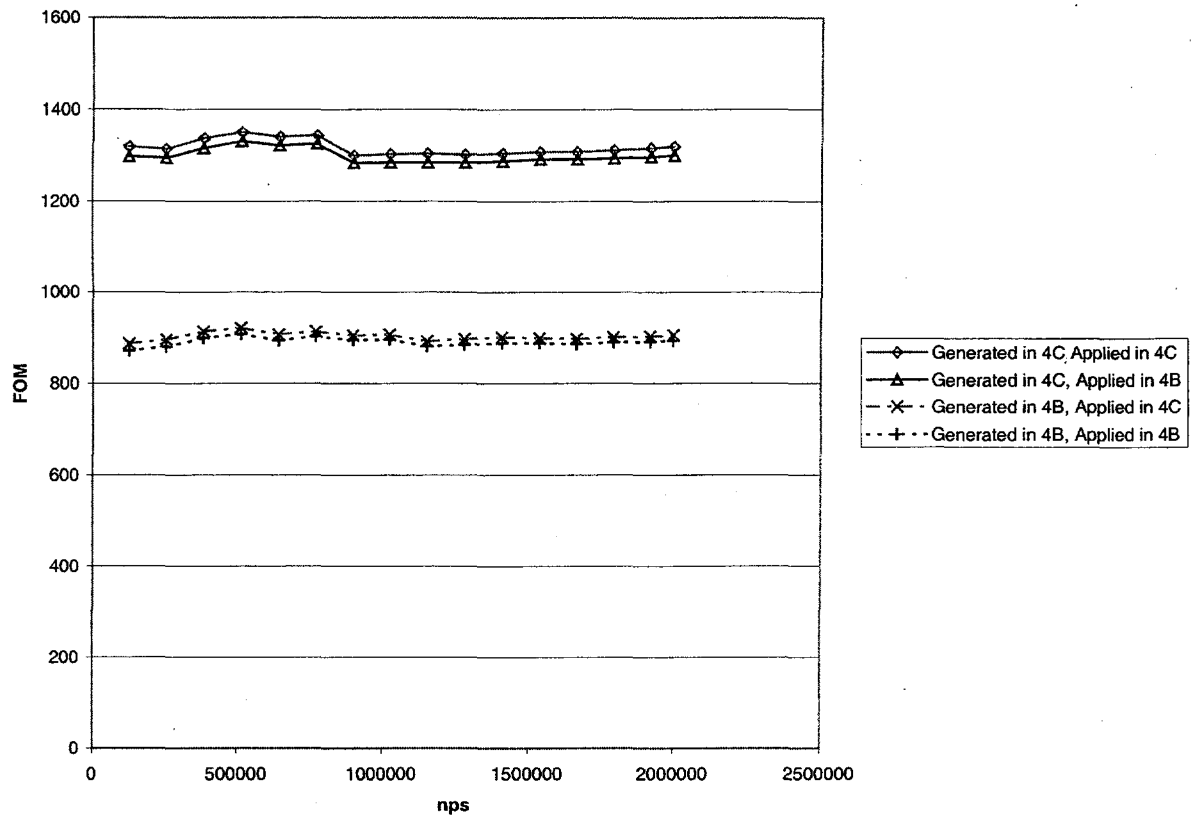

Fig. 6.1d: Class problem.

B. Window Generation

1. Skyshine Problem

MCNP4C generates cell-based weight windows more effectively than MCNP4B, as demonstrated in Fig. 6.1a. The weight windows generated in 4B evidently lead to poor convergence as suggested by the sharp fall in the figure-of-merit and a slope just under 3, although the calculated means were correct in all cases. Windows generated in 4C outperformed 4B windows by 66.8% when executed in 4C. When executed in 4B, 4C windows outperformed 4B windows by 67.6%.

2. Fusion Problem

MCNP4C generates cell-based weight windows more effectively than MCNP4B, as demonstrated in Fig. 6.1b. The windows generated with 4C outperformed the windows generated by 4B by 14.7% when executed in 4C. When executed in 4B, 4C windows outperformed 4B windows by 20.8%.

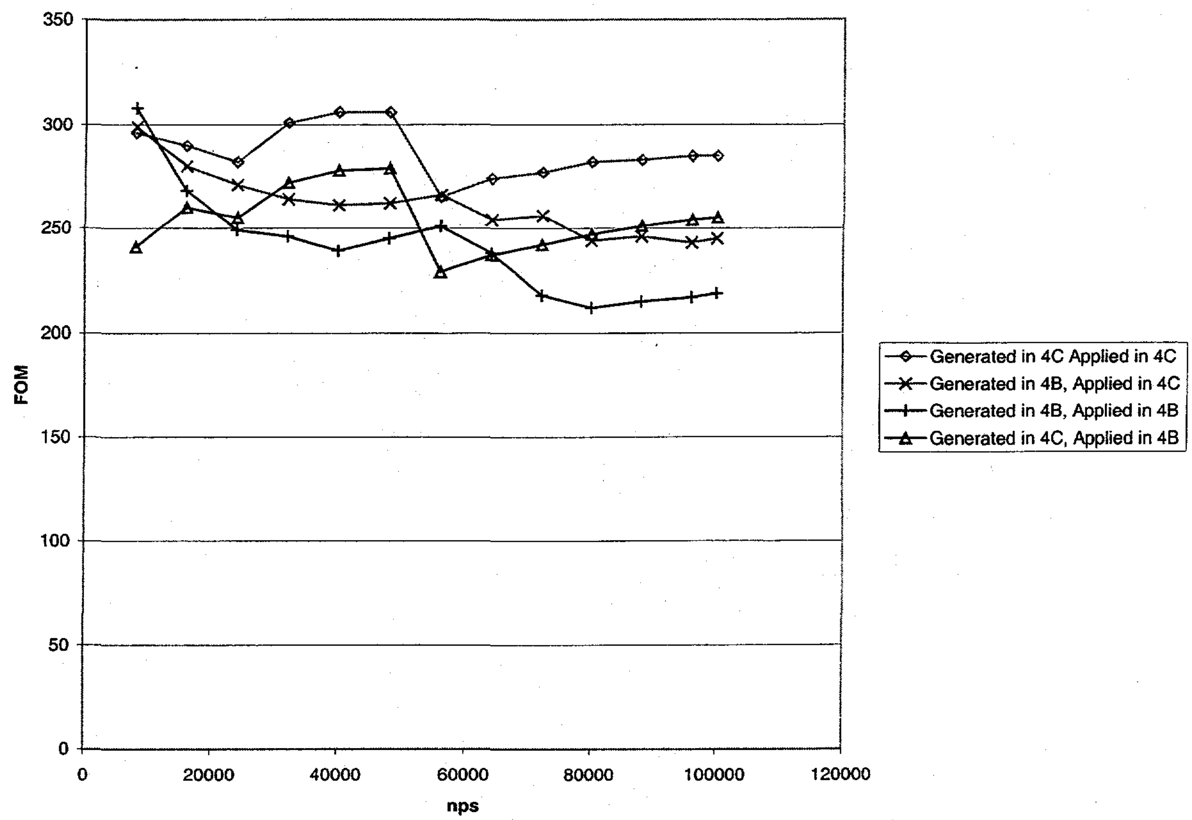

Fig. 6.1e: Oil well logging.

<u>3. Air Over Ground Problem</u>

MCNP4C generated cell-based windows slightly less effectively that MCNP4B in this particular problem, as demonstrated in Fig. 6.1c. Runs executed in 4C performed 2.5% slower with windows generated in 4C than with window generated in 4B. Runs executed in 4B performed 1.7% slower with windows generated in 4C than with windows generated in 4B.

<u>4. Class Variance Reduction Problem</u>

MCNP4C generated cell-based weight windows more effectively than MCNP4B in this problem, as demonstrated in Fig. 6.1d. Windows generated by 4C outperformed 4B windows by 45.4% when applied in 4B. When applied in 4C, windows generated in 4C outperformed 4B windows by 45.6%.

<u>5. Oil Well Problem</u>

MCNP4C generated cell-based windows more effectively than MCNP4B in this particular problem, as demonstrated in Fig. 6.1e. Runs executed in 4C performed 16.3% better with windows generated in 4C than with windows generated in 4B. Runs executed in 4B performed 16.4% better with windows generated in 4C than with windows generated in 4B.

C. Mesh-Based Weight Windows

1. Skyshine Problem

The mesh-based window generator outperformed both cell-based importance and cell-based window techniques in 4C and 4B by about a factor of 4. The performance of the mesh varied only slightly based upon the initial guesses of cell importances, and geometry subdivision insignificantly affected the solution. This variation is shown in Fig. 6.2c, comparing the applied mesh-based window runs to a run with cell-based windows generated in 4C and applied in 4C. Performance is obviously a function of the mesh configuration. Sensitivity of performance to coarse grid location and the number of fine grids might be the subject of future investigations.

Meshes generated from runs expert-guessed importances and from simply defined, binary-valued importances produced similar figures of merit, indicating that a satisfactory mesh can be produced without any prior knowledge of the problem. The simply defined geometry performed only about 10% poorer than the expert-generated mesh, due to a more poorly converged mesh-generation run.

An additional concern surrounding mesh-based weight windows was whether high mesh weights caused by incomplete sampling of the geometry would force a weight cut-off game in those regions, limiting the effectiveness of the windows. A run (not shown) was performed in which a smoothed set of windows replaced the input weights for the complex, expert-guessed run. The results were identical, suggesting that the weight cut-off game was not a large burden on performance. The weight cut-off card was set to a conservative value of -10^{-5} in both runs, however, so a thorough test must be performed at a larger value for more meaningful results.

2. Fusion Problem

The mesh-based window generator in 4C performed about 3.4% better than cell-based techniques in 4C for the second-generation runs when the mesh was generated in the detailed geometry using expert importances. The performance of the mesh varied according to the initial setup, as seen in Fig. 6.2b. The run performed in a simplified geometry (here 42 cells as opposed to 177) had a figure-of-merit 20-30% that of the run generated and applied using expert importances. To understand why, the meshes generated from the expert importance 177-cell initial run and the binary importance 177-cell initial run were tried on the 177 and 42-cell geometries as shown in Fig. 6.3a. For either geometry the expert mesh is superior to the binary mesh, and for either mesh the simple geometry is better than the detailed geometry. From Fig. 6.3a we observe that the expert mesh, generated from a run with good importances, is better than the binary-generated mesh run which just had ones and zeros for importances. Also, the simple geometry using the binary-generated mesh outperforms the expert importance, complex geometry using the same mesh by 31.1%. This speed-up can only be due to the less complicated cell make-up, as no weight-cutoff game was played in either run. A similar improvement of 28.4% was observed in the expert mesh when applied to the simple-geometry model and applied to the binary importance model.

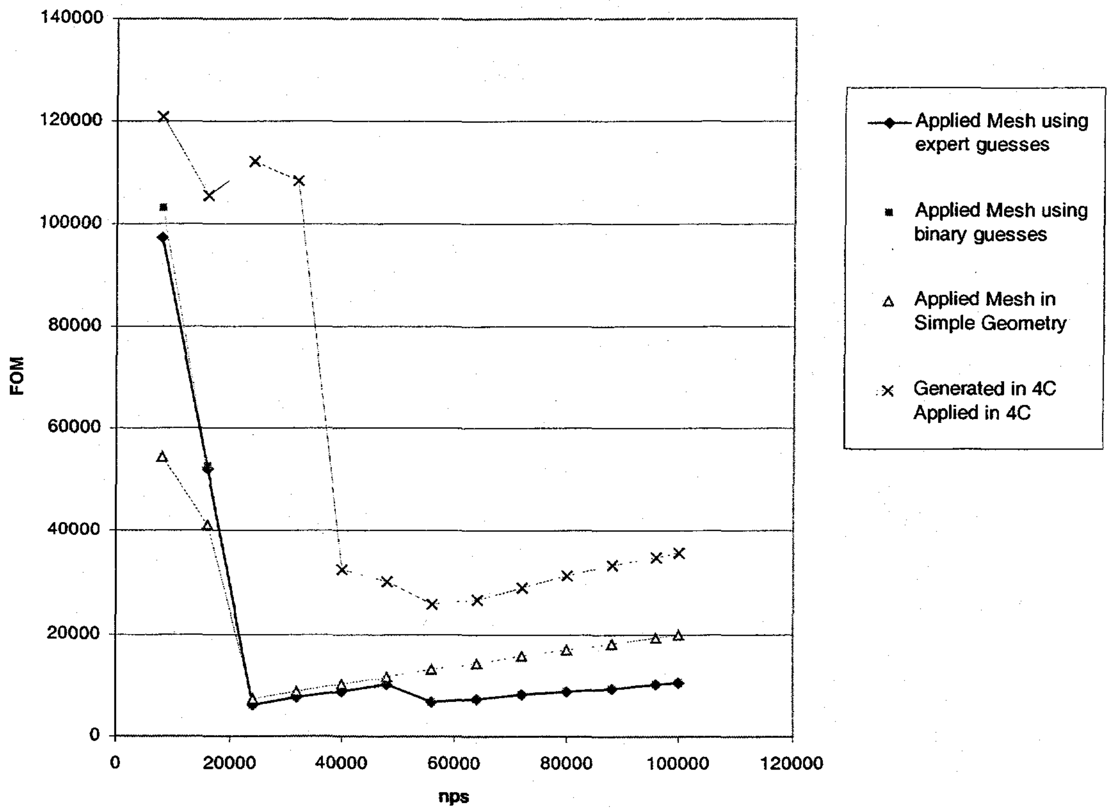

Fig. 6.2a: Air over ground problem.

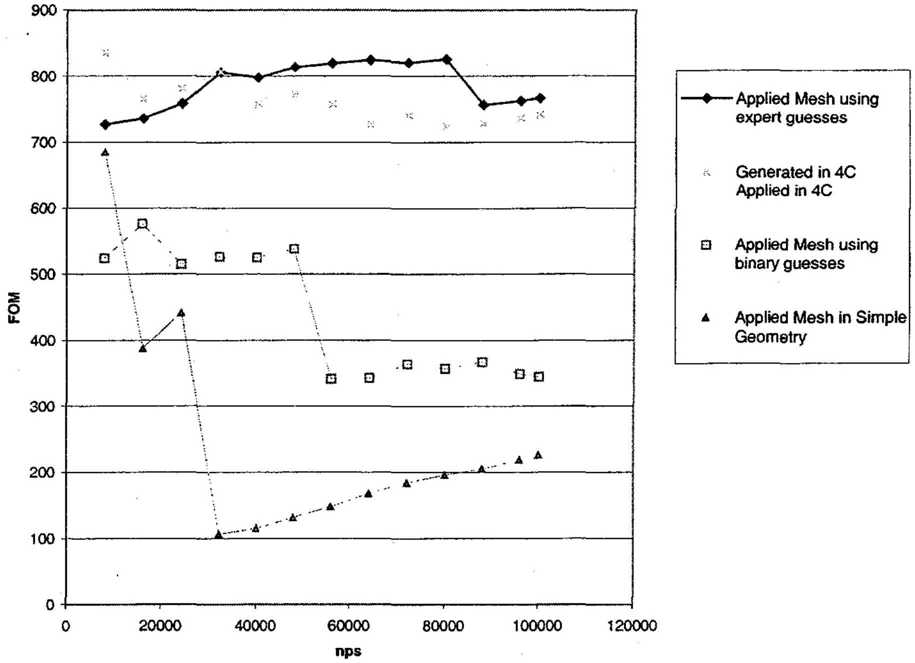

Fig. 6.2b: Fusion problem.

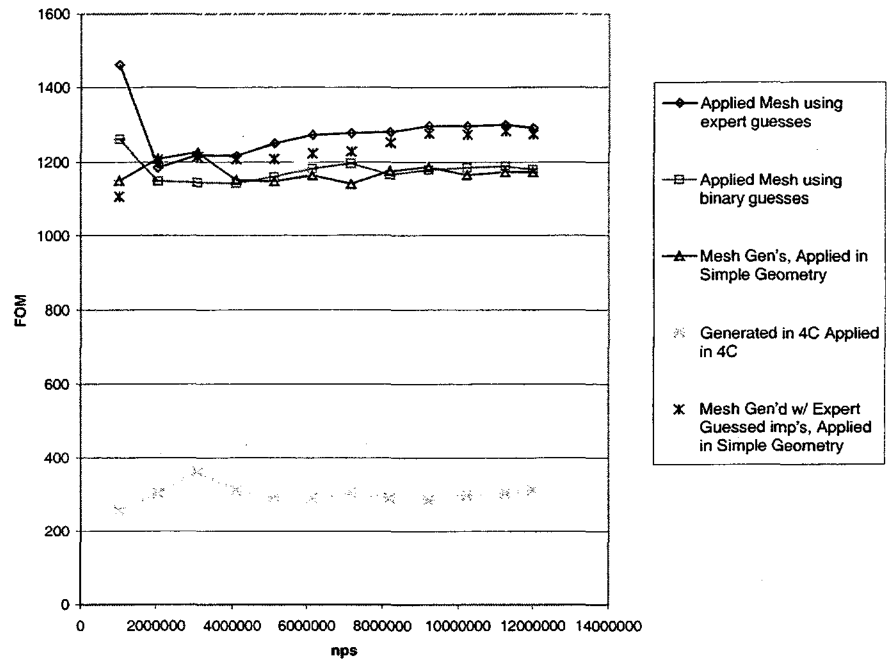

Fig. 6.2c: Skyshine problem.

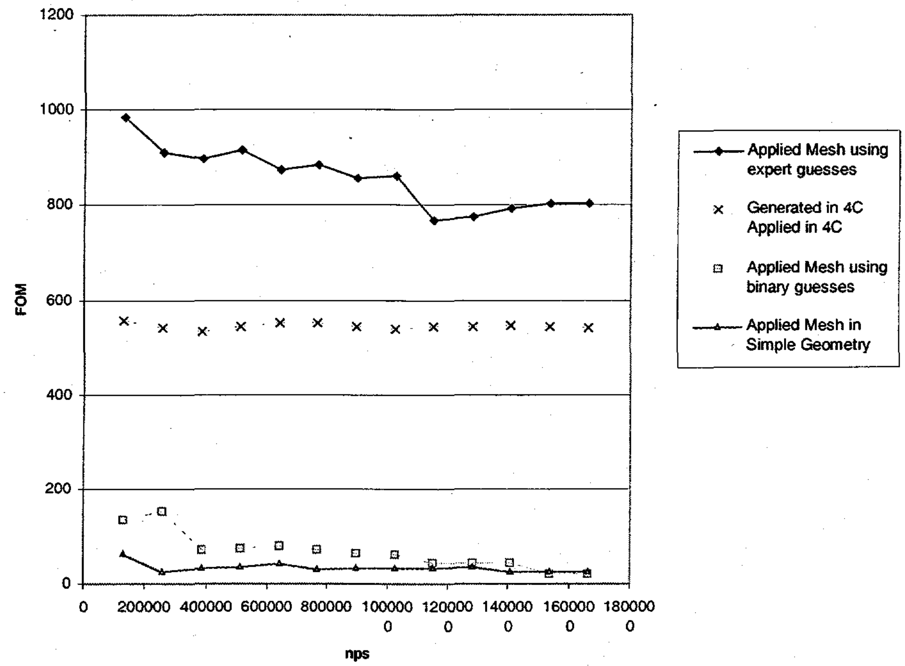

Fig. 6.2d: Class problem.

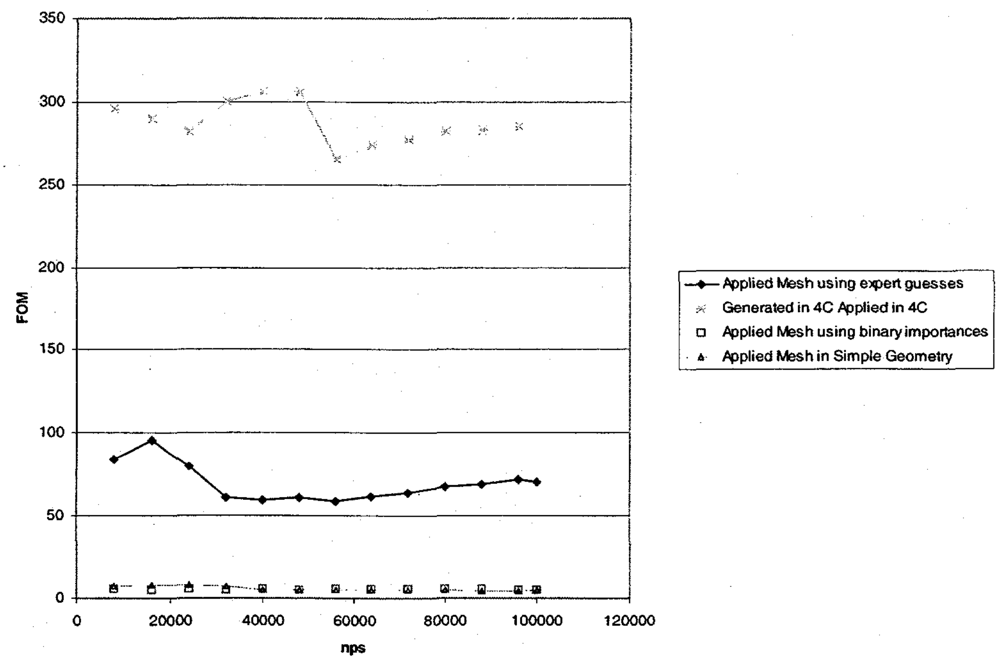

Fig. 6.2e: Oil well.

Another investigation was performed to determine the performance of mesh-based weight windows in iteration. All three fusion models (detailed geometry with expert importance function, detailed geometry with binary importances, and simple geometry with binary importances) were run for five generations, resulting in the originally generated mesh and two successive improved meshes. Selected results are shown in Fig. 6.3b and indicate that after 2-3 generations, the mesh-based wiindows can equal or better the original expert, cell-based windows (Fig. 6.2b).

3. Air Over Ground Problem

From Fig. 6.2a it is observed that mesh-based windows generated by the simple geometry were comparable to those generated by the detailed geometry. Thus subdivision is not necessary on this problem. Windows generated from the complex model with binary initial importances are also as good as those generated using expert importances in detailed geometry. Again, the geometry subdivision proves unnecessary.

All calculations had convergence problems due to the source bias not matching the weight windows. In all calculations applying the windows, all source particles started below the window value. When poorly combined in this manner, the two techniques perform worse than either technique alone, in effect canceling out benefits while increasing computational overhead. (The advisability of using source biasing alone in such cases has been recommended by H. Lichtenstein.[7])

This failing points out the need for a simple method of renormalizing the windows to lower (or higher if required) values than originally generated. Note that to generate usable windows, the initial generating run had to be run almost to convergence. If there had been a mechanism for matching source bias to the generated windows or renormalizing the windows, then we speculate that windows could be used and iterated upon from shorter generating runs.

The poor match between generated windows and source bias implies that the expert-guessed source bias and importances were far from ideal. Thus we further speculate that if there were a means of correctly adjusting generated windows with source bias, then the new weight window generator would give even better results than expert guesses rather than comparable answers. Even with the current limitations, the first iteration of runs applying the generated windows had a FOM 100 times better than the first iteration of the expert–guessed importances, which exhibited identical non-convergent behavior and at 10^5 particles reached a figure-of-merit of 113.

4. Class Variance Reduction Problem

The expert-importance generated mesh performed 51.6% better than cell-based techniques in 4C in the second-generation runs. The mesh application runs using binary importances in the complex geometry and the simple geometry performed far worse than the cell-based techniques, as shown in Fig. 6.2d.

Upon iterating the mesh-based weight windows, a large improvement over the initial mesh application runs, which were far from converged, was observed in the binary importance and simple models. The simple model error was reduced from 86% to 0.9% in 5 generations, whereas the binary model error was reduced from 52% to 0.7%. This success is shown in Fig. 6.3c. The results indicate that after enough generations, the mesh-based model betters the original expert, cell-based model. Noteworthy in these results is the apparent degradation of the simple model in the third iteration and the subsequent recovery in the fourth and fifth generations and the convergence of the simple and binary models despite large errors and small slopes in the generating run.

5. Oil Well Problem

The mesh-based window generator in 4C performed much poorer than cell-based techniques in 4C for the second-generation runs. The performance of the mesh varied according to the initial setup, as seen in Fig. 6.2e. The run performed in a simplified geometry had a much lower figure-of-merit than the run generated and applied using expert importances, but all mesh-based runs were outperformed by the cell-based run generated and applied in 4C.

Another investigation was performed to determine the performance of mesh-based weight windows during iterations. All three models were run for five additional generations, resulting in the originally generated mesh and four successive improved meshes. The results are shown in Fig. 6.3d and indicate that after enough generations, the figure-of-merit for the mesh-based model is within a factor of two of the original expert, cell-based model. Again, the generating runs were run to 20% relative error and iterated upon.

Originally a cylindrical mesh was used, yielding the poor results of Fig. 6.2c. Later, a rectangular mesh was used yielding the better results in Fig. 6.3d. The rectangular mesh is far faster than the cylindrical mesh and should be used preferentially.

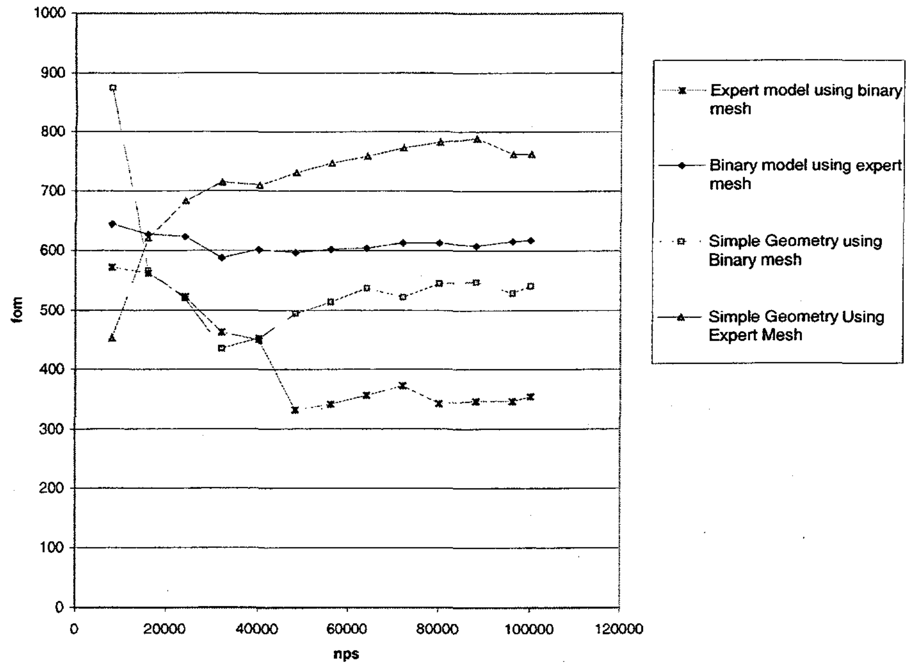

Fig. 6.3a: Fusion problem.

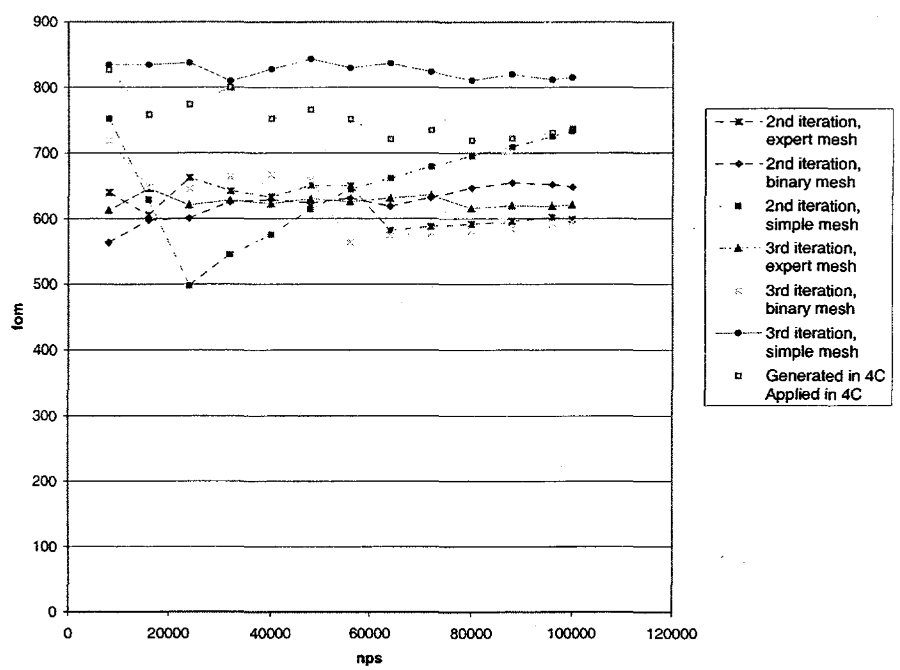

Fig. 6.3b: Fusion problem.

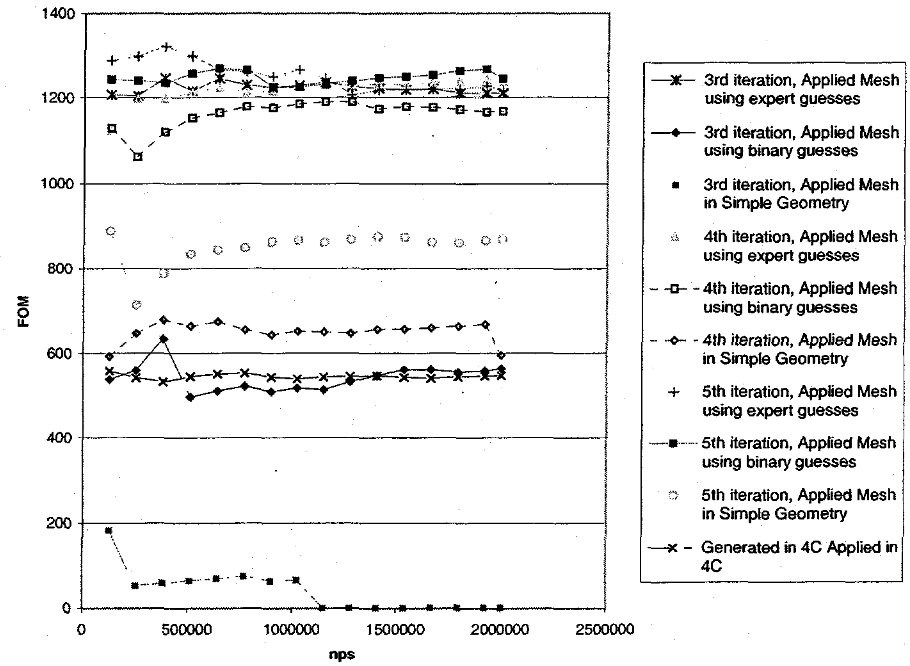

Fig. 6.3c: Class problem.

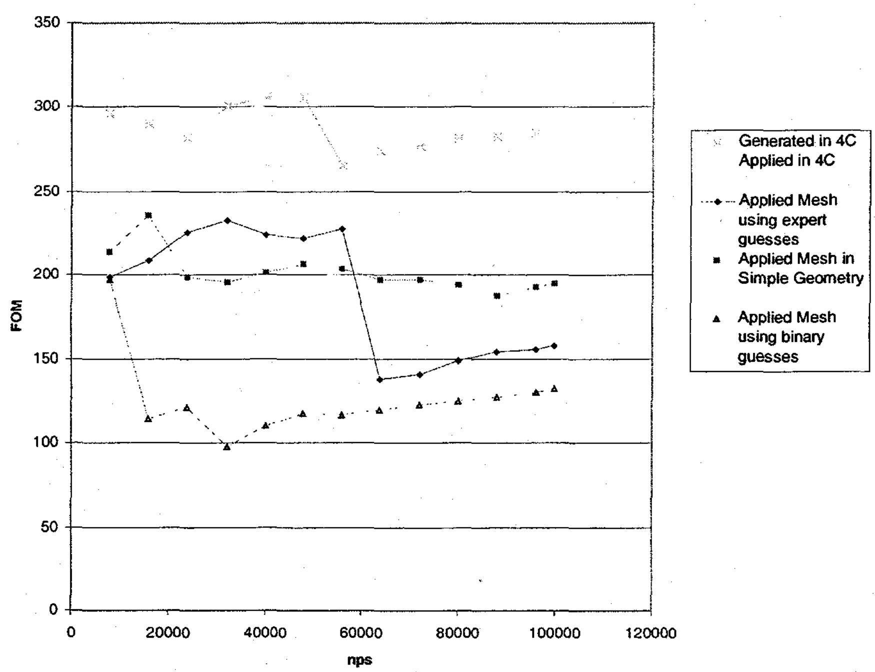

Fig. 6.3d: Fifth iteration, oil well.

VII. GUIDELINES

Our experience with the MCNP4C weight windows and weight window generator leads us to the following recommended guidelines for their utilization.

Whether using cell-based or mesh-based generated weight windows, if the generated windows are poor they will not improve the figure-of-merit (FOM) for the calculation of interest. On the other hand, if the generating run is converged, then there is no need to utilize the generated windows because the answer will be good enough. We therefore suggest the following methodology to properly utilize the weight window generator.

A. WHEN TO USE CELL-BASED OR MESH-BASED WINDOWS

If the calculational geometry is finely divided into cells appropriate for variance reduction, then cell-based windows are adequate, faster, and easier to understand and utilize. MCNP will automatically print out a table of adjacent weight windows whose ratio differs by more than a factor of 4 making it easier to identify badly generated windows. These can then be adjusted manually. Cell-based windows can also be input in the INP file so that it is easier to keep track of which importance function was actually used for a given calculation.

We recommend the use of cell-based weight windows when the problem geometry is sufficiently subdivided so that the importance function does not differ by more than a factor of 4 from cell to cell. In reality, most problems are not sufficiently subdivided in geometry to effectively utilize cell-based weight windows.

We recommend the use of mesh-based weight windows when the importance function varies significantly within important geometric cells. Our experience is that a variation by more than a factor of 10 within an important geometric cell justifies either further subdividing the geometry for cell-based windows or using mesh-based weight windows. Thus the mesh-based windows are recommended for most problems because further subdivision of a geometry for variance reduction is difficult. Generally the mesh-based windows have been observed to outperform the cell-based windows.

Note that the DXTRAN sphere cutoffs are utilized with cell-based weight windows and not mesh-based windows, which may affect your choice of cell- or meshed-based windows when using DXTRAN.

Point detector contribution (PD card) and DXTRAN contribution (DXC card) roulette games work only for cells and not meshes. If these variance reduction games are needed, subdividing cells rather than utilizing meshes may be warranted.

B. Guidelines for Specifying Superimposed Meshes.

The MCNP4C mesh card specifies the mesh upon which weight windows will be generated. In subsequent runs utilizing the generated weight windows, this mesh is carried over.

We recommend that the superimposed mesh be slightly larger than the underlying problem. If it is not, then particles may still be in the problem but not be able to determine the appropriate weight window. A warning error will be issued, and there is no appropriate weight control.

Although the external mesh boundaries should not lie on problem surfaces, but extend beyond them, we have no recommendation for internal problem surfaces even though which mesh cell weight window is used when a particle crosses a problem surface will be determined by roundoff. We have observed no adverse effects whether the mesh lies on internal surfaces or is slightly offset.

Fine meshes should be spaced about 1 mean free path apart, unless finer spacing is required to get close to problem surface boundaries. We have tried "smart" meshes in which case we paid attention to the problem surfaces inside the mesh, and "dumb" meshes in which case the mesh was set up with no concern about the underlying geometry. The smart meshes provide better results, but the dumb meshes are generally not too bad. It may not be worth the effort to finely tune the meshes to the underlying geometry.

If the resulting mesh-based weight windows have lots of zeros, then the mesh is probably too fine so that good estimates cannot be made in all the mesh cells. If the resulting mesh-based weight windows have values that vary greatly between adjacent meshes, then the meshes are too coarse. It is difficult to assess the quality of the meshes by looking at the mesh file (WWOUT, WWONE, WWINP); a means of visualizing the mesh values would be helpful.

The rectangular xyz mesh is much more efficient than the cylindrical $rz\theta$ mesh. In the oil well logging benchmark problem with the off-center, non-rotationally symmetric tool, we could not get satisfactory results with the cylindrical mesh. Therefore, we recommend preferential use of the rectangular mesh.

C. PROCEDURE FOR GENERATING WEIGHT WINDOWS

The weight window generator works by keeping track of the total weight passing through a given cell (in optional WWGE time or energy bins) and how much scores. The importance is the scoring weight divided by the total weight, and this is approximately the adjoint solution. The generated windows are the inverse, namely the total weight divided by the scoring weight normalized to the reference cell weight. If the scoring tally is poorly converged, then the generated weight windows will also be poorly converged. If the scoring tally is well converged, then there is probably not much point in generating a new set of weight windows.

We recommend using the weight window generator iteratively. Use a crude guess of the importance function to generate a set of windows, and then use these windows to generate better windows. Generally 2 - 4 generating runs are needed.

For the first weight window generator run we have the following recommendations:

In the first weight window generator run, generate windows on an easy tally. Suppose you want to calculate the response to a detector. In the first generator run, optimize on a simple tally, such as a surface tally, near the detector or in the direction of the detector. This optimization will get you an importance function that gets particles headed towards the detector. Then using this good importance function, you can optimize on the final tallies in the detector in subsequent generator runs. The tally for which you first generate windows should be a tally for which it is easy to get results, and not necessarily the final tally result you want, in order to make the generator problem run quickly.

In the first weight window generator run, use a single energy or time group (WWGE card). If you have many weight window energy or time groups on the WWGE card, then the estimates in each group will be more difficult to obtain and may produce a poor importance function. The weight window generator automatically gives you a single group set of generated windows (WWONE file) whenever you request multiple groups (WWOUT file). If the generated multigroup windows have lots of zeros (no window generator estimate made for the mesh or cell), then use the single group windows in the next iteration. Or you can do a short run with both the single group and multigroup windows and choose whichever gives the better figure-of-merit.

Run the weight window generator long enough to get a 10% - 20% relative error for the reference tally of the generator (1st entry on WWG card.) If you get a lower relative error than

10%, then you are probably better off doing an iteration with the new windows rather than generating them longer. If you get a higher relative error, then the windows may be garbage. If you have a high relative error you can do the following:

1. Run the generating run longer. This choice is usually poor because the importance function is probably not very good and you may never converge to a better relative error.
2. Use a better importance function if the information gained from this run is sufficient to guide you in choosing a better importance function. Unfortunately, coming up with a better choice is usually difficult.
3. Optimize on a simpler tally that is not the one you ultimately want, but gets particles to head towards more important regions.

Once you get better than a 10% error for the tally you are interested in, you can use the windows generated in this calculation and stop iterating further. Or, if it appears that you still cannot achieve the desired accuracy and pass all the statistical checks in a reasonable amount of time, you can continue iterating, using multiple energy or time bins (WWGE card) to get more efficient weight windows in subsequent iterations.

If the windows in subsequent generation run iterations do not change much or do not improve the figure-of-merit much, you've probably generated the optimum windows for your WWGE choices. You should either stop iterating or try finer energy or time bins on your WWGE card.

If the figure-of-merit gets worse in subsequent generator iterations, go back to the generating run with the better figure-of-merit and run it longer (or change the importance function or reference tally) to generate better windows. The windows should improve the figure-of-merit in each subsequent iteration.

If you are using cell-based weight windows, be sure to check the OUTP file table that lists the ratio of generated windows from cell to cell. If the windows in adjacent cells vary by too much, you may need to iterate some more, subdivide your geometry, or change to mesh-based weight windows.

With a good set of windows (less than 10% error on the reference tally in the generating run) you can now safely turn on additional variance reduction schemes such as the exponential transform to further improve problem performance. The exponential transform should not be used with a bad set of weight windows because you may have false convergence. Source energy bias is also better turned on only after the energy-dependent windows indicate the optimum target weights for the source cell energy bias. The same is true for source time bias, biasing of source cells if there are multiple source cells, and other source biases such as directional biasing.

When you have your final set of generated windows, you should consider turning off the generator to save the 20%-40% computational time penalty. Of if you have mesh-based windows, you may consider switching to a cell-based window generator just so the code prints out the adjoint solution for the reference tally as the new generated windows. If low-window values (high importances) are generated near problem boundaries, this may indicate your geometry was truncated and needs to be extended further. If important regions have a zero or high-window values, then these cells may be under sampled. The cell-based windows are not just a good importance function, but a good diagnostic tool as well.

We recommend that once you pass all statistical tests, run for 50% longer and see if you still pass them to ensure the calculation is completely converged.

D. Summary of Recommendations

1. Use mesh-based windows unless the problem geometry is sufficiently subdivided to use cell-based windows.
2. Use the weight window generator iteratively. In the first iteration, generate windows for an easier tally than the one you ultimately want and generally use only the single-group generated windows.
3. Run the weight window generator long enough to get a 10% - 20% relative error for the reference tally of the generator before using those windows in a subsequent run.
4. Once you pass all statistical tests, run 50% longer.

E. Guidelines for Using Weight Windows

Our previous experience with weight windows and this study indicate the following guidelines for use of the weight window variance reduction technique once the windows are generated.

1. WWP Card Entries

There are 6 entries on the WWP card:

WWP W_1 W_2 W_3 W_4 W_5 W_6

with defaults

WWP 5 3 5 0 0 0

These entries are:

W_1 upper weight window bound is W_1 times the lower bound specified on the WWN card.

W_2 When rouletting, restore weight to W_2 times the lower bound specified on the WWN card.

W_3 Never split or roulette more than W_3 for 1.

W_4 Play weight window game at W_4=-1 collision, W_4=1 surfaces, or W_4=0 both (default).

W_5 = 0 Cell-based weight windows (default) =1 Convert importances to cell-based importances = -1 Read cell or mesh based windows from WWINP file.

W_6 = 0 WWE bins are for energy (default) =1 WWE bins are for time.

We see no reason to change the defaults. Whether or not to use mesh-based windows (W_5) is discussed in Section VII.A. Where to play the weight window game (W_4) and when to use $W_5 = 1$ is discussed below.

Weight windows are nearly always more effective than importances. If you use importances (because they are more intuitive), consider converting them to weight windows simply by adding the following WWP card:

WWP 5 3 5 0 W_5

The 5th entry converts the importance to weight windows with a lower weight bound of W_5/I where I is the input importance for each cell. In shielding problems this simple conversion will usually improve efficiency by up to 20%. If w0 is the average source weight, and W_1 is the value of the 1st WWP entry, good values of W_5 are

$$w0/W_1 < W_5 < w0$$

Generally W_5 = .5 w0 or W_5 = .25 w0 are good values.

The weight window game can be played at surfaces, collisions, or both. The surface-only weight window is turned on by W_4 = 1 on the WWP card. The collision-only weight window is turned on by W_4 = -1 on the WWP card. The default is to play the weight window game at both cell surfaces and collisions, W_4 = 0.

Prior to MCNP4C, the surface-only game utilized the weight cutoff game at collisions which was disastrous unless the weight cutoff was chosen sufficiently low. As a result of this study, the surface-only weight window game now uses analog capture by default and does no weight checking if analog capture is turned off. We see no advantage in using surface-only weight windows unless the problem material is nearly purely scattering, in which case the surface-only window saves the effort to check the windows at scatters. However, in a pure scatterer, it may be advantageous to use the exponential transform, in which case the weights should be checked at each collision. With a mesh-based weight window, the surface-only checking may be a disaster since the weights will not be checked in the mesh except at problem surfaces. We therefore recommend against using the surface-only weight window.

The weight window game can also be played at collisions only. Prior to MCNP4C if importances were specified in addition to windows, surface splitting and roulette were played at surfaces if collision-only windows were also specified or the window of the cell being entered was zero. In MCNP4C, surface splitting and roulette is completely turned off if the weight window is turned on. We know of no advantages to using the collision-only window.

We recommend using the default weight-window game at both collisions and surfaces.

<u>2. *Importance Sampling and Weight Cutoff Game.*</u>

Prior to MCNP4C the weight window game was strongly affected by the weight cutoff game and importance splitting at surfaces. If the default weight cutoffs (CUT card) were used, results could be disastrous.

In MCNP4B importance splitting at surfaces occurred for:

1. collision-only windows;
2. whenever the window of the entering cell was zero;
3. inside DXTRAN spheres for cell-based windows only

In MCNP4C importance splitting at surfaces does not occur when weight windows are used.

In both MCNP4B and MCNP4C the DXTRAN weight cutoff game is played inside DXTRAN spheres at collisions for cell-based windows but not for mesh-based windows.

In MCNP4B the weight cutoff game was played with weight windows at collisions in the following circumstances when analog capture was not specified.

1. surface-only windows, but not at surface sources;
2. whenever the window of the collision cell was zero, but not for the secondary particles produced at collisions;
3. for the 2nd and subsequent forced collision particles in a cell if the forced collision parameter is positive and surface-only windows are specified.

In MCNP4C weight windows now follow the following rules:

1. For surface-only windows, analog capture is the default. If the weight cutoff game is specified there is no weight control or cutoff game at collisions.
2. If the window of the collision cell is zero, the weight cutoff game is played for both primary and secondary particles at collisions, but roulette is limited to 1-for-2.
3. For the 2nd and subsequent forced collision particles in a cell if the forced collision parameter is positive and surface-only windows are specified, then no further collisions are forced, and there is no further weight control.

These rules are complicated. In MCNP4B they were inconsistent. They may be stated more simply as follows:

In general, in MCNP4C, the rules are:

1. For zero windows (at a surface entering a zero-window cell or at collisions) the weight cutoff game is played at surfaces and collisions, but roulette is never more severe than 1-for-2. Otherwise, the weight cutoff game is not played.
2. Analog capture is the default for surface-only windows.
3. The DXTRAN weight cutoff game is played inside DXTRAN spheres for cell-based windows only.

MCNP4C will track MCNP4B if analog capture was specified or if the weight cutoff game had a weight so low it was not played. The surface-only weight window is different and significantly better. If the weight cutoff game is not adjusted by the user to be below the lowest weight window, MCNP4C gives good results while MCNP4B has disastrous results with severe roulette games.

Thus, we have the following recommendations for the weight cutoff game. In MCNP4B either all windows had to be nonzero, or analog capture had to be played, or the weight cutoff had to be set below the lowest weight window in the problem. Weight windows needed to be played at both surfaces and collisions, and all importances, if specified, should have been unity. These are still reasonable approaches in MCNP4C, but it is no longer disastrous if the default weight cutoff game is used now that there is a 1-for-2 weight cutoff game roulette limiter in zero window cells and surface-only windows use analog capture by default. Thus, in MCNP4C, the default CUT card is generally sufficient with cell- or mesh-based weight windows; there are no known option combinations that lead to disaster.

VIII. RECOMMENDATIONS FOR FUTURE MCNP DEVELOPMENT

Mesh Visualization: It is presently very difficult to assess the quality of generated mesh-based weight windows. Do the values vary too much from mesh cell to mesh cell indicating poor convergence or too coarse of a mesh? Are there too many zeros (undertimed weight windows), particularly in important parts of the problem? Perhaps a warning or printout could be provided in the OUTP file. The best solution would be a means of plotting the superimposed mesh with the MCNP geometry plotter with a color scale for the mesh values or to be able to have three-dimensional mesh plots.

Smoothing: Perhaps zero windows and large variations in windows from mesh cell to mesh cell could be treated with a smoothing algorithm. We attempted to smooth mesh values manually, but our limited experience was that smoothing is both difficult and potentially ineffective. Any smoothing algorithm should be optimum and carefully assessed.

Mesh Extrapolation: An alternative to smoothing a mesh is to have the code, upon encountering a zero weight window in a mesh, use the last nonzero weight window. Unfortunately, such a scheme would be difficult to implement (was the last nonzero weight window for the same particle or track from the bank?) and would increase the bank size even when mesh-based windows are not used. Also, using the last nonzero window would override the present weight cutoff game (with a 1-for-2 split limiter added in MCNP4C) and not get rid of particles in truly unimportant parts of the problem geometry.

Normalization: In the air-over-ground problem, which had a strong spatial source bias, 100% of the source particles had weights below the windows. Though it is possible to renormalize the mesh by rerunning the generating run with a different source normalization value (3rd entry on the WWG card), it would be far more efficient to be able to renormalize an existing mesh on the subsequent run that uses it. We recommend an additional parameter on the WWP card to renormalize the mesh by a user-specified amount. Then source and other biases could be compensated for by renormalizing the mesh until as many source particles started above the mesh as below.

Automatic Source Bias: In many problems source spatial, energy, directional or time bias is desired. It would be very useful if MCNP could automatically bias the source so that source particles are born inside their weight windows. We presently have no idea how this could be done.

DXTRAN and detector contributions. Presently the DXTRAN contribution card (DXC) and detector contribution card (PDn) are very useful when certain problem regions are unlikely to make significant contributions to DXTRAN or detector tallies. When simplified geometries are used with large cells, which is now made possible by the mesh-based weight windows, the (cell-based) DXC and PD cards are no longer useful because the importance of contributing to the DXTRAN or detector varies too much over the cell. It would be useful if MCNP could automatically play the DXC and PDn games when the mesh-based weight window is used. How could this be done? Let j be the mesh index where the highest DXTRAN or detector score is made. Let k be the mesh index where the source or collision event occurs. Let W_j and W_k be the corresponding weight window lower bounds in mesh cells j and k. Let i be the cell of the collision or source event. Then, if the DXC or PDn entry for cell i is negative, let the DXC/PDn roulette game be played if the DXTRAN or detector pseudoparticle weight (without attenuation)

$$W = W_o * p(\mu) / 2 * \pi * R**2$$

is less than

$$W < W_j/W_k * W_a$$

where W_a is the average weight scoring to the DXTRAN sphere or detector. Roulette could be limited to 1 for 10 or 1 for 100 maximum. Perhaps there is a better algorithm. Any algorithm would require careful assessment.

Testing: The superimposed mesh capability needs to be tested with lattices/repeated structures, criticality problems, and time-dependent weight windows.

Implemented recommendations. As a result of this study, the following features have already been added to MCNP4C:

1. a 1-for-2 splitting limiter for the weight cutoff game in meshes or cells with zero weight windows. The MCNP4B unlimited roulette game frequently caused false convergence unless the weight cutoff was set very low, in which case the

benefits of a weight cutoff game in unimportant regions with zero windows was lost.

2. analog capture is the default when using surface-only weight windows.
3. The PROBID identification is written to WWONE and WWOUT files so that when they are used in subsequent problems as the WWINP file, you can tell which run created the weight windows utilized. For cell-based windows read from a WWINP file, PRINT TABLE 20 is always turned on so that you know which weight windows you are using.
4. The following MCNP4B subtlety has been added back into MCNP4C: When cell-based weight windows are turned on, collided parts of a forced collision play analog capture in DXTRAN spheres if the DXTRAN weight cutoffs are zero.

IX. CONCLUSIONS

A. Utilization of Weight Windows

Whether cell-based weight windows are generated in MCNP4B or MCNP4C or elsewhere, the utilization of them in MCNP4C is comparable to that in MCNP4B. In the fusion problem, MCNP4B was 6% better; in the air-over ground problem, MCNP4C was 5% better; in the oil well problem, MCNP4C was 12% better. These differences are small and may be caused by other new MCNP4C features.

B. Generation of Weight Windows

MCNP4C generates cell-based weight windows more effectively than MCNP4B. In the five problems examined, regardless of where the windows were generated, MCNP4C outperformed MCNP4B by

67% in the skyshine problem

15% in the fusion problem

46% in the class variance reduction problem

16% in the oil well problem.

In the air over ground problem, both MCNP4B and MCNP4C generated windows were comparable in performance only because the source spatial bias hid the relative performance.

C. Mesh-Based Windows Can Outperform Cell-Based Windows

Mesh-based windows can outperform both cell-based importances and cell-based windows. In the skyshine problem, they were 10% better and in the class variance reduction problem, they were 52% better. However, they were only 50% as good in the oil well problem with a rectangular mesh and much worse with a cylindrical mesh. They were comparable in the fusion problem. They were also comparable in the air-over-ground problem whose results were inconclusive because of the source biasing. Perhaps a better choice of mesh would have improved the oil well problem results. Clearly, it is possible to outperform expert-developed cell-based windows with mesh-based windows in many cases.

Of course, it is also possible to do much worse if meshes are chosen improperly, cylindrical rather than rectangular geometry is chosen, inappropriately (oil well problem), and windows are insufficiently converged. The recommendations of Section VIII may make mesh-based windows easier to use, but expert judgement is still required.

D. Subdividing Geometries for Importances Is No Longer Needed

Generally, use of the mesh-based weight windows makes it no longer necessary to subdivide geometries for variance reduction. With sufficient iterations, the mesh-based windows in a simple geometry outperformed expert-devised cell-based windows in the fusion and class problems. Reasonable performance was achieved with mesh-based windows applied to a simple geometry for the other problems.

We believe it is no longer necessary to subdivide geometries extensively for variance reduction because mesh-based weight windows can be used.

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A1: Base Model, Skyshine Problem


```
message:
datapath=/usr/local/codes/data/mc/type1

gamma  ray skyshine experiment  d hollowell 3/90
c cell cards
 1    1  -.001124   -1       +7   -20      #31
 2    1  -.001124   +1  -2  +7   -20
 3    1  -.001124   +2  -3  +7   -20
 4    1  -.001124   +3  -4  +7   -20
 5    1  -.001124   +4  -5  +7   -20
 6    1  -.001124       +5  -6  +7   -20
 7          0           +6:   -42 :  +26
21    1  -.001124   -1       +7   +20
22    1  -.001124   +1  -6  +7   +20  -21
23    1  -.001124       -6  +7   +21  -22
24    1  -.001124       -6  +7   +22  -23
25    1  -.001124       -6  +7   +23  -24
26    1  -.001124       -6  +7   +24  -25
27    1  -.001124       -6  +7   +25  -26
31    0                     +7   +30 -31 -32
40    0                     -7   +42   -31
41    2  -2.6           -6  -7   +31  +40
42    2  -2.6           -6  -40  +31  +41
43    2  -2.6           -6  -41  +31  +42

 1      so      3000.                   $  a concentric spherical shell
 2      so     13000.                   $  a concentric spherical shell
 3      so     35000.                   $  a concentric spherical shell
 4      so     55000.                   $  a concentric spherical shell
 5      so     75000.                   $  a concentric spherical shell
 6      so    100000.                   $  an outer boundary to the problem
 7      pz      0.                      $  the ground/air interface
20      kz       -60.   20.516   +1    $  cone with xy plane radius 217cm
21      kz      -665.   20.516   +1    $  cone with xy plane radius 3000cm
22      kz     -2882.   20.516   +1    $  cone with xy plane radius 13000cm
23      kz     -7759.   20.516   +1    $  cone with xy plane radius 35000cm
24      kz    -12193.   20.516   +1    $  cone with xy plane radius 55000cm
25      kz    -16627.   20.516   +1    $  cone with xy plane radius 75000cm
26      kz    -22169.   20.516   +1    $  cone with xy plane radius 100000cm
c       cz  125.                        $  columation silo inner diameter
30      cz  117.75                      $  columation silo inner diameter
c       cz  129.41                      $  columation silo inner diameter
31      cz  217.5                       $  columation silo outer diameter
32      pz  229.                        $  plane at the top of the silo
40      pz   -3.                        $  underground plane for photon imp.
41      pz   -6.                        $  underground plane for photon imp.
42      pz   -9.                        $  underground plane for photon imp.

c       the importances have been found, more or less, by trial and error
 imp:p      1  1.7  2  3.3  6.7  17.  0
          10. 2.0  3  7.0  27.  100.  400.
             0.    0.   2.       4.   6.
c
c     material #1 is dry air, and #2 is dirt
c
m1       6012.02p  .000125     7014.02p   .686910
         8016.02p  .301248    18040.02p   .011717
m2       8016.02p   .46133    14028.02p    .28038
        13027.02p  .08272     26056.02p    .05598
        20040.02p  .04126     11023.02p    .02346
c
 mode p
c
c
 sdef pos = 0. 0. 198.  erg = d1
```

```
 sc1  for cobalt 60 photons
 si1  1  1.173  1.322
 sp1  d  1.     1.
c
c
f75z:p   100. 70000.  99.
fm75     4.541e-05  1 -5 -6
c
c          the low energy photons are not worth the bother
c          since they are below the detector response function cutoff
cut:p      1.e+33 0.001
c
c  turn off brem
phys:p 2j 1
nps     1e5
prdmp 3j 2
print
c wwg 75 1 0
c wwp:p  5 3 5 0 -1
c mesh  ref 0 0 198
c     origin 0.001 0.001 -9.001
c     axs 0 0 1
c     vec 1 0 0
c     geom cyl
c     imesh  117 217 40000  80000 120000
c     iints   5 4r
c     jmesh   9 238 40000  80000  120000
c     jints   5 4r
c     kmesh   .5  1
c     kints   1 1r
```

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02:47:27

A2: Variations from Base Model, Skyshine Problem


```
gr1a differences
---------xxxxxxxx------------
gr1b differences
83c83
< c wwg 75 1 0
---
> wwg 75 1 0
---------xxxxxxxx------------
gr2a differences
---------xxxxxxxx------------
gr2b differences
80c80
< nps     1e5
---
> nps     1e5  $ used to be 3e6
83c83
< c wwg 75 1 0
---
> wwg 75 1 0
---------xxxxxxxx------------
gr3a differences
80c80
< nps     1e5
---
> nps     5e4
83c83
< c wwg 75 1 0
---
> c wwg 75 0 0
86,96c86,95
< c     origin 0.001 0.001 -9.001
< c     axs 0 0 1
< c     vec 1 0 0
< c     geom cyl
< c     imesh  117 217 40000  80000 120000
< c     iints   5 4r
< c     jmesh   9 238 40000  80000  120000
< c     jints   5 4r
< c     kmesh   .5  1
< c     kints   1 1r
<
---
> c       origin 0.001 0.001 -9.001
> c       axs 0 0 1
> c       vec 1 0 0
> c       geom cyl
> c       imesh  117 217 40000  80000 120000
> c       iints   5 4r
> c       jmesh   9 238 40000  80000  120000
> c       jints   5 4r
> c       kmesh   .5  1
> c       kints   1 1r
---------xxxxxxxx------------
gr3b differences
80c80
< nps     1e5
---
> nps     5e4
83c83
< c wwg 75 1 0
---
> wwg 75 0 0
85,96c85,95
< c mesh  ref 0 0 198
< c     origin 0.001 0.001 -9.001
< c     axs 0 0 1
< c     vec 1 0 0
< c     geom cyl
< c     imesh  117 217 40000  80000 120000
< c     iints   5 4r
< c     jmesh   9 238 40000  80000  120000
< c     jints   5 4r
< c     kmesh   .5  1
< c     kints   1 1r
<
---
> mesh  ref 0 0 198
>        origin 0.001 0.001 -9.001
>        axs 0 0 1
>        vec 1 0 0
>        geom cyl
>        imesh  117 217 40000  80000 120000
>        iints   5 4r
>        jmesh   9 238 40000  80000  120000
>        jints   5 4r
>        kmesh   .5  1
>        kints   1 1r
---------xxxxxxxx------------
gr4a differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.  2.       4.   6.
---
>  imp:p      1  5r  0
>           1 6r
>              0.     0.  1 2r
80c80
< nps     1e5
---
> nps     5e4
---------xxxxxxxx------------
gr4b differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.  2.       4.   6.
---
>  imp:p      1  5r  0
>           1 6r
>              0.     0.  1 2r
80c80
< nps     1e5
---
> nps     5e4
83c83
< c wwg 75 1 0
---
> wwg 75 0 0
85,95c85,95
< c mesh  ref 0 0 198
< c     origin 0.001 0.001 -9.001
< c     axs 0 0 1
< c     vec 1 0 0
< c     geom cyl
< c     imesh  117 217 40000  80000 120000
< c     iints   5 4r
< c     jmesh   9 238 40000  80000  120000
< c     jints   5 4r
< c     kmesh   .5  1
```

A2: Variations from Base Model, Skyshine Problem


```
< c     kints   1 1r
---
> mesh  ref 0 0 198
>        origin 0.001 0.001 -9.001
>        axs 0 0 1
>        vec 1 0 0
>        geom cyl
>        imesh  117 217 40000  80000 120000
>        iints   5 4r
>        jmesh   9 238 40000  80000  120000
>        jints   5 4r
>        kmesh   .5  1
>        kints   1 1r
---------xxxxxxxx------------
wwr14b differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.   2.       4.   6.
---
> c imp:p      1  1.7  2  3.3  6.7  17.  0
> c          10. 2.0  3  7.0  27.  100.  400.
> c             0.     0.   2.       4.   6.
76c76
< cut:p      1.e+33 0.001
---
> cut:p      1.e+33 0.001 -1e-5
80c80
< nps     1e5
---
> nps     1.2e7
84c84
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5
96,97c96,101
<
<
---
> c  ww's from gr1be go here
> wwe:p  1.0000E+02
> wwn1:p   5.0000E-01  1.8417E-01  1.7790E-01  1.5298E-01  1.7079E-01
>           6.4379E-01 -1.0000E+00  2.1127E+00  1.1781E-01  1.1467E-01
>           7.2320E-02  2.2348E-02  8.1732E-03  1.3297E-01 -1.0000E+00
>          -1.0000E+00  4.0821E-01  2.2190E+00  5.0570E+00
---------xxxxxxxx------------
wwr14c differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.   2.       4.   6.
---
> c imp:p      1  1.7  2  3.3  6.7  17.  0
> c          10. 2.0  3  7.0  27.  100.  400.
> c             0.     0.   2.       4.   6.
76c76
< cut:p      1.e+33 0.001
---
> cut:p      1.e+33 0.001 -1e-5
80c80
< nps     1e5
---
> nps     1.2e7
84c84
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
wwr24b differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.   2.       4.   6.
---
> c imp:p      1  1.7  2  3.3  6.7  17.  0
> c          10. 2.0  3  7.0  27.  100.  400.
> c             0.     0.   2.       4.   6.
76c76
< cut:p      1.e+33 0.001
---
> cut:p      1.e+33 0.001 -1e-5
80c80
< nps     1e5
---
> nps     1.2e7
84c84
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5
96,97c96,101
<
<
---
> c     4b ww's from gr2bo go here
> wwe:p  1.0000E+02
> wwn1:p   5.0000E-01  9.5659E-01  8.5999E-01  7.0531E-01  8.5534E-01
>           1.0203E+00 -1.0000E+00  3.0769E+00  2.9439E-01  2.8199E-01
>           1.7866E-01  5.9022E-02  2.3745E-02  1.6293E-01 -1.0000E+00
>          -1.0000E+00  1.0593E+00  6.4326E+00  8.1144E+00
\ No newline at end of file
---------xxxxxxxx------------
wwr24c differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<           10. 2.0  3  7.0  27.  100.  400.
<              0.     0.   2.       4.   6.
---
> c imp:p      1  1.7  2  3.3  6.7  17.  0
> c          10. 2.0  3  7.0  27.  100.  400.
> c             0.     0.   2.       4.   6.
76c76
< cut:p      1.e+33 0.001
---
> cut:p      1.e+33 0.001 -1e-5
80c80
< nps     1e5
---
> nps     1.2e7
84c84
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
wwr3 differences
76c76
< cut:p      1.e+33 0.001
---
> cut:p      1.e+33 0.001  $ just a checl-1e-5
84c84
< c wwp:p  5 3 5 0 -1
```

```
---
> wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
wwr4 differences
50,52c50,52
<  imp:p      1  1.7  2  3.3  6.7  17.  0
<            10. 2.0  3  7.0  27.  100.  400.
<               0.     0.   2.       4.   6.
---
>  imp:p      1  5r  0
>            1 6r
>               0.     0.   1 2r
84c84
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
```

Table A3: Explanation of Runs Performed in Assessment

Run	Explanation	Code Run
Gr1a	Expert importances, no wwg, no ww used.	MCNP4C
Gr1b	Same as gr1a, but cell-based ww's generated.	MCNP4C
Gr2a	Expert importances, no wwg, no ww used.	MCNP4B
Gr2b	Same as gr2a, but cell-based ww's generated.	MCNP4B
Gr3a	Expert importances, complex geometry, no wwg, no ww used.	MCNP4C
Gr3b	Same as gr3b, but mesh-based ww's generated.	MCNP4C
Gr4a	Binary importances, complex geometry, no wwg, no ww used.	MCNP4C
Gr4b	Same as gr4a, but mesh-based ww's generated.	MCNP4C
Gr5a	Binary importances, simple geometry, no wwg, no ww used.	MCNP4C
Gr5b	Same as gr5a, but mesh-based ww's generated.	MCNP4C
Wwr14b	Applies cbww generated in gr1b	MCNP4B
Wwr14C	Applies cbww generated in gr1b	MCNP4C
Wwr24b	Applies cbww generated in gr2b	MCNP4B
Wwr24C	Applies cbww generated in gr2b	MCNP4C
WWr3	Applies mbww generated in gr3b	MCNP4C
Wwr4	Applies mbww generated in gr4b	MCNP4C
Wwr5	Applies mbww generated in gr5b	MCNP4C

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A4: Simplified Model, Skyshine Problem -gr5b

```
message:
datapath=/usr/local/codes/data/mc/type1

gamma  ray skyshine experiment  d hollowell 3/90
c new cell description using simplified geometry:
1     1  -.001124   +7 -6  #31        $  air around source
2     2  -2.6       -7 +42 -26  #3    $ dirt down below
3     0             -7 +42 -31        $ void under source
7     0              +6:   -42 :  +26  $ ROW
31    0              +7   +30 -31 -32  $ source silo

 6     so    100000.                 $  an outer boundary to the problem
 7     pz     0.                     $  the ground/air interface
26     kz    -22169.   20.516   +1   $  cone with xy plane radius 100000cm
30     cz  117.75                    $  columation silo inner diameter
31     cz  217.5                     $  columation silo outer diameter
32     pz  229.                      $  plane at the top of the silo
42     pz   -9.                      $  underground plane for photon imp.

c        the importances have been found, more or less, by trial and error
imp:p    1  1  0  0  0
c
c     material #1 is dry air, and #2 is dirt
c
m1   6012.02p .000125 7014.02p .686910 8016.02p .301248 18040.02p .011717
m2     8016.02p  .46133     14028.02p  .28038     13027.02p  .08272
     26056.02p  .05598     20040.02p  .04126     11023.02p  .02346
c
 mode p
c
c
 sdef pos = 0. 0. 198.  erg = d1
 sc1  for cobalt 60 photons
 si1  1  1.173  1.322
 sp1  d  1.     1.
c
c        the ring detectors are set up to give dose, which will
c         later be understood in terms of dose/source strength
c
f75z:p   100. 70000.  99.
fm75     4.541e-05  1 -5 -6
c
c          the low energy photons are not worth the bother
c          since they are below the detector response function cutoff
cut:p      1.e+33 0.001
c
nps     5e4
print
phys:p 2j 1
c wwp:p 5 3 5 0 -1
wwg 75 0 0
mesh  ref 0 0 198
      origin 0.001 0.001 -9.001
      axs 0 0 1
      vec 1 0 0
      geom cyl
      imesh  117 217 40000  80000 120000
      iints   5 4r
      jmesh   9 238 40000  80000  120000
      jints   5 4r
      kmesh   .5  1
      kints   1 1r
```

B1: Base Model in Fusion Problem


```
message:
datapath=/usr/local/codes/data/mc/type1

fusion spectra problem
   1 1 7.506e-2 1 -2 10 -21 -22 29 $ floor cell $
   2 1 7.506e-2 7 -8 10 -21 -22 29 $ ceiling cell $
   3 1 7.506e-2 2 -7 10 -21 -22 23 $ left wall cell $
   4 1 7.506e-2 2 -7 10 -21 -28 29 $ right wall cell $
   5 1 7.506e-2 2 -7 20 -21 -23 28 $ front wall cell $
   6 2 4.614e-5 2 -4 10 -11 -23 32 $ left door cell $
   7 2 4.614e-5 2 -4 10 -11 -33 34 $ middle door cell $
   8 2 4.614e-5 2 -4 10 -11 -35 28 $ right door cell $
   9 1 7.506e-2 4 -7 10 -11 -23 32 $ concrete above left door $
  10 1 7.506e-2 4 -7 10 -11 -33 34 $ concrete above middle door
  11 1 7.506e-2 4 -7 10 -11 -35 28 $ concrete above right door
  12 1 7.506e-2 2 -4 10 -11 -32 33 $ concrete cell betwn 1/m doors
  13 1 7.506e-2 2 -4 10 -11 -34 35 $ concrete cell betwn m/r doors
  14 1 7.506e-2 4 -7 10 -11 -32 33 $ wall concrete above cell 12
  15 1 7.506e-2 4 -7 10 -11 -34 35 $ wall concrete above cell 13
  16 2 4.614e-5 2 -4 11 -12 -23 32 $ air cell btwn left door & block back
  17 2 4.614e-5 2 -4 11 -12 -33 34 $ air cell btwn middle door & block back
  18 2 4.614e-5 2 -4 11 -12 -35 28 $ air cell btwn right door & block back
  19 2 4.614e-5 2 -4 11 -12 -32 33 $ air cell btwn cell12 door & block back
  20 2 4.614e-5 2 -4 11 -12 -34 35 $ air cell btwn cell13 door & block back
  21 2 4.614e-5 4 -7 11 -12 -23 32 $ air cell btwn cell 9 door & block back
  22 2 4.614e-5 4 -7 11 -12 -33 34 $ air cell btwn cell10 door & block back
  23 2 4.614e-5 4 -7 11 -12 -35 28 $ air cell btwn cell11 door & block back
  24 2 4.614e-5 4 -7 11 -12 -32 33 $ air cell btwn cell14 door & block back
  25 2 4.614e-5 4 -7 11 -12 -34 35 $ air cell btwn cell15 door & block back
  26 2 4.614e-5 6 -7 12 -15 -23 32 $ cells 26-35: air cells abv the block
  27 2 4.614e-5 6 -7 12 -15 -32 33
  28 2 4.614e-5 6 -7 12 -15 -33 34
  29 2 4.614e-5 6 -7 12 -15 -34 35
  30 2 4.614e-5 6 -7 12 -15 -35 28
  31 2 4.614e-5 6 -7 15 -17 -23 32
  32 2 4.614e-5 6 -7 15 -17 -32 33
  33 2 4.614e-5 6 -7 15 -17 -33 34
  34 2 4.614e-5 6 -7 15 -17 -34 35
  35 2 4.614e-5 6 -7 15 -17 -35 28
  36 2 4.614e-5 2 -3 12 -15 -23 32 $ cells 36-47: air cells left of block
  37 2 4.614e-5 2 -3 12 -15 -32 24
  38 2 4.614e-5 2 -3 15 -17 -23 32
  39 2 4.614e-5 2 -3 15 -17 -32 24
  40 2 4.614e-5 3 -4 12 -15 -23 32
  41 2 4.614e-5 3 -4 12 -15 -32 24
  42 2 4.614e-5 3 -4 15 -17 -23 32
  43 2 4.614e-5 3 -4 15 -17 -32 24
  44 2 4.614e-5 4 -6 12 -15 -23 32
  45 2 4.614e-5 4 -6 12 -15 -32 24
  46 2 4.614e-5 4 -6 15 -17 -23 32
  47 2 4.614e-5 4 -6 15 -17 -32 24
  48 2 4.614e-5 2 -3 12 -15 -27 35 $ cells 48-59: air cells right of block
  49 2 4.614e-5 2 -3 12 -15 -35 28
  50 2 4.614e-5 2 -3 15 -17 -27 35
  51 2 4.614e-5 2 -3 15 -17 -35 28
  52 2 4.614e-5 3 -4 12 -15 -27 35
  53 2 4.614e-5 3 -4 12 -15 -35 28
  54 2 4.614e-5 3 -4 15 -17 -27 35
  55 2 4.614e-5 3 -4 15 -17 -35 28
  56 2 4.614e-5 4 -6 12 -15 -27 35
  57 2 4.614e-5 4 -6 12 -15 -35 28
  58 2 4.614e-5 4 -6 15 -17 -27 35
  59 2 4.614e-5 4 -6 15 -17 -35 28
  60 2 4.614e-5 6 -7 17 -40 -23 32 $ cells 60-69: air cells abv thermal shield
  61 2 4.614e-5 6 -7 17 -40 -32 33
  62 2 4.614e-5 6 -7 17 -40 -33 34
  63 2 4.614e-5 6 -7 17 -40 -34 35
  64 2 4.614e-5 6 -7 17 -40 -35 28
  65 2 4.614e-5 6 -7 40 -20 -23 32
  66 2 4.614e-5 6 -7 40 -20 -32 33
  67 2 4.614e-5 6 -7 40 -20 -33 34
  68 2 4.614e-5 6 -7 40 -20 -34 35
  69 2 4.614e-5 6 -7 40 -20 -35 28
  70 2 4.614e-5 2 -3 17 -40 -23 32 $ cells 70-81: air cells left of thermal shield
  71 2 4.614e-5 2 -3 17 -40 -32 24
  72 2 4.614e-5 2 -3 40 -20 -23 32
  73 2 4.614e-5 2 -3 40 -20 -32 24
  74 2 4.614e-5 3 -4 17 -40 -23 32
  75 2 4.614e-5 3 -4 17 -40 -32 24
  76 2 4.614e-5 3 -4 40 -20 -23 32
  77 2 4.614e-5 3 -4 40 -20 -32 24
  78 2 4.614e-5 4 -6 17 -40 -23 32
  79 2 4.614e-5 4 -6 17 -40 -32 24
  80 2 4.614e-5 4 -6 40 -20 -23 32
  81 2 4.614e-5 4 -6 40 -20 -32 24
  82 2 4.614e-5 2 -3 17 -40 -27 35 $ cells 82-93: air cells right of thermal shield
  83 2 4.614e-5 2 -3 17 -40 -35 28
  84 2 4.614e-5 2 -3 40 -20 -27 35
  85 2 4.614e-5 2 -3 40 -20 -35 28
  86 2 4.614e-5 3 -4 17 -40 -27 35
  87 2 4.614e-5 3 -4 17 -40 -35 28
  88 2 4.614e-5 3 -4 40 -20 -27 35
  89 2 4.614e-5 3 -4 40 -20 -35 28
  90 2 4.614e-5 4 -6 17 -40 -27 35
  91 2 4.614e-5 4 -6 17 -40 -35 28
  92 2 4.614e-5 4 -6 40 -20 -27 35
  93 2 4.614e-5 4 -6 40 -20 -35 28
  94 4 8.75e-2 3 -5 -25 26 15 -41 $ cells 94-103: air and shield cells inside
  95 4 8.75e-2 3 -5 -25 26 41 -42 $ the concrete box
  96 4 8.75e-2 3 -5 -25 26 42 -43
  97 4 8.75e-2 3 -5 -25 26 43 -44
  98 6 .11150 3 -5 -25 26 44 -45
  99 4 8.75e-2 3 -5 -25 26 45 -46
 100 6 .11150 3 -5 -25 26 46 -47
 101 4 8.75e-2 3 -5 -25 26 47 -48
1021 2 4.614e-5 3 -5 -25 26 461 -462
1022 2 4.614e-5 3 -5 -25 26 462 -463
1023 2 4.614e-5 3 -5 -25 26 463 -49
 102 2 4.614e-5 3 -5 -25 26 48 -461
 103 2 4.614e-5 3 -5 -25 26 49 -17
 104 2 4.614e-5 3 -9 -25 26 17 -18 $ air cell btwn inner box and thermal shield
 105 2 4.614e-5 3 -9 -30 31 19 -40 $ cells 105-106: air cells fitting between
 106 2 4.614e-5 3 -9 -30 31 40 -20 $ the thermal shield and the front wall
 107 2 4.614e-5 9 -6 -24 27 17 -18 $ cells 107-109: air cells between the upper
 108 2 4.614e-5 9 -6 -24 27 18 -40 $ horizontal edge of the concrete block
 109 2 4.614e-5 9 -6 -24 27 40 -20 $ and the front wall
 110 2 4.614e-5 2 -3 -24 27 17 -18 $ cells 110-112: air cells between the
 111 2 4.614e-5 2 -3 -24 27 18 -40 $ lower horizontal edge of the concrete
 112 2 4.614e-5 2 -3 -24 27 40 -20 $ box  and the front wall
 113 2 4.614e-5 3 -9 -24 25 17 -18 $ cells 113-118: air cells between the
 114 2 4.614e-5 3 -9 -24 25 18 -40 $ right and left vertical concrete box
 115 2 4.614e-5 3 -9 -24 25 40 -20 $ walls and the front wall
 116 2 4.614e-5 3 -9 -26 27 17 -18
 117 2 4.614e-5 3 -9 -26 27 18 -40
 118 2 4.614e-5 3 -9 -26 27 40 -20
 119 0 -36 12 -13 $ vacuum inside beamline
 120 0 -36 13 -14 $ vacuum inside iron can
 121 0 14 -15 -38 $ vacuum inside iron pipe
 122 3 8.48e-2 36 -37 12 -13 $ beamline
 123 3 8.48e-2 36 -39 13 -14 $ iron can
```

```
 124 3 8.48e-2 38 -39 14 -15 $ iron pipe
 125 5 1.1139e-1 37 -39 12 -13
 126 1 7.506e-2 5 -6 12 -15 -24 33 $ cells 126-134: concrete box top cells
 127 1 7.506e-2 5 -6 12 -15 -33 34
 128 1 7.506e-2 5 -6 12 -15 -34 27
 129 1 7.506e-2 5 -6 15 -45 -24 33
 130 1 7.506e-2 5 -6 15 -45 -33 34
 131 1 7.506e-2 5 -6 15 -45 -34 27
 132 1 7.506e-2 5 -6 45 -17 -24 33
 133 1 7.506e-2 5 -6 45 -17 -33 34
 134 1 7.506e-2 5 -6 45 -17 -34 27
 135 1 7.506e-2 2 -3 12 -15 -24 33 $ cells 135-143: cncr box bottom cells
 136 1 7.506e-2 2 -3 12 -15 -33 34
 137 1 7.506e-2 2 -3 12 -15 -34 27
 138 1 7.506e-2 2 -3 15 -45 -24 33
 139 1 7.506e-2 2 -3 15 -45 -33 34
 140 1 7.506e-2 2 -3 15 -45 -34 27
 141 1 7.506e-2 2 -3 45 -17 -24 33
 142 1 7.506e-2 2 -3 45 -17 -33 34
 143 1 7.506e-2 2 -3 45 -17 -34 27
 144 1 7.506e-2 -24 25 3 -50 12 -15 $ cells 144-149: concrete box left
 145 1 7.506e-2 -24 25 3 -50 15 -45 $ vertical wall cells
 146 1 7.506e-2 -24 25 3 -50 45 -17
 147 1 7.506e-2 -24 25 50 -5 12 -15
 148 1 7.506e-2 -24 25 50 -5 15 -45
 149 1 7.506e-2 -24 25 50 -5 45 -17
 150 1 7.506e-2 -26 27 3 -50 12 -15 $ cells 150-155: concrete box right
 151 1 7.506e-2 -26 27 3 -50 15 -45 $ vertical wall cells
 152 1 7.506e-2 -26 27 3 -50 45 -17
 153 1 7.506e-2 -26 27 50 -5 12 -15
 154 1 7.506e-2 -26 27 50 -5 15 -45
 155 1 7.506e-2 -26 27 50 -5 45 -17
 156 1 7.506e-2 3 -5 -25 26 39 12 -51 $ cells 156-164: inner concrete box cells
 157 1 7.506e-2 3 -5 -25 26 39 51 -52
 158 1 7.506e-2 3 -5 -25 26 39 52 -53
 159 1 7.506e-2 3 -5 -25 26 39 53 -54
 160 1 7.506e-2 3 -5 -25 26 39 54 -55
 161 1 7.506e-2 3 -5 -25 26 39 55 -56
 162 1 7.506e-2 3 -5 -25 26 39 56 -57
 163 1 7.506e-2 3 -5 -25 26 39 57 -58
 164 1 7.506e-2 3 -5 -25 26 39 58 -15
c      165 2 4.614e-5 9 -5 -25 26 18 -40 $ cells 165-170: air cells centered
c      166 2 4.614e-5 9 -5 -25 26 40 -20 $ around the thermal shield
 167 2 4.614e-5 -25 30 3 -9 18 -40
 168 2 4.614e-5 -25 30 3 -9 40 -20
 169 2 4.614e-5 -31 26 3 -9 18 -40
 170 2 4.614e-5 -31 26 3 -9 40 -20
 171 4 8.75e-2 18 -19 3 -9 -30 31 $ thermal shield
 172 0 -1  $ void cell below the concrete room
 173 0  8 $ void cell above the concrete room
 174 0  1 -8 -22 29 -10 $ void cell behind the rear wall
 175 0  1 -8 -22 29 21  $ void cell in front of the front wall
 176 0  1 -8 22 $ void cell left of the room
 177 0  1 -8 -29 $ void cell right of the room

   1 pz -91.44
   2 pz 0 $ upper floor plane
   3 pz 81.2 $ inner box bottom/lower thermal shield edge
   4 pz 218.4 $ door upper edge
   5 pz 253.92 $ inner box top
   6 pz 317.50 $ concrete box top
   7 pz 495.30 $ ceiling plane (lower)
   8 pz 586.74 $ ceiling plane (upper)
   9 pz 233.60 $ upper thermal shield edge
  10 py -29.21 $ rear wall plane (rear)
  11 py 0 $ rear wall plane (front)
  12 py 160.02 $ rear of concrete box
  13 py 208.28 $ end of paraffin
  14 py 225.56 $ rear edge of iron can
  15 py 253.06 $ end of iron pipe/rear of inner box
  16 py 232.02 $ plane of target
  17 py 353.06 $ front of concrete box
  18 py 436.52 $ front of thermal shield
  19 py 441.60 $ rear of thermal shield
  20 py 570.20 $ front wall plane (inside)
  21 py 661.64 $ front wall plane (outside)
  22 px 91.44  $ left wall plane (outside)
  23 px 0     $ left wall plane (inside)
  24 px -200.66 $ left side of concrete box
  25 px -278.76 $ left side of inner box
  26 px -434.97 $ right side of inner box
  27 px -513.08 $ right side of concrete box
  28 px -716.28 $ right wall plane (inside)
  29 px -807.72 $ right wall plane (outside)
  30 px -280.66 $ left edge of thermal shield
  31 px -433.06 $ right edge of thermal shield
  32 px -114.3  $ right edge of left door
  33 px -300.99 $ left edge of middle door
  34 px -415.29 $ right edge of middle door
  35 px -601.98 $ left edge of right door
  36 c/y -356.87 157.4 4.5   $ beamline inner surface
  37 c/y -356.87 157.4 5.0   $ beamline outer surface
  38 c/y -356.87 157.4 8.87  $ iron pipe inner surface
  39 c/y -356.87 157.4 16.37 $ iron pipe outer surface
  40 py 470
  41 py 263.06
  42 py 273.06
  43 py 283.54
  44 py 288.62
  45 py 293.70
  46 py 298.78
  47 py 303.86
  48 py 308.94
 461 py 313.06
 462 py 323.06
 463 py 333.06
  49 py 343.06
  50 pz 160
  51 py 170
  52 py 180
  53 py 190
  54 py 200
  55 py 210
  56 py 220
  57 py 230
  58 py 240

mode n
wwp:n 4 3 2
wwe:n  1.0000e+02
wwn1:n   3.2446e-02  7.8625e-03  2.5425e-02  1.7255e-02  6.0036e-03
          7.7608e-02  3.9481e-01  1.0301e-02  3.5103e-02  4.6676e-02
          5.0000e+00  4.6969e-02  2.0462e-02  3.5945e-02  1.5961e-01
          1.4453e-02  1.4230e-01  2.1147e-02  3.0946e-02  3.2175e-02
          1.7738e-02  1.8876e-02  3.9898e-02  1.5179e-02  2.6615e-02
          3.6745e-03  8.6901e-03  1.2525e-02  1.5171e-02  2.0444e-02
          6.1477e-03  3.5162e-03  3.9786e-03  1.2553e-02  8.5232e-03
          4.4977e-03  8.2814e-03  3.8399e-03  4.2528e-03  5.9635e-03
          7.7350e-03  5.1349e-03  5.9786e-03  1.3009e-02  1.1947e-02
          8.2556e-03  8.4287e-03  8.0848e-03  1.3831e-02  4.0587e-03
```

```
          4.9501e-03  1.1265e-02  1.1909e-02  6.9351e-03  9.2351e-03
          8.5290e-03  1.0439e-02  2.6011e-05  1.1591e-02  7.3075e-03
          2.2030e-03  2.3839e-03  5.7589e-03  9.0534e-03  9.4602e-03
          3.6748e-03  1.9666e-03  3.0570e-03  2.0990e-03  3.9418e-03
          2.9593e-03  4.5857e-03  1.2167e-03  2.7485e-03  2.4278e-03
          1.5232e-03  1.7544e-03  4.3403e-03  1.7663e-03  2.6624e-03
          3.5265e-03  3.2728e-03  2.1006e-03  3.9924e-03  2.6043e-05
          2.1373e-03  2.5724e-03  1.2843e-03  1.0302e-03  1.4356e-03
          1.2100e-03  1.1058e-03  7.0201e-04  3.3391e-01  1.0928e-01
          3.4995e-02  1.0450e-02  5.5611e-03  1.7142e-03  9.6638e-04
          4.9823e-04  8.1812e-04  7.4174e-04  6.6202e-04  8.4147e-04
          5.8902e-04  6.0071e-04  3.2920e-04  8.1447e-04  1.0684e-03
          8.0835e-04  1.3830e-03  1.3101e-03  1.2927e-03  1.5245e-03
          7.1450e-04  8.6551e-04  8.4362e-04  9.6889e-04  9.2964e-04
          1.6216e-03  3.0052e+00  4.4974e+00  4.9798e-01  2.7601e+00
          1.0000e+01  1.0779e+00  5.0000e+00  7.0750e-03  2.4874e-02
          3.7824e-02  5.4701e-03  4.2745e+00  5.0000e+00  1.5644e-03
          1.6395e-03  7.1571e-07  9.9881e-02  1.5411e+00  1.2582e-01
          1.2729e-02  5.0612e-02  8.0674e-02  5.7957e-04  1.2393e-03
          2.9755e-03  1.9004e-01  1.4316e-01  6.2365e-04  2.6084e-01
          2.0931e-01  7.5104e-04  3.2267e+00  1.9934e-01  1.9722e-03
          2.0724e-01  6.8896e-02  2.0353e-03  3.9201e-01  1.2993e+00
          2.6799e+00  5.0000e+00  1.0000e+01  1.0000e+01  1.0000e+01
          5.0000e+00  1.6933e+00  2.9015e-04  3.4640e-04  5.7251e-04
          7.5752e-04  3.1696e-04 -1.0000e+00 -1.0000e+00 -1.0000e+00
         -1.0000e+00 -1.0000e+00 -1.0000e+00
sdef pos=-356.87 232.02 157.4 dir=d1 erg=fdir=d2 rad=d3 vec=0 1 0
     sur=16
si1  a  -1.0000 -.99619 -.98481 -.96593 -.93969
        -.90631 -.86603 -.81915 -.76604 -.70711
        -.64279 -.57358 -.50000 -.42262 -.34202
        -.25882 -.17365 -.08716  .00000  .08716
         .17365  .25882  .34202  .42262  .50000
         .57358  .64279  .70711  .76604  .81915
         .86603  .90631  .93969  .96593  .98481
         .99619  1.0000
sp1      .874 .874 .875 .876 .877
         .879 .882 .884 .888 .891
         .895 .899 .904 .909 .914
         .919 .924 .930 .935 .941
         .946 .952 .957 .962 .967
         .972 .976 .981 .985 .988
         .991 .994 .996 .998 .999
         1.0 1.0
ds2  q  -.99619 180 -.98481 175 -.96593 170 -.93962 165 -.90631 160
        -.86603 155 -.81915 150 -.76604 145 -.70711 140 -.64279 135
        -.57358 130 -.50000 125 -.42262 120 -.34202 115 -.25882 110
        -.17365 105 -.08716 100  0.0000 95   .08716 90   .17365 85
         .25882 80   .34202 75   .42262 70   .50000 65   .57358 60
         .64279 55   .70711 50   .76604 45   .81915 40   .86603 35
         .90631 30   .93969 25   .96593 20   .98481 15   .99619 10
         1.0000 5
si3  h 0 .64
sp3  d -21 1
si5  h 15.106 15.110
sp5  d 0 1
si10 h 15.095 15.106
sp10 d 0 1
si15 h 15.075 15.095
sp15 d 0 1
si20 h 15.049 15.075
sp20 d 0 1
si25 h 15.015 15.049
sp25 d 0 1
si30 h 14.974 15.015
sp30 d 0 1
si35 h 14.927 14.974
sp35 d 0 1
si40 h 14.873 14.927
sp40 d 0 1
si45 h 14.814 14.873
sp45 d 0 1
si50 h 14.750 14.814
sp50 d 0 1
si55 h 14.681 14.750
sp55 d 0 1
si60 h 14.608 14.681
sp60 d 0 1
si65 h 14.532 14.608
sp65 d 0 1
si70 h 14.453 14.532
sp70 d 0 1
si75 h 14.372 14.453
sp75 d 0 1
si80 h 14.289 14.372
sp80 d 0 1
si85 h 14.206 14.289
sp85 d 0 1
si90 h 14.123 14.206
sp90 d 0 1
si95 h 14.040 14.123
sp95 d 0 1
si100 h 13.958 14.040
sp100 d 0 1
si105 h 13.878 13.958
sp105 d 0 1
si110 h 13.800 13.878
sp110 d 0 1
si115 h 13.725 13.800
sp115 d 0 1
si120 h 13.654 13.725
sp120 d 0 1
si125 h 13.586 13.654
sp125 d 0 1
si130 h 13.522 13.586
sp130 d 0 1
si135 h 13.464 13.522
sp135 d 0 1
si140 h 13.410 13.464
sp140 d 0 1
si145 h 13.362 13.410
sp145 d 0 1
si150 h 13.320 13.362
sp150 d 0 1
si155 h 13.284 13.320
sp155 d 0 1
si160 h 13.254 13.284
sp160 d 0 1
si165 h 13.230 13.254
sp165 d 0 1
si170 h 13.214 13.230
sp170 d 0 1
si175 h 13.203 13.214
sp175 d 0 1
si180 h 13.200 13.203
sp180 d 0 1
f5:n  -310.87 386.52 157.4 1
e5       .85 .95 1.05 1.15 1.25 1.35 1.45 1.55 1.65 1.75 1.85 1.95
         2.15 2.35 2.55 2.75 2.95 3.15 3.35 3.55 3.75 3.95 4.15 4.45
         4.75 5.05 5.35 5.65 5.95 6.25 6.55 6.85 7.25 7.75 8.25 8.75
```

```
       9.25 9.75 10.25 10.75 11.25 11.75 12.55 13.35 14.15 14.95
       15.75 16.55
em5    1 10 10r 5 10r 3.33 8r 2.5 2 8r 1.25 5r
c    f15:p -356.87 386.52 157.4 1
c    e15    .72 .76 .80 .84 .88 .92 .96 1.0 1.04 1.08 1.15 1.2 1.25
c      1.3 1.35 1.4 1.45 1.5 1.55 1.6 1.65 1.72 1.8 1.88 1.96
c      2.04 2.12 2.2 2.28 2.36 2.45 2.55 2.65 2.75 2.85 2.95 3.05
c      3.15 3.25 3.35 3.45 3.55 3.66 3.79 3.93 4.06 4.19 4.32
c      4.45 4.58 4.71 4.84 4.97 5.1 5.23 5.4 5.57 5.74 5.91 6.08
c      6.25 6.42 6.6 6.8 7.0 7.2 7.4 7.6 7.8 8.0 8.2 8.4 8.6 8.8 9.0
c      9.2 9.4 9.6 9.8 10
c    em15   1 25 8r 14.286 20 9r 14.286 12.5 7r 11.111 10 10r 9.0909 7.6923
c      7.1429 7.6923 9r 5.8824 6r 5.5556 5 16r
cut:n 1e33 .850 -1e-5 -1e-5$ ignore neutrons below the detector response
c wwg  5 121 0 -310.87 386.52 157.4
fq5  e d
ft5   geb  .03 .08                $ mcnp4 patch format
c    ft5  geb 0 .282842713 .375        $ mcnp4a format
m1     1001 7.86e-3
       8016 4.39e-2
      11023 1.05e-3
      12000 1.40e-4
      13027 2.39e-3
      14000 1.58e-2
      19000 6.90e-4
      20000 2.92e-3
      26000 3.10e-4
m3    26000 8.48e-2
m4    24000 1.77e-2
      25055 1.77e-3
      26000 6.02e-2
      28000 7.83e-3
m2     7014 3.64e-5
       8016 9.74e-6
m5    1001 5.926e-2
      6000 3.338e-2
      8016 1.125e-2
      3006 5.565e-4
      3007 6.944e-3
m6     1001 7.13e-2
       6000 3.41e-2
       5010 4.87e-4
       5011 1.97e-3
print
nps   1e5
prdmp 3j 1
```

B2: Variations from Base Model in Fusion Problem

```
fg1a differences
---------xxxxxxxx------------
fg1b differences
405c405
< c wwg  5 121 0 -310.87 386.52 157.4
---
> wwg  5 121 0 -310.87 386.52 157.4
---------xxxxxxxx------------
fg2a differences
---------xxxxxxxx------------
fg2b differences
405c405
< c wwg  5 121 0 -310.87 386.52 157.4
---
> wwg  5 121 0 -310.87 386.52 157.4
---------xxxxxxxx------------
fg3a differences
---------xxxxxxxx------------
fg3b differences
405c405
< c wwg  5 121 0 -310.87 386.52 157.4
---
> wwg  5 0 0 -310.87 386.52 157.4
436a437,449
> mesh    ref     -356.87 232.02 157.4
>         origin  -807.7201 -29.2101 -91.4401
>         geom     xyz
>         imesh    91.44 205.74 294.64 372.75 374.66 392.43
>                 506.73 527.06 528.96 607.06 693.42 807.72
>                 899.16
>         iints     5 12r
>         jmesh    29.21 189.41 237.49 254.77 261.23 282.27
>                 382.27 465.73 470.81 599.41 690.85
>         jints   5 10r
>         kmesh  91.44 172.64 309.84 325.04 345.36 408.94
>                586.44 678.18
>         kints    5 7r
\ No newline at end of file
---------xxxxxxxx------------
fg4a differences
249,286c249,250
< wwp:n 4 3 2
< wwe:n  1.0000e+02
< wwnl:n    3.2446e-02  7.8625e-03  2.5425e-02  1.7255e-02  6.0036e-03 (cont)...
---
> imp:n 1 171r 0 5r
> c wwp:n 4 3 2
405c369
< c wwg  5 121 0 -310.87 386.52 157.4
---
> wwg  5 0 0 -310.87 386.52 157.4
436a401,414
> mesh    ref     -356.87 232.02 157.4
>         origin  -807.7201 -29.2101 -91.4401
>         geom     xyz
>         imesh    91.44 205.74 294.64 372.75 374.66 392.43
>                 506.73 527.06 528.96 607.06 693.42 807.72
>                 899.16
>         iints     5 12r
>         jmesh    29.21 189.41 237.49 254.77 261.23 282.27
>                 382.27 465.73 470.81 599.41 690.85
>         jints   5 10r
>         kmesh  91.44 172.64 309.84 325.04 345.36 408.94
>                586.44 678.18
>         kints    5 7r
>
---------xxxxxxxx------------
fwwl4b differences
250,286c250
< wwe:n  1.0000e+02
< wwnl:n    3.2446e-02  7.8625e-03  2.5425e-02  1.7255e-02  6.0036e-03 (cont)
---------xxxxxxxx------------
fwwl4c differences
249,286c249
< wwp:n 4 3 2
< wwe:n  1.0000e+02
< wwnl:n    3.2446e-02  7.8625e-03  2.5425e-02  1.7255e-02  6.0036e-03 (cont)
---
> c wwe:n  1.0000e+02
436a401,437
> wwe:n  1.0000E+02
> wwnl:n    6.0564E-02  2.1691E-02  2.0794E-02  2.3855E-02  1.1450E-02 (cont)
> c wwe:n  1.0000e+02
436a401,437
> wwe:n  1.0000E+02
> wwnl:n    6.0564E-02  2.1691E-02  2.0794E-02  2.3855E-02  1.1450E-02 (cont)
---
> imp:n 1 171r 0 5r
> wwp:n 4 3 2 0 -1
---------xxxxxxxx------------
fww4 differences
249,286c249,250
< wwp:n 4 3 2
< wwe:n  1.0000e+02
< wwnl:n    3.2446e-02  7.8625e-03  2.5425e-02  1.7255e-02  6.0036e-03 (cont)
```

Table B3: Explanation of Runs Performed in Assessment

Run	Explanation	Code Run
Fg1a	Expert importances, no wwg, no ww used.	MCNP4C
Fg1b	Same as Fg1a, but cell-based ww's generated.	MCNP4C
Fg2a	Expert importances, no wwg, no ww used.	MCNP4B
Fg2b	Same as Fg2a, but cell-based ww's generated.	MCNP4B
Fg3a	Expert importances, complex geometry, no wwg, no ww used.	MCNP4C
Fg3b	Same as Fg3b, but mesh-based ww's generated.	MCNP4C
Fg4a	Binary importances, complex geometry, no wwg, no ww used.	MCNP4C
Fg4b	Same as Fg4a, but mesh-based ww's generated.	MCNP4C
Fg5a	Binary importances, simple geometry, no wwg, no ww used.	MCNP4C
Fg5b	Same as Fg5a, but mesh-based ww's generated.	MCNP4C
Fww14b	Applies cbww generated in Fg1b	MCNP4B
Fww14C	Applies cbww generated in Fg1b	MCNP4C
Fww24b	Applies cbww generated in Fg2b	MCNP4B
Fww24C	Applies cbww generated in Fg2b	MCNP4C
Fww3	Applies mbww generated in Fg3b	MCNP4C
Fww4	Applies mbww generated in Fg4b	MCNP4C
Fww5	Applies mbww generated in Fg5b	MCNP4C

B4: Simplified Geometry Model in Fusion Problem -fg5b


```
message:
datapath=/usr/local/codes/data/mc/type1

fusion spectra problem
    1 1 7.506e-2 1 -2 10 -21 -22 29 $ floor cell $
    2 1 7.506e-2 7 -8 10 -21 -22 29 $ ceiling cell $
    3 1 7.506e-2 2 -7 10 -21 -22 23 $ left wall cell $
    4 1 7.506e-2 2 -7 10 -21 -28 29 $ right wall cell $
    5 1 7.506e-2 2 -7 20 -21 -23 28 $ front wall cell $
    6 2 4.614e-5 2 -4 10 -11 -23 32 $ left door cell $
    7 2 4.614e-5 2 -4 10 -11 -33 34 $ middle door cell $
    8 2 4.614e-5 2 -4 10 -11 -35 28 $ right door cell $
    9 1 7.506e-2 4 -7 10 -11 -23 32 $ concrete above left door $
   10 1 7.506e-2 4 -7 10 -11 -33 34 $ concrete above middle door
   11 1 7.506e-2 4 -7 10 -11 -35 28 $ concrete above right door
   12 1 7.506e-2 2 -4 10 -11 -32 33 $ concrete cell betwn 1/m doors
   13 1 7.506e-2 2 -4 10 -11 -34 35 $ concrete cell betwn m/r doors
   14 1 7.506e-2 4 -7 10 -11 -32 33 $ wall concrete above cell 12
   15 1 7.506e-2 4 -7 10 -11 -34 35 $ wall concrete above cell 13
   16 2 4.614e-5 2 -7 11 -12 -23 28 $ air cell btwn left door & block back
   17 2 4.614e-5 6 -7 12 -17 -23 28 $ cells 26-35: air cells abv the block
   18 2 4.614e-5 2 -6 12 -20 -23 24 $ cells 36-47: air cells left of block
   19 2 4.614e-5 6 -7 17 -20 -23 28 $ cells 60-69: air cells abv thermal shield
   20 2 4.614e-5 2 -6 12 -20 -27 28 $ cells 48-59: air cells right of block
   21 4 8.75e-2 3 -5 -25 26 15 -44 $ cells 94-103: air and shield cells inside
   22 6 .11150 3 -5 -25 26 44 -45
   23 4 8.75e-2 3 -5 -25 26 45 -46
   24 6 .11150 3 -5 -25 26 46 -47
   25 4 8.75e-2 3 -5 -25 26 47 -48
   26 2 4.614e-5 3 -5 -25 26 48 -17
   27 2 4.614e-5 3 -9 -25 26 17 -18 $ air cell btwn inner box and thermal shield
   28 2 4.614e-5 3 -9 -30 31 19 -20 $ cells 105-106: air cells fitting between
   29 2 4.614e-5 3 -9 -26 27 17 -20
   30 2 4.614e-5 9 -6 -24 27 17 -20 $ cells 107-109: air cells between the upper
   31 2 4.614e-5 2 -3 -24 27 17 -20 $ cells 110-112: air cells between the
   32 2 4.614e-5 3 -9 -24 25 17 -20 $ cells 113-118: air cells between the
   33 0 -36 12 -13 $ vacuum inside beamline
   34 0 -36 13 -14 $ vacuum inside iron can
   35 0 14 -15 -38 $ vacuum inside iron pipe
   36 3 8.48e-2 36 -37 12 -13 $ beamline
   37 3 8.48e-2 36 -39 13 -14 $ iron can
   38 3 8.48e-2 38 -39 14 -15 $ iron pipe
   39 5 1.1139e-1 37 -39 12 -13
   40 1 7.506e-2  5 -6 12 -17 -24 27 $ cells 126-134: concrete box top cells
   41 1 7.506e-2  2 -3 12 -17 -24 27 $ cells 135-143: cncr box bottom cells
   42 1 7.506e-2 -24 25 3 -5 12 -17 $ cells 144-149: concrete box left
   43 1 7.506e-2 -26 27 3 -5 12 -17 $ cells 150-155: concrete box right
   44 1 7.506e-2 3 -5 -25 26 39 12 -15 $ cells 156-164: inner concrete box cells
c       165 2 4.614e-5 9 -5 -25 26 18 -40 $ cells 165-170: air cells centered
c       166 2 4.614e-5 9 -5 -25 26 40 -20 $ around the thermal shield
   45 2 4.614e-5 -25 30 3 -9 18 -20
   46 2 4.614e-5 -31 26 3 -9 18 -20
   47 4 8.75e-2 18 -19 3 -9 -30 31 $ thermal shield
   48 0 -1  $ void cell below the concrete room
   49 0  8 $ void cell above the concrete room
   50 0  1 -8 -22 29 -10 $ void cell behind the rear wall
   51 0  1 -8 -22 29 21  $ void cell in front of the front wall
   52 0  1 -8 22 $ void cell left of the room
   53 0  1 -8 -29 $ void cell right of the room

    1 pz -91.44
    2 pz 0 $ upper floor plane
    3 pz 81.2 $ inner box bottom/lower thermal shield edge
    4 pz 218.4 $ door upper edge
    5 pz 253.92 $ inner box top
    6 pz 317.50 $ concrete box top
    7 pz 495.30 $ ceiling plane (lower)
    8 pz 586.74 $ ceiling plane (upper)
    9 pz 233.60 $ upper thermal shield edge
   10 py -29.21 $ rear wall plane (rear)
   11 py 0 $ rear wall plane (front)
   12 py 160.02 $ rear of concrete box
   13 py 208.28 $ end of paraffin
   14 py 225.56 $ rear edge of iron can
   15 py 253.06 $ end of iron pipe/rear of inner box
   16 py 232.02 $ plane of target
   17 py 353.06 $ front of concrete box
   18 py 436.52 $ front of thermal shield
   19 py 441.60 $ rear of thermal shield
   20 py 570.20 $ front wall plane (inside)
   21 py 661.64 $ front wall plane (outside)
   22 px 91.44  $ left wall plane (outside)
   23 px 0      $ left wall plane (inside)
   24 px -200.66 $ left side of concrete box
   25 px -278.76 $ left side of inner box
   26 px -434.97 $ right side of inner box
   27 px -513.08 $ right side of concrete box
   28 px -716.28 $ right wall plane (inside)
   29 px -807.72 $ right wall plane (outside)
   30 px -280.66 $ left edge of thermal shield
   31 px -433.06 $ right edge of thermal shield
   32 px -114.3  $ right edge of left door
   33 px -300.99 $ left edge of middle door
   34 px -415.29 $ right edge of middle door
   35 px -601.98 $ left edge of right door
   36 c/y -356.87 157.4 4.5   $ beamline inner surface
   37 c/y -356.87 157.4 5.0   $ beamline outer surface
   38 c/y -356.87 157.4 8.87  $ iron pipe inner surface
   39 c/y -356.87 157.4 16.37 $ iron pipe outer surface
   44 py 288.62
   45 py 293.70
   46 py 298.78
   47 py 303.86
   48 py 308.94

mode n
imp:n 1 46r 0 5r
sdef pos=-356.87 232.02 157.4 dir=d1 erg=fdir=d2 rad=d3 vec=0 1 0
     sur=16
si1  a  -1.0000 -.99619 -.98481 -.96593 -.93969
         -.90631 -.86603 -.81915 -.76604 -.70711
         -.64279 -.57358 -.50000 -.42262 -.34202
         -.25882 -.17365 -.08716  .00000  .08716
          .17365  .25882  .34202  .42262  .50000
          .57358  .64279  .70711  .76604  .81915
          .86603  .90631  .93969  .96593  .98481
          .99619  1.0000
sp1       .874 .874 .875 .876 .877
          .879 .882 .884 .888 .891
          .895 .899 .904 .909 .914
          .919 .924 .930 .935 .941
          .946 .952 .957 .962 .967
          .972 .976 .981 .985 .988
          .991 .994 .996 .998 .999
          1.0 1.0
ds2  q  -.99619 180 -.98481 175 -.96593 170 -.93962 165 -.90631 160
        -.86603 155 -.81915 150 -.76604 145 -.70711 140 -.64279 135
        -.57358 130 -.50000 125 -.42262 120 -.34202 115 -.25882 110
        -.17365 105 -.08716 100 0.0000 95   .08716 90   .17365 85
         .25882 80   .34202 75   .42262 70   .50000 65   .57358 60
```

```
        .64279 55   .70711 50   .76604 45   .81915 40   .86603 35
        .90631 30   .93969 25   .96593 20   .98481 15   .99619 10
        1.0000 5
si3   h 0 .64
sp3   d -21 1
si5   h 15.106 15.110
sp5   d 0 1
si10 h 15.095 15.106
sp10 d 0 1
si15 h 15.075 15.095
sp15 d 0 1
si20 h 15.049 15.075
sp20 d 0 1
si25 h 15.015 15.049
sp25 d 0 1
si30 h 14.974 15.015
sp30 d 0 1
si35 h 14.927 14.974
sp35 d 0 1
si40 h 14.873 14.927
sp40 d 0 1
si45 h 14.814 14.873
sp45 d 0 1
si50 h 14.750 14.814
sp50 d 0 1
si55 h 14.681 14.750
sp55 d 0 1
si60 h 14.608 14.681
sp60 d 0 1
si65 h 14.532 14.608
sp65 d 0 1
si70 h 14.453 14.532
sp70 d 0 1
si75 h 14.372 14.453
sp75 d 0 1
si80 h 14.289 14.372
sp80 d 0 1
si85 h 14.206 14.289
sp85 d 0 1
si90 h 14.123 14.206
sp90 d 0 1
si95 h 14.040 14.123
sp95 d 0 1
si100 h 13.958 14.040
sp100 d 0 1
si105 h 13.878 13.958
sp105 d 0 1
si110 h 13.800 13.878
sp110 d 0 1
si115 h 13.725 13.800
sp115 d 0 1
si120 h 13.654 13.725
sp120 d 0 1
si125 h 13.586 13.654
sp125 d 0 1
si130 h 13.522 13.586
sp130 d 0 1
si135 h 13.464 13.522
sp135 d 0 1
si140 h 13.410 13.464
sp140 d 0 1
si145 h 13.362 13.410
sp145 d 0 1
si150 h 13.320 13.362
sp150 d 0 1
si155 h 13.284 13.320
sp155 d 0 1
si160 h 13.254 13.284
sp160 d 0 1
si165 h 13.230 13.254
sp165 d 0 1
si170 h 13.214 13.230
sp170 d 0 1
si175 h 13.203 13.214
sp175 d 0 1
si180 h 13.200 13.203
sp180 d 0 1
f5:n  -310.87 386.52 157.4 1
e5      .85 .95 1.05 1.15 1.25 1.35 1.45 1.55 1.65 1.75 1.85 1.95
        2.15 2.35 2.55 2.75 2.95 3.15 3.35 3.55 3.75 3.95 4.15 4.45
        4.75 5.05 5.35 5.65 5.95 6.25 6.55 6.85 7.25 7.75 8.25 8.75
        9.25 9.75 10.25 10.75 11.25 11.75 12.55 13.35 14.15 14.95
        15.75 16.55
em5     1 10 10r 5 10r 3.33 8r 2.5 2 8r 1.25 5r
cut:n 1e33 .850 -1e-5 -1e-5$ ignore neutrons below the detector response
wwg   5 0 0 -310.87 386.52 157.4
fq5   e d
ft5     geb  .03 .08                       $ mcnp4 patch format
c       ft5  geb 0 .282842713 .375         $ mcnp4a format
m1      1001 7.86e-3
        8016 4.39e-2
       11023 1.05e-3
       12000 1.40e-4
       13027 2.39e-3
       14000 1.58e-2
       19000 6.90e-4
       20000 2.92e-3
       26000 3.10e-4
m3     26000 8.48e-2
m4     24000 1.77e-2
       25055 1.77e-3
       26000 6.02e-2
       28000 7.83e-3
m2      7014 3.64e-5
        8016 9.74e-6
m5     1001 5.926e-2
       6000 3.338e-2
       8016 1.125e-2
       3006 5.565e-4
       3007 6.944e-3
m6      1001 7.13e-2
        6000 3.41e-2
        5010 4.87e-4
        5011 1.97e-3
print
nps   1e5
prdmp 3j 1
mesh      ref      -356.87 232.02 157.4
          origin   -807.7201 -29.2101 -91.4401
          geom       xyz
          imesh    91.44 205.74 294.64 372.75 374.66 392.43
                  506.73 527.06 528.96 607.06 693.42 807.72
                  899.16
          iints    5 12r
          jmesh    29.21 189.41 237.49 254.77 261.23 282.27
                  382.27 465.73 470.81 599.41 690.85
          jints    5 10r
          kmesh    91.44 172.64 309.84 325.04 345.36 408.94
                  586.44 678.18
          kints    5 7r
```

C1: Base Model in Air Over Ground Problem


```
message:
datapath=/usr/local/codes/data/mc/type1

co60 benchmark problem
c        this mcnp benchmark problem models the radiation dose received
c    at three feet above an essentially infinite plane source of cobalt-
c    60 uniformly spread over a field.  this problem is modelled by gen-
c    erating a disk plane source of isotropic 1.1725 and 1.33 mev(equi-
c    probable) gamma rays which is centered at the origin.  this disk
c    source has a one-kilometer radius and is centered at the origin-the
c    entire problem is bounded by a one-kilometer radius sphere centered
c    at the origin which is cut into two hemispheres by the plane source.
c    the hemisphere above the source is filled with air and the hemi-
c    sphere below the source is filled with soil.  the soil and air den-
c    sities are taken as 1.13 g/cm3 and 0.00129 g/cm3, repectively,
c    from profio, et al., in the ornl radiation benchmark experiments,
c    chapter four.  the problem is further broken into concentric hem-
c    ispherical shell cells in the air and hemispherical shells cut by
c    planes in the soil-these planes are 5-6 cm apart and are parallel
c    to the source plane.  5-6 cm is the mean free path length of co-
c    60 gamma rays in the soil-the hemispherical shells above and be-
c    low the ground are 100 m apart, which is the mfp of these gammas
c    in air.
c
c   NOTE that someone butchered this problem with many many
c   unnecessary cells below the -23 surface
c
    1 2 -.00129 1 19 -5
    2 1 -1.13 -1 2 19 -5
    3 1 -1.13 -2 3 19 -5
    4 1 -1.13 -3 4 19 -5
    5 2 -.00129 1 5 -6
    6 1 -1.13 -1 2 5 -6
    7 1 -1.13 -2 3 5 -6
    8 1 -1.13 -3 4 5 -6
    9 2 -.00129 1 6 -7
   10 1 -1.13 -1 2 6 -7
   11 1 -1.13 -2 3 6 -7
   12 1 -1.13 -3 4 6 -7
   13 2 -.00129 1 7 -8
   14 1 -1.13 -1 2 7 -8
   15 1 -1.13 -2 3 7 -8
   16 1 -1.13 -3 4 7 -8
   17 2 -.00129 1 8 -9
   18 1 -1.13 -1 2 8 -9
   19 1 -1.13 -2 3 8 -9
   20 1 -1.13 -3 4 8 -9
   21 2 -.00129 1 9 -10
   22 1 -1.13 -1 2 9 -10
   23 1 -1.13 -2 3 9 -10
   24 1 -1.13 -3 4 9 -10
   25 2 -.00129 1 10 -11
   26 1 -1.13 -1 2 10 -11
   27 1 -1.13 -2 3 10 -11
   28 1 -1.13 -3 4 10 -11
   29 2 -.00129 1 11 -12
   30 1 -1.13 -1 2 11 -12
   31 1 -1.13 -2 3 11 -12
   32 1 -1.13 -3 4 11 -12
   33 2 -.00129 1 12 -13
   34 1 -1.13 -1 2 12 -13
   35 1 -1.13 -2 3 12 -13
   36 1 -1.13 -3 4 12 -13
   37 2 -.00129 1 13 -14
   38 1 -1.13 -1 2 13 -14
   39 1 -1.13 -2 3 13 -14
   40 1 -1.13 -3 4 13 -14
   41 0       14:-23
   42 2 -.00129 1 -15 #142
   43 1 -1.13 -1 2 -15
   44 1 -1.13 -2 3 -15
   45 1 -1.13 -3 4 -15
   46 1 -1.13 -4 20 -15
   47 1 -1.13 -20 21 -15
   48 1 -1.13 -21 22 -15
   49 1 -1.13 -22 23 -15
c  50 1 -1.13 -23 -15
   51 2 -.00129 1 15 -16
   52 1 -1.13 -1 2 15 -16
   53 1 -1.13 -2 3 15 -16
   54 1 -1.13 -3 4 15 -16
   55 1 -1.13 -4 20 15 -16
   56 1 -1.13 -20 21 15 -16
   57 1 -1.13 -21 22 15 -16
   58 1 -1.13 -22 23 15 -16
c  59 1 -1.13 -23 15 -16
   60 2 -.00129 1 16 -17
   61 1 -1.13 -1 2 16 -17
   62 1 -1.13 -2 3 16 -17
   63 1 -1.13 -3 4 16 -17
   64 1 -1.13 -4 20 16 -17
   65 1 -1.13 -20 21 16 -17
   66 1 -1.13 -21 22 16 -17
   67 1 -1.13 -22 23 16 -17
c  68 1 -1.13 -23 16 -17
   69 2 -.00129 1 17 -18
   70 1 -1.13 -1 2 17 -18
   71 1 -1.13 -2 3 17 -18
   72 1 -1.13 -3 4 17 -18
   73 1 -1.13 -4 20 17 -18
   74 1 -1.13 -20 21 17 -18
   75 1 -1.13 -21 22 17 -18
   76 1 -1.13 -22 23 17 -18
c  77 1 -1.13 -23 17 -18
   78 2 -.00129 1 18 -19
   79 1 -1.13 -1 2 18 -19
   80 1 -1.13 -2 3 18 -19
   81 1 -1.13 -3 4 18 -19
   82 1 -1.13 -4 20 18 -19
   83 1 -1.13 -20 21 18 -19
   84 1 -1.13 -21 22 18 -19
   85 1 -1.13 -22 23 18 -19
c  86 1 -1.13 -23 18 -19
   87 1 -1.13 -4 20 19 -5
   88 1 -1.13 -20 21 19 -5
   89 1 -1.13 -21 22 19 -5
   90 1 -1.13 -22 23 19 -5
c  91 1 -1.13 -23 19 -5
   92 1 -1.13 -4 20 5 -6
   93 1 -1.13 -20 21 5 -6
   94 1 -1.13 -21 22 5 -6
   95 1 -1.13 -22 23 5 -6
c  96 1 -1.13 -23 5 -6
   97 1 -1.13 -4 20 6 -7
   98 1 -1.13 -20 21 6 -7
   99 1 -1.13 -21 22 6 -7
  100 1 -1.13 -22 23 6 -7
c 101 1 -1.13 -23 6 -7
  102 1 -1.13 -4 20 7 -8
  103 1 -1.13 -21 22 7 -8
```

C1: Base Model in Air Over Ground Problem


```
   104 1 -1.13 -22 23 7 -8
c  105 1 -1.13 -23 7 -8
   106 1 -1.13 -4 20 8 -9
   107 1 -1.13 -20 21 8 -9
   108 1 -1.13 -21 22 8 -9
   109 1 -1.13 -22 23 8 -9
c  110 1 -1.13 -23 8 -9
   111 1 -1.13 -4 20 9 -10
   112 1 -1.13 -20 21 9 -10
   113 1 -1.13 -21 22 9 -10
   114 1 -1.13 -22 23 9 -10
c  115 1 -1.13 -23 9 -10
   116 1 -1.13 -4 20 10 -11
   117 1 -1.13 -20 21 10 -11
   118 1 -1.13 -21 22 10 -11
   119 1 -1.13 -22 23 10 -11
c  120 1 -1.13 -23 10 -11
   121 1 -1.13 -4 20 11 -12
   122 1 -1.13 -20 21 11 -12
   123 1 -1.13 -21 22 11 -12
   124 1 -1.13 -22 23 11 -12
c  125 1 -1.13 -23 11 -12
c   126 1 -1.13 -4 20 11 -12
c   127 1 -1.13 -20 21 11 -12
c   128 1 -1.13 -21 22 11 -12
c   129 1 -1.13 -22 23 11 -12
c  130 1 -1.13 -23 11 -12
   131 1 -1.13 -4 20 12 -13
   132 1 -1.13 -20 21 12 -13
   133 1 -1.13 -21 22 12 -13
   134 1 -1.13 -22 23 12 -13
c  135 1 -1.13 -23 12 -13
   136 1 -1.13 -4 20 13 -14
   137 1 -1.13 -20 21 13 -14
   138 1 -1.13 -21 22 13 -14
   139 1 -1.13 -22 23 13 -14
c  140 1 -1.13 -23 13 -14
   141 1 -1.13 -20 21 7 -8
   142 2 -.00129 -24

     1 pz 0
     2 pz -6
     3 pz -12
     4 pz -18
     5 so 1e4
     6 so 2e4
     7 so 3e4
     8 so 4e4
     9 so 5e4
    10 so 6e4
    11 so 7e4
    12 so 8e4
    13 so 9e4
    14 so 1e5
    15 so 2e2
    16 so 1e3
    17 so 3e3
    18 so 5e3
    19 so 7e3
    20 pz -24
    21 pz -30
    22 pz -36
    23 pz -42
    24 s 0 0 91.44 .5
```

```
mode p
c        importances:  the importances of the cells were originally
c     tailored to decrease by a factor of two for every mean free path
c     length further away from the origin the cell is.  however, the im-
c     portances were later modified to equalize particle populations(to
c     within a factor of ten of one another) in each cell.
imp:p  2         1.21      .233      .113      609
       .377      .0213     .0312     .168      .0463
c  11
       1.94e-3   1.57e-3   .0643     .0121     1.43e-3
       1e-4      .0275     7e-3      1e-4      1e-4
c  21
       .0175     1e-3      1e-4      1e-4      5.39e-3
       6.51e-4   3.32e-4   1e-3      3.05e-3   3e-3
c  31
       2e-3      2e-3      2.52e-3   1.02e-4   1e-4
       1e-3      1e-3      1e-4      1e-4      1e-4
c  41
       0         1e4       1.14e4    1343      538.3
       976       193       44.44     92.51
c  51
       513       955       36.7      7.42      .562
       .209      .1        1                   36.06
c  61
       37.79     .446      .150      .113      .0766
       .0326      .1                 8.78      12.52
c  71
       .259      .122      .0551     .011      .0138
       .1                  4.03      3.06      .444
c  81
       .0571     6.56e-3   5.45e-3   7.10e-3   1e-2
                .0506    4.17e-3   5.78e-4   1e-3
c  91
                 6.83e-3   3.72e-4   4.04e-4   3.28e-4
                 9.45e-4   3.012e-3  1.53e-3   1e-3
c  101
                 1e-4      27r       1e4
sdef  sur=1 dir= d3 rad=d2 erg=d1
si3   h      -1      1
sp3   d        0.0     1.0
si1   1 1.1725  1.33
sp1   d   1.0      1.0
c            source biasing:  the source was broken into seventeen concentric
c      rings for statistical biasing.  the two inner rings were chosen to
c      match the first two cosine bins for the kerma tally to improve their
c      statistics.  the biases themselves were chosen originally according
c      to a 1/r distribution and then softened by trial and error.
si2   a 0 68.58 121.92 200 1000 3000 4000 5e3 1e4 2e4 3e4 4e4 5e4
        6e4 7e4 8e4 9e4 1e5
sp2   0 .006858 .012192 .02 .10 .3 .4 .5 1 2 3 4 5 6 7 8 9 10
sb2   0 70 100 150 200 120 32 8 3.3 1.3 .4 .28 .11 .060 .023
      .013 .00075 .0004
c           a point detector was placed 91 cm(3 ft) above the ground
c     at the origin-its tally was then multiplied by an fm card as
c     shown to obtain the dose absorbed there.  this was done to obtain
c     the dose buildup factor.
c      f5:p   0 0 91.44 1
c      fm5  5.20704e-5 2 -5 -6
c      fq5    s f
dd    0
c      to calculate the angular kerma rate per steradian by cosine bins,
c      a dxtran sphere was used to statistically concentrate particles
c      near a .5 cm spherical shell centered three feet above the ground
c      at the origin.  cosine tallies were then taken of the angular dose
c      received over the sphere, and these cosines were relative to a
```

```
c     normal vector to the plane source pointing upward along the z-axis.
c     the kerma rate was obtained by multiplying each cosine bin by
c     1.59155 to divide by steradians and then multiplied by 1317.25 to
c     obtain the kerma rate in each bin--how these constants were determined
c     can be seen in the help file in the subdirectory containing this input
c     file.  the f1 tally was further subdivided into into collided and un-
c     collided flux using the ft1 option with the fu1 0 999 card, which
c     tallies particles which have not collided at all and those which have
c     collided between 1 and 999 times.  the cosine bin normal vector was
c     also specified withe ft1 card frv option.
dxt:p 0 0 91.44 1e-10 .501 1e-29 1e-30
f1:p  24
c1    -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 0
      .1 .2 .3 .4 .5 .6 .7 .8 .9 1 t
cm1  1.59155 19r
fq1   c u
fm1   1317.25 2 -5 -6
ft1   frv 0 0 1 inc
fu1   0 999      $ a bit of trickery
prdmp 3j 1
m1   8016 -0.34
     11023  -0.01
     12000  -0.10
     13027  -0.03
     14000  -0.18
     16032  -0.03
     20000  -0.01
     26000  -0.29
     28000  -0.01
m2   7014 -0.7818
     8016 -0.2097
     18000 -0.0073
     12000 -0.0012
print
nps  1e5
c wwg 1 0 0
cut:p j 0.01 -1e-18
c wwp:p  5 3 5 0 -1
c mesh ref  0 0 0
c       origin 0.001 0.001 -42.001
c       axs 0 0 1
c       vec 1 0 0
c       geom cyl
c       imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
c       iints  2  2   2   2   2   2  10
c       jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042
c       jints 1 1 1  1   1 1  1   1  1    1    1    1    1    10
c       kmesh  .5   1
c       kints   1  1
```

C2: Variations from Base Model, Air Over Ground -ag1a


```
ag1a differences
---------xxxxxxxx------------
ag1b differences
296c296
< c wwg 1 0 0
---
> wwg 1 42 0
---------xxxxxxxx------------
ag2a differences
56c56
---------xxxxxxxx------------
ag2b differences
296c296
< c wwg 1 0 0
---
> wwg 1 42 0
---------xxxxxxxx------------
ag3a differences
297d296
< cut:p j 0.01 -1e-18
---------xxxxxxxx------------
ag3b differences
296,297c296
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
---
> wwg 1 0 0
299,309c298,308
< c mesh ref  0 0 0
< c       origin 0.001 0.001 -42.001
< c       axs 0 0 1
< c       vec 1 0 0
< c       geom cyl
< c       imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
< c       iints  2  2   2   2   2   2  10
< c       jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042
< c       jints 1 1 1  1   1 1  1   1  1    1    1    1    1   10
< c       kmesh  .5   1
< c       kints   1  1
---
> mesh ref  0 0 0
>       origin 0.001 0.001 -42.001
>       axs 0 0 1
>       vec 1 0 0
>       geom cyl
>       imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
>       iints  2  2   2   2   2   2  10
>       jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042.01
>       jints 1 1 1  1   1 1  1   1  1    1    1    1    1   10
>       kmesh  .5   1
>       kints   1  1
---------xxxxxxxx------------
ag4a differences
56c56
< imp:p  2        1.21      .233      .113      609
<          .377      .0213     .0312     .168     .0463 (cont)
---
> imp:p  1 39r 0 1 84r
> c    Going to binary importances
> c          2        1.21      .233      .113      609
> c          .377      .0213     .0312     .168     .0463 (cont)
297d298
< cut:p j 0.01 -1e-18
---------xxxxxxxx------------
ag4b differences
202,203c202,205
< imp:p  2        1.21      .233      .113      609
<          .377      .0213     .0312     .168     .0463  (cont)
---
> imp:p  1 39r 0 1 84r
> c    Going to binary importances
> c          2        1.21      .233      .113      609
> c          .377      .0213     .0312     .168     .0463  (cont)
296,297c298
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
---
> wwg 1 0 0
299,309c300,310
< c mesh ref  0 0 0
< c       origin 0.001 0.001 -42.001
< c       axs 0 0 1
< c       vec 1 0 0
< c       geom cyl
< c       imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
< c       iints  2  2   2   2   2   2  10
< c       jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042
< c       jints 1 1 1  1   1 1  1   1  1    1    1    1    1   10
< c       kmesh  .5   1
< c       kints   1  1
---
> mesh ref  0 0 0
>       origin 0.001 0.001 -42.001
>       axs 0 0 1
>       vec 1 0 0
>       geom cyl
>       imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
>       iints  2  2   2   2   2   2  10
>       jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042.01
>       jints 1 1 1  1   1 1  1   1  1    1    1    1    1   10
>       kmesh  .5   1
>       kints   1  1
---------xxxxxxxx------------
aww14b differences
202,232c202,222
< imp:p  2        1.21      .233      .113      609  (cont)
---
> c imp:p  2        1.21      .233      .113      609  (cont)
296,298c286,288
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
< c wwp:p  5 3 5 0 -1
---
> c wwg 1 42 0
> wwp:p  5 3 5
> cut:p 0 0.01 -1e-18
309a300,326
> wwe:p  1.0000E+02
> wwn1:p   1.1493E+04  8.8822E+03  9.7426E+05  3.0525E+06  3.3328E+04  (cont)
---------xxxxxxxx------------
aww14c differences
202,232c202,222
< imp:p  2        1.21      .233      .113      609  (cont)
---
> c imp:p  2        1.21      .233      .113      609 (cont)
296,298c286,288
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
< c wwp:p  5 3 5 0 -1
---
```

```
> c wwg 1 42 0
> wwp:p  5 3 5
> cut:p 0 0.01 -1e-18
309a300,326
> wwe:p  1.0000E+02
> wwn1:p   1.1493E+04  8.8822E+03  9.7426E+05  3.0525E+06  3.3328E+04 (cont)
---------xxxxxxxx------------
aww24b differences
202,232c202,222
< imp:p  2        1.21      .233      .113      609 (cont)
---
> c imp:p  2        1.21      .233      .113      609 (cont)
296,298c286,288
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
< c wwp:p  5 3 5 0 -1
---
> c wwg 1 42 0
> wwp:p  5 3 5
> cut:p 0 0.01 -1e-18
309a300,326
> wwe:p  1.0000E+02
> wwn1:p   1.9307E+08  1.9093E+08  3.0710E+09  1.2996E+09  6.9348E+08 (cont)
---------xxxxxxxx------------
aww24c differences
202,232c202,222
< imp:p  2        1.21      .233      .113      609 (cont)
---
> c imp:p  2        1.21      .233      .113      609 (cont)
296,298c286,288
< c wwg 1 0 0
< cut:p j 0.01 -1e-18
< c wwp:p  5 3 5 0 -1
---
> c wwg 1 42 0
> wwp:p  5 3 5
> cut:p 0 0.01 -1e-18
309a300,326
> wwe:p  1.0000E+02
> wwn1:p   1.9307E+08  1.9093E+08  3.0710E+09  1.2996E+09  6.9348E+08 (cont)
---------xxxxxxxx------------
aww3 differences
296a297
> wwp:p  5 3 5 0 -1
298d298
< c wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
aww4 differences
202,203c202,205
< imp:p  2        1.21      .233      .113      609
<        .377     .0213     .0312     .168      .0463 (cont)
---
> imp:p  1 39r 0 1 84r
> c    Going to binary importances  (cont)
297,298c299
< cut:p j 0.01 -1e-18
< c wwp:p  5 3 5 0 -1
---
> wwp:p  5 3 5 0 -1
---------xxxxxxxx------------
```

Table C3: Explanation of Runs Performed in Assessment

Run	Explanation	Code Run
Ag1a	Expert importances, no wwg, no ww used.	MCNP4C
Ag1b	Same as Ag1a, but cell-based ww's generated.	MCNP4C
Ag2a	Expert importances, no wwg, no ww used.	MCNP4B
Ag2b	Same as Ag2a, but cell-based ww's generated.	MCNP4B
Ag3a	Expert importances, complex geometry, no wwg, no ww used.	MCNP4C
Ag3b	Same as Ag3b, but mesh-based ww's generated.	MCNP4C
Ag4a	Binary importances, complex geometry, no wwg, no ww used.	MCNP4C
Ag4b	Same as Ag4a, but mesh-based ww's generated.	MCNP4C
Ag5a	Binary importances, simple geometry, no wwg, no ww used.	MCNP4C
Ag5b	Same as Ag5a, but mesh-based ww's generated.	MCNP4C
Aww14b	Applies cbww generated in Ag1b	MCNP4B
Aww14C	Applies cbww generated in Ag1b	MCNP4C
Aww24b	Applies cbww generated in Ag2b	MCNP4B
Aww24C	Applies cbww generated in Ag2b	MCNP4C
Aww3	Applies mbww generated in Ag3b	MCNP4C
Aww4	Applies mbww generated in Ag4b	MCNP4C
Aww5	Applies mbww generated in Ag5b	MCNP4C

```
message:
datapath=/usr/local/codes/data/mc/type1

co60 benchmark problem
c         this mcnp benchmark problem models the radiation dose received
c     at three feet above an essentially infinite plane source of cobalt-
c     60 uniformly spread over a field.  this problem is modelled by gen-
c     erating a disk plane source of isotropic 1.1725 and 1.33 mev(equi-
c     probable) gamma rays which is centered at the origin.  this disk
c     source has a one-kilometer radius and is centered at the origin-the
c     entire problem is bounded by a one-kilometer radius sphere centered
c     at the origin which is cut into two hemispheres by the plane source.
c     the hemisphere above the source is filled with air and the hemi-
c     sphere below the source is filled with soil.  the soil and air den-
c     sities are taken as 1.13 g/cm3 and 0.00129 g/cm3, repectively,
c     from profio, et al., in the ornl radiation benchmark experiments,
c     chapter four.  the problem is further broken into concentric hem-
c     ispherical shell cells in the air and hemispherical shells cut by
c     planes in the soil-these planes are 5-6 cm apart and are parallel
c     to the source plane.  5-6 cm is the mean free path length of co-
c     60 gamma rays in the soil-the hemispherical shells above and be-
c     low the ground are 100 m apart, which is the mfp of these gammas
c     in air.
c
   1 2 -.00129 1  -14  24
   2 2 -.00129 -24
   3 1 -1.13 -1 23  -14
   4 0       14:-23

    1 pz 0
   14 so 1e5
   23 pz -42
   24 s 0 0 91.44 .5

mode p
imp:p 1 1 1 0
sdef  sur=1 dir= d3 rad=d2 erg=d1
si3   h      -1      1
sp3   d       0.0    1.0
si1   1 1.1725  1.33
sp1   d   1.0     1.0
si2   a 0 68.58 121.92 200 1000 3000 4000 5e3 1e4 2e4 3e4 4e4 5e4
        6e4 7e4 8e4 9e4 1e5
sp2   0 .006858 .012192 .02 .10 .3 .4 .5 1 2 3 4 5 6 7 8 9 10
sb2   0 70 100 150 200 120 32 8 3.3 1.3 .4 .28 .11 .060 .023
      .013 .00075 .0004
dd    0
dxt:p 0 0 91.44 1e-10 .501 1e-29 1e-30
f1:p  24
c1    -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 0
       .1 .2 .3 .4 .5 .6 .7 .8 .9 1 t
cm1   1.59155 19r
fq1    c u
fm1    1317.25 2 -5 -6
ft1    frv 0 0 1 inc
fu1    0 999      $ a bit of trickery
prdmp 3j 1
m1    8016 -0.34
      11023  -0.01
      12000  -0.10
      13027  -0.03
      14000  -0.18
      16032  -0.03
      20000  -0.01
      26000  -0.29
      28000  -0.01
m2    7014 -0.7818
      8016 -0.2097
      18000 -0.0073
      12000 -0.0012
print
nps  1e5
wwg 1 0 0
c  wwp:p  5 3 5 0 -1
mesh ref  0 0 0
        origin 0.001 0.001 -42.001
        axs 0 0 1
        vec 1 0 0
         geom cyl
        imesh  2e2 1e3 3e3 5e3 7e3 1e4 100000.01
        iints  2  2   2   2   2   2  10
        jmesh 6 12 18 24 30 36 41 242 1042 3042 5042 7042 10042 100042.01
        jints 1 1 1  1   1 1  1   1  1    1    1    1    1   10
        kmesh  .5   1
        kints   1  1
```

D1: Base Model, Oil Well Problem


```
message:
datapath=/usr/local/codes/data/mc/type1

testprob12  ==>> porosity tool model
c    ================================================================
c    ================================================================
c    ===>>> run       : prob12
c    ===>>> tool      : generic porosity tool
c    ===>>> source    : ambe
c    ===>>> borehole  : 8" bh, fw
c    ===>>> formation : 20 pu limestone, fw
c    ===>>> casing    : none
c    ===>>> detector  : he-3 at 4 atomospheres
c    ===>>>             near : 1"odx3"  at 7.5" centerline from source
c    ===>>>             far  : 2"odx10" at  20" centerline from source
c    ===>>> shielding : none
c    ===>>> sonde     : solid iron
c    ===>>> weights   : xtrapt/diffusion
c    ===>>>  generate weights using wwp patch with factor of 2.0 to far det
c    ===>>>       using a factor of 8.0; only use 50k particles
c    ===>>> physics   : thermal cutin changed to -200
c    ===>>>             s(a,b) added for water
c    ================================================================
c    ================================================================
c
c
c    ================================================================
c    ===== zone cards
c    ================================================================
c    ===== near detector
c    ================================================================
c
   1    1   -0.000502     -1     +13     -14                        $ det_n
c
c    ================================================================
c    ===== far detector
c    ================================================================
c
   2    1   -0.000502     -2     +16     -19                        $ det_f
c
c    ================================================================
c    ===== source region
c    ================================================================
c
   3    2   -7.86         -3     +11     -12                        $ sourc
c
c    ================================================================
c    ===== iron sonde
c    ================================================================
c
   4    2   -7.86         -3     +10     -11                        $ sonde
   5    2   -7.86         -3     +12     -13                        $ sonde
   6    2   -7.86         +1      -3     +13     -14                $ sonde
   7    2   -7.86         -3     +14     -15                        $ sonde
   8    2   -7.86         -3     +15     -16                        $ sonde
   9    2   -7.86         +2      -3     +16     -17                $ sonde
  10    2   -7.86         +2      -3     +17     -18                $ sonde
  11    2   -7.86         +2      -3     +18     -19                $ sonde
  12    2   -7.86         -3     +19     -20                        $ sonde
  13    2   -7.86         -3     +20     -21                        $ sonde
  14    2   -7.86         -3     +21     -22                        $ sonde
c
c    ================================================================
c    ===== borehole
c    ================================================================
c
  15    3   -1.0        +3     -5     -4     +10    -11          $ bh
  16    3   -1.0        +3     -5     -4     +11    -12          $ bh
  17    3   -1.0        +3     -5     -4     +12    -13          $ bh
  18    3   -1.0        +3     -5     -4     +13    -14          $ bh
  19    3   -1.0        +3     -5     -4     +14    -15          $ bh
  20    3   -1.0        +3     -5     -4     +15    -16          $ bh
  21    3   -1.0        +3     -5     -4     +16    -17          $ bh
  22    3   -1.0        +3     -5     -4     +17    -18          $ bh
  23    3   -1.0        +3     -5     -4     +18    -19          $ bh
  24    3   -1.0        +3     -5     -4     +19    -20          $ bh
  25    3   -1.0        +3     -5     -4     +20    -21          $ bh
  26    3   -1.0        +3     -5     -4     +21    -22          $ bh
  27    3   -1.0        +3     -5     +4     +10    -11          $ bh
  28    3   -1.0        +3     -5     +4     +11    -12          $ bh
  29    3   -1.0        +3     -5     +4     +12    -13          $ bh
  30    3   -1.0        +3     -5     +4     +13    -14          $ bh
  31    3   -1.0        +3     -5     +4     +14    -15          $ bh
  32    3   -1.0        +3     -5     +4     +15    -16          $ bh
  33    3   -1.0        +3     -5     +4     +16    -17          $ bh
  34    3   -1.0        +3     -5     +4     +17    -18          $ bh
  35    3   -1.0        +3     -5     +4     +18    -19          $ bh
  36    3   -1.0        +3     -5     +4     +19    -20          $ bh
  37    3   -1.0        +3     -5     +4     +20    -21          $ bh
  38    3   -1.0        +3     -5     +4     +21    -22          $ bh
c
c    ================================================================
c    ===== formation region to radius=15 cm
c    ================================================================
c
  39    4   -2.3688     +5     -6     -23    -24    +10    -11    $ form
  40    4   -2.3688     +5     -6     -23    -24    +11    -12    $ form
  41    4   -2.3688     +5     -6     -23    -24    +12    -13    $ form
  42    4   -2.3688     +5     -6     -23    -24    +13    -14    $ form
  43    4   -2.3688     +5     -6     -23    -24    +14    -15    $ form
  44    4   -2.3688     +5     -6     -23    -24    +15    -16    $ form
  45    4   -2.3688     +5     -6     -23    -24    +16    -17    $ form
  46    4   -2.3688     +5     -6     -23    -24    +17    -18    $ form
  47    4   -2.3688     +5     -6     -23    -24    +18    -19    $ form
  48    4   -2.3688     +5     -6     -23    -24    +19    -20    $ form
  49    4   -2.3688     +5     -6     -23    -24    +20    -21    $ form
  50    4   -2.3688     +5     -6     -23    -24    +21    -22    $ form
  51    4   -2.3688     +5     -6     -23    +24    +10    -11    $ form
  52    4   -2.3688     +5     -6     -23    +24    +11    -12    $ form
  53    4   -2.3688     +5     -6     -23    +24    +12    -13    $ form
  54    4   -2.3688     +5     -6     -23    +24    +13    -14    $ form
  55    4   -2.3688     +5     -6     -23    +24    +14    -15    $ form
  56    4   -2.3688     +5     -6     -23    +24    +15    -16    $ form
  57    4   -2.3688     +5     -6     -23    +24    +16    -17    $ form
  58    4   -2.3688     +5     -6     -23    +24    +17    -18    $ form
  59    4   -2.3688     +5     -6     -23    +24    +18    -19    $ form
  60    4   -2.3688     +5     -6     -23    +24    +19    -20    $ form
  61    4   -2.3688     +5     -6     -23    +24    +20    -21    $ form
  62    4   -2.3688     +5     -6     -23    +24    +21    -22    $ form
  63    4   -2.3688     +5     -6     +23    -24    +10    -11    $ form
  64    4   -2.3688     +5     -6     +23    -24    +11    -12    $ form
  65    4   -2.3688     +5     -6     +23    -24    +12    -13    $ form
  66    4   -2.3688     +5     -6     +23    -24    +13    -14    $ form
  67    4   -2.3688     +5     -6     +23    -24    +14    -15    $ form
  68    4   -2.3688     +5     -6     +23    -24    +15    -16    $ form
  69    4   -2.3688     +5     -6     +23    -24    +16    -17    $ form
  70    4   -2.3688     +5     -6     +23    -24    +17    -18    $ form
  71    4   -2.3688     +5     -6     +23    -24    +18    -19    $ form
  72    4   -2.3688     +5     -6     +23    -24    +19    -20    $ form
  73    4   -2.3688     +5     -6     +23    -24    +20    -21    $ form
```

```
 74   4   -2.3688    +5   -6   +23   -24   +21   -22   $ form
 75   4   -2.3688    +5   -6   +23   +24   +10   -11   $ form
 76   4   -2.3688    +5   -6   +23   +24   +11   -12   $ form
 77   4   -2.3688    +5   -6   +23   +24   +12   -13   $ form
 78   4   -2.3688    +5   -6   +23   +24   +13   -14   $ form
 79   4   -2.3688    +5   -6   +23   +24   +14   -15   $ form
 80   4   -2.3688    +5   -6   +23   +24   +15   -16   $ form
 81   4   -2.3688    +5   -6   +23   +24   +16   -17   $ form
 82   4   -2.3688    +5   -6   +23   +24   +17   -18   $ form
 83   4   -2.3688    +5   -6   +23   +24   +18   -19   $ form
 84   4   -2.3688    +5   -6   +23   +24   +19   -20   $ form
 85   4   -2.3688    +5   -6   +23   +24   +20   -21   $ form
 86   4   -2.3688    +5   -6   +23   +24   +21   -22   $ form
c
c    =============================================================
c    ===== formation region to radius=25 cm
c    =============================================================
c
 87   4   -2.3688    +6   -7   -23   -24   +10   -11   $ form
 88   4   -2.3688    +6   -7   -23   -24   +11   -12   $ form
 89   4   -2.3688    +6   -7   -23   -24   +12   -13   $ form
 90   4   -2.3688    +6   -7   -23   -24   +13   -14   $ form
 91   4   -2.3688    +6   -7   -23   -24   +14   -15   $ form
 92   4   -2.3688    +6   -7   -23   -24   +15   -16   $ form
 93   4   -2.3688    +6   -7   -23   -24   +16   -17   $ form
 94   4   -2.3688    +6   -7   -23   -24   +17   -18   $ form
 95   4   -2.3688    +6   -7   -23   -24   +18   -19   $ form
 96   4   -2.3688    +6   -7   -23   -24   +19   -20   $ form
 97   4   -2.3688    +6   -7   -23   -24   +20   -21   $ form
 98   4   -2.3688    +6   -7   -23   -24   +21   -22   $ form
 99   4   -2.3688    +6   -7   -23   +24   +10   -11   $ form
100   4   -2.3688    +6   -7   -23   +24   +11   -12   $ form
101   4   -2.3688    +6   -7   -23   +24   +12   -13   $ form
102   4   -2.3688    +6   -7   -23   +24   +13   -14   $ form
103   4   -2.3688    +6   -7   -23   +24   +14   -15   $ form
104   4   -2.3688    +6   -7   -23   +24   +15   -16   $ form
105   4   -2.3688    +6   -7   -23   +24   +16   -17   $ form
106   4   -2.3688    +6   -7   -23   +24   +17   -18   $ form
107   4   -2.3688    +6   -7   -23   +24   +18   -19   $ form
108   4   -2.3688    +6   -7   -23   +24   +19   -20   $ form
109   4   -2.3688    +6   -7   -23   +24   +20   -21   $ form
110   4   -2.3688    +6   -7   -23   +24   +21   -22   $ form
111   4   -2.3688    +6   -7   +23   -24   +10   -11   $ form
112   4   -2.3688    +6   -7   +23   -24   +11   -12   $ form
113   4   -2.3688    +6   -7   +23   -24   +12   -13   $ form
114   4   -2.3688    +6   -7   +23   -24   +13   -14   $ form
115   4   -2.3688    +6   -7   +23   -24   +14   -15   $ form
116   4   -2.3688    +6   -7   +23   -24   +15   -16   $ form
117   4   -2.3688    +6   -7   +23   -24   +16   -17   $ form
118   4   -2.3688    +6   -7   +23   -24   +17   -18   $ form
119   4   -2.3688    +6   -7   +23   -24   +18   -19   $ form
120   4   -2.3688    +6   -7   +23   -24   +19   -20   $ form
121   4   -2.3688    +6   -7   +23   -24   +20   -21   $ form
122   4   -2.3688    +6   -7   +23   -24   +21   -22   $ form
123   4   -2.3688    +6   -7   +23   +24   +10   -11   $ form
124   4   -2.3688    +6   -7   +23   +24   +11   -12   $ form
125   4   -2.3688    +6   -7   +23   +24   +12   -13   $ form
126   4   -2.3688    +6   -7   +23   +24   +13   -14   $ form
127   4   -2.3688    +6   -7   +23   +24   +14   -15   $ form
128   4   -2.3688    +6   -7   +23   +24   +15   -16   $ form
129   4   -2.3688    +6   -7   +23   +24   +16   -17   $ form
130   4   -2.3688    +6   -7   +23   +24   +17   -18   $ form
131   4   -2.3688    +6   -7   +23   +24   +18   -19   $ form
132   4   -2.3688    +6   -7   +23   +24   +19   -20   $ form
133   4   -2.3688    +6   -7   +23   +24   +20   -21   $ form
134   4   -2.3688    +6   -7   +23   +24   +21   -22   $ form
c
c    =============================================================
c    ===== formation region to radius=40 cm
c    =============================================================
c
135   4   -2.3688    +7   -8   -23   -24   +10   -11   $ form
136   4   -2.3688    +7   -8   -23   -24   +11   -12   $ form
137   4   -2.3688    +7   -8   -23   -24   +12   -13   $ form
138   4   -2.3688    +7   -8   -23   -24   +13   -14   $ form
139   4   -2.3688    +7   -8   -23   -24   +14   -15   $ form
140   4   -2.3688    +7   -8   -23   -24   +15   -16   $ form
141   4   -2.3688    +7   -8   -23   -24   +16   -17   $ form
142   4   -2.3688    +7   -8   -23   -24   +17   -18   $ form
143   4   -2.3688    +7   -8   -23   -24   +18   -19   $ form
144   4   -2.3688    +7   -8   -23   -24   +19   -20   $ form
145   4   -2.3688    +7   -8   -23   -24   +20   -21   $ form
146   4   -2.3688    +7   -8   -23   -24   +21   -22   $ form
147   4   -2.3688    +7   -8   -23   +24   +10   -11   $ form
148   4   -2.3688    +7   -8   -23   +24   +11   -12   $ form
149   4   -2.3688    +7   -8   -23   +24   +12   -13   $ form
150   4   -2.3688    +7   -8   -23   +24   +13   -14   $ form
151   4   -2.3688    +7   -8   -23   +24   +14   -15   $ form
152   4   -2.3688    +7   -8   -23   +24   +15   -16   $ form
153   4   -2.3688    +7   -8   -23   +24   +16   -17   $ form
154   4   -2.3688    +7   -8   -23   +24   +17   -18   $ form
155   4   -2.3688    +7   -8   -23   +24   +18   -19   $ form
156   4   -2.3688    +7   -8   -23   +24   +19   -20   $ form
157   4   -2.3688    +7   -8   -23   +24   +20   -21   $ form
158   4   -2.3688    +7   -8   -23   +24   +21   -22   $ form
159   4   -2.3688    +7   -8   +23   -24   +10   -11   $ form
160   4   -2.3688    +7   -8   +23   -24   +11   -12   $ form
161   4   -2.3688    +7   -8   +23   -24   +12   -13   $ form
162   4   -2.3688    +7   -8   +23   -24   +13   -14   $ form
163   4   -2.3688    +7   -8   +23   -24   +14   -15   $ form
164   4   -2.3688    +7   -8   +23   -24   +15   -16   $ form
165   4   -2.3688    +7   -8   +23   -24   +16   -17   $ form
166   4   -2.3688    +7   -8   +23   -24   +17   -18   $ form
167   4   -2.3688    +7   -8   +23   -24   +18   -19   $ form
168   4   -2.3688    +7   -8   +23   -24   +19   -20   $ form
169   4   -2.3688    +7   -8   +23   -24   +20   -21   $ form
170   4   -2.3688    +7   -8   +23   -24   +21   -22   $ form
171   4   -2.3688    +7   -8   +23   +24   +10   -11   $ form
172   4   -2.3688    +7   -8   +23   +24   +11   -12   $ form
173   4   -2.3688    +7   -8   +23   +24   +12   -13   $ form
174   4   -2.3688    +7   -8   +23   +24   +13   -14   $ form
175   4   -2.3688    +7   -8   +23   +24   +14   -15   $ form
176   4   -2.3688    +7   -8   +23   +24   +15   -16   $ form
177   4   -2.3688    +7   -8   +23   +24   +16   -17   $ form
178   4   -2.3688    +7   -8   +23   +24   +17   -18   $ form
179   4   -2.3688    +7   -8   +23   +24   +18   -19   $ form
180   4   -2.3688    +7   -8   +23   +24   +19   -20   $ form
181   4   -2.3688    +7   -8   +23   +24   +20   -21   $ form
182   4   -2.3688    +7   -8   +23   +24   +21   -22   $ form
c
c    =============================================================
c    ===== formation region to radius= 60 cm
c    =============================================================
c
183   4   -2.3688    +8   -9   -23   -24   +10   -11   $ form
184   4   -2.3688    +8   -9   -23   -24   +11   -12   $ form
185   4   -2.3688    +8   -9   -23   -24   +12   -13   $ form
186   4   -2.3688    +8   -9   -23   -24   +13   -14   $ form
187   4   -2.3688    +8   -9   -23   -24   +14   -15   $ form
188   4   -2.3688    +8   -9   -23   -24   +15   -16   $ form
```

```
189   4  -2.3688     +8    -9    -23    -24    +16    -17    $ form
190   4  -2.3688     +8    -9    -23    -24    +17    -18    $ form
191   4  -2.3688     +8    -9    -23    -24    +18    -19    $ form
192   4  -2.3688     +8    -9    -23    -24    +19    -20    $ form
193   4  -2.3688     +8    -9    -23    -24    +20    -21    $ form
194   4  -2.3688     +8    -9    -23    -24    +21    -22    $ form
195   4  -2.3688     +8    -9    -23    +24    +10    -11    $ form
196   4  -2.3688     +8    -9    -23    +24    +11    -12    $ form
197   4  -2.3688     +8    -9    -23    +24    +12    -13    $ form
198   4  -2.3688     +8    -9    -23    +24    +13    -14    $ form
199   4  -2.3688     +8    -9    -23    +24    +14    -15    $ form
200   4  -2.3688     +8    -9    -23    +24    +15    -16    $ form
201   4  -2.3688     +8    -9    -23    +24    +16    -17    $ form
202   4  -2.3688     +8    -9    -23    +24    +17    -18    $ form
203   4  -2.3688     +8    -9    -23    +24    +18    -19    $ form
204   4  -2.3688     +8    -9    -23    +24    +19    -20    $ form
205   4  -2.3688     +8    -9    -23    +24    +20    -21    $ form
206   4  -2.3688     +8    -9    -23    +24    +21    -22    $ form
207   4  -2.3688     +8    -9    +23    -24    +10    -11    $ form
208   4  -2.3688     +8    -9    +23    -24    +11    -12    $ form
209   4  -2.3688     +8    -9    +23    -24    +12    -13    $ form
210   4  -2.3688     +8    -9    +23    -24    +13    -14    $ form
211   4  -2.3688     +8    -9    +23    -24    +14    -15    $ form
212   4  -2.3688     +8    -9    +23    -24    +15    -16    $ form
213   4  -2.3688     +8    -9    +23    -24    +16    -17    $ form
214   4  -2.3688     +8    -9    +23    -24    +17    -18    $ form
215   4  -2.3688     +8    -9    +23    -24    +18    -19    $ form
216   4  -2.3688     +8    -9    +23    -24    +19    -20    $ form
217   4  -2.3688     +8    -9    +23    -24    +20    -21    $ form
218   4  -2.3688     +8    -9    +23    -24    +21    -22    $ form
219   4  -2.3688     +8    -9    +23    +24    +10    -11    $ form
220   4  -2.3688     +8    -9    +23    +24    +11    -12    $ form
221   4  -2.3688     +8    -9    +23    +24    +12    -13    $ form
222   4  -2.3688     +8    -9    +23    +24    +13    -14    $ form
223   4  -2.3688     +8    -9    +23    +24    +14    -15    $ form
224   4  -2.3688     +8    -9    +23    +24    +15    -16    $ form
225   4  -2.3688     +8    -9    +23    +24    +16    -17    $ form
226   4  -2.3688     +8    -9    +23    +24    +17    -18    $ form
227   4  -2.3688     +8    -9    +23    +24    +18    -19    $ form
228   4  -2.3688     +8    -9    +23    +24    +19    -20    $ form
229   4  -2.3688     +8    -9    +23    +24    +20    -21    $ form
230   4  -2.3688     +8    -9    +23    +24    +21    -22    $ form
c
c    ===============================================================
c    ===== external void
c    ===============================================================
c
231   0              +9                                           $ exter
                   : -10                                          $ exter
                   : +22                                          $ exter

c
c    ===============================================================
c    ===== surface cards
c    ===============================================================
c    ===== general symbols
c    ===============================================================
c    ===============================================================
c    ===== detectors
c    ===============================================================
c
   1  cy        1.27                                              $ c_nea
   2  cy        2.54                                              $ c_far
c
c    ===============================================================
```

```
c    ===== tool, borehole and formation cylinders
c    ===============================================================
c
   3  cy       3.81                                               $ c_too
   4  cy       8.255                                              $ c_hal
   5  c/y     -6.34      0.0      10.16                           $ c_bh
   6  c/y     -6.34      0.0      15.0                            $ c_for
   7  c/y     -6.34      0.0      25.0                            $ c_for
   8  c/y     -6.34      0.0      40.0                            $ c_for
   9  c/y     -6.34      0.0      60.0                            $ c_for
c
  10  py     -38.1                                                $ btm
  11  py      -5.0                                                $ b_sou
  12  py       5.0                                                $ t_sou
  13  py      15.24                                               $ b_nea
  14  py      22.86                                               $ t_nea
  15  py      30.0                                                $ plane
  16  py      38.1                                                $ b_far
  17  py      46.0                                                $ plane
  18  py      54.0                                                $ plane
  19  py      63.5                                                $ t_far
  20  py      70.0                                                $ plane
  21  py      82.5                                                $ plane
  22  py     101.6                                                $ top
c
c    ===============================================================
c    ===== divide formation into 4 pieces
c    ===============================================================
c
  23  p        1.0       0.0       1.0       0.0                  $ p1
  24  p        1.0       0.0      -1.0       0.0                  $ p2

c
c    ===============================================================
c    ===== data cards
c    ===============================================================
c
mode   n
print 102
drxs
c
c    ===============================================================
c    ==== material #    1
c    ===============================================================
c    name     = helium-3
c    density =    0.000502 g/cc
c
  m1    2003.60c 1.00000
c
c    ===============================================================
c    ==== material #    2
c    ===============================================================
c    name     = iron
c    density =    7.8600 g/cc
c
  m2   26000.50c 1.00000
c
c    ===============================================================
c    ==== material #    3
c    ===============================================================
c    name     = borehole fluid - fw
c    density =    1.0000 g/cc
c
  m3    1001.60c 0.66667      8016.60c 0.33333
c
```

```
c    ================================================================
c    ==== material #    4
c    ================================================================
c    name    = formation - 20 pu limestone, fw
c    density =    2.3688 g/cc
c
  m4    1001.60c 0.15675      6012.50c 0.15298      8016.60c 0.53730
c
c    ================================================================
c    ==== material #    5
c    ================================================================
c    name    = formation - 1 pu limestone, fw
c    density =    2.6939 g/cc
c
  m5    1001.60c 0.00818      6012.50c 0.19755      8016.60c 0.59673
c
c
c    ================================================================
c    ===== s(a,b) treatment
c    ================================================================
c
mt3   lwtr
mt4   lwtr.01
mt5   lwtr.01t
c
c    ================================================================
c    ===== neutron source => ambe neutron source
c    ================================================================
c
c        sdir     0.0   1.0   0.0  0.6  0.5
 sdef     cel=3 wgt=1 erg=d1 dir=d2 vec= 0.0 1.0 0.0
 si1               .0026126  .0408000  .0673800  .0865170
        .1110900  .1227700  .1356900  .1499600  .1647300
        .1831600  .2024200  .2237100  .2427400  .2732400
        .3019700  .3337300  .3683300  .4076200  .4504900
        .4978700  .5502300  .6081000  .6720600  .7427400
        .8208500  .9071800  1.002600  1.108000  1.224600
        1.353400  1.495700  1.653000  1.826800  2.019000
        2.231300  2.466000  2.725300  3.011900  3.328700
        3.678800  4.065700  4.493300  4.965900  5.488100
        6.065300  6.703200  7.408200  8.187300  9.048400
       10.000000 11.052000
 sp1    .000000   .005728   .003977   .002886   .003685
        .001752   .001938   .002141   .002366   .002615
        .002889   .003193   .003530   .003900   .004310
        .004764   .005265   .005819   .006431   .007107
        .007854   .008681   .009594   .010602   .011717
        .012950   .014313   .012208   .013505   .014918
        .016482   .016790   .016973   .020516   .022661
        .025052   .027678   .037100   .051803   .046116
        .046571   .051469   .063324   .068786   .051124
        .046359   .056039   .060159   .037157   .028095
        .019113
sp2   -31 0.5
c
c    ================================================================
c    ===== tallies
c    ================================================================
c
fq0    e  f
c    ================================================================
c    =====  tally 44, absorption rate in cells 2 (far)
c    ================================================================
f44:n  2
fc44   neutron total reaction rate in cells 1 (near) and 2 (far)
e44    0.1e-6  0.41e-6 10.6e-6 101e-6 1.5e-3 26e-3 .49 2.7 12.2 17.3
em44   1 9r
fm44    1.0023e-04  1  103
c
c    ================================================================
c    =====  cutoffs
c    ================================================================
c
phys:n  14  14
cut:n   830000  0.0
thtme   0
prdmp   3j 1
ctme    3600
tmp1    0.0253e-6  230r
c vol     1          230r
c area    1           23r
c
wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01
        1.3183e-02  1.2343e-01  5.4376e-03  5.4376e-03  5.4376e-03
        5.4376e-03  5.4376e-03  3.9857e-01  5.4376e+02  5.4376e+02
        2.7765e+02  7.5563e-01  6.5276e-02  1.8178e-01  7.0702e-03
        5.4376e-03  5.4376e-03  5.4376e-03  2.7976e-02  2.7976e-02
        6.9505e+01  5.4376e+02  7.8168e+01  1.2746e+00  3.1653e-01
        1.8776e-01  1.5314e-02  5.4376e-03  5.4376e-03  5.4376e-03
        2.9537e-02  2.9537e-02  1.0680e+01  5.4376e+02  7.8002e+01
        6.0885e+00  1.9371e+00  4.1142e-01  8.4630e-02  2.2850e-02
        2.2850e-02  2.2851e-02  1.0777e-01  1.0777e-01  6.4436e+00
        5.4376e+02  3.0382e+01  1.0628e+00  2.2054e-01  1.0523e-01
        1.0598e-02  5.4376e-03  5.4376e-03  5.4376e-03  2.0858e-02
        2.0858e-02  2.9028e+00  5.4376e+02  3.6225e+01  9.3802e-01
        2.2052e-01  1.0528e-01  1.0603e-02  5.4376e-03  5.4376e-03
        5.4376e-03  1.9844e-02  1.9844e-02  3.4659e+00  5.4376e+02
        5.6288e+01  4.8798e-01  5.6185e-02  8.8100e-02  5.4376e-03
        5.4376e-03  5.4376e-03  5.4376e-03  1.2737e-02  1.2737e-02
        6.3683e+00  5.4376e+02  7.7442e+01  1.1057e+01  2.2675e+00
        6.0164e-01  2.0593e-01  9.7778e-02  9.7778e-02  9.7799e-02
        2.8976e-01  2.8976e-01  5.1704e+00  4.0053e+02  1.0606e+01
        1.2840e+00  2.5166e-01  6.2879e-02  1.7525e-02  8.2302e-03
        8.2302e-03  8.2311e-03  2.9484e-02  2.9484e-02  7.1153e-01
        4.1813e+02  1.1420e+01  1.4398e+00  2.5168e-01  6.2878e-02
        1.7524e-02  9.8269e-03  9.8269e-03  9.8282e-03  3.3765e-02
        3.3765e-02  7.6667e-01  2.0561e+02  4.7561e+00  4.9360e-01
        1.0839e-01  2.6856e-02  6.5165e-03  5.4376e-03  5.4376e-03
        5.4376e-03  1.0606e-02  1.0606e-02  3.1804e-01  5.4376e+02
        5.4376e+02  5.2172e+01  6.3354e+00  6.3354e+00  1.7651e+00
        8.3526e-01  8.3526e-01  8.3583e-01  8.3583e-01  2.3211e+00
        3.0391e+01  1.4502e+02  1.4502e+02  3.5676e+00  5.3502e-01
        5.3502e-01  1.4243e-01  5.1731e-02  5.1731e-02  5.1760e-02
        5.1760e-02  1.5475e-01  2.1337e+00  2.2354e+02  2.2354e+02
        5.4783e+00  8.0092e-01  8.0092e-01  2.1635e-01  8.2825e-02
        8.2825e-02  8.2873e-02  8.2873e-02  2.4264e-01  3.2576e+00
        5.8205e+01  5.8205e+01  1.4125e+00  1.9358e-01  1.9358e-01
        4.8765e-02  1.8193e-02  1.8193e-02  1.8202e-02  1.8202e-02
        5.7382e-02  8.5697e-01  5.4376e+02  5.4376e+02  1.9501e+02
        4.3795e+01  4.3795e+01  1.8594e+01  1.1175e+01  1.1175e+01
        1.1188e+01  1.1188e+01  2.2115e+01  1.2401e+02  3.1569e+02
        3.1569e+02  1.7356e+01  3.1466e+00  3.1466e+00  1.3307e+00
        1.0193e+00  1.0193e+00  1.0204e+00  1.0204e+00  2.0302e+00
        1.1171e+01  3.1575e+02  3.1575e+02  1.7358e+01  4.0853e+00
        4.0853e+00  1.7341e+00  1.0194e+00  1.0194e+00  1.0205e+00
        1.0205e+00  2.0303e+00  1.1172e+01  8.3890e+01  8.3890e+01
        4.6086e+00  1.0557e+00  1.0557e+00  4.3674e-01  2.5267e-01
        2.5267e-01  2.5294e-01  2.5294e-01  5.1594e-01  2.9604e+00
       -1.0000e+00
wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02
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        1.9247e-02  1.1756e-02  1.9036e-03  4.5802e-04  4.2660e-04
        4.6101e-04  2.0273e-03  9.2488e-03  7.7646e-01  1.5880e+00
        1.5880e+00  3.2581e-01  5.6523e-02  8.4317e-02  6.3782e-03
        7.9420e-04  7.6414e-04  7.9513e-04  9.9312e-03  9.9312e-03
        1.3818e+00  1.5880e+00  1.5880e+00  1.5880e+00  3.2129e-01
        2.0132e-01  1.9183e-02  3.7223e-03  3.3823e-03  3.7288e-03
        4.2937e-02  4.2937e-02  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  8.6552e-01  2.2900e-01  5.6212e-02  1.6773e-02
        1.6773e-02  1.6965e-02  6.0314e-02  6.0314e-02  1.5880e+00
        1.5880e+00  1.5880e+00  7.0903e-01  1.1152e-01  4.3747e-02
        9.0062e-03  2.5991e-03  2.5991e-03  2.6214e-03  2.1023e-02
        2.1023e-02  6.2600e-01  1.5880e+00  1.5880e+00  6.0060e-01
        1.1429e-01  4.4277e-02  9.2444e-03  2.1392e-03  2.1392e-03
        2.1579e-03  1.8356e-02  1.8356e-02  5.8795e-01  1.5880e+00
        1.5880e+00  2.5971e-01  4.7687e-02  1.9363e-02  4.1038e-03
        1.0309e-03  1.0309e-03  1.0374e-03  8.5303e-03  8.5303e-03
        3.0474e-01  1.5880e+00  1.5880e+00  1.5880e+00  1.3679e+00
        4.2220e-01  1.7796e-01  9.6109e-02  9.6109e-02  9.9062e-02
        3.0572e-01  3.0572e-01  1.5880e+00  1.5880e+00  1.5880e+00
        1.0978e+00  1.7900e-01  5.2649e-02  2.0479e-02  1.1504e-02
        1.1504e-02  1.1829e-02  4.5590e-02  4.5590e-02  7.0268e-01
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        2.0222e-02  1.2029e-02  1.2029e-02  1.2354e-02  4.8261e-02
        4.8261e-02  7.4323e-01  1.5880e+00  1.5880e+00  4.6283e-01
        8.2036e-02  2.3525e-02  8.7609e-03  4.0469e-03  4.0469e-03
        4.1419e-03  1.8180e-02  1.8180e-02  3.0805e-01  1.5880e+00
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        1.4073e+00  1.4073e+00  1.4452e+00  1.4452e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  7.5695e-01
        7.5695e-01  2.9543e-01  1.0399e-01  1.0399e-01  1.0656e-01
        1.0656e-01  3.5910e-01  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.1149e+00  1.1149e+00  4.3249e-01  1.6244e-01
        1.6244e-01  1.6680e-01  1.6680e-01  5.4930e-01  1.5880e+00
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        1.3673e-01  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00  1.5880e+00
        1.5880e+00  1.5880e+00  1.5880e+00  1.1394e+00  6.7161e-01
        6.7161e-01  6.9171e-01  6.9171e-01  1.5656e+00  1.5880e+00
       -1.0000e+00
wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01
        2.5989e-02  9.6579e-03  2.7290e-03  7.7101e-04  7.5365e-04
        7.7837e-04  3.3590e-03  6.3425e-03  2.1031e-01  7.4392e-01
        7.4392e-01  2.8421e-01  8.3287e-02  7.1040e-02  9.6361e-03
        1.2119e-03  1.2386e-03  1.2144e-03  7.2849e-03  7.2849e-03
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        3.9413e-01  5.0412e-02  8.6695e-03  8.6385e-03  8.7032e-03
        1.0651e-01  1.0651e-01  7.4392e-01  7.4392e-01  7.4392e-01
        7.4392e-01  7.4392e-01  3.8527e-01  1.0286e-01  3.1077e-02
        3.1077e-02  3.1603e-02  1.0566e-01  1.0566e-01  7.4392e-01
        7.4392e-01  7.4392e-01  7.4392e-01  1.4784e-01  6.5230e-02
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        3.1621e-03  2.6527e-02  2.6527e-02  7.4392e-01  7.4392e-01
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        2.6799e-02  2.7828e-02  1.2044e-01  1.2044e-01  7.4392e-01
        7.4392e-01  7.4392e-01  7.4392e-01  3.4999e-01  1.2104e-01
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        1.2085e-01  7.4392e-01  7.4392e-01  7.4392e-01  7.4392e-01
        1.7893e-01  6.2291e-02  2.5493e-02  1.1093e-02  1.1093e-02
        1.1453e-02  5.2194e-02  5.2194e-02  7.4392e-01  7.4392e-01
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        6.0480e-01  6.3601e-01  6.3601e-01  7.4392e-01  7.4392e-01
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        2.3194e-03  5.6218e-03  1.0135e-02  1.1683e-01  5.0000e-01
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        3.1627e-03  3.1948e-03  3.1849e-03  9.7673e-03  9.7673e-03
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        1.5339e-01  4.4614e-02  1.3383e-02  1.2935e-02  1.3586e-02
        5.9066e-02  5.9066e-02  5.0000e-01  5.0000e-01  5.0000e-01
        5.0000e-01  5.0000e-01  2.6053e-01  1.0159e-01  3.6332e-02
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        5.0000e-01  5.0000e-01  5.0000e-01  3.8364e-01  3.8364e-01
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         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01
         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01
         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01
         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01
         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01
         6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  5.5474e-01
         5.5474e-01  5.6948e-01  5.6948e-01  6.5593e-01  6.5593e-01
        -1.0000e+00
wwg       44 0 0
c wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
rdum      0.8
wwp:n     5  3  5
wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
nps  8e5
mesh     ref  0 0 0
         origin 0.001 -38.101 0.001
```

```
axs 0 1 0
vec 1 0 0
geom cyl
imesh   1.27 2.54  3.81 15  20   40  60  80
iints  10  10    10   10  10  10   10  10
jmesh   33 43 53.24 60.86 76.1 101.5 139.8
jints 10  10 10    10     10   10    10
kmesh   0.25 .5  .75    1
kints 10    10  10   10
```

99/11/12
15:47:06

D2: Variations From Base Model, Oil Well Problem

```
og1a differences
----------xxxxx--------------
og1b differences
708,709c708,709
< c wwg        44 3 0
< c wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> wwg        44 3 0
> wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
----------xxxxx--------------
og2a differences
----------xxxxx--------------
og2b differences
708,709c708,709
< c wwg        44 3 0
< c wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> wwg        44 3 0
>  wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
----------xxxxx--------------
og3a differences
----------xxxxx--------------
og3b differences
708c708
< c wwg        44 3 0
---
> wwg        44 0 0
714,724c714,724
< c mesh    ref  0 0 0
< c        origin 0.001 -38.101 0.001
< c        axs 0 1 0
< c        vec 1 0 0
< c        geom cyl
< c        imesh   1.27 2.54  3.81 15  20   40  60  80
< c        iints  10  10     10   10  10  10    10  10
< c        jmesh   33 43 53.24 60.86 76.1 101.5 139.6
< c        jints 10  10 10    10      10   10     10
< c        kmesh   0.25 .5  .75    1
< c        kints 10    10  10    10
---
> mesh    ref  0 0 0
>        origin 0.001 -38.101 0.001
>        axs 0 1 0
>        vec 1 0 0
>        geom cyl
>        imesh   1.27 2.54  3.81 15  20   40  60  80
>        iints  10  10     10   10  10  10    10  10
>        jmesh   33 43 53.24 60.86 76.1 101.5 139.8
>        jints 10  10 10    10      10   10     10
>        kmesh   0.25 .5  .75    1
>        kints 10    10  10    10
----------xxxxx--------------
og4a differences
463a464
> imp:n  1 229r 0
473,707d473
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01 (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02 (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01 (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01 (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01 (cont)
711,712c477,478
< wwp:n      5  3  5
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> c wwp:n      5  3  5
> c wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
----------xxxxx--------------
og4b differences
463a464
> imp:n  1 229r 0
465c466
< cut:n   830000  0.0
---
> cut:n   830000  0.0
473,708c474
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01 (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02 (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01 (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01 (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01 (cont)
< c wwg        44 3 0
---
> wwg        44 0 0
711,712c477,478
< wwp:n      5  3  5
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> c wwp:n      5  3  5
> c wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
714,724c480,490
< c mesh    ref  0 0 0
< c        origin 0.001 -38.101 0.001
< c        axs 0 1 0
< c        vec 1 0 0
< c        geom cyl
< c        imesh   1.27 2.54  3.81 15  20   40  60  80
< c        iints  10  10     10   10  10  10    10  10
< c        jmesh   33 43 53.24 60.86 76.1 101.5 139.6
< c        jints 10  10 10    10      10   10     10
< c        kmesh   0.25 .5  .75    1
< c        kints 10    10  10    10
---
> mesh    ref  0 0 0
>        origin 0.001 -38.101 0.001
>        axs 0 1 0
>        vec 1 0 0
>        geom cyl
>        imesh   1.27 2.54  3.81 15  20   40  60  80
>        iints  10  10     10   10  10  10    10  10
>        jmesh   33 43 53.24 60.86 76.1 101.5 139.8
>        jints 10  10 10    10      10   10     10
>        kmesh   0.25 .5  .75    1
>        kints 10    10  10    10
----------xxxxx--------------
oww14b differences
465c465
< cut:n   830000  0.0
---
> cut:n   830000  0.0   -.1  -.05
467c467
< prdmp    3j 1
---
> prdmp    3j 2
473,707d472
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01 (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02 (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01 (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01 (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01 (cont)
```

D2: Variations From Base Model, Oil Well Problem


```
712,713c477
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
< nps  8e5
---
> nps 1e5
715c479
< c        origin 0.001 -38.101 0.001
---
> c        origin 0.001 -38.001 0.001
724a489,724
> wwe:n  4.1399E-07  1.0130E-04  2.6058E-02  2.7253E+00  1.7333E+01
> wwn1:n   2.8361E-01  1.2133E-04  0.0000E+00  0.0000E+00  1.6678E+01 (cont)
> wwn2:n   1.3004E-01  2.6945E-04  4.4455E+01  0.0000E+00  8.1770E-01 (cont)
> wwn3:n   6.3580E-02  8.2689E-04  2.7404E+00  0.0000E+00  5.8465E-01 (cont)
> wwn4:n   4.4863E-02  1.5362E-03  1.2681E+00  6.5260E+00  3.0904E-01 (cont)
> wwn5:n   1.7756E-02  4.4858E-03  5.0000E-01  3.0477E+00  1.0193E-01 (cont)
----------xxxxx--------------
oww14c differences
465c465
< cut:n   830000  0.0
---
> cut:n   830000  0.0   -.1  -.05
467c467
< prdmp   3j 1
---
> prdmp   3j 2
473,707d472
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01  (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02  (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01  (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01  (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01  (cont)
712,713c477
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
724a489,724
> wwe:n  4.1399E-07  1.0130E-04  2.6058E-02  2.7253E+00  1.7333E+01
> wwn1:n   2.8361E-01  1.2133E-04  0.0000E+00  0.0000E+00  1.6678E+01 (cont)
> wwn2:n   1.3004E-01  2.6945E-04  4.4455E+01  0.0000E+00  8.1770E-01 (cont)
> wwn3:n   6.3580E-02  8.2689E-04  2.7404E+00  0.0000E+00  5.8465E-01 (cont)
> wwn4:n   4.4863E-02  1.5362E-03  1.2681E+00  6.5260E+00  3.0904E-01 (cont)
> wwn5:n   1.7756E-02  4.4858E-03  5.0000E-01  3.0477E+00  1.0193E-01 (cont)
----------xxxxx--------------
oww24b differences
465c465
< cut:n   830000  0.0
---
> cut:n   830000  0.0   -.1  -.05
467c467
< prdmp   3j 1
---
> prdmp   3j 2
473,707d472
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01  (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02  (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01  (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01  (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01  (cont)
712,713c477
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
715c479
< c        origin 0.001 -38.101 0.001
---
> c        origin 0.001 -38.001 0.001
724a489,724
> wwe:n  4.1399E-07  1.0130E-04  2.6058E-02  2.7253E+00  1.7333E+01
> wwn1:n   3.1151E-01  6.1907E-04  0.0000E+00  0.0000E+00  2.2485E+01 (cont)
> wwn2:n   1.7369E-01  9.8770E-04  8.6021E+00  0.0000E+00  1.6672E+00 (cont)
> wwn3:n   5.6939E-02  2.9006E-03  5.8225E+00  0.0000E+00  7.8767E-01 (cont)
> wwn4:n   9.3729E-02  4.8202E-03  3.4337E+00  2.4721E-01  1.0855E+00 (cont)
> wwn5:n   9.1026E-02  9.4268E-03  5.0000E-01  4.6919E-01  3.9345E-01 (cont)
----------xxxxx--------------
oww24c differences
465c465
< cut:n   830000  0.0
---
> cut:n   830000  0.0   -.1  -.05
467c467
< prdmp   3j 1
---
> prdmp   3j 2
473,707d472
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01  (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02  (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01  (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01  (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01  (cont)
712,713c477
< wwe:n    4.1399-7 1.013-4 2.6058-2 2.7253 17.333
715c479
< c        origin 0.001 -38.101 0.001
---
> c        origin 0.001 -38.001 0.001
724a489,724
> wwe:n  4.1399E-07  1.0130E-04  2.6058E-02  2.7253E+00  1.7333E+01
> wwn1:n   3.1151E-01  6.1907E-04  0.0000E+00  0.0000E+00  2.2485E+01 (cont)
> wwn2:n   1.7369E-01  9.8770E-04  8.6021E+00  0.0000E+00  1.6672E+00 (cont)
> wwn3:n   5.6939E-02  2.9006E-03  5.8225E+00  0.0000E+00  7.8767E-01 (cont)
> wwn4:n   9.3729E-02  4.8202E-03  3.4337E+00  2.4721E-01  1.0855E+00 (cont)
> wwn5:n   9.1026E-02  9.4268E-03  5.0000E-01  4.6919E-01  3.9345E-01 (cont)
----------xxxxx--------------
oww3 differences
463a464
> imp:n  1 229r 0
467c468
< prdmp   3j 1
---
> prdmp   3j 2
473,707d473
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01  (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02  (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01  (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01  (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01  (cont)
711,712c477,478
< wwp:n      5  3  5
< wwe:n     4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> wwp:n      5  3  5  0 -1
> c wwe:n     4.1399-7 1.013-4 2.6058-2 2.7253 17.333
715c481
< c        origin 0.001 -38.101 0.001
---
> c        origin 0.001 -38.001 0.001
----------xxxxx--------------
oww4 differences
463a464
> imp:n  1 229r 0
467c468
< prdmp   3j 1
---
```

```
> prdmp   3j 2
473,707d473
< wwn1:n  5.4376e-03  5.4376e-03  5.4376e+02  5.4376e+02  1.8431e-01 (cont)
< wwn2:n  1.7757e-02  5.4350e-04  1.5880e+00  1.5880e+00  9.6258e-02 (cont)
< wwn3:n  2.4622e-01  9.9597e-03  7.4392e-01  7.4392e-01  1.0193e-01 (cont)
< wwn4:n  5.0000e-01  1.9691e-01  5.0000e-01  5.0000e-01  1.2681e-01 (cont)
< wwn5:n  6.5593e-01  6.5593e-01  6.5593e-01  6.5593e-01  2.0210e-01 (cont)
711,712c477,478
< wwp:n      5  3  5
< wwe:n     4.1399-7 1.013-4 2.6058-2 2.7253 17.333
---
> wwp:n      5  3  5  0 -1
> c wwe:n     4.1399-7 1.013-4 2.6058-2 2.7253 17.333
715c481
< c        origin 0.001 -38.101 0.001
---
> c        origin 0.001 -38.001 0.001
----------xxxxx--------------
```

Table D3: Explanation of Runs Performed in Assessment

Run	Explanation	Code Run
Og1a	Expert importances, no wwg, no ww used.	MCNP4C
Og1b	Same as Og1a, but cell-based ww's generated.	MCNP4C
Og2a	Expert importances, no wwg, no ww used.	MCNP4B
Og2b	Same as Og2a, but cell-based ww's generated.	MCNP4B
Og3a	Expert importances, complex geometry, no wwg, no ww used.	MCNP4C
Og3b	Same as Og3b, but mesh-based ww's generated.	MCNP4C
Og4a	Binary importances, complex geometry, no wwg, no ww used.	MCNP4C
Og4b	Same as Og4a, but mesh-based ww's generated.	MCNP4C
Og5a	Binary importances, simple geometry, no wwg, no ww used.	MCNP4C
Og5b	Same as Og5a, but mesh-based ww's generated.	MCNP4C
Oww14b	Applies cbww generated in Og1b	MCNP4B
Oww14C	Applies cbww generated in Og1b	MCNP4C
Oww24b	Applies cbww generated in Og2b	MCNP4B
Oww24C	Applies cbww generated in Og2b	MCNP4C
Oww3	Applies mbww generated in Og3b	MCNP4C
Oww4	Applies mbww generated in Og4b	MCNP4C
Oww5	Applies mbww generated in Og5b	MCNP4C

D4: Simplified Model, Oil Well Problem


```
message:
datapath=/usr/local/codes/data/mc/type1

testprob12  ==>> porosity tool model
c    ================================================================
c    ==================================================================
c    ===>>>  run       : prob12
c    ===>>>  tool      : generic porosity tool
c    ===>>>  source    : ambe
c    ===>>>  borehole  : 8" bh, fw
c    ===>>>  formation : 20 pu limestone, fw
c    ===>>>  casing    : none
c    ===>>>  detector  : he-3 at 4 atomospheres
c    ===>>>              near : 1"odx3"  at 7.5" centerline from source
c    ===>>>              far  : 2"odx10" at  20" centerline from source
c    ===>>>  shielding : none
c    ===>>>  sonde     : solid iron
c    ===>>>  weights   : xtrapt/diffusion
c    ===>>>   generate weights using wep patch with factor of 2.0 to far det
c    ===>>>       using a factor of 8.0; only use 50k particles
c    ===>>>  physics   : thermal cutin changed to -200
c    ===>>>              s(a,b) added for water
c    ==================================================================
c    ==================================================================
c
c
c    ==================================================================
c    ===== zone cards
c    ==================================================================
c    ===== near detector
c    ==================================================================
c
   1    1   -0.000502    -1     +13     -14                        $ det_n
c
c    ==================================================================
c    ===== far detector
c    ==================================================================
c
   2    1   -0.000502    -2     +16     -19                        $ det_f
c
c    ==================================================================
c    ===== source region
c    ==================================================================
c
   3    2   -7.86        -3     +11     -12                        $ sourc
c
c    ==================================================================
c    ===== iron sonde
c    ==================================================================
c
c  OR equally we could have done it easier with:
  4     2   -7.86        -3     +10     -22    &
                             #1 #2 #3          $ sonde, minus src, d1, d2
c
c    ==================================================================
c    ===== borehole    (water fill around iron sonde and detectors)
c    ==================================================================
c
  5    3   -1.0          +3      -5       +10    -22            $ bh
c
c    ==================================================================
c    ===== formation region to limit of model  (not radialy broken-up)
c    ==================================================================
c
  6    4   -2.3688       +5      -9    +10     -22     $ form
```

```
c
c
c    ==================================================================
c    ===== external void
c    ==================================================================
c
c
   7    0                +9                                       $ exter
                      :  -10                                      $ exter
                      :  +22                                      $ exter

c
c    ==================================================================
c    ===== surface cards
c    ==================================================================
c    ===== general symbols
c    ==================================================================
c    ==================================================================
c    ===== detectors
c    ==================================================================
c
   1  cy        1.27                                              $ c_nea
   2  cy        2.54                                              $ c_far
c
c    ==================================================================
c    ===== tool, borehole and formation cylinders
c    ==================================================================
c
   3  cy        3.81                                              $ c_too
c   4  cy        8.255                                            $ c_hal
   5  c/y      -6.34       0.0        10.16                       $ c_bh
c   6  c/y      -6.34       0.0        15.0                        $ c_for
c   7  c/y      -6.34       0.0        25.0                        $ c_for
c   8  c/y      -6.34       0.0        40.0                        $ c_for
   9  c/y      -6.34       0.0        60.0                        $ c_for
c
  10  py      -38.1                                               $ btm
  11  py       -5.0                                               $ b_sou
  12  py        5.0                                               $ t_sou
  13  py       15.24                                              $ b_nea
  14  py       22.86                                              $ t_nea
c 15  py       30.0                                               $ plane
  16  py       38.1                                               $ b_far
c 17  py       46.0                                               $ plane
c 18  py       54.0                                               $ plane
  19  py       63.5                                               $ t_far
c 20  py       70.0                                               $ plane
c 21  py       82.5                                               $ plane
  22  py      101.6                                               $ top
c
c    ==================================================================
c    ===== divide formation into 4 pieces
c    ==================================================================
c
c 23  p         1.0        0.0        1.0        0.0              $ p1
c 24  p         1.0        0.0       -1.0        0.0              $ p2

c
c    ==================================================================
c    ===== data cards
c    ==================================================================
c
mode   n
print 102
drxs
c
```

```
c    ================================================================
c    ==== material #    1
c    ================================================================
c    name     = helium-3
c    density =    0.000502 g/cc
c
   m1    2003.60c 1.00000
c
c    ================================================================
c    ==== material #    2
c    ================================================================
c    name     = iron
c    density =    7.8600 g/cc
c
   m2   26000.50c 1.00000
c
c    ================================================================
c    ==== material #    3
c    ================================================================
c    name     = borehole fluid - fw
c    density =    1.0000 g/cc
c
   m3    1001.60c 0.66667      8016.60c 0.33333
c
c    ================================================================
c    ==== material #    4
c    ================================================================
c    name     = formation - 20 pu limestone, fw
c    density =    2.3688 g/cc
c
   m4    1001.60c 0.15675      6012.50c 0.15298      8016.60c 0.53730
c
c    ================================================================
c    ==== material #    5
c    ================================================================
c    name     = formation - 1 pu limestone, fw
c    density =    2.6939 g/cc
c
   m5    1001.60c 0.00818      6012.50c 0.19755      8016.60c 0.59673
c
c
c    ================================================================
c    ===== s(a,b) treatment
c    ================================================================
c
mt3   lwtr
mt4   lwtr.01
mt5   lwtr.01t
c
c    ================================================================
c    ===== neutron source => ambe neutron source
c    ================================================================
c
c        sdir      0.0   1.0   0.0  0.6  0.5
 sdef      cel=3 wgt=1 erg=d1 dir=d2 vec= 0.0 1.0 0.0
 si1                .0026126  .0408000  .0673800  .0865170
        .1110900  .1227700  .1356900  .1499600  .1647300
        .1831600  .2024200  .2237100  .2427400  .2732400
        .3019700  .3337300  .3683300  .4076200  .4504900
        .4978700  .5502300  .6081000  .6720600  .7427400
        .8208500  .9071800  1.002600  1.108000  1.224600
        1.353400  1.495700  1.653000  1.826800  2.019000
        2.231300  2.466000  2.725300  3.011900  3.328700
        3.678800  4.065700  4.493300  4.965900  5.488100
        6.065300  6.703200  7.408200  8.187300  9.048400
```

```
        10.000000 11.052000
 sp1      .000000   .005728   .003977   .002886   .003685
          .001752   .001938   .002141   .002366   .002615
          .002889   .003193   .003530   .003900   .004310
          .004764   .005265   .005819   .006431   .007107
          .007854   .008681   .009594   .010602   .011717
          .012950   .014313   .012208   .013505   .014918
          .016482   .016790   .016973   .020516   .022661
          .025052   .027678   .037100   .051803   .046116
          .046571   .051469   .063324   .068786   .051124
          .046359   .056039   .060159   .037157   .028095
          .019113
sp2    -31 0.5
c
c    ================================================================
c    ===== tallies
c    ================================================================
c
fq0    e  f
c
f44:n  2
fc44   neutron total reaction rate in cells 1 (near) and 2 (far)
e44    0.1e-6  0.41e-6 10.6e-6 101e-6 1.5e-3 26e-3 .49 2.7 12.2 17.3
em44   1 9r
fm44    1.0023e-04  1  103
c
phys:n  14  14
cut:n   830000  0.0
imp:n 1 5r 0
thtme   0
prdmp   3j 1
ctme    3600
tmp1    0.0253e-6  6r
c vol      1           230r
c area     1            23r
c
wwg  44 0 0
c wwge:n 4.1399-7 1.013-4 2.6058-2 2.7253 17.333
rdum       0.8
c  wwp:n      5  3  5
c wwe:n      4.1399-7 1.013-4 2.6058-2 2.7253 17.333
nps  8e5
mesh      ref  0 0 0
          origin 0.001 -38.101 0.001
          axs 0 1 0
          vec 1 0 0
          geom cyl
          imesh   1.27 2.54  3.81 15  20   40  60  80
          iints  10  10    10   10  10  10   10  10
          jmesh   33 43 53.24 60.86 76.1 101.5 139.8
          jints 10  10 10    10     10   10    10
          kmesh   0.25 .5  .75    1
          kints 10    10  10   10
```

08/06/99
15:46:27

E1: Base Model in Class Problem

```
message:
datapath=/usr/local/codes/data/mc/type1

analog calculation of mfe problem, except for .01 MeV energy cutoff
 1     0         (1 -21):-2
 2     1 -2.03  -1  -3   2
 3     1 -2.03  -1  -4   3
 4     1 -2.03  -1  -5   4
 5     1 -2.03  -1  -6   5
 6     1 -2.03  -1  -7   6
 7     1 -2.03  -1  -8   7
 8     1 -2.03  -1  -9   8
 9     1 -2.03  -1  -10  9
10     1 -2.03  -1  -11  10
11     1 -2.03  -1  -12  11
12     1 -2.03  -1  -13  12
13     1 -2.03  -1  -14  13
14     1 -2.03  -1  -15  14
15     1 -2.03  -1  -16  15
16     1 -2.03  -1  -17  16
17     1 -2.03  -1  -18  17
18     1 -2.03  -1  -19  18
19     1 -2.03  -1  -20  19
20     0        -1  -21  20
21     1 -.0203 -1  -22  21
22     0         1   21 -22
23     0                 22

 1     cy  100
 2     py  0
 3     py  10
 4     py  20
 5     py  30
 6     py  40
 7     py  50
 8     py  60
 9     py  70
10     py  80
11     py  90
12     py  100
13     py  110
14     py  120
15     py  130
16     py  140
17     py  150
18     py  160
19     py  170
20     py  180
21     py  2000
22     py  2010

c        the following is  pseudo-concrete
m1    1001 -.010      6012 -.001       8016 -.529
     13027 -.034     14000 -.337      26000 -.014
sdef   x=0 y=1.e-6 z=0 cel=2 wgt=1  erg=d1
si1    2 2.00000001 14 14.00000001
sp1    0 .5 .5 1
nps    2e6  $ e5 orig
f1:n   20
f4:n   21
cut:n  j 0.01     $ .01 Mev energy cutoff
fy5:n  2005 200 0
dd5    -5.e-18
dd1    -3.e-10
pd0    0 19r 1 0 0
```

```
fc1:n 0 19r 1 0 0
dxt:n 0 2005 0 100.2 100.2
dxc:n 0 .01 8r .016 .032 .064 .128 .25 .5 1 1 1 0 3r
ext:n 0 .7y 17r 0 0 0 0
c wwg 5 2 0
c
wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
wwn1:n  -1.0000E+00  20.         20.         20.         20.
         20.         20.         20.         20.         20.
         20.         5.          1.          .2          .02
         .002        .0003       5.7035E-05  1.5996E-05  0.0000E+00
         0.          0.0000E+00 -1.0000E+00
wwn2:n  -1.0000E+00  4.          4.          4.          4.
         4.          4.          4.          4.          4.
         2.6523E+00  1.2598E-01  3.9091E-02  1.6071E-03  4.0000E-04
         8.0000E-05  4.2936E-05  5.7152E-06  3.0000E-06  0.0000E+00
         0.          0.0000E+00 -1.0000E+00
wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01
         3.7383E-02  5.9539E-03  4.3697E-03  2.2019E-03  6.3324E-04
         2.0000E-04  1.1691E-04  5.1585E-05  3.0000E-05  1.0000E-05
         5.0000E-06  4.0000E-06  3.0000E-06  3.0000E-06  0.0000E+00
         0.          0.0000E+00 -1.0000E+00
wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02
         1.3878E-02  4.7117E-03  1.3020E-03  7.3584E-04  3.0848E-04
         1.4364E-04  7.0384E-05  6.5234E-05  3.8834E-05  2.9889E-05
         1.0544E-05  5.5095E-06  3.4483E-06  3.0000E-06  0.0000E+00
         0.          0.0000E+00 -1.0000E+00
```

E2: Variations from Base Model in Class Problem

```
vg1a differences
---------xxxxxxxx------------
vg1b differences
70c70,71
< c wwg 5 2 0
---
> wwg 5 2 0
> wwge:n 1.0000 2.0100E+00  1.000E+01  1.0000E+02
---------xxxxxxxx------------
vg2a differences
---------xxxxxxxx------------
vg2b differences
70c70,71
< c wwg 5 2 0
---
> wwg 5 2 0
> wwge:n 1.0000 2.0100E+00  1.000E+01  1.0000E+02
---------xxxxxxxx------------
vg3a differences
92a93,104
> c mesh  ref 0 1e-6 0
> c       origin .001 -.001 .001
> c       axs 0 1 0
> c       vec 1 0 0
> c       geom cyl
> c       imesh  100.002 210.002
> c       iints  5  1
> c       jmesh  180.002 2000.001 2010.002
> c       jints   18  1   1
> c       kmesh   .5 1
> c       kints   1 1
>
---------xxxxxxxx------------
vg3b differences
70c70,72
< c wwg 5 2 0
---
> wwg 5 0 0
> c c wwge:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
> wwge:n 1.0000 2.0100E+00  1.000E+01  1.0000E+02
92a95,105
> mesh  ref 0 1e-6 0
>        origin .001 -.001 .001
>        axs 0 1 0
>        vec 1 0 0
>        geom cyl
>        imesh  100.002 210.002
>        iints  5  1
>        jmesh  180.002 2000.001 2010.002
>        jints   18  1   1
>        kmesh   .5 1
>        kints   1 1
---------xxxxxxxx------------
vg4a differences
72,92c72,84
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.       (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.        (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> imp:n 0 1 17r 1 1 1 0
> c mesh  ref 0 1e-6 0
> c       origin .001 -.001 .001
> c       axs 0 1 0
> c       vec 1 0 0
> c       geom cyl
> c       imesh  100.002 210.002
> c       iints  5  1
> c       jmesh  180.002 2000.001 2010.002
> c       jints   18  1   1
> c       kmesh   .5 1
> c       kints   1 1
>
---------xxxxxxxx------------
vg4b differences
70c70,72
< c wwg 5 2 0
---
> wwg 5 0 0
> c c wwge:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
> wwge:n 1.0000 2.0100E+00  1.000E+01  1.0000E+02
72,92c74,85
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.       (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.        (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> imp:n 0 1 17r 1 1 1 0
> mesh  ref 0 1e-6 0
>        origin .001 -.001 .001
>        axs 0 1 0
>        vec 1 0 0
>        geom cyl
>        imesh  100.002 210.002
>        iints  5  1
>        jmesh  180.002 2000.001 2010.002
>        jints   18  1   1
>        kmesh   .5 1
>        kints   1 1
---------xxxxxxxx------------
vwwl4b differences
72,93c72,93
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.       (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.        (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> wwp:n 5 3 5
> wwe:n  1.0000E+00  2.0100E+00  1.0000E+01  1.0000E+02
> wwn1:n  -1.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00(cont)
> wwn2:n  -1.0000E+00  8.3040E+05  1.7239E+05  6.5044E+04  8.1138E+03(cont)
> wwn3:n  -1.0000E+00  7.9011E-01  1.9176E-01  8.1280E-02  3.5532E-02(cont)
> wwn4:n  -1.0000E+00  5.0000E-01  7.7294E-02  3.2164E-02  1.4113E-02(cont)
---------xxxxxxxx------------
vwwl4c differences
72,93c72,93
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.       (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.        (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> wwp:n 5 3 5
> wwe:n  1.0000E+00  2.0100E+00  1.0000E+01  1.0000E+02
> wwn1:n  -1.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00(cont)
> wwn2:n  -1.0000E+00  8.3040E+05  1.7239E+05  6.5044E+04  8.1138E+03(cont)
> wwn3:n  -1.0000E+00  7.9011E-01  1.9176E-01  8.1280E-02  3.5532E-02(cont)
```

```
> wwn4:n  -1.0000E+00  5.0000E-01  7.7294E-02  3.2164E-02  1.4113E-02(cont)
---------xxxxxxxx------------
vww24b differences
72,93c72,93
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.        (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.         (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> wwp:n 5 3 5
> wwe:n  1.0000E+00  2.0100E+00  1.0000E+01  1.0000E+02
> wwn1:n  -1.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00(cont)
> wwn2:n  -1.0000E+00  5.8717E+05  1.3290E+06  8.4391E+04  1.6996E+04(cont)
> wwn3:n  -1.0000E+00  9.1788E-01  7.2191E-01  2.8551E-01  1.2481E-01(cont)
> wwn4:n  -1.0000E+00  5.0000E-01  3.5990E-01  1.4519E-01  5.8004E-02(cont)
---------xxxxxxxx------------
vww24c differences
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.        (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.         (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> wwp:n 5 3 5
> wwe:n  1.0000E+00  2.0100E+00  1.0000E+01  1.0000E+02
> wwn1:n  -1.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00(cont)
> wwn2:n  -1.0000E+00  5.8717E+05  1.3290E+06  8.4391E+04  1.6996E+04(cont)
> wwn3:n  -1.0000E+00  9.1788E-01  7.2191E-01  2.8551E-01  1.2481E-01(cont)
> wwn4:n  -1.0000E+00  5.0000E-01  3.5990E-01  1.4519E-01  5.8004E-02(cont)
---------xxxxxxxx------------
vww3 differences
70,92c70,83
< c wwg 5 2 0
< c
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.        (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.         (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> c wwg 5 0 0
> imp:n 0 1 17r 1 1 1 0
> wwp:n 5 3 5 0 -1
> c mesh  ref 0 1e-6 0
> c       origin .001 -.001 .001
> c       axs 0 1 0
> c       vec 1 0 0
> c       geom cyl
> c       imesh  100.002 210.002
> c       iints  5  1
> c       jmesh  180.002 2000.001 2010.002
> c       jints   18  1   1
> c       kmesh   .5 1
> c       kints   1 1
---------xxxxxxxx------------
vww4 differences
58c58
< nps   2e6  $ e5 orig
---
> nps   2e6
61c61
< cut:n j 0.01     $ .01 Mev energy cutoff
---
> cut:n j 0.01      $ .01 Mev energy cutoff
70,92c70,83
< c wwg 5 2 0
< c
< wwe:n 1.0000E-01  2.0100E+00  1.3900E+01  1.0000E+02
< wwn1:n  -1.0000E+00  20.         20.         20.         20.        (cont)
< wwn2:n  -1.0000E+00  4.          4.          4.          4.         (cont)
< wwn3:n  -1.0000E+00  0.9         5.8078E-01  2.6818E-01  1.2206E-01(cont)
< wwn4:n  -1.0000E+00  5.0000E-01  1.7473E-01  7.5007E-02  3.5717E-02(cont)
---
> wwg 5 0 0
> imp:n 0 1 17r 1 1 1 0
> wwp:n 5 3 5 0 -1
> c mesh  ref 0 1e-6 0
> c       origin .001 -.001 .001
> c       axs 0 1 0
> c       vec 1 0 0
> c       geom cyl
> c       imesh  100.002 210.002
> c       iints  5  1
> c       jmesh  180.002 2000.001 2010.002
> c       jints   18  1   1 .
> c       kmesh   .5 1
> c       kints   1 1
---------xxxxxxxx------------
```

Table E3: Explanation of Runs Performed in Assessment

Run	Explanation	Code Run
Vg1a	Expert importances, no wwg, no ww used.	MCNP4C
Vg1b	Same as Vg1a, but cell-based ww's generated.	MCNP4C
Vg2a	Expert importances, no wwg, no ww used.	MCNP4B
Vg2b	Same as Vg2a, but cell-based ww's generated.	MCNP4B
Vg3a	Expert importances, complex geometry, no wwg, no ww used.	MCNP4C
Vg3b	Same as Vg3b, but mesh-based ww's generated.	MCNP4C
Vg4a	Binary importances, complex geometry, no wwg, no ww used.	MCNP4C
Vg4b	Same as Vg4a, but mesh-based ww's generated.	MCNP4C
Vg5a	Binary importances, simple geometry, no wwg, no ww used.	MCNP4C
Vg5b	Same as Vg5a, but mesh-based ww's generated.	MCNP4C
Vww14b	Applies cbww generated in Vg1b	MCNP4B
Vww14C	Applies cbww generated in Vg1b	MCNP4C
Vww24b	Applies cbww generated in Vg2b	MCNP4B
Vww24C	Applies cbww generated in Vg2b	MCNP4C
Vww3	Applies mbww generated in Vg3b	MCNP4C
Vww4	Applies mbww generated in Vg4b	MCNP4C
Vww5	Applies mbww generated in Vg5b	MCNP4C

```
message:
datapath=/usr/local/codes/data/mc/type1

analog calculation of mfe problem, except for .01 MeV energy cutoff
 1     0        (1 -21):-2   $ oustide cyl+below ground, below zero
 2     1 -2.03  -1  -20   2  $ cement channel
20     0        -1  -21  20  $ void channel
21     1 -.0203 -1  -22  21  $ aerated cement
22     0         1   21 -22 -5 $ void channel to ring detector
23     0                 22  $ above row
24     0         1   21 -22 5  $ zero importance void outside of detector

 1     cy  100
 2     py  0
 5     cy  210
20     py  180
21     py  2000
22     py  2010

c        the following is  pseudo-concrete
m1     1001 -.010      6012 -.001      8016 -.529
     13027 -.034     14000 -.337     26000 -.014
sdef   x=0 y=1.e-6 z=0 cel=2 wgt=1  erg=d1
si1    2 2.00000001 14 14.00000001
sp1    0 .5 .5 1
nps    2e6
f1:n   20
f4:n   21
cut:n j 0.01  $ .01 Mev energy cutoff
fy5:n 2005 200 0
dd5    -5.e-18
dd1    -3.e-10
pd5    0 0 0 1 0 0 0
pd0    0 1 0 1 1 0 0
fc1:n 0 0 0 1 0 0 0
dxt:n 0 2005 0 100.2 100.2
dxc:n 0 1 0 3r 0
ext:n 0 .7y 0 0 0 0 0
imp:n 0 1 1 1 1 0 0
c wwp 5 3 5 0 -1
wwg 5 0 0
c c wwge:n 1.0000E-01  2.0100E+00  1.0000E+01  1.0000E+02
wwge:n 1.0000 2.0100E+00  1.000E+01  1.0000E+02
print
mesh   ref 0 1e-6 0
       origin .001 -.001 .001
       axs 0 1 0
       vec 1 0 0
       geom cyl
       imesh  100.002 210.002
       iints  5  1
       jmesh  180.002 2000.001 2010.002
       jints   18  1   1
       kmesh   .5 1
       kints   1 1
```