The Accuracy of NOVICE Electron Shielding Calculations

Thomas M. Jordan
Experimental and Mathematical Physics Consultants
Post Office Box 3191 Gaithersburg, MD 20885 USA

Abstract--NOVICE Monte Carlo calculations of electron transport are compared with SHIELDOSE and ITS calculations and with experimental data for an empty electronics box. The accuracy of NOVICE solid angle sectoring methods relative to Monte Carlo methods is discussed for simple shield geometries.

Introduction

The NOVICE code[1] has a description of space system geometry and radiation sources and detectors that is shared by several neutral and charged particle analysis methods. For total dose calculations, the code can use either adjoint Monte Carlo particle simulation or the ray tracing/sectoring approximation.

NOVICE Monte Carlo electron transport calculations are compared with calculations by other codes and with experimental measurements. The Monte Carlo data are then compared with sectoring calculations on the same geometry models to determine typical errors for the sectoring methods.

SHIELDOSE Comparison

The SHIELDOSE[2] code is used by many organizations for calculating dose attenuation data in slab and solid sphere aluminum shield geometries. SHIELDOSE has a database of Monte Carlo calculations from the ETRAN[3] code. Figure 1 shows the agreement between NOVICE (adjoint Monte Carlo option) and SHIELDOSE for a slab geometry shield exposed to fission spectrum electrons. Similar agreement has been obtained on many environments over the past ten years.

ITS-ACCEPT Comparison

The NOVICE and ITS-ACCEPT[4] codes were both applied to a large aluminum spherical shell, 25 cm outside radius and 5 mm thick. Figure 2 indicates the agreement between calculated differential spectra for a point 1.5 mm inside the external surface with an isotropic fission electron environment.

Electron Dose Experiment

Van Gunten reports[5] an extensive set of measurements for electron dose inside hollow aluminum boxes. Boxes are nominal 20 cm (8 inch) cubes with dosimeters every 5 cm (2 inches) in all three directions. Box wall thicknesses were 0.76, 1.52 3.18 and 6.35 mm (30, 60, 125, and 250 mils) of aluminum. Each box was irradiated on one side while using a rotating fixture to simulate cosine current (isotropic fluence) exposure. Measurements were made for mono-energetic electrons with energies from 1 to 4 MeV in 0.25 MeV steps.

The mono-energetic data were weighted to approximate geosynchronous and fission electron spectra. Figures 3 and 4 show the agreement between the experiment and calculation for the fission spectrum on the box centerline and in the corner. Figure 5 is a similar comparison on the box centerline for the geosynchronous electron spectrum. Figures 6 and 7 are comparisons for monoenergetic electrons of 1 and 3 MeV.

Ray-Trace/Sectoring

Ray-trace/sectoring methods use several approximations to predict radiation levels in complex geometry models. These methods divide the solid angle around a detector point into a number of sectors. For each solid angle sector, a ray is then traced from the detector point to the outside of the space system. Finally, the mass thickness along the ray is summed and then used to interpolate a set of tabulated attenuation data for an idealized shield geometry, giving the dose for that sector.

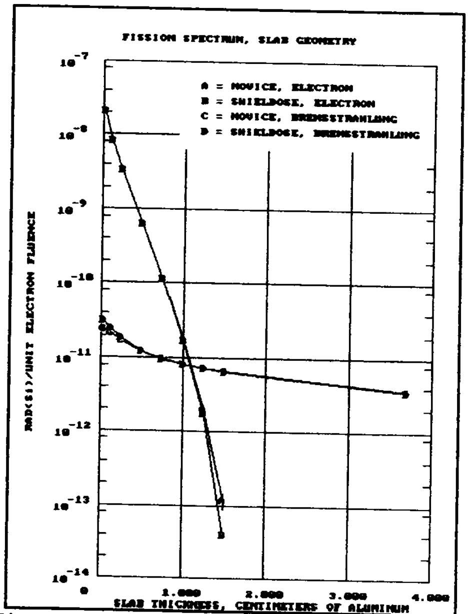

Figure 1: Fission Electron Attenuation in Aluminum.

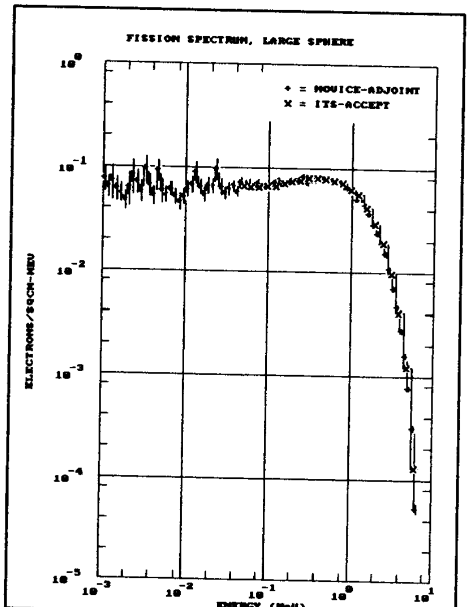

Figure 2: Differential Spectrum 1.5 mm inside the Outer Edge of an Aluminum Spherical Shell.

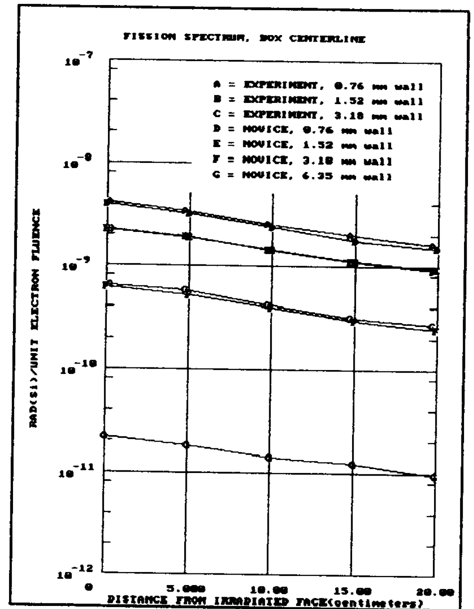

Figure 3: Fission Electron Dose on the Centerline of a Hollow Aluminum Box.

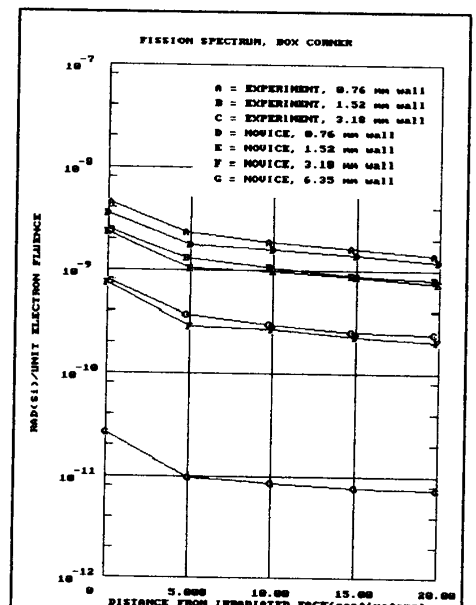

Figure 4: Fission Electron Dose in the Corner of a Hollow Aluminum Box.

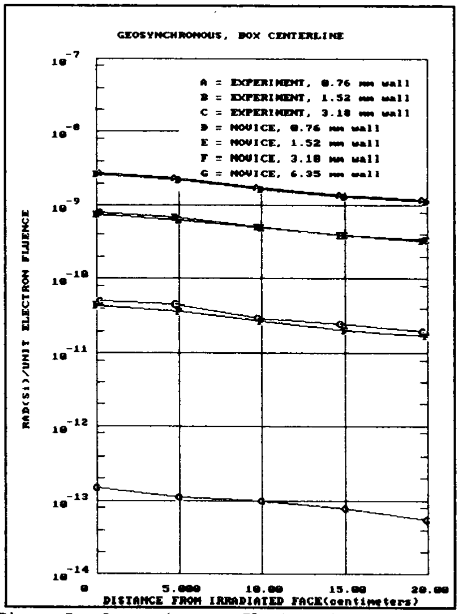

Figure 5: Geosynchronous Electron Dose on the Centerline of a Hollow Aluminum Box

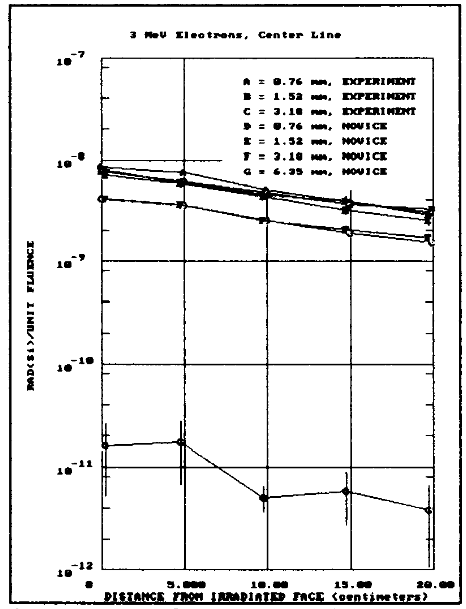

Figure 7: 3 MeV Electron Dose on the Centerline of a Hollow Aluminum Box

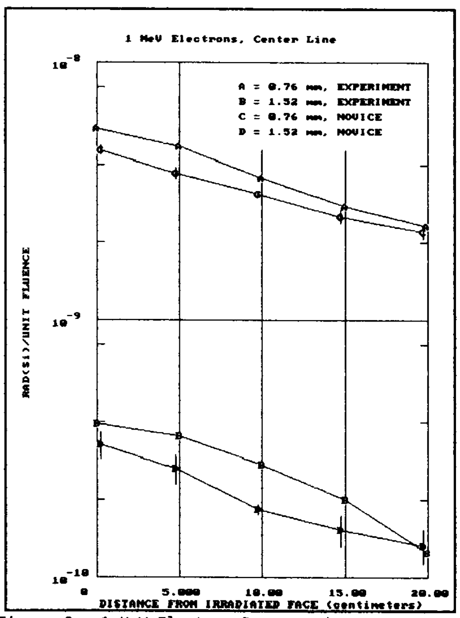

Figure 6: 1 MeV Electron Dose on the Centerline of a Hollow Aluminum Box

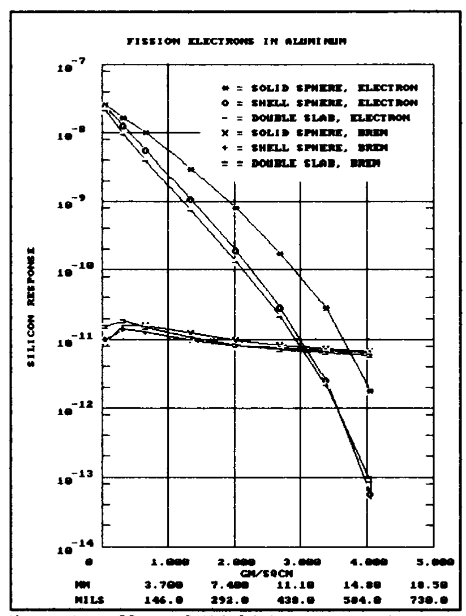

Figure 8: Effect of Shield Geometry on the Attenuation of Fission Electrons in Aluminum

This "straight-ahead" modeling is adequate for heavy ions which have very little angular deflection as they traverse shields. However, the straight-ahead modeling is often inadequate for electrons where the transport is dominated by angular deflections.

A part of the difficulty is indicated in Figure 8, which contains attenuation data for fission electrons in slab, spherical shell, and solid sphere aluminum shields. Notice that the spherical shell attenuation data lies just above and parallel to the slab attenuation data, and that the solid sphere and spherical shell attenuation data diverge by a factor-of-ten before the total dose is dominated by the secondary bremsstrahlung dose. Thus, even in simple spherical shield geometries, it is difficult to predict the accuracy of electron sectoring calculations since the dose level changes from a solid sphere result to a spherical shell result as the cavity dimensions around the detector point increase.

An assessment of electron sectoring accuracy has been made using two data sets: the Monte Carlo calculations on the experimental box discussed above, and a set of benchmark calculations[6]. The benchmark data include adjoint and forward Monte Carlo calculations on 15 different problems. These problems range from simple slabs, boxes, cylinders, and spheres to concentric spheres with different composition. Modeled radiation environments were isotropic fluences of 0.75 MeV, 5 MeV, geosynchronous, and fission electrons.

The benchmark calculations and the experiment calculations constitute more than 300 data points on electron dose. Ray-trace/sectoring calculations were performed for these data points using two sectoring models to determine the accuracy of sectoring relative to Monte Carlo calculations. The first sectoring method interpolated solid sphere geometry attenuation data using the mass thickness for each solid angle sector. The second sectoring method interpolated spherical shell geometry attenuation data using an estimate of the "minimum mass thickness"[7] for each solid angle sector. Results of the comparisons are given in Table I.

The following general comments can be made about the sectoring approximation:

a) Solid sphere attenuation data interpolated using the actual mass thickness over predicts dose by more than a factor of two on about ten percent of the data points.

b) Spherical shell attenuation data interpolated using the minimum path thickness under predicts dose by more than a factor of two on somewhat less than ten percent of the data points.

Thus, neither of these two methods is clearly superior. However, in the absence of a Monte Carlo prediction method, the solid sphere attenuation data should be used to avoid under predicting radiation levels. Where the sectoring method indicates a need for shielding/hardening, an adjoint Monte Carlo calculation of the actual dose level may obviate the hardening requirement.

Conclusions

Forward and adjoint Monte Carlo methods are in excellent agreement with each other on problems that can be solved by both methods. For simulation of mono-energetic electron beam sources, the forward Monte Carlo method should be used. For dose at a point in a space system exposed to an omni-directional electron environment, the adjoint Monte Carlo option of the NOVICE code is, computationally, the superior method.

Excellent agreement was obtained between adjoint Monte Carlo calculations and experimental measurements on a hollow aluminum box for electron spectra. The largest disagreement was seen for the mono-energetic source data.

Sectoring methods applied to electron dose in space systems are an approximation, and at best usually provide an upper bound. Adjoint Monte Carlo calculations may be warranted before using shielding or other hardening approaches based on sectoring results.

Table I

Comparison of Sectoring With Monte Carlo Calculations

Description of Data	Sectoring Method: Solid Sphere	Sectoring Method: Shell Sphere
Benchmarks, 175 data points		
Within +-10% of Monte Carlo	98 pts	93 pts
Within +-50% of Monte Carlo	138	158
Low, more than factor of 2	0	17
High, more than factor of 2	20	0
Experiment, 130 data points		
Within +-10% of Monte Carlo	38 pts	89 pts
Within +-50% of Monte Carlo	90	130
Low, more than factor of 2	0	0
High, more than factor of 2	10	0

References

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