Development of Point Kernel Gamma Ray Shielding Code

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Abstract

MCkeff code developed at the Manipal Centre for Natural Sciences, Manipal Academy of Higher Education, Manipal, meant for estimating the neutron multiplication factor of fissile systems and is currently extended to solve gamma ray shielding problems in complex source-shield geometries by point kernel method. The MCkeff code adopts the input file format of MCNP, a widely used Monte Carlo code, in which any arbitrary configuration of shield materials contained in cells can be described by its bounding surfaces (linear and quadratic) by combining them with Boolean operators of intersection, and union. And the radiation source characteristics are specified by the ”SDEF” card (geometry, energy and angular distribution). The code identifies the problem type (criticality or shielding) by the presence or absence of an ”SDEF” card. Besides this, in extended MCkeff code, the keyword ”point kernel” is used in a comment card of an input file to specify a shielding problem. This way, the same input file without any modification can be used for detailed simulation by the Monte Carlo code MCkeff.

Keywords: point kernel, Gamma shielding, radiation transport simulation

1. Introduction

Point kernel techniques divide large-volume sources into arbitrary, predefined smaller volumes, which are regarded as point sources with appropriate source weights. A small source’s centroid coordinates are calculated, and these positions are considered as its location. An optical path traversed in the source and shield

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media up to the detector location is estimated to calculate geometrical and material attenuations. The total flux is then calculated by multiplying this by the appropriate buildup factor (which accounts for scattered contributions). Summing over all the sampled points yields the flux for the entire volume source. In the present work, MCkeff [1] has been modified to work with point kernel methodology, which takes a similar input format as that of MCNP [2].

2. Material and Methods

Since analytical solutions are not for complex shielding problems, Monte Carlo codes are used. However, these codes also cannot provide precise results when the optical distance between the source and the tally point is large. In such situations, Point kernel techniques are usually employed for shield design analysis. For a unit strength source emitting a photon of energy 'E' located at a point rs and the detector at an end rt, the un-collided response is

$$G_o(r_s, r_t, E) = \frac{R(E)}{4\pi\,|r_s - r_t|^2} e^{-\mu E|r_s - r_t|} \tag{1}$$

Here $G_o(r_s, r_t, \mathrm{E})$ is the uncollided dose point kernel and equals the dose at rt per particle of energy E emitted isotropically at rs. With this point kernel, the uncollided dose due to an arbitrarily distributed source can be found by first decomposing (conceptually) the source into a set of contiguous effective point sources and then summing (integrating) the dose produced by each point source. The uncollided response estimated thus is multiplied by a buildup factor to account for the scattered portion of the response.

3. Results and Discussion

With the help of newly added functionality in the MCkeff code, one can use the code to solve radiation shielding problems. Typical uncollided flux (UCF) estimated by the MCNP [2] code and MCkeff code is compared in the following table for several extended sources. The description of the problem can be found elsewhere [3]

From the table 1, it is clear that the flux in both cases, i.e., uncollided flux and the flux with the shielding material, is in good agreement with that of MCNP, and the code MCkeff can be effectively used as a point kernel code as well.

4. Conclusion

MCkeff extended code can handle a variety of gamma-ray sources such as points, lines, spheres, cylinders, boxes etc. Verification and validation of the code have been done by a number of benchmark problems available in the literature. The results presented in this paper demonstrate the accuracy and efficiency of the code in complex geometries.

References

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Table 1: Comparison of results from MCkeff and MCNP

SN	Problem title	UCF* 3.7e+10 MCNP Code	UCF* 3.7e+10 MCKeff Code	Medium MCNP	Medium MCKeff
1	Two Point Isotropic Sources at Different Positions→2P	2.734e+05 5.413e-01	2.734e+05 5.414e-01	9.123e+04 1.804e-01 2.089e-01	9.110e+04 1.804e-01 1.862e-01
2	Point Isotropic Source with Discrete Energy Photons→P4DE	2.944e+05 6.922e-01	2.945e+05 6.925e-01	1.727e+04 5.655e-02 1.264e-01	1.660e+04 5.647e-02 1.768e-01
3	Point Isotropic Source with a Histogram of Energies→P4HE	2.944e+05 3.713e-01	2.945e+05 4.531e-01	3.743e+03 9.505e-03 2.532e-02	6.585e+03 1.877e-02 7.825e-02
4	Point Isotropic Source with Tabulated Energy Distribution→P7AE	2.944e+05 1.541e+00	2.945e+05 1.509e+00	4.707e+04 2.215e-01 3.875e-01	3.790e+04 2.004e-01 4.398e-01
5	Two Point Sources with Different Energy Distributions →(FPOS)	3.153e+05 5.030e-01	3.155e+05 5.030e-01	2.179e+05 3.803e-01 4.063e-01	2.183e+05 3.813e-01 3.840e-01
6	Rectangular Parallelepiped Parallel to Axes →RPP	2.912e+05 6.748e-01	2.945e+05 6.824e-01	2.641e+05 6.116e-01 6.443e-01	1.587e+04 3.678e-02 1.723e-01
7	Sphere→SPH	2.968e+05 6.878e-01	2.631e+05 6.879e-01	2.634e+05 6.101e-01 6.396e-01	2.631e+05 6.097e-01 6.440e-01
8	Cylinder→RCC	3.244e+05 7.518e-01	3.245e+05 7.520e-01	3.185e+05 7.380e-01 7.430e-01	3.184e+05 7.377e-01 7.456e-01
9	Two Cylindrical Sources with Different Energy Photons→FERG	4.136e+05 8.986e-01	4.142e+05 9.000e-01	3.791e+05 8.479e-01 8.524e-01	3.795+05 8.491e-01 8.740e-01
10	Line Source: Degenerate Rectangular Parallelepiped →RPLX	2.937e+05 6.891e-01	2.945e+05 6.824e-01	1.008e+05 2.325e-01 3.163e-01	1.017e+05 2.356e-01 3.145e-01
11	Disk Source: Degenerate Cylindrical Source →RCXY	2.962e+05 6.865e-01	2.963e+05 6.866e-01	1.618e+05 3.739e-01 4.628e-01	1.609e+05 3.729e-01 4.772e-01
12	Plane Source: Degenerate Rectangular Parallelepiped →RPXY	2.949e+05 5.839e-01	2.950e+05 5.841e-01	6.722e+04 1.324e-01 2.333e-01	6.638e+04 1.314e-01 2.757e-01
13	Line Source: Degenerate Cylindrical Source →RCLX	2.974e+05 6.891e-01	2.974e+05 6.893e-01	1.008e+05 2.325e-01 3.164e-01	1.017e+05 2.356e-01 3.145e-01