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INTRODUCTION

The MCNP Radiation-Shielding Validation Suite[1] was created to assess the impact on dose rates and attenuation factors of future improvements in the MCNP Monte Carlo code[2] or its nuclear data libraries. However, it does not currently contain any deep-penetration cases. For this reason, a set of deep-penetration benchmarks has been investigated for possible inclusion in the Suite.

EXPERIMENTS

Ref. 3 describes a series of experiments designed to systematically evaluate the effectiveness of various shielding materials. Those experiments measured the dose rate from a ^{252}Cf source at the outer surface of various thicknesses of those shielding materials. The source strength was 5.45x10^7 neutrons per second for three of the materials and 5.33x10^7 for the other, with an average energy of 2.35 MeV

The shielding materials included in the experiments were Resin-F, NS-4-FR, Krafton-HB, and Type 304 Stainless Steel. Resin-F is a synthetic resin that contains boron to reduce the production of secondary gamma rays by thermal neutrons. NS-4-FR is an epoxy resin that also contains boron. Krafton-HB is another synthetic resin that contains boron, and it was developed as an advanced shielding material for fast breeder reactors. Type 304 Stainless Steel is a good shielding material for gamma rays but a poor one for neutrons. However, because it does slow fast neutrons down into the keV region through inelastic scattering, it can be used to enhance the neutron-shielding capabilities of other materials.

This set of experiments employed the four shielding materials both separately and in combination. In this study, however, the analysis is limited to shields of a single material.

The detector used in the experiments was an Aloka moderating-type neutron survey meter. A dose conversion factor of 1.5 count/s per μSv/hr was employed for the neutron detector, based on the manufacturer's manual.

Figure 1 shows the geometrical arrangement of the experiment. The source was placed in a paraffin howitzer, which was described as a cube of dimensions 50 cm by 50 cm by 50 cm with a cone that has an aspect ratio of 45º. As the Figure shows, the source was placed near the apex of the cone.

The detector was placed at 115 cm from the ^{252}Cf source. The slabs of shielding materials were placed so that the back edge of the slab was 100 cm from the source. The thickness of the slabs was increased in the direction of the source in increments of 5 cm up to a maximum thickness of 30 cm, with a 1cm gap between layers. There were two exceptions to this process: (1) the maximum thickness of the NS-4-FR shield was 25 cm, and (2) the thickness of the Krafton-HB shields was increased in increments of 5.3 cm, up to a maximum thickness of 31.8 cm.

Ref. 3 contains graphs of the results but does not tabulate specific values. However, specific measured values and their associated uncertainties were given to us by its principal author for NS-4-FR, Resin-F, and SS 304.[4] The uncertainties all are less than 2%. The values for the Krafton-HB measurements were obtained by scanning the graph from Ref. 3 and digitizing the values.

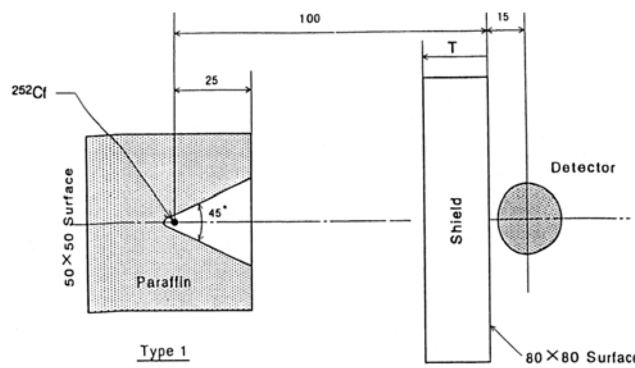

Fig. 1. Schematic of Geometry for Benchmarks.

MODEL DESCRIPTION

The MCNP5 modeling was meant to represent the actual experimental setup as closely as possible. When specific information was not available, reasonable assumptions were made. For example, the composition of the paraffin was taken from the MCNP criticality primer,[5] at a nominal density of 0.93 g/cc. Similarly, the ^{252}Cf source was modeled using a Watt fission spectrum.

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The detector was modeled as an air-filled right circular cylinder, with a length of 20 cm and diameter of 10.5 cm. The entire configuration is immersed in air at a nominal density of 0.001293 g/cc, comprised of 78.084% nitrogen, 20.9476% oxygen and 0.9684% argon. Room return was not modeled, because the measured data as reported had been adjusted to remove such effects. The composition of each shielding material is consistent with the specifications given in Ref. 3.

RESULTS

MCNP5 calculations were performed for each thickness of each shielding material, using 10,000 to 15,000,000 histories per case. No variance-reduction techniques were applied. Nuclear data for interactions with neutrons, photons, and electrons were taken from the ENDF66,[6] MCPLIB04,[7] and EL03[8] libraries, respectively. ENDF66 is based on release 6 of ENDF/B-VI, while MCNPLIB04 is based on release 8, the final release of ENDF/B-VI.

The results from the MCNP5 calculations are presented in Table I along with the ratio relative to the corresponding measured values ("C/E"). The standard deviations from the MCNP5 calculations are less than 5% for each case, and so are the C/E ratios for almost all of them. The dose rates were obtained by applying flux-to-dose conversion factors based on values from the ANSI standard given in the MCNP5 manual.

Most of the dose rates calculated by MCNP5 for SS-304, NS-4-FR, and Krafton-HB are within 5% of the measured results, and all but two are within 10%. Those two (15 cm of NS-4-FR and 26.5 cm of Krafton-HB) appear to be anomalies, because they are substantially different than all the other ratios for those materials. The results for Krafton-HB all are lower than the measured results, but — with the exception of the aforementioned anomaly at 15 cm — only marginally so. In contrast, the results for Resin-F are consistently higher than the measured values.

CONCLUSIONS

Overall, the MCNP5 results match the measured values quite well. Furthermore, with the exception of Resin-F, there is no systematic trend in the ratio of calculated to measured results.

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TABLE I. MCNP5 Results.

Shield Thickness (cm)	Calculated Dose (μSv/hr)	C / E
SS-304		
0	627.05 ± 2.63	0.92 ± 0.01
5	515.44 ± 20.15	1.05 ± 0.04
10	364.19 ± 1.89	1.02 ± 0.01
15	262.33 ± 1.92	1.00 ± 0.01
20	196.24 ± 1.31	1.02 ± 0.01
25	141.45 ± 1.08	1.00 ± 0.01
30	102.37 ± 0.05	0.99 ± 0.02
Resin-F		
0	641.17 ± 2.69	0.93 ± 0.01
5	352.03 ± 17.04	1.04 ± 0.05
10	157.30 ± 1.60	1.06 ± 0.01
15	73.55 ± 0.78	1.13 ± 0.02
20	33.33 ± 0.74	1.14 ± 0.03
25	16.84 ± 0.53	1.23 ± 0.04
30	7.84 ± 0.25	1.17 ± 0.04
NS-4-FR		
0	641.17 ± 2.69	0.93 ± 0.01
5	340.11 ± 10.61	1.04 ± 0.03
10	148.81 ± 6.99	1.06 ± 0.05
15	61.07 ± 3.19	0.87 ± 0.05
20	29.10 ± 1.57	1.07 ± 0.06
25	13.17 ± 0.66	1.03 ± 0.05
Krafton-HB		
0	641.17 ± 2.69	0.93 ± 0.02
5.3	295.08 ± 2.18	0.97 ± 0.02
10.6	124.01 ± 1.44	0.97 ± 0.02
15.9	52.47 ± 2.60	0.94 ± 0.05
21.2	22.80 ± 1.32	0.91 ± 0.06
26.5	9.99 ± 0.46	0.83 ± 0.05
31.8	5.26 ± 0.25	0.96 ± 0.05

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