Photon Skyshine Experiment Benchmark

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INTRODUCTION

A benchmark analysis is described for an experiment performed in 1977 at the Kansas State University Nuclear Engineering Shielding Facility in which skyshine from ^{60}Co photon sources was measured at distances in air up to 700 m. The intent of the experiment was to provide this information as benchmark data against which to compare calculated data. For this reason the experiment was carefully documented, and the geometry was kept simple to facilitate computer modeling. Benchmark calculations for the experiment were performed with the MCNP5 code using ENDF/B-VI nuclear cross-section data. The simulation model was an updated and enhanced version of the model described in a 1993 benchmark analysis [1].

DESCRIPTION OF THE ACTUAL WORK

Description of Experiment

Photon skyshine measurements were performed using three ^{60}Co sources with nominal activities of 10.33, 229.1, and 3,804 Ci. Sources were nickel-plated ^{60}Co pellets within cylindrical volumes with diameters of 0.693, 0.693, and 2.527 cm and lengths of 0.635, 1.905, and 2.54 cm. Each measurement was performed with one of the sources placed within an annular concrete silo with 91.44 cm (3 ft) thick walls. Each source was contained in one of two steel casks mounted on a cart. Cart mobility and slide movements in the casks allowed sources to be horizontally centered within the silo and raised 2.54 cm above the top of the cask to the required height of 1.98 m above grade. Concrete wedges and lead bricks lining the top of the silo collimated the source into a 150.5° vertical-conical beam.

Gamma radiation exposure rates were measured using a 25.4 cm diameter, high-pressure (25 atm), argon-filled ionization chamber. Measurements were made at distances of 50, 100, 200, 300, 400, 500, 600, and 700 m from the source at 1 m above the ground. Because the height of the silo exceeded 1 m and the walls were thick, only radiation that scattered from the air outside the silo (skyshine), the outside walls and base of the silo, and the ground (groundshine) was detected.

Background measurements were taken. Also, spectra were measured at locations along the 700 m baseline and used to generate multiplicative energy correction factors for the sources. These were required because of the non-flat energy response of the detector.

Description of Simulation Model

A section of the MCNP simulation-model geometry encompassing the concrete silo is shown in Fig. 1. (The remainder of the model consists of ground and air.) The approach adopted was to simplify the model while including details sufficient to ensure accurate results. (Sensitivity calculations were performed to ensure the validity of the simplified model.) The annular silo was separated into a large center region and two smaller inner and outer regions of radial thickness 10 and 5 cm, respectively. The center annular region was assigned zero importance to eliminate particle transport and increase computational efficiency.

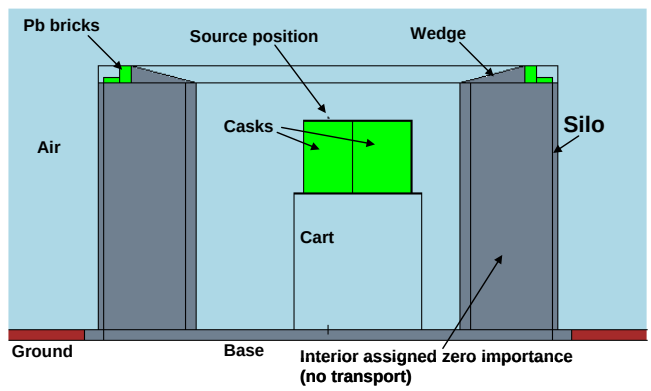

Fig. 1. Elevation view of skyshine experiment MCNP model.

The casks were modeled as cylinders rather than the complex actual shape with the "bulging" center section. The cask interiors were assumed to be lead. The exterior consisted of a 0.635 cm thick top steel plate and 0.3175 cm thick radial steel walls. The cart was modeled as a rectangular, air-filled box with wall thickness of 0.3175 cm. Details such as the wheels, guide rail, etc., were omitted.

Concrete wedges, which defined the 150.5° conical angle, were modeled as an azimuthally-symmetric ring. Lead bricks adjacent to the wedges were modeled as two annuli.

The model extended to a radius of 1000 m and a height of 500 m. MCNP variance reduction was achieved by cell-based importance values that increased radially and decreased vertically. For this purpose the air was divided into nine radial and three vertical zones.

Because of Compton scattering within the encapsulating material, the ^{60}Co gamma spectra were altered from the ideal point-source configuration. However, calculated source spectra from [1] enabled source representation as an isotropic point source omitting the structure of the encapsulating material.

Because of the radial symmetry of the geometry, MCNP ring-detector tallies (F5a) at the radial locations of the measurements at a height of 1 m above grade were used. The actual detectors were not modeled because the experiment detectors were calibrated to measure exposure rates in air. ENDF/B-VI MCNP5 dose response multipliers and an additional conversion factor were used to calculate gamma radiation exposure rates (μR/h/Ci).

Materials included air, ground, concrete, steel, and lead. Compositions for ground and concrete were those recommended by the American National Standard ANSI/ANS-6.6.6-1987 [2]. Air composition was obtained from [1]. A generic carbon steel composition from the Oak Ridge National Laboratory SCALE computer code system was used. A handbook theoretical-density value was assumed for lead.

Particle transport was limited to photons and used the MCNP default "Detailed Treatment" methodology with coherent scattering turned off.

RESULTS

Measured and calculated exposure rates are summarized and compared in Table 1. Corrections for background and the multiplicative correction factors have been applied to the measured values.

Each MCNP calculation was performed with 1×10^7 source histories on a Linux-cluster PC, which resulted in an uncertainty (precision) of ~0.15% and required ~900 to ~1300 min.

Table 1. Measured and Calculated Photon Skyshine Data

Distance from Source (m)	Source (Ci)	Exposure Rate (μR/h/Ci)		Diff. (%)
		Measured	Calculated	
50	10.33	24.24	24.43	0.78
100	10.33	9.66	9.231	-4.44
200	10.33	2.425	2.456	1.28
300	229.1	0.76	0.8526	12.2
400	229.1	0.31	0.3310	6.77
500	229.1	0.117	0.1366	16.7
600	3804	0.0542	0.05486	1.22
700	3804	0.0244	0.02416	-0.98

An analysis was performed to assess uncertainties attributed to experiment and the MCNP model. The combined uncertainties identify the expected level of agreement between experiment and calculation and determine if the differences shown in Table 1 are feasible.

Experimental uncertainties of ~5% and ~4% were attributed to the source activity and source correction factors, respectively [1]. No further experimental uncertainty values were reported, although there was concern regarding the effects of uncertainties in the atmospheric conditions and terrain topology. Care was taken to obtain atmospheric information for the day on which the experimental data related to this analysis were obtained; however, it was implicitly assumed that conditions were constant throughout the course of the day. Also, measurements were performed from which it was concluded that the exposure rate was not sensitive to terrain features.

Additional uncertainties related to the following factors were investigated using the simulation model: material densities and composition, source spectra and location, model dimensions, and variations in atmospheric conditions. It was determined that uncertainties from all effects except the atmospheric conditions were small and totaled ~2.5%. Uncertainties resulting from estimated variations in the atmospheric conditions were estimated to be ~4%. In summary, the total combined average estimated uncertainty was ~8%.

With the exception of the measurements at 300 and 500 m, results show agreement with experimental data and are within the ~8% uncertainty estimate, and a viable benchmark is established for these locations (50, 100, 200, 400, 600, and 700 m). The calculated results at 300 and 500 m were found to be consistent with similar earlier calculations [1], which also showed disagreement with experimental values. It is concluded that there were very likely measurement anomalies at these two locations that prohibited agreement between experimental and simulated values within the estimated levels of uncertainty. Possible anomalies include a large terrain depression, unaccounted-for fluctuations in atmospheric conditions, or electronic instabilities.

ACKNOWLEDGEMENTS

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REFERENCES

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