Chapter 5 Appendix 1

VALIDATION OF AIR-OVER-GROUND CALCULATIONS OF PROMPT-NEUTRON AND GAMMA-RAY KERMA

William. E. Loewe
Lawrence Livermore National Laboratory

Chapters 1 to 3 discuss the input parameters required for the validation of air-over-ground calculation of prompt-neutron and gamma-ray kerma. These parameters include the source intensity as a function of energy and direction, the source location, and the composition of air and ground as functions of location. The discussion here is restricted to the validation of the transport calculation itself, including both technique and cross sections.

Loewe et al[1] addressed exhaustively the accuracy of transport calculations of neutrons and the secondary gamma rays they produce in air and ground. Table 1, which abstracts the conclusions of that article, shows the mean ratio of calculated to measured kerma in tissue for six different experiments, all of the relevant data are in the open literature. The percentages are their estimates of the uncertainties in the ratios. They are the relative standard deviations the author estimated for each of the experiments due to the combination of experimental errors and errors in curve fitting. For the fission sources of interest here, the author concluded that calculated neutron kerma can be expected to be about 10% low and calculated gamma-ray kerma, about 20% low out to 2000 m from the hypocenter, the range of interest in the reassessment.

Judging from (1) estimated experimental errors, (2) use of modern techniques, (3) redundancy of experimental teams, (4) opportunity for remeasurement and reinterpretation of data, and (5) special attention to quantitative definition of the experimental arrangement, by far the most accurate measured data included in the comparisons discussed by Loewe et al[1] and included in Table 1 were obtained with the Army Pulse Radiation Division (APRD) bare reactor located 14 m above the ground (described by Kazi et al[2]). Table 2 is also an extract from Loewe et al based just on the APRD results.

A general agreement to roughly ±15% can be seen between calculated and measured values as far as 1600 m from the hypocenter. (As discussed by Kazi et al, the neutron kerma

Table 1. Accuracy of Kerma Calculations for Air-Over-Ground Radiation Transport – Average Ratio of Calculated and Measured Kerma with Standard Deviation of the Ratio

Range		Source Spectrum	
		14-MeV	Fission
1500 m	Neutron kerma	1.02 ± 15%	0.97 ± 13%
	Secondary gamma-ray kerma	0.82 ± 20%	0.79 ± 8%
2000 m	Neutron kerma	0.88 ± 16%	0.92 ± 19%
	Secondary gamma-ray kerma	0.73 ± 21%	0.87 ± 10%

Table 2. Kerma in Tissue for a Fission Source in Air-Over-Ground Geometry, Using Modern Cross Sections and Calculational Techniques

Range (m)	Ratio, Calculated/Measured		
	Neutron Kerma*	Gamma Kerma*	Neutron Fluence >3 MeV
100	1.09	1.06	1.14
170	1.15	0.91	1.02
300	1.30	0.94	0.98
400	1.37	0.90	1.08
1080	1.13	0.80	1.00
1618	0.90	0.91	–

*By Loewe et al[1]

disparity at 300 to 400 m is due to nearby trees that were not modeled in the calculations; these data were omitted in reaching the conclusion.)

One of the primary teams contributing to the measured APRD data in Table 2 was that from the Defense Research Establishment Ottawa (DREO). After the initial report, they revised their data reduction methods, and now quote measured values[3] that compare with the original calculations shown in Table 3. Their results now give ratios closer to unity and suggest that a calculated accuracy within 10% for both neutron and gamma-ray kerma can be expected for a fission source as far as 1500 m, even when the ground-air interface is a major factor.

Loewe and Mendelsohn[4] had anticipated accuracies of about this level for the atmospheric transport of the severely degraded fission spectrum actually exiting the Hiroshima and Nagasaki bombs. In particular, the applicability of the calculation technique used by Loewe et al[1] and Loewe and Mendelsohn[4] exclusive of cross-section adequacy, was established for these source spectra. Since then, refinements they have made have strengthened their confidence even more. Accuracy of cross-section data for use with severely degraded fission sources was thought at one time to be subject to some uncertainty, due to comparisons of spectra of the sort shown by Kazi et al[2] for 1000 m ground range, in which measured values fall lower than calculated values by roughly 30% at energies below 1 or 2 MeV. However, the same reinterpretation by DREO mentioned above results in the before-and-after comparison of measured spectra shown in Figure 1, where an adjustment upward by

Table 3. Transport Calculations for APRD, Including Revised Results from DREO (Robitaille[3])

Range (m)	LLNL Calculated / DREO Measured	
	Neutron Kerma	Gamma Kerma
100	1.08*	1.06
170	1.06*	0.91
300	1.30*	0.94
400	1.28*	0.90
1080	0.92*	0.80
1618	0.90	0.91

*Revised by Robitaille [3]

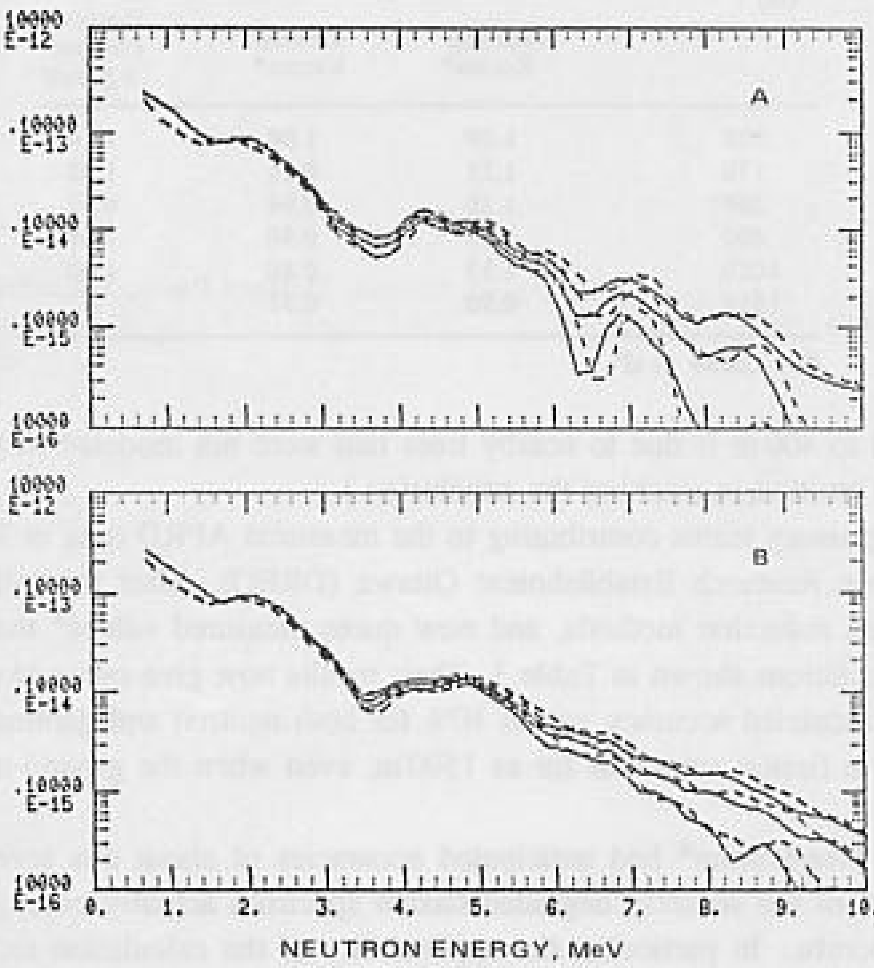

Figure 1. Neutron spectra at 1080 m using latest unfolding procedure (solid curves) compared to previous analysis (dotted). (A) determined in 1981. (B) determined in 1982

roughly 30% is shown for energies below 1 to 2 MeV. This evidence leads to the conclusion that calculations of fission sources and of Hiroshima or Nagasaki bomb sources will have similar expected accuracies.

Some additional comparisons have been made with data obtained at field tests of nuclear weapons, but these data are of substantially inferior quality, are often only fragmentary due to classification restrictions, and are of doubtful or uncertain applicability. The quality is affected by the occurrence of shock-wave phenomena that cannot be neglected and by the conditions at old weapon field tests that precluded repeating experimental work. Applicability is questionable because the Hiroshima and Nagasaki atomic bombs gave severely degraded neutron emission spectra, unlike those from almost all subsequent nuclear explosions for which measurements were made. Comparisons of calculated and measured kerma values for gamma rays at one pertinent field test, Ranger Fox, are given in the section where calculation techniques for delayed radiation (where temporal effects due to shock waves are important) are discussed. Comparisons to threshold detector data, which sample a portion of the fluence spectra and are thus only indirectly related to kerma, are shown in the section on neutron measurements.

References

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