✓ **UNLIMITED DISTRIBUTION ILLIMITÉE**

D.C.B.R.L. REPORT NO. [illegible]

NUCLEAR SCIENCE AND ENGINEERING: 27, 464-488

Technical Notes

Air-Ground Interface Effects on the Exposure from Elevated ^{137}Cs γ Sources*

C. E. Clifford and G. D. Wait

Defence Chemical, Biological and Radiation Laboratories,
Defence Research Board, Ottawa, Canada

Received August 19, 1966

Present techniques for calculating the exposure from distributed sources of γ radiation are based on calculations of the distributions of radiation from isotropic γ sources in infinite homogeneous media[1]. It has been recognized that the presence of the ground could be a significant factor and considerable work has been done to determine the extent to which the ground could modify the exposures calculated for an infinite medium[2-11]. The early work of Soole[3] described the exposure dose measurements as a function of exposure angle for a ^{60}Co source at a height of $5\frac{1}{2}$ ft and detectors at a height of $3\frac{1}{2}$ ft as detector distances were increased from 100 to 400 yards. It was found that the presence of the ground reduced the exposure dose buildup factors considerably below their corresponding values at comparable distances, measured in mean free paths (mfp), in infinite water media. Soole also found that the exposure dose increased with detector height when measured to heights of 10 ft at radial distances of 100 and 517 yards. The calculations of Berger[2] for a source at the air-ground interface showed that the presence of the ground increased the exposure dose buildup factors at detector positions near the ground above their corresponding values in an infinite medium for close-in source positions, and reduced the buildup factors below the infinite medium values at distances greater than 0.4 mfp. These effects of the density interface on the exposure dose near the ground from a point isotopic source at, or near, the interface have been confirmed in experiments by several investigators[4-10].

Most of the work on interface effects has been carried out with sources either on, or close to, the air-ground interface. Although some results are available on interface effects for elevated sources[2,5,11], most of this work is for a limited range of detector positions or for source heights much greater than those where distributed sources of contamination are likely to be a problem. This concentration on ground contamination followed from the assumption that possible contaminants, such as fission products from a reactor accident or from military-weapons fallout, would not be retained above ground, for example on foliage, to any significant extent. However, recent studies of the retention on foliage of volcanic ash from Mount Irazu in Costa Rica have shown that large retention factors are possible. This raises interesting questions about the effect of elevated sources on the exposure in a contamination field and about the interpretation of measurements obtained in an aerial radiological survey over a foliated area. To aid in answering these questions, a study was made of the air-ground correction factors for point isotropic gamma sources at source heights likely to be of interest for foliar retention problems. It is appreciated that other factors, such as the density of the foliage, also would be significant.

Point isotropic ^{137}Cs gamma sources of 1, 10, and 100 Ci were exposed at heights of 1, 3, 6, 12, and 19 m, at horizontal distances to 300 m. These sources emit γ rays of 0.662 MeV which are close to the average energy of the γ's from fission products several hours after fission. All measurements were normalized to a constant source output. Exposure measurements were made for a detector height of one meter, over a ground of flat pasture. Earlier work had shown that surface roughness could have a marked effect on the exposure near the ground from a contaminated interface[12]. However, it was believed that the ground roughness effect would be much less important for elevated sources.

Exposures were measured with Baldwin-Farmer BD-11 ionization chambers for radial distances to 130 m and these measurements were extended to 300 m with shielded geiger counters, a pressurized ion chamber, a C_6F_6 liquid scintillator dosimeter, and with nitrogen-annealed LiF

---

*Issued as DCBRL Report 509.

[1] L. V. SPENCER, "Structure Shielding Against Fallout Radiation from Nuclear Weapons," NBS Monograph 42 (1962).

[2] M. J. BERGER, "Calculation of Energy Dissipation by Gamma Radiation near the Interface between Two Media," *J. Appl. Phys.*, 28, 1502 (1957).

[3] B. W. SOOLE, "The Angular Distribution of Multiply-Scattered γ-Radiation," *Proc. Roy. Soc.*, A 230, 343 (1955).

[4] F. TITUS, "Measurement of the Gamma-Ray Dose near the Interface between Two Media," *Nucl. Sci. Eng.*, 3, 609 (1958).

[5] V. N. SAKHAROV, V. I. KOLESNIKOV-SVINAREV, V. A. NAZARENKO, and E. I. ZABIDAROV, "Angular Distribution of Radiation Emitted by Au^{198}, Scattered in the Air Above the Earth," *At. Energ. (USSR)*, 7, 266 (1959).

[6] C. E. CLIFFORD, J. A. CARRUTHERS, and J. R. CUNNINGHAM, "γ-Radiation at Air-Ground Interfaces with Distributed Cs^{137}," *Can. J. Phys.*, 38, 504 (1960).

[7] V. I. KUKHTEVICH, B. P. SHEMETENKO, and B. I. SINITSYN, "Co^{60} γ-Ray Dosage Measurements in the Neighbourhood of Two Media Interface," *At. Energ. (USSR)*, 8, 66 (1960).

[8] R. E. REXROAD and M. A. SCHMOKE, "Scattered Radiation and Free Field Dose Rates From Distributed Cobalt-60 and Cesium-137 Sources," NDL-TR-2, Army Chemical Corps Nuclear Defense Lab., Army Chemical Center, Md. (1963).

[9] J. BATTER, "Cobalt and Iridium Buildup Factors Near the Ground/Air Interface," *Trans. Am. Nucl. Soc.*, 6, 198 (1963).

[10] K. O'BRIEN and J. E. McLAUGHLIN, "Gamma-Ray Propagation at the Air-Ground Interface," *Trans. Am. Nucl. Soc.*, 6, 201 (1963); and CEX-61 · 1, Div. of Biol. and Med., Civil Effects Test Operations, USAEC (1963).

[11] F. F. HAYWOOD, "Spatial Dose Distribution in Air-Over-Ground Geometry," *Health Phys.*, 11, 185 (1965).

[12] C. E. CLIFFORD, "Effects of the Ground on the γ Dose from Distributed ^{137}Cs Sources," *Can. J. Phys.*, 42, 2373 (1964).

thermoluminescent dosimeters. The exposure vs distance distributions obtained with each of these detectors, with the exception of the LiF dosimeters, were normalized to the BD-11 ionization chamber readings at a radial distance of 130 m. Beyond this distance, the exposure was assumed to be the average of that obtained from these distributions together with the LiF dosimeter exposures. Since the LiF dosimeters had very little energy dependence, their individual exposure readings could be included without normalization. The accuracy of the exposure determinations decreased beyond the normalization point, and by 300-m distance, the average deviation from the mean value was about 10%. Out to 130 m, at least 6 BD-11 measurements were made at each detector position and the exposure variations were less than 1%.

Since the slant range in mean free paths (mfp) from the source to a detector varied with the temperature and pressure, it was necessary to correct the observed exposures to their corresponding values under standard conditions. For ^{137}Cs γ's (0.66 MeV), the mass absorption coefficient for air was assumed to be 0.0770 cm^2/g. The measured values were multiplied by the square of the slant range in m^2 and plotted against the actual range in mfp at the time the exposure had been made. The resulting curve for a given source height was used to obtain the exposures at a standard temperature and pressure (760 mm and 22°C) for the source-to-detector geometries used in the measurements. In general, the corrected values were within 3% of the observed values.

Table I lists the air-dose-exposure buildup factors obtained where the buildup factor is the ratio of the observed exposure-to-the exposure that would be produced by primary unscattered radiation from the source. The primary dose exposure output of a source was determined from ionization chamber measurements at source-to-detector distances of 40 and 50 cm for the source fully exposed at a height of 1 m above a "ground" of lead.

The effect of the air-ground interface on the exposure from an elevated source can be expressed by a boundary correction factor *K* which indicates the extent to which the exposure calculated for an infinite medium has been altered by the presence of the ground. Figure 1 shows *K* values from the present work for source heights of 1, 6, and 19 m. The values obtained at source heights of 3 and 12 m were intermediate to these curves. These values were obtained from Table I by dividing the observed buildup factors in air by the buildup factors at corresponding distances, in mfp, in an infinite medium of water[13]. The dashed lines are the *K* values calculated by Berger[2] for an isotropic point source of 1.28 MeV on a smooth, plane, air-ground interface and at a height of 0.5 mfp above the plane where air and ground were assumed to have the same scattering properties per unit mass as water. Since the γ source energies in Berger's calculations and in this work are in the Compton scatter region, the *K* values should be comparable for distances expressed in mean free paths. The general behavior of an enhancement of the exposure due to the presence of the ground at close-in source positions, and a decrease of the exposure from distant sources, is consistent with earlier work with sources on a smooth air-ground interface. However, it is noteworthy that as the source distance increases, the experimental values at source heights of one and six meters are less than the calculated values at a height of zero.

TABLE I

Exposure Buildup Factors for Elevated 0.66-MeV γ Source (^{137}Cs) for a Detector Height of 1 Meter

Radial Distance To Source (In meters)	Height of Source Meters				
	1	3	6	12	19
1	1.00	1.04	1.08	1.25	1.35
3	1.04	1.09	1.12	1.25	1.35
5	1.08	1.12	1.14	1.25	1.35
10	1.15	1.19	1.21	1.28	1.37
15	1.19	1.24	1.26	1.32	1.39
20	1.21	1.26	1.32	1.35	1.42
25	1.24	1.28	1.37	1.39	1.45
30	1.27	1.30	1.41	1.44	1.49
40	1.33	1.37	1.47	1.52	1.56
50	1.40	1.45	1.54	1.60	1.65
65	1.51	1.57	1.64	1.72	1.78
80	1.62	1.68	1.76	1.84	1.90
100	1.77	1.84	1.91	1.99	2.07
130	1.99	2.06	2.13	2.23	2.33
150	2.13	2.20	2.25	2.38	2.52
175	2.30	2.38	2.45	2.56	2.74
200	2.46	2.52	2.64	2.77	2.93
225	2.60	2.65	2.80	2.98	3.13
300	3.39	3.52	3.64	3.76	3.90

The interface effects observed with close-in and distant point sources will partially cancel out when measurements with point sources are used to deduce the exposure due to extended planes of contamination. It is of particular interest, therefore, to compare the exposures from elevated

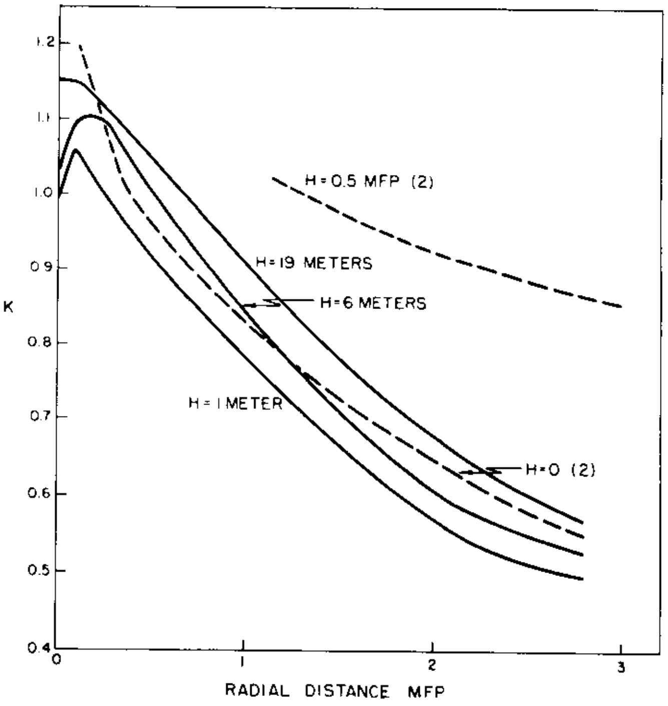

Fig. 1. Air-ground boundary correction factors *K*. The solid lines are values for ^{137}Cs (0.66 MeV) source heights H = 1, 6, and 19 m for a detector height of 1 m. The dashed lines are values calculated by Berger[2] for a 1.28-MeV γ source.

---

[13] H. GOLDSTEIN and J. E. WILKINS, "Calculations of the Penetration of Gamma Rays," NYO-3075, New York Operations Office, USAEC (1954).

source planes with those calculated with infinite medium parameters that ignore the ground. The exposure due to uniform contamination can be obtained from a series of point source measurements by multiplying the observed exposure at a horizontal projected distance of R by $2\pi R$ and plotting the result as a function of R. The area under this curve then gives the exposure due to a uniform contamination per unit area equal to the strength of the point source. Table II shows the exposures for elevated source planes of 1 mCi ^{137}Cs/m^2 that are obtained with the buildup factors of Table I. The exposure dose output of ^{137}Cs was taken as 0.30 R/(h Ci) at 1 m. The bracketed value after each entry gives the exposure as a percentage of its corresponding value in an infinite air medium. Three regions of uniform contamination are considered—from 0 to 10, 10 to 50, and 50 to 300 m. At all source heights, the effect of the air-ground interface is most pronounced in the region of 50 to 300 m radius. However, the contribution to the total exposure from this region would be further reduced in a practical problem by the absorption of radiation in the foliage, or other material, that supports the elevated sources.

TABLE II

Exposures at Height 1 Meter due to Elevated 0.66-MeV γ Source Planes (^{137}Cs)

Height of Source Plane (In meters)	Radial Limits of Contamination of 1 mCi^{137}Cs/m^2		
	0 - 10 m	10 - 50 m	50 - 300 m
	mR/h	mR/h	mR/h
1	4.51[b] (101%)[a]	3.03 (101%)	2.12 (78%)
3	3.30 (105%)	3.02 (100%)	2.06 (76%)
6	1.63 (105%)	3.07 (107%)	2.18 (81%)
12	0.63 (110%)	2.52 (108%)	2.17 (82%)
19	0.29 (112%)	1.94 (109%)	2.23 (86%)

[a] The values in parentheses after each entry give the exposure as a percentage of its corresponding value calculated for an infinite air medium.

[b] This value is for uniform contamination from 1 to 10 m.

It would appear, therefore, that infinite medium calculations of the exposure dose in air, or air-like materials, can be applied to problems involving elevated, uniformly distributed γ sources without introducing large errors. For individual elevated sources, the effects of the air-ground interface could be most pronounced. However, for many problems it should be possible to apply the boundary correction factors calculated by Berger[2] for a source on the ground, with an accuracy of ± 20%.