SHS

UNCLASSIFIED

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0349906 0

ORNL-2019
Special

cy. 4

AIR SCATTERING OF Co^{60} GAMMA RAYS: THEORY VERSUS EXPERIMENT

H. S. Moran

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
UCC
POST OFFICE BOX P · OAK RIDGE, TENNESSEE

UNCLASSIFIED

UNCLASSIFIED

ORNL-2019

Copy No. _____

Contract No. W-7405-eng-26

Applied Nuclear Physics Division

AIR SCATTERING OF Co^{60} GAMMA RAYS: THEORY VERSUS EXPERIMENT

Hubert S. Moran*

Date Issued

MAR 21 1956

OAK RIDGE NATIONAL LABORATORY
Operated by
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
Post Office Box P
Oak Ridge, Tennessee

*Pratt and Whitney Aircraft

UNCLASSIFIED

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0349906 0

INTERNAL DISTRIBUTION

1. C. E. Center
2. Biology Library
3. Health Physics Library
4-5. Central Research Library
6. Reactor Experimental Engineering Library
7-26. Laboratory Records Department
27. Laboratory Records, ORNL R.C.
28. A. M. Weinberg
29. L. B. Emlet (K-25)
30. J. P. Murray (Y-12)
31. J. A. Swartout
32. E. H. Taylor
33. E. D. Shipley
34. A. H. Snell
35. F. C. VonderLage
36. W. H. Jordan
37. S. J. Cromer
38. G. E. Boyd
39. R. A. Charpie
40. S. C. Lind
41. F. L. Culler
42. A. Hollaender
43. J. H. Frye, Jr.
44. M. T. Kelley
45. G. H. Clewett
46. R. S. Livingston
47. K. Z. Morgan
48. T. A. Lincoln
49. A. S. Householder
50. C. P. Keim
51. C. S. Harrill
52. C. E. Winters
53. D. S. Billington
54. D. W. Cardwell
55. E. M. King
56. A. J. Miller
57. E. P. Blizard
58. D. D. Cowen
59. W. M. Breazeale (consultant)
60. M. J. Skinner
61. R. B. Murray
62. R. R. Dickison
63. A. Simon
64. A. Auslender
65. H. A. Bethe (consultant)
66. C. E. Clifford
67. J. B. Dee
68. A. P. Fraas
69. F. L. Keller
70. F. C. Maienschein
71. H. S. Moran
72. F. H. Murray
73. R. W. Peelle
74. R. H. Ritchie
75. C. D. Zerby
76. ORNL - Y-12 Technical Library, Document Reference Section

EXTERNAL DISTRIBUTION

77. R. F. Bacher, California Institute of Technology
78. Atomic Energy Commission, Oak Ridge (H. M. Roth)
79-81. Atomic Energy Commission, Washington (Ralph Allen, C. R. Horner, and A. F. Thompson)
82. Boeing Airplane Company, Seattle (B. F. Ruffner)
83. Bureau of Aeronautics (R. Zirkind)
84. CVAC, Fort Worth (R. N. Little)
85. Convair, San Diego (G. B. Nicoloff)
86. Wright Aero (H. Reese)
87. Douglas (V. V. Holmes)
88-90. General Electric Company (ANPD) (F. W. Mezger (2) and T. R. Mitchell)
91. Glenn L. Martin (T. F. Nagey)

92. Lockheed (F. A. Cleveland)
93. NDA (H. Goldstein)
94. Power Plant Laboratory - WADC (WCLPU) (E. S. Wilson)
95-96. Col. C. D. Gasser (WCSN) (Attn: J. R. Hood)
97-98. Pratt & Whitney (C. F. deGanahl and R. I. Strough)
99-100. Chief of Naval Research (L. A. Beach and R. Minogue)
101. Argonne National Laboratory (Marshall Grotenhuis)
102. Rand Corporation (Herman Kahn)
103. Knolls Atomic Power Laboratory (H. E. Stone)
104. WAPD (J. J. Taylor)
105. Brookhaven National Laboratory (M. Fox)
106. Electric Boat Company (T. W. Dunn)
107-109. Technical Information Extension, Oak Ridge

Abstract

For a Co^{60} source at 15 meters, the air-scattered gamma dose rate predicted by theory is excerpted from ORNL-1575, pp. 167-203. This is compared with experimental measurements for the same source and comparable geometry reported by Convair in CVAC-170T. After applying an appropriate correction for ground scattering as estimated in NARF-55-16T (Convair), the two results are found to be in substantial agreement.

AIR SCATTERING OF Co^{60} GAMMA RAYS: THEORY VERSUS EXPERIMENT

In the past few years considerable data on the scattering of gamma radiation in air has become available. Some of this information is based on theoretical considerations, and some is derived directly from experimental measurements. It is the purpose of this paper to determine, insofar as possible, the order of agreement between the two approaches.

All of the experimental data used in this paper involves the air scattering of gamma rays from a Co^{60} source. For this reason, the comparison between theory and experiment must be restricted to an example taken at the appropriate gamma energies (1.17 and 1.33 Mev). Another restriction arises from the source-ground-detector geometries used for the two approaches. The theoretical attack is based on a source-detector separation of 15 meters with no ground present, while the experimental measurements were made at separation distances of from 7.5 to 70.8 ft, and at heights above the ground of from 9.0 to 57.0 ft. It was decided to make a comparison between the effective dose-rate buildups, due to air scattering, predicted by theory and observed experimentally, for the same geometry: a source-detector separation of 49.2 ft (15 meters), at a height of 50 ft. For both cases an isotropic Co^{60} source of 1 disintegration/sec was assumed.

First, the uncollided dose rate was calculated in a straightforward manner, allowing for both inverse-square and air attenuations, as follows:

(1) For 1 1.17-Mev photon/sec

$$\lambda_1 = 1.33 \times 10^4 \text{ cm}, \qquad d = 1.5 \times 10^3 \text{ cm}$$

$$d/\lambda_1 = 0.113$$

$$\phi_1 = e^{-d/\lambda_1}/4\pi d^2 = 3.16 \times 10^{-8} \text{ photon cm}^{-2} \text{ sec}^{-1} \text{ at } 1.17 \text{ Mev}$$

$$= 3.70 \times 10^{-8} \text{ Mev cm}^{-2} \text{ sec}^{-1}$$

(2) For 1 1.33-Mev photon/sec

$$\lambda_2 = 1.46 \times 10^4 \text{ cm}, \qquad d = 1.5 \times 10^3 \text{ cm}$$

$$d/\lambda_2 = 0.103$$

$$\phi_2 = e^{-d/\lambda_2}/4\pi d^2 = 3.19 \times 10^{-8} \text{ photon cm}^{-2} \text{ sec}^{-1} \text{ at } 1.33 \text{ Mev}$$

$$= 4.24 \times 10^{-8} \text{ Mev cm}^{-2} \text{ sec}^{-1}$$

$$\text{Total flux} = \phi_1 + \phi_2 = 7.94 \times 10^{-8} \text{ Mev cm}^{-2} \text{ sec}^{-1}$$

Taking 1 r/hr = 5.5×10^5 Mev cm^{-2} sec^{-1},

$$\text{Total Uncollided Dose Rate} = 144 \times 10^{-15} \text{ r/hr}$$

Second, the singly scattered dose rate predicted by theory was excerpted from ORNL-1575.[1] In that paper, the singly scattered dose rate to be expected for a source-detector separation distance of 49.2 ft (15 meters) is reported. Other parameters involved are source energy and various factors dependent upon interposed shielding materials and dimensions. For the problem at hand, the latter factors need not be considered, since the experimental data were taken with no shielding, as such, present. Accordingly, it was necessary to obtain from ORNL-1575 the singly scattered gamma-ray dose rate without detector shielding.

1. E. P. Blizard and H. Goldstein, "Report of the 1953 Summer Shielding Session," ORNL-1575, pp. 170-203 (July 12, 1954). (Classified)

at the appropriate gamma energies. This information is present in ORNL-1575, but only implicitly. The curves of Fig. III-E-24a, p. 203, exhibit dose rates for various shield configurations versus source energy. However, a curve for no shielding is not presented. Ordinates of the curves are

$$I(D,E_o)/S_o = \int_0^{\pi} F(D,E_o,\psi,d)\, d\psi \left[(r/hr)/(Mev/sec) \right]$$

plotted against abscissae of $E_o(mc^2)$, where

I = dose-rate, r/hr.

S_o = source strength, energy radiated per unit time, isotropically.

D = source-receiver distance.

$F(D,E_o,\psi)$ = singly scattered dose rate at a distance D due to a unit source emitting photons of energy E_o at angle ψ only.

The F-function above is displayed as a function of ψ for D = 15 meters and for values of E_o of 1.5, 3.0, 6.0, and 12.0 mc^2 in Figs. III-E-11,12,13,14, respectively, in ORNL-1575, pp. 188-192. These four curves were integrated numerically from $\psi = 0$ to $\psi = \pi$, thus obtaining four points determining the needed curve not presented in Fig. III-E-24a. This new curve was carefully drawn on semilog paper and the required dose rates read off, as follows

At E_o = 1.17 Mev = 2.29 mc^2, $I(D,E_o)/S_o = 4.10 \times 10^{-15}$ (r/hr)/(Mev/sec)
$= 4.80 \times 10^{-15}$ r/hr

At E_o = 1.33 Mev = 2.60 mc^2, $I(D,E_o)/S_o = 3.70 \times 10^{-15}$ (r/hr)/(Mev/sec)
$= 4.92 \times 10^{-15}$ r/hr

Total singly scattered dose rate (theoretical) = 9.72×10^{-15} r/hr. Thus the effective buildup in gamma dose rate, due to single air scatter (theoretical) is found to be

$$\text{Buildup}_{th} = \frac{144 + 9.7}{144} = 1.07$$

Next, the scattered dose rate, for the same source and separation distance but with the ground present 50 ft below the source-detector axis, was interpolated from experimental data reported by Convair.[2] For a height of 50 ft and a separation distance of 49.2 ft (15 meters), a total scattered dose rate of 0.495 mr/hr/curie of Co^{60} = 13.4×10^{-15} r/hr/disintegration/sec was observed. But this scattered dose rate includes ground-scattered gammas. An estimate of the ground-scattered dose rate, for the same parameters has been made by Convair[3] as being 0.09 mr/hr/curie of Co^{60} = 2.4×10^{-15} r/hr/disintegration/sec.

Subtracting this estimated ground-scattered dose rate from the observed total scattered dose rate gives 11.0×10^{-15} r/hr/disintegration/sec as a measure of the total air-scattered dose rate for all air-scattered gammas except those that would reach the detector after being scattered below a plane 50 ft beneath the source-detector axis. So the effective buildup in gamma dose rate, due to single plus multiple air scatter (observed, with the exception noted) is found to be

$$\text{Buildup}_{OB} = \frac{144 + 11}{144} = 1.08$$

2. B. L. Jones, J. W. Harris, and W. P. Kunkel, "Air and Ground Scattering of Cobalt 60 Gamma Radiation," CVAC-170T (March, 1955).
3. M. L. Coffman and B. T. Kimura, "Gamma Ray Ground Scattering for Co^{60} and GTR Sources, " NARF-55-16T (May, 1955). (Classified)

The theoretical buildup factor neglects multiple scatter, while the factor based on experiment neglects part of the scattering volume. With regard to multiple scatter, Trice[4] has reported, "It is found for a separation distance of 30 meters that the second-scattered gamma beam could not be more than 2% of the first-scattered beam. It is noticed, also, that second scattering becomes more important than first at great distances; similarly at smaller distances, second scatterings are of smaller relative magnitudes." Regarding the neglect of part of the scattering volume, it may be inferred that the air scatter beyond the 50-ft plane will be relatively small because the minimum single scattering angle is then 127-deg, for which the gamma energy degradation is over 80%, and for which $\frac{d\sigma}{d\Omega}$ is but 10% of its maximum. These two items neglected both appear to be small; their inclusion would operate in the same sense on both the theoretical and experimental figures.

In summary, it is believed that the theoretical results (Ref.1) for gammas scattered to the detector are substantially in agreement with Convair's experimental data (Ref. 2, 3).

4. James B. Trice, NEPA-1297-STR-21 (February, 1950).