DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 377TH AIR BASE WING (AFMC)

377 CS/SCBIF (FOIA Manager)
2051 Wyoming Blvd., S.E.
Kirtland AFB NM 87117-5607

28 October 1999

John Greenewald, Jr.

Dear Mr Greenewald

This is in response to your Freedom of Information Act request of 24 September 1999, for information Initial Nuclear Radiation From Low Yield Fission Weapons. The request was received by my office on 27 October 1999.

To avoid any delays in processing future request made under the Act, please address your letters to 377 CS/SCBIF (FOIA Manager), 2051 Wyoming Blvd., S.E., Kirtland AFB NM 87117-5607. We will respond to your request not later than 29 November 1999.

Sincerely

MARVIN L. EVANS
Freedom of Information Act Manager

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 377TH AIR BASE WING (AFMC)

377 CS/SCBIF (FOIA Manager)
2051 Wyoming Blvd., S.E.
Kirtland AFB NM 87117-5607

9 December 1999

John Greenewald, Jr.

Dear Mr Greenewald

This is in response to your Freedom of Information Act request of 24 September 1999, for information initial Nuclear Radiation From Low Yield Fission Weapons. The request was received by my office on 27 October 1999.

To process your request properly, we need a time extension because we must consult with DOE about a further review of the documents you are asking for. Also, if you are a registered DTIC user it would be to your advantage to request the document from DITC.

We will respond to you as soon as possible.

Sincerely

Marvin L. Evans
MARVIN L. EVANS
Freedom of Information Act Manager

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 377TH AIR BASE WING (AFMC)

2 June 2000

377 ABW/JA
2000 Wyoming Blvd.
Kirtland AFB, NM 87117-5000

John Greenewald, Jr.

RE: Request for Report of Initial Nuclear Radiation From Low Yield Fission Weapons, Report No. AFSWC-TN-56-14

Dear Mr. Greenewald,

This message is in response to your letter dated 24 September 1999 in the referenced matter. Thank you for your patience in waiting for this decision. In an effort to provide a fair and objective review of your request for information under the Freedom of Information Act (FOIA) 5 U.S.C. §552 *et seq.* (1994 & Supp. II 1996), we also consulted the Department of Energy regarding information in their control. They are in the process of reviewing additional information that may be relevant to your request. After careful review of the portion of your request that relates to information in our control, I have determined that only a limited amount of information may be disclosed to you. As you may already know, FOIA exempts from disclosure any information that is classified. The fact of the existence or nonexistence of information which would reveal a connection or interest in the matters relating to those set forth in your request is classified in accordance with Executive Order 12958 (Attachment). As a result, a portion of your request is denied pursuant to 5 U.S.C. §552(b)(1).

If you decide to appeal this decision, please forward your request to the Secretary of the Air Force at the address provided below. Your appeal must include this letter and a written statement stating the basis by which you believe information should not be denied. Your package is due to the Secretary of the Air Force within 60 calendar days from the date of this letter.

Secretary of the Air Force
THRU: 377th CS/SCBIF (FOIA Manager)
2051 Wyoming Blvd. S.E.
Kirtland AFB NM 87117-5607

Sincerely,

DAVID M. PRONCHICK, Colonel, USAF
Staff Judge Advocate

Attachments:
Report No. AFSWC-TN-56-14
Executive Order 12958

cc: 377 CS/SCBIF (FOIA Manager)

TN-56-14

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AFSWC-TN-56-14

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INITIAL NUCLEAR RADIATION FROM LOW YIELD FISSION WEAPONS

by

EDWIN N. YORK
Captain USAF

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Research Directorate
AIR FORCE SPECIAL WEAPONS CENTER
Air Research and Development Command
Kirtland Air Force Base
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Approved by:
Macpherson Morgan
Lt Colonel, USAF
Chief, Effects Division

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ABSTRACT

The information presented is based on an evaluation of field test measurements, laboratory experiments, and theoretical calculations. Brief descriptions are given of the basic physical processes which produce initial nuclear radiation, of the methods used to evaluate existing data, and of the methods of calculation. (U)

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

EDWARD F. WALKER
Colonel USAF
Chief of Staff

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the many persons who have aided him in the preparation of this study. He is particularly grateful to Capt Roger E. Boyd and Lt Don A. Baker of the Research Directorate, Air Force Special Weapons Center, for their assistance throughout the work; to Lt Gunning Butler of the Research Directorate, AFSWC, who performed the machine calculations; to Dr. Hugh C. Paxton and Dr. Robert G. Keepin, Jr. of the Los Alamos Scientific Laboratory, for their cooperation in providing neutron exposures to film dosimeters; and to Mr. Ross G. Larrick, Capt James B. Graham, Mr. Thomas B. Hurley, Mr. Robert Marmiroli, and Mr. Ockie Johnson of the Evans Signal Laboratory for their cooperation in calibrating and processing the film dosimeters. (U)

CONTENTS

1. PURPOSE.

The purpose of this study was to compute initial nuclear radiation doses from low yield weapons at altitudes up to 100,000 feet MSL, and to present the results in a manner that would permit the greatest flexibility of use for operational planning purposes. (U)

2. CONCLUSIONS.

3. RECOMMENDATIONS.

It is recommended that the curves presented in this study be used for operational planning purposes. For more detailed planning in the case of a rapidly moving receiver, it is recommended that machine calculations be used. (U)

4. BACKGROUND.

Manuscript released by author December 1956.

5. DISCUSSION.

a. Initial nuclear radiation sources

The initial nuclear radiation from a nuclear fission weapon may be considered to originate from the following sources.

(1) Gamma radiation from the fission process.

(2) Neutrons from the fission process.

(3) Gamma radiation from fast neutron recoils (inelastic scattering).

(4) Gamma radiation from the radiative capture of prompt neutrons by nitrogen in the atmosphere.

(5) Gamma radiation from the fission products.

(6) Delayed neutrons from the fission products.

(7) Gamma radiation from the radiative capture of delayed neutrons by nitrogen in the atmosphere.

(8) Black body electromagnetic radiation in the low X-ray energy region. (U)

Delayed neutrons are only a fraction of the total number of neutrons released and may be neglected in comparison with the number of neutrons released during the fission reaction. As shown in reference 3, the number of delayed neutrons per fission is 0.0173 for U-235, 0.044 for U-238, and 0.0067 for Pu-239. Gamma radiation from the capture of delayed neutrons by nitrogen may also be neglected for low yield weapons. (U)

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* For the purpose of this study initial nuclear radiation is defined as the neutron and gamma radiation emitted during approximately the first minute after a nuclear detonation. For a discussion of the physics of a nuclear detonation, see reference 2.

d. Gamma radiation.

Published values for absorption coefficients of gamma radiation (the absorption coefficient being the reciprocal of the mean free path) are nearly always for measurements made under conditions of good geometry.* Such values are useful for laboratory work, since it is usually possible to arrange good geometry conditions in a laboratory. Under field conditions, however, multiple scattering becomes quite important; and absorption coefficients determined under laboratory conditions are not directly applicable. This difficulty may be surmounted by using a correction factor called the buildup factor, or by using effective absorption coefficients and apparent mean free paths. The buildup factor may be defined as the factor by which good geometry calculations must be multiplied in order to correct for the multiple scattering contribution. An apparent mean free path is simply defined as the mean free path actually observed under field conditions. (U)

Measurements of initial gamma radiation as a function of distance from the point of detonation permit an apparent mean free path to be determined easily. It is necessary only to multiply the measured dose per KT at a given distance by the square of the distance (to remove inverse square dependence), and to plot these values as a function of distance. It is customary to plot the results on semi-log paper since this gives very nearly a straight line. Usually it is assumed that a straight line relationship does exist, and a straight line is drawn through the data points. The resulting line is characterized by an intercept value which for convenience is usually expressed in terms of dose at unit distance, e. g., roentgens per kiloton at one yard, and by a slope which may be expressed as the apparent mean free path. (U)

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* Good geometry is a rather loose term denoting an experiment in which scattered radiation does not reach the detector.

Recently some preliminary results of a Monte Carlo calculation being made at NBS on the effect of the air-ground interface on propagation of gamma radiation have been received, as described in reference 12. These preliminary results show that for a Co-60 radiation at 3 mean free paths, the dose near the air-ground interface is 65% of the free air dose. This indicates that the effect of the ground surface may be greater than that calculated by using a simple, forward-scattering model. (U)

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[*] Back scattering decreases with increasing energy. For a 10-Mev source, and an approximate treatment, it may be ignored.

(U) The relative air densities for the various altitudes are listed in table 2.

TABLE 2

RELATIVE AIR DENSITY AT VARIOUS ALTITUDES

Altitude (ft)	Relative Density	Altitude (ft)	Relative Density
Sea level	1.0000	60,000	0.09413
10,000	0.7385	70,000	0.05821
20,000	0.5328	80,000	0.03600
30,000	0.3741		
40,000	0.2462	90,000	0.02226
50,000	0.1522	100,000	0.01377 (U)

(3) Nitrogen-capture gamma radiation.

The decay scheme for Nitrogen-15 given by Kinsey, reference 14, was used as the basis for determining the nitrogen-capture gamma radiation energies. Since the decay scheme as reported is not complete, the missing low-energy components were added. These were determined by taking the fewest components which would complete the decay scheme and thus satisfy the conservation of energy. Table 3 lists the gamma ray energies used.* (U)

TABLE 3

GAMMA RAYS FROM THE REACTION N-14 + n → N-15 + γ

Energy (Mev)	Relative Intensity	% of Disintegrations
10.815 ± 0.015	1.00	19.10
9.156 ± 0.030	0.09	1.72
8.278 ± 0.016	0.19	3.54
7.356 ± 0.012	0.56	10.70
7.164 ± 0.010	0.19	3.54
6.318 ± 0.010	0.90	17.20
5.554 ± 0.010	1.50	28.60
5.287 ± 0.010	2.30	44.00
4.485 ± 0.010	0.80	15.30
	Added to Complete Decay Scheme	
3.87	0.22	4.21
3.66	0.41	7.85
3.46	0.78	15.00
2.99	0.23	4.31
2.54	0.41	7.85
2.07	0.13	2.40
1.87	0.23	4.31
1.66	0.31	5.93
1.04	0.10	1.90. (U)

---

* After the calculations were made it was found that the additions were of minor importance, since they contributed only 18% of the nitrogen-capture gamma radiation dose at small distances and even less at large distances. (U)

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The attenuation for each component was computed separately on an IBM 650 electronic computer using build-up factors obtained from Goldstein and Wilkins, reference 15, and absorption coefficients obtained from NBS 1003, reference 10. The total nitrogen-capture gamma radiation attenuation was then obtained by summation of the separate components. The dose-distance curves obtained are shown in figure 2. (U)

(3) Fission product gamma radiation.

Fission products emit gamma radiation with a variety of energies and decay periods. If the relative abundance, gamma radiation energies, and decay periods of the short-lived fission products were known, it would be possible, at least theoretically, to compute the fission-product gamma radiation dose for any time or distance of interest. Since these parameters are not known for short times after fission, it is necessary to base calculations on a generalized energy spectrum and decay rate. (For a discussion of the present state of knowledge concerning fission product gamma radiation at early times, see AFSWP 502B, reference 17.) (U)

For attenuation calculations, the Motz energy spectrum was divided into 80 energy increments from 0.1 to 8.0 Mev. The attenuation for each increment was computed separately on an IBM 650 electronic computer in a manner directly analogous to that used for nitrogen-capture gamma radiation. The total fission-product gamma radiation attenuation was then obtained by summation of the separate increments. The fission-product gamma radiation dose-distance curves are shown in figure 3. (U)

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g. Use of curves.

Figures 1 through 4 are curves which show the prompt neutron dose, the nitrogen-capture gamma dose, the fission-product gamma dose, and the total dose for a stationary receiver as a function of horizontal distance for various burst altitudes from 10,000 feet to 100,000 feet. Also presented are isodose lines from 0.01 to 100,000 rem on a plot having a height of burst and horizontal distance as coordinates. Horizontal distance is to be interpreted as the distance from the detonation to the receiver with the two at the same altitude. The NACA air density corresponding to the burst height was used in computing the ranges. The curves have been drawn for a yield of 1 kiloton. For other yields the values obtained from the curves should be multiplied by the yield in kilotons. (U)

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For a more general solution it is recommended that machine calculations be used. The input parameters given in appendix II should be used for making the calculations. (U)

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APPENDIX I

NEUTRON SENSITIVITY OF FILM DOSIMETERS

Neutron corrections to the TEAPOT gamma-dose data were obtained from the results of neutron film sensitivity tests which were made at Los Alamos. The film packs used in the experiment were supplied, calibrated, and read by the film dosimetry group at Evans Signal Laboratory, Belmar, New Jersey. The film was calibrated with a Co^{60} source at ESL at the same time the experimental exposures were made at Los Alamos. The film types tested in the experiment included the following: (U)

Table 5

FILM TYPES TESTED FOR NEUTRON SENSITIVITY

Film Pack	DuPont Film Type	Recommended Exposure Range (roentgens)
150-2	606	25-600
	1290	40-600
553	606	25-600
	510	9-100
	502	2.5-12

(U)

The neutron component of the film blackening was treated as the sum of a response to low-energy (gold) neutrons and that due to the high-energy neutron Rep dose. This division of the film neutron sensitivity was accomplished with the use of the Godiva neutron flux calibration data furnished by the N-2 division of LASL. The Godiva neutron flux curves show that the flux at short ranges from the assembly consists essentially of high-energy neutrons. This fact allows the computation of the film neutron sensitivity to the high-energy rep dose. Since the percentage of gold neutrons in the Godiva flux increases with distance, the difference in the total neutron film blackening and that computed from the high-energy rep dose sensitivity at distant stations may be attributed to the gold neutron response. If the perturbations in the neutron flux caused by the film pack holders are assumed to be small, the value of the gold neutron sensitivity of the emulsions is the number of gold neutrons/cm^2 necessary to cause the same film blackening as 1 roentgen of Co^{60} gamma radiation.* (U)

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* Hereafter, the term "film R" is used to designate the amount of film blackening caused by exposure to 1 roentgen of Co^{60} gamma radiation.

The neutron sensitivity of the various emulsions, as calculated by the foregoing procedure, gives neutron exposures which agree with the observed values at each station within the limits of the experimental errors. The results of these calculations are shown in table 7. (U)

The deviations listed are the average deviations of the individual film readings from the mean value. (U)

These values for film sensitivity to neutrons are in general agreement with values which have been quoted in the literature. Table 8 is a partial list of published values. (U)

The gold neutron flux was obtained directly from the gold detector measurements taken at Operation TEAPOT. (U)

The transmission of gamma radiation through the atmosphere depends primarily on the density of air along the path traversed. The air density of course varies with altitude, and whenever the source and receiver are at different altitudes, the air density varies along the path traversed by the gamma radiation. Calculations of the transmission of gamma radiation as a function of the areal density* of air traversed were made using an IBM 650 electronic computer. The results are listed in table 11 and are shown in figure 8 for nitrogen-capture gamma radiation and for fission-product gamma radiation. Neutron transmission is also included in the figure for comparison. (U)

In order to use the calculated values for neutron transmission, it was necessary to know the integrated value of the areal density along the path traversed. This value was obtained from the equation:

$$\mathrm{g/cm^2} = C\,\frac{P_1 - P_2}{G} \times \frac{x}{\Delta H} \tag{12}$$

---

* Areal density is defined as the product of the density and the path length, or ρx. For a varying density, areal density $= \int \rho dx$.

APPENDIX II (Con.)

where P_2 = pressure at receiver altitude in atmospheres
P_1 = pressure at source altitude in atmospheres
G = gravitational constant, cm/sec^2
x = distance from source to receiver in yards
ΔH = altitude difference from receiver to source in yards
C = a constant, $\dfrac{\text{g sec}^2}{\text{cm}^3\ \text{atm.}}$

for P_1 and P_2 in atmospheres, the value of C/G is 1033.23

For small values of ΔH, the areal density along the path from source to receiver was obtained by multiplying the average density between the source and receiver altitudes by the path length. (U)

APPENDIX III

EFFECTS OF THE AIR/GROUND INTERFACE

Calculations of the attenuation of gamma radiation in air were based on buildup factors computed by Goldstein and Wilkins in reference 15 for an infinite homogeneous water medium. The use of buildup factors computed for water should be valid for air, since the primary interaction of gamma radiation with low atomic number absorbers such as water and air is Compton scattering. Multiple scattering for Compton interactions, and hence the buildup factors, will depend only upon the number of electrons present, provided photoelectric absorption and pair production are negligible, and will be nearly the same for all low Z materials on a normalized density basis. (U)

The use of buildup factors computed for an infinite homogeneous medium is valid for bursts at altitude, provided the air is reasonably homogeneous for the distances considered. For high yield weapons large distances are of interest, and effects due to variations in density with altitude may become important; but for low yield weapons, variations in density are not excessive. Most field test measurements have been made for surface stations however, and the assumption of an infinite homogeneous medium is not valid near the air-ground boundary. Since it was desired to utilize field test measurements to normalize calculated values for fission-product gamma radiation, a study was undertaken to estimate the effects of the air-ground interface from a simple calculation scheme. In order to keep the calculations as simple as possible, a high-energy (10 Mev) source was chosen. For high-energy gamma radiation, scattering is predominately in a forward direction, and back scattering can be neglected without causing large errors. This reduces the number of calculations by about a factor of 2. (U)

Starting with a 10-Mev-gamma source, and considering only forward scattered radiation, buildup factors were computed to 4 mean free paths in a homogeneous air medium. Differential Compton scattering cross sections for the calculations were obtained by use of the Klein-Nishina equation. Total absorption cross sections were taken from NBS 1003. (U)

Angular distribution was taken in 10° increments about the horizontal and about the lateral axes. Because of symmetry it was necessary to compute only 9 increments about the horizontal axis, (0 to 90°), and 18 increments about the lateral axis, (0 to 180°). All the radiation emitted in each angular segment was assumed to be along the centerline of the segment, and all interactions which occurred within 1 mean free path were assumed to take place at a point at a distance of 1 mean free path. Thus all first interactions were assumed to occur at a set of points (9 x 18), each a distance of 1 mean free path from the source. Each point was then taken as a source for the next step in the calculation. A new set of coordinates was selected for each point, with the horizontal axis along the centerline of the original segment. Again 9 angular increments were taken about the horizontal axis and 18 about the lateral axis. In this case, each of the 9 increments about the horizontal axis corresponded to a different scattering angle of the original radiation and therefore to a different energy. All interactions occuring within 1 mean free path along each segment were assumed to occur at a point at a distance of 1 mean free path for the energy being considered. Each of these points in turn was taken as a source for the next step in the calculation. This procedure was repeated until a distance corresponding to 4 mean free paths of the original 10 Mev source was reached. The dose at a given distance was obtained by adding the dose from each of the angular segments that intersected a common point at that distance. This dose was compared to the dose from the unscattered radiation to obtain the buildup factor. Because the number of calculations increased exponentially with distance, the buildup factors at distances beyond 4 mean free paths were not computed. (U)

A measure of the validity of computing buildup factors in this manner can be obtained by comparing the results with buildup factors computed by Goldstein and Wilkins. Table 13 lists the buildup factors obtained by neglecting back-scattering along with those computed by Goldstein and Wilkins for a 10 Mev source. (U)

Table 13

BUILDUP FACTORS FOR 10-MEV GAMMA RADIATION IN FREE AIR

Number of Mean Free Paths	Buildup Factors B(r)		B(r) - 1		
	NDA	AFSWC	NDA	AFSWC	% Difference
1	1.32	1.26	0.32	0.26	-15
2	1.63	1.59	0.63	0.59	-7
3		1.83		0.83	
4	2.22	2.11	1.22	1.11	-10

(U)

As expected, the values computed by neglecting back scattering are lower than those computed by Goldstein and Wilkins of the Nuclear Development Corporation of America. (U)

Calculations were next made of buildup factors with the source and receiver at the earth's surface. The ground was assumed to have a uniform density 2,000 times that of air and to have the same effective atomic number as air. These assumptions do not introduce a significant error while they considerably reduce the calculations required. The actual ground density varies somewhat for different locations, but a density of 2.4 to 2.5 g/cm^3 is a fair average for most soil types. 2.45 g/cm^3 is 2,000 times the NACA sea level air density. The effective atomic number for soil is about 12 or 13 compared to about 7 for air. For low atomic numbers such as these, the photoelectric absorption and pair production cross sections (which depend on the atomic number Z) are small. (U)

The same calculation scheme as for the free air case was used with the mean free path distances in the absorber taken as 1/2,000 the mean free path distance in air. To simplify the calculations somewhat, the first interaction below the interface was assumed to occur at the surface, and all radiation scattered downward after the second interaction below the interface was assumed to be completely absorbed. These two simplifications are partially compensating.

APPENDIX III (Con.)

If the first interaction is assumed to occur at the surface, slightly higher values will be given for the amount of radiation reflected back into the air than if the interaction occurred some distance below the surface; if the radiation scattered downward after two interactions below the surface is neglected, there will be slight decreases in the amount of radiation getting back into the air. Again because of the exponential increase in the number of calculations with distance, 4 mean free paths was the maximum distance to which the calculations were made. However, it was found that the ratio of the buildup factor for the air/ground case compared to the free air case could be approximated by small-angle scattering only. That is, the contribution of multiple scattering considering only angles of 0-10° had approximately the same ratio of air/ground compared to free air as the total multiple scattering contribution. This greatly reduced the number of calculations and permitted the determination of this ratio out to 12 mean free paths. Table 14 lists the results of this calculation. (U)

Table 14

EFFECT OF THE GROUND SURFACE ON BUILDUP FACTORS FOR 10 MEV

Number of Mean Free Paths	$\frac{(B(r)-1)\ \text{Air/Ground}}{(B(r)-1)\ \text{Free Air}}$	Number of Mean Free Paths	$\frac{B(r)-1)\ \text{Air/Groun}}{B(r)-1)\ \text{Free Air}}$
1	0.85	6	0.58
2	0.75	8	0.53
3	0.68	10	0.45
4	0.62	12	0.42

(U)

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