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UNITED STATES ATOMIC ENERGY COMMISSION

NYO-4507

**ESTIMATION OF LUNG DOSE FROM THE
RADIOACTIVE CLOUD ASSOCIATED WITH A
NUCLEAR DETONATION**

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March 1953
[TIS Issuance Date]

New York Operations Office, AEC

Classification cancelled (or changed **UNCLASSIFIED**)
by authority of Walter H. J. Di Giovanni
dated 8-17-56 TIE, date 9-17-56
by H. Kerr

Technical Information Service, Oak Ridge, Tennessee

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ABSTRACT

A method is developed for estimating the dose to the lungs of a person exposed to the airborne radioactive dust from the cloud associated with a nuclear detonation. The analysis is applied to data collected at a point about 275 miles from the test site in the Fall, 1951, weapons tests in Nevada.

EFFECTS OF ATOMIC WEAPONS (Special)

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ESTIMATION OF LUNG DOSE FROM THE RADIOACTIVE CLOUD ASSOCIATED WITH A NUCLEAR DETONATION

By Hanson Blatz and Leonard R. Solon

Measurements made of radioactive air dust collected near ground level at a point about 275 miles from the test site in the Fall, 1951, weapons tests in Nevada (Reference 1) showed activity up to 2×10^5 disintegrations per minute per cubic meter of air (0.1 c per cubic meter). Figure 1 exhibits a curve obtained by measurement of radioactive dust samples showing the specific activity (disintegrations/min/meter³) at the point of collection, as a function of the time in hours after the explosion. It is seen that about 22 hours elapse between the arrival of the cloud and restoration of the atmospheric activity to normal background. The sampling was done in successive periods of from 1/4 hour to 3 1/3 hours duration.

An attempt is made here, with certain simplifying assumptions, to estimate the radiological dose to the lungs of a person living in the area during the period of high activity.

It is known that the activity of the fission products is given to a close order of approximation by the following expression, (Reference 2, P.252):

$$A_t = A_1 t^{-n} \quad \dots (1)$$

where A_t is the activity at time t after the detonation. A_1 is the activity after unit time while n is an empirical constant of the order of unity. Reference 1 gives $n = 1.2$.

To facilitate calculation of the lung dose to a person living in this environment of high activity, the following assumptions have been made:

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1. The breathing rate, B, is uniform and equal to 10 cubic meter for 24 hours.
2. 100% of the radioactive dust inhaled is retained by the lung, i.e., the exhaled breath contains no radioactivity. This is obviously a very conservative assumption.
3. Elimination from the lung can be represented by an exponential function of the form e^{-kt} where $k = \frac{0.693}{T}$ and T, the so-called "biological half-life" will be taken as 15, 30 and 90 days respectively.
4. The mean energy of all the disintegrations shall be taken as 0.4 MEV.
5. The inhaled activity is uniformly distributed throughout the lung mass, the latter taken as 1 kg.

The method of attack is as follows. Figure (1) is partitioned into ten two-hour activity periods. An average disintegration rate is calculated for each period and it is assumed that the radioactive decay of the inhaled dust is governed by a time dependence characteristic of the mid-point, t_j , of the two hour interval. The total number of disintegrations at any later time t_2 is obtained by integrating between t_j and t_2 . By summing up the contributions of all the two hour intervals, the cumulative dose at time t_2 is obtained.

Designating the product of the disintegration rate, breathing rate and the j^{th} interval (i.e. 2 hours) by I_j , the number of disintegrations, D_j , at t_2 from this interval is given by:

$$D_j = \int_{t_j}^{t_2} I_j \left(\frac{x}{x_j} \right)^{-m} e^{-k(x-t_j)} dx \quad \dots (2)$$

where $k = .693/T$.

A change of variable yields

$$D_j = \frac{I_j t_j^m e^{k t_j}}{k^{1-m}} \int_b^a u^{-m} e^{-u} du \dots (3)$$

where $u = kt$, $a = kt_2$, $b = kt_j$

Now,

$$\int_b^a u^{-m} e^{-u} du = \int_b^\infty u^{-m} e^{-u} du - \int_a^\infty u^{-m} e^{-u} du \dots (4)$$

and by the simple transformation $y = \frac{u}{b}$ one obtains

$$\int_b^\infty u^{-m} e^{-u} du = b^{1-m} \int_1^\infty y^{-m} e^{-by} dy \dots (5)$$

Expression (5) is the Gold function

$$E_m(b) = \int_1^\infty y^{-m} e^{-by} dy$$

tabulated for integral values of n in Reference 3. Some of the important properties of this function are assembled in Reference 4 and elsewhere.

Writing in terms of these functions, equation (3) becomes

$$D_j = \frac{I_j t_j^m e^{k t_j}}{k^{1-m}} [b^{1-m} E_m(b) - a^{1-m} E_m(a)] \dots (6)$$

To relate the number of disintegrations to the dose, the following conversion has been used assuming uniform distribution of activity through the 1 kg. lung mass:

$$\left(\frac{D_j}{1000g} \right) \left(\frac{0.4 \text{ MEV}}{\text{DIS}} \right) \left(\frac{1.72 \times 10^{-5} \text{ MRFP-GM}}{\text{MEV}} \right) \dots (7)$$

Using (6) and (7) the doses in millireps have been calculated for

$t_2 = 37$ hours (one day after incidence), 168 hours (1 week) 720 hours (1 month), 1440 hours (2 months) 2160 hours (3 months), 4320 hours (6 months) and 8640 hours (1 year). The average activities of the intervals in Figure (1) were obtained by numerical integration.

Values of the constants used are recapitulated below:

$$n = 1.2$$

$$k = \frac{0.693}{T} = 9.625 \times 10^4 \text{ hrs.}^{-1}$$

where T is the biological half-life of 30 days (720 hours).

$$B = \frac{10 \text{ meters}^3}{24 \text{ hours}} = 0.417 \text{ meter}^3/\text{hour}.$$

The approximate nature of the calculations justifies linear interpolation between E_0 and E_1 for $E_{1.2}$ in the tables of Reference 3. For more precise work, tables with a finer mesh are much to be desired. Cumulative doses are shown in the table and exhibited graphically in Figure (2).

For purposes of comparison, one might mention that a routine chest X-ray can produce a dose to the lungs of up to 1 or 1000 milliroentgens. It is seen that the radioactive cloud considered in this paper does not constitute a health hazard.

CUMULATIVE DOSES

	T = 15 days	T = 30 days	T = 90 days
t(h)	Dose (mrep)	Dose (mrep)	Dose (mrep)
37	3.10	3.38	3.43
168 (1 week)	8.70	9.73	10.87
720 (1 mo.)	10.90	12.81	15.03
1440 (2 mo.)	11.13	13.40	16.21
2160 (3 mo.)	11.16	13.55	16.68
4320 (6 mo.)	11.17	13.62	17.15
8640 (1 yr.)	11.17	13.63	17.31
∞	11.17	13.63	17.34

FIGURE 1

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References

1. Thirteenth Semi-Annual Report of the Atomic Energy Commission.
2. The Effects of Atomic Weapons, U.S. Government Printing Office,
June 1950.
3. The Functions $E_n(x) = \int_0^\infty e^{-xu} u^n du$
G. Placzek, N.R.C. Report No. ME-1.
4. A Table of Integrals Involving the Functions $E_n(x) = \int_0^\infty e^{-xu} u^n du$
J. LeCaine, N.R.C. Report No. ME-131.

APPENDIX IAir Samples

<u>Date</u>	<u>Time</u>	<u>Time Interval</u>	<u>Activity*</u>
11/29/51	22:40		2.9×10^2
11/30/51	1:00	3.33 hrs	"
	2:00	1.00	2.9×10^4
	3:20	1.33	1.0×10^5
	4:30	1.167	1.2×10^5
	5:00	0.50	1.1×10^5
	5:30	0.50	1.3×10^5
	6:10	0.67	1.9×10^5 (max)
	6:45	0.58	1.2×10^5
	7:10	0.42	1.4×10^5
	7:40	0.50	1.1×10^5
	8:20	0.67	1.3×10^5
	8:45	0.42	8.0×10^4
	9:00	0.25	7.0×10^4
	11:00	2.00	5.2×10^4
	12:00	1.00	4.6×10^4
	14:00	2.00	1.4×10^4
	16:00	2.00	1.6×10^4
	18:00	2.00	6.3×10^3
	20:30	2.50	2.8×10^3
	(to 22:30) - end of sampling		

* Beta disintegrations per minute per cubic meter of collected air.