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The effect of a composite atmosphere on radiant exposure from a nuclear explosion

Kinney, Gilbert Ford

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Gilbert Ford Kinney

THE EFFECT OF A COMPOSITE ATMOSPHERE ON
RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION.

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THE EFFECT OF A COMPOSITE ATMOSPHERE ON RADIANT EXPOSURE FROM A NUCLEAR EXPLOSION

By

G. F. Kinney
Professor of Chemical Engineering

RESEARCH PAPER NO. 9

October 1956

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THE EFFECT OF A COMPOSITE ATMOSPHERE
ON RADIANT EXPOSURE
FROM A NUCLEAR EXPLOSION

Thermal radiation effects accompanying a nuclear weapon detonation have been described in some detail (1,2). It has been indicated that the damaging effects of thermal radiation are to be correlated with total radiant energy received per unit area, and that within limits are not greatly dependent on the rate of reception.

A quantitative relation between radiant exposure (Q) at a distance (D) and the total radiant energy emitted (E) is provided by equation 3.35.1 of reference (1).

$$Q = \frac{E}{4\pi D^2} e^{-kD} \quad (1)$$

The total radiant energy is assigned a value of 6.7×10^{12} calories for a nominal (20KT) atomic bomb.

The term e^{-kD} of this equation represents numerically the transmission of the atmosphere (here assumed uniform). It is a correction for the atmospheric attenuation caused primarily by a scattering out from a direct beam, although with smog or smoky haze absorption may also contribute. The scattering in of indirect radiation and the effects of multiple scattering are neglected). Item (k) of the equation is called the attenuation coefficient, extinction coefficient, or, less appropriately, the absorption coefficient. Its value is a function of wave length, as evidenced for example by the changing colors of the setting sun. However

this variation is not large in magnitude and the atmosphere may be assigned average values that apply for the wave length range 0-10 μ (reference 3). Coefficient (k) has the units of reciprocal length, making the product (kD) a dimensionless ratio. This ratio has been identified as the optical thickness of the (uniform) atmosphere.

A composite atmosphere is characterized by a variety of attenuation with different coefficients (k_1, k_2, \dots), each effective over paths with distances (d_1, d_2, \dots). Here more than one transmission term of the form e^{-kd} is required. Adapting equation (1) to provide for this, and also converting into working units,

$$\psi = \frac{575 n}{(D')^2} (e^{-k_1 d_1} \cdot e^{-k_2 d_2} \dots) \quad (2)$$

where

- D' = slant range (total distance) in thousands of feet, and equals $(d_1 + d_2 + \dots)$
- d_1, d_2 = lengths of paths characterized by attenuation coefficients k_1, k_2 , with units such that the optical thickness (kd product) is without units.
- k_1, k_2 = attenuation coefficients
- n = energy yield in terms of a nominal (20KT) atomic burst.

A mean attenuation coefficient (k') for a composite atmosphere may be defined so that the results of simpler equation (1) conform with those obtained from equation (2). That is,

$$k' = k_1(d_1/D) + k_2(d_2/D + \dots) \quad (3)$$

each coefficient for portions of a composite path being weighted in accordance with its fractional path length. For a continuum the corresponding form is

$$k' = (1/D) \int_0^D k d(D) \quad (4)$$

indicated integration, if necessary, may be performed graphically on a plot of k vs distance. From these relations it follows that an attenuation coefficient based on an average visibility distance is not representative of a composite atmosphere.

The relation of equation (2) is conveniently utilized if expressed in a logarithmic or a decibel form. Taking logarithms to base 10,

$$\log_{10} Q = 2.579 + \log n - 2 \log D' - \frac{1}{2.303} (k_1 d_1 + k_2 d_2 + \dots) \quad (5)$$

where Q = radiant exposure, calories per square centimeter
 n = size of burst, in units of 20KT
 D' = slant range, thousands of feet

In this relation the kd items have become additive terms. It also can be noted that items of the form $kd/(2.303)$ correspond to an optical density, $\log_{10} (I/I_0)$, but for thermal radiation, and likewise are convenient additive terms.

A nomographic solution for relation (5) is presented in figure I, with slant range in feet. Entry to the nomograph is ordinarily at a given yield and slant range. A line through these points to the Q' scale gives a value for radiant exposure without attenuation. Attenuation is provided for by extending a line from the Q' scale through the pertinent value of kd (total for all parts of the path) to the scale for Q . Alternatively, allowance is made for the attenuation in one portion of path length by using a kd value for that portion. For additional attenuation in other path lengths transfer is made back to the Q' scale through the zero point of the kd scale, providing identical values on the Q' scales. A line from the new point on the Q' scale through the new kd to the Q scale is made as before. Note that the Q and Q' scales are symmetrical about the zero point of the kd scale.

Attenuation coefficients for various paths may be estimated from visibility distances (3). Figure 2 gives the International Visibility Code Indices for various visibility distances, and provides corresponding k values per kilometer and per nautical mile. One nautical mile is 1.852 kilometers, and for these purposes may be taken as 6000 feet. The k value of 0.014 per kilometer (0.026 per nautical mile) represents a lower limit value for "pure" air at standard density. There is also some sort of upper limit of applicability for purposes of estimating radiant exposure through fog or smog, for any effect of "scattering in" is ignored here.

To make the results obtained from these relations meaningful some estimate of the possible damage that might be inflicted is needed. Figure 3 provides a condensed summary of selected information of this type as given in reference (1). Also provided are approximate threshold values for the destruction of a dark grey cellulose material (actually a paper stock) for a variety of thicknesses (4).

ACKNOWLEDGMENT

A nomograph on which figure (1) is based was prepared during the school year 1954-55 as a class project by members of the RW2 section:

LT. Thomas J. Murphy, Jr., USN
LT. Maurice A. Horn, USN
LT. Richard C. Branton, USN
LT. Thomas D. Pfundstein, USN

Their interest and effort are responsible for this report.

The threshold energy values of figure (4) were reviewed by Mr. S.B. Martin of the U.S. Naval Radiological Defense Laboratory. The nomograph of figure (1) was reviewed by Dr. W.B. Plum of the same laboratory. Their assistance is gratefully acknowledged.

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1. Effects of Atomic Weapons, Combat Forces Press, 1950
2. AFSWP-700
3. The atmospheres of the Earth and Planets, 2nd edition. Edited by Gerard P. Kuiper; Chapter III, Scattering in the Atmospheres of the Earth and Planets, H.C. van de Hulst. University of Chicago Press, 1951.
4. S.B. Martin, private communication

SYMBOLS

D Total distance

D' Slant range, thousands of feet

d Path distance

E Total radiant energy

k Attenuation coefficient in units of reciprocal length consistent with those of path length d.

k' Mean attenuation coefficient for a composite path

n Energy release in terms of nominal (20 KT) weapon

Q Radiant exposure, calories per square centimeter

Q' Radiant exposure before allowance for attenuation

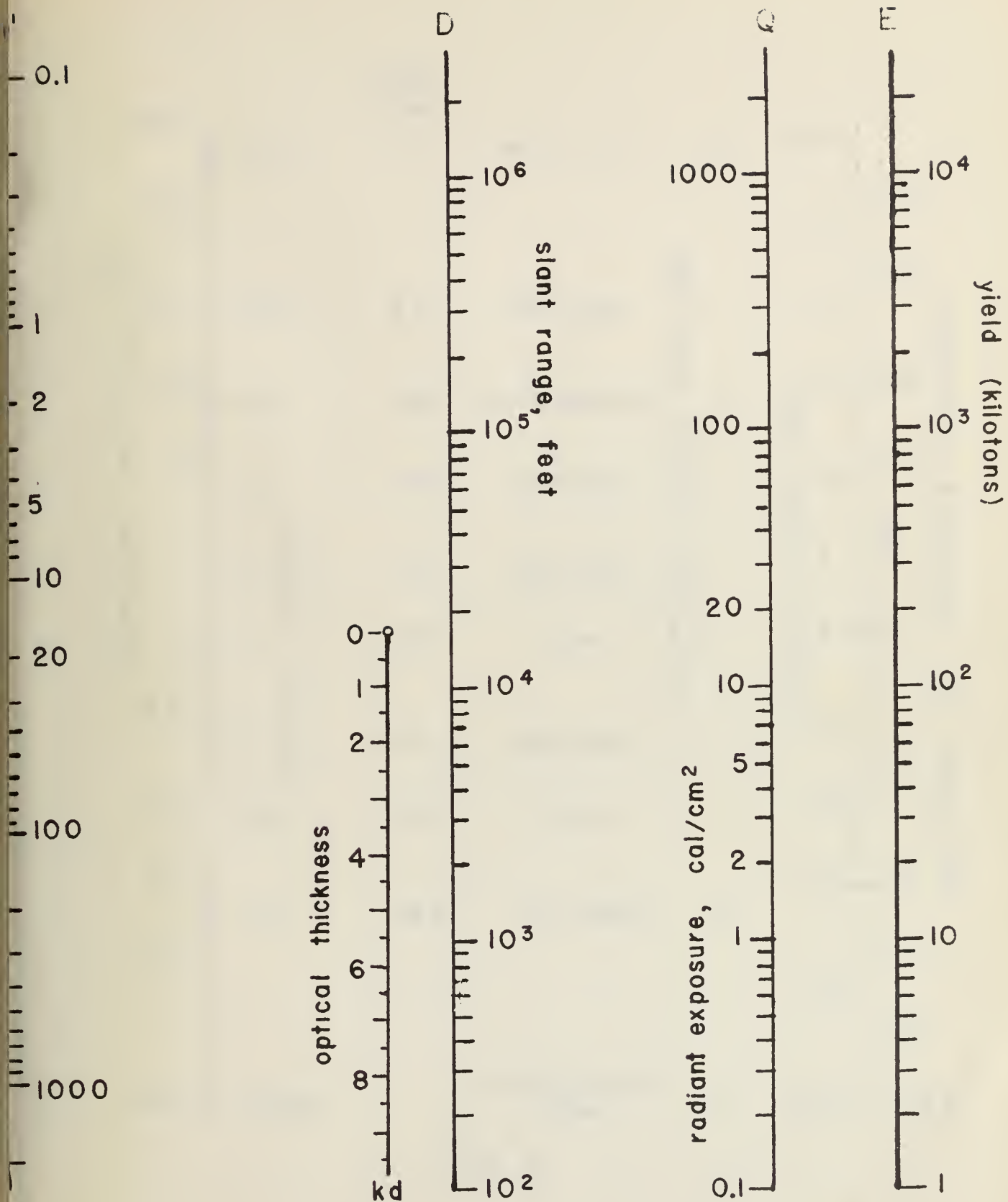


Fig. 1

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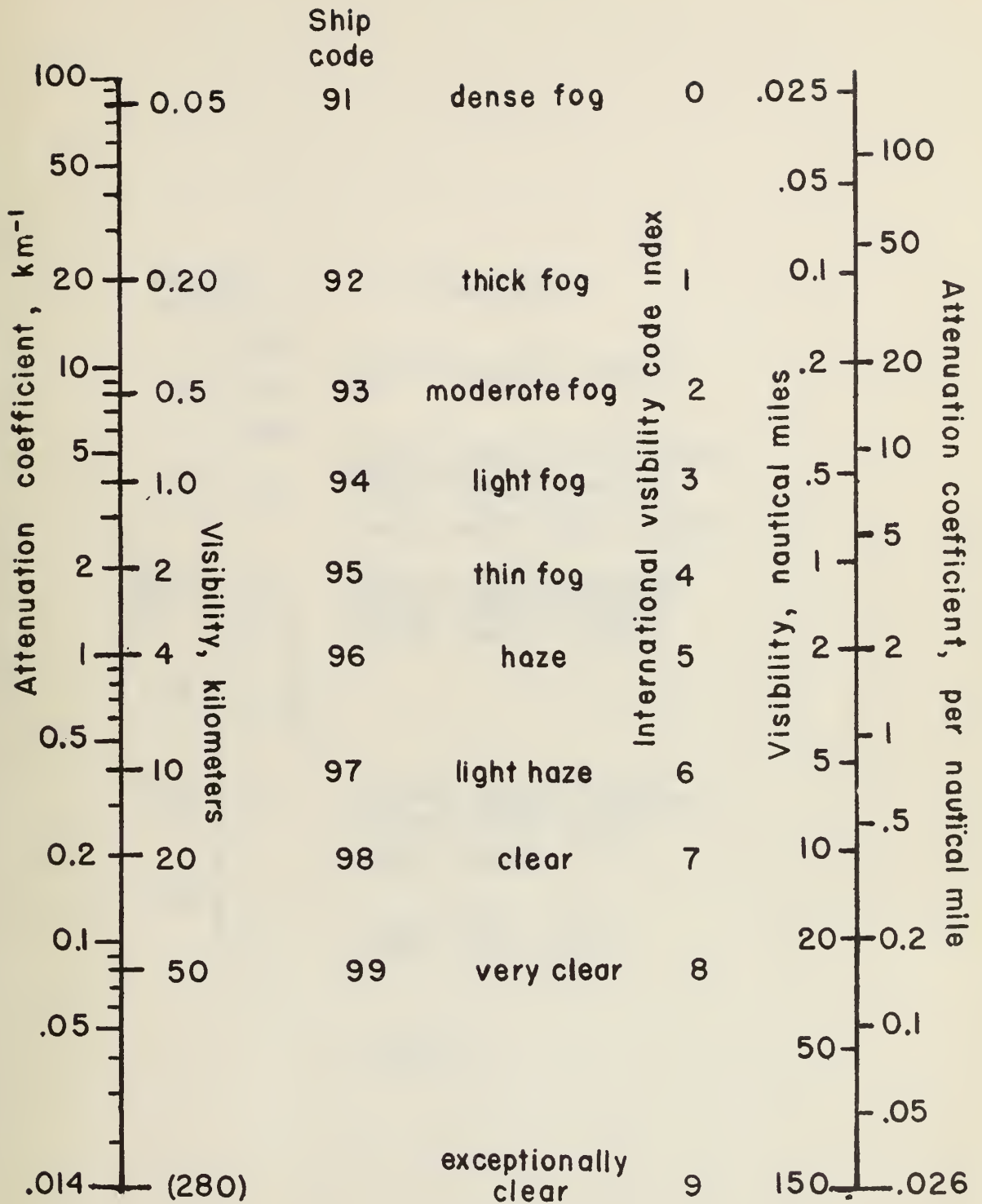


Fig. 2



Year	Value
1900	100
1901	95
1902	90
1903	85
1904	80
1905	75
1906	70
1907	65
1908	60
1909	55
1910	50
1911	45
1912	40
1913	35
1914	30
1915	25
1916	20
1917	15
1918	10
1919	5
1920	0

1920



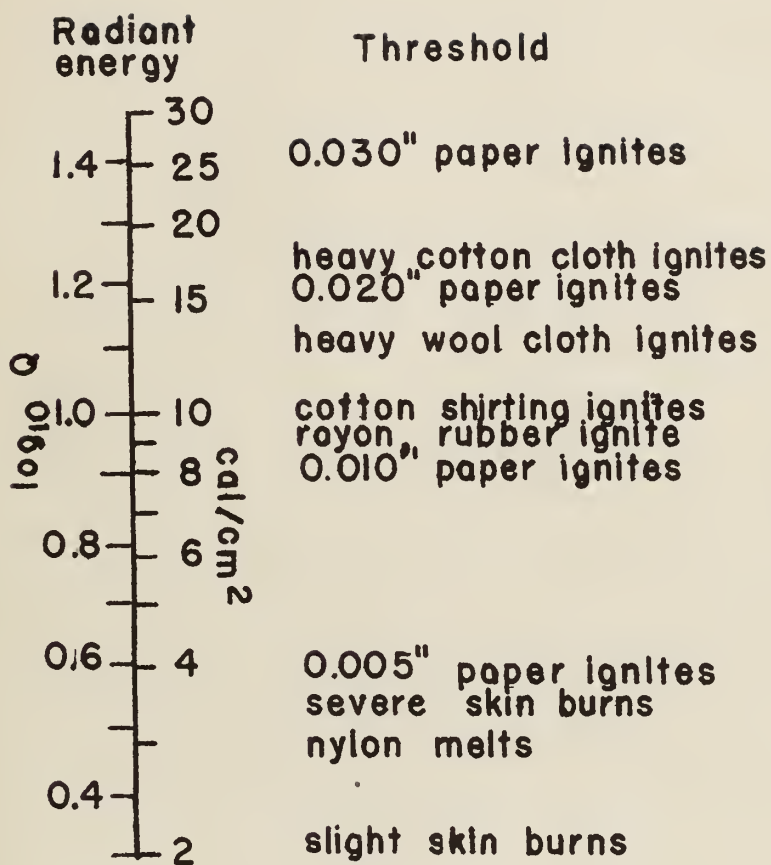


Fig. 3

Year	Population	Area
1850	100,000	100
1860	150,000	150
1870	200,000	200
1880	250,000	250
1890	300,000	300
1900	350,000	350
1910	400,000	400
1920	450,000	450
1930	500,000	500
1940	550,000	550
1950	600,000	600
1960	650,000	650
1970	700,000	700
1980	750,000	750
1990	800,000	800
2000	850,000	850
2010	900,000	900
2020	950,000	950



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