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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 5.35.1 of reference (1).

\[ Q = \frac{E}{4\pi D^2} e^{-kD} \]  

(1)

The total radiant energy is assigned a value of \(6.7 \times 10^{12}\) 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\(\mu\) (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 \((k_1, k_2, \ldots)\), each effective over paths with distances \((d_1, d_2, \ldots)\). 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,

\[
q = \frac{575_n}{(D')^2} \left( e^{-k_1d_1} \cdot e^{-k_2d_2} \cdots \right) \tag{2}
\]

where \(D'\) = slant range (total distance) in thousands of feet, and equals \((d_1 + d_2 + \ldots)\)

\(d_1, d_2 \ldots\) = lengths of paths characterized by attenuation coefficients \(k_1, k_2, \ldots\) with units such that the optical thickness \((kd\text{ product})\) is without units.

\(k_1, k_2 \ldots\) = 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,

\[
k' = k_1\left(\frac{d_1}{D}\right) + k_2\left(\frac{d_2}{D} + \ldots\right)\tag{3}
\]
each coefficient for portions of a composite path being weighted in accordance with its fractional path length. For a continuum the corresponding form is

\[
k' = \frac{1}{D} \int_0^D k \, d(D) \tag{4}
\]
indicated integration, if necessary, may be performed graphically
a plot of k vs distance. From these relations it follows that an
attenuation coefficient based on an average visibility distance
not be representative of a composite atmosphere.

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

\[
\log \frac{Q}{10} = 2.579 + \log n - 2 \log D' - \left(\frac{1}{2.303} \log \left(\frac{k_d + k_d}{1.12}\right) + \ldots\right) \tag{5}
\]

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

this relation the \(kd\) items have become additive terms. It also can
noted that items of the form \(kd/(2.303)\) correspond to an optical den-

\[
\log_{10} \left(\frac{I}{I_o}\right), \text{ but for thermal radiation, and likewise are con-
\]
ent additive terms.

A nomographic solution for relation (5) is presented in figure I, with
yield expressed in terms of equivalent tons of TNT and the slant
range in feet. Entry to the nomograph is ordinarily at a given yield
slant range. A line through these points to the \(Q'\) scale gives a
value for radiant exposure without attenuation. Attenuation is pro-
duced by extending a line from the \(Q'\) scale through the pertinent
item of kd (total for all parts of the path) to the scale for \(Q\). Or
\(Q\)natively, allowance is made for the attenuation in one portion of
path length by using a \(kd\) value for that portion. For additional
\(Q\)ation in other path lengths transfer is made back to the \(Q'\) scale
g through the zero point of the \(kd\) scale, providing identical values on the
\(kd\) and \(Q'\) scales. A line from the new point on the \(Q'\) scale through
new \(kd\) to the \(Q\) scale is made as before. Note that the \(Q\) and \(Q'\)
values 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 1.853 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:

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   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.

REFERENCES

2. AFSWP-700
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
Fig. 2
Threshold

0.030" paper ignites

heavy cotton cloth ignites
0.020" paper ignites
heavy wool cloth ignites

cotton shirting ignites
royon, rubber ignite
0.010" paper ignites

0.005" paper ignites
severe skin burns
nylon melts

slight skin burns

Fig. 3
The effect of a composite atmosphere on radiant exposure from a nuclear explosion.
The effect of a composite atmosphere on...