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A THEORY OF DECONTAMINATION OF FALLOUT FROM NUCLEAR DETONATIONS

PART II. METHODS FOR ESTIMATING THE COMPOSITION OF CONTAMINATED SYSTEMS (U)

by
C.F. Miller

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U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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ABSTRACT

Empirical equations are developed from correlations of fallout data for estimating the composition of fallout from detonations on land or at sea as a function of weapon yield and type, height of burst, and other parameters. The compositions are given in terms of the two contour-ratios defined in Part I of this study,* namely, the mass contour ratio and the fraction-of-device contour ratio. The effect of weapon yield, downwind distance from ground zero, induced activities, fraction of fission yield, height of burst, fractionation, terrain features, instrument response, extraneous debris, and meteorology on the values of the two contour ratios is discussed.

ADMINISTRATIVE INFORMATION

This work was done for the Bureau of Ships, under RTD&E Project Number S-F011 05 12. It is part of the investigation designated Program B-1, Problem 5, which is described in this Laboratory's Technical Program For Fiscal Years 1960 and 1961, Revision #1, 1 July 1959.

*C.F. Miller, Theory of Decontamination, Part I. U. S. Naval Radiological Defense Laboratory Report USNRDL-460, 15 July 1958.

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SUMMARY

The Problem

The experimental investigations of the effectiveness and efficiency of decontamination procedures using synthetic fallout and the operational evaluations of the data require knowledge of the composition of fallout from various conditions of detonation. In the experimental investigations, a realistic range of fallout mass deposits is needed to design experiments in which operationally useful data can be obtained; in this case it is necessary that the simulated fallout be as similar to real fallout as possible. Knowledge of fallout composition is also necessary to understand and correlate decontamination data from past field tests with those obtained by use of the simulants. In operational evaluations of decontamination efficiencies, the radiation intensities associated with the fallout mass and radioactive elements is needed to estimate the true reduction in dose that is associated with the efficiency of a decontamination procedure. No methods are presently available for estimating the composition of fallout and no summary of the available data has been previously made.

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The Findings

The mass contour ratio, defined in mg/sq ft/r/hr at 1 hr, and the fraction-of-device contour ratio, defined in r/hr at 1 hr $x(\text{sq ft})^{-1}$, are first discussed in terms of ideal explosion conditions in which all the activity produced is mixed uniformly with the crater mass and is deposited uniformly over an ideal plane. In this case, a single value of each contour ratio results for a given detonation. Discussion of the effect on the idealized contour ratios of weapon yield, type of weapon, height or depth of burst, fractionation, distance from ground zero, instrument response, and terrain roughness lead to the following general relationship of

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$$M_r(t) = \frac{K(x,W)}{b\ q\ \alpha_\lambda \left[D_{fp}(t) r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]}$$

for the mass contour ratio, and

$$FD_r(t) = \frac{6.89 \times 10^{-24}\ W^{-1}}{b\ q\ \left[D_{fp}(t)\ r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]}$$

for the fraction-of-device contour ratio, in which

$i_j(t)$ is the (r/hr)/(atom/sq ft) for the r/hr at a height of 3 ft from the jth induced radionuclide uniformly deposited on an ideal plane,
c_j is the capture-to-fission ratio for the jth nuclide,
r_j is radiochemical "R" value for the jth nuclide with respect to the cloud composition,
D_j is the instrument response relative to Co^{60} when calibrated by standard procedures,
$i_{fp}(t)$ is the (r/hr)/(fission/sq ft) for the r/hr at a height of 3 ft due to fission products from thermal-neutron fission of U^{235} uniformly deposited on an ideal plane,
$r_{fp}(t)$ is the gross fission-product "R" value with respect to the ionization rate from unfractionated U^{235} fission products based on Mo^{99},
$D_{fp}(t)$ is the gross instrument response relative to Co^{60} when calibrated by standard procedures,
q is the terrain factor,
b is the ratio of fission to total yield,
α_λ is the mass correction factor to a surface burst,
K(x,W) is a parameter depending only on distance and yield and has the units mg/fission,
x is the distance (downwind) from ground zero in feet, and
W is the total yield in KT.

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Factors for converting d/s to r/hr for $i_j(t)$ for various possible induced activities are given in reference 2. Likely values of c_j for tamper induced radionuclides from various types of weapons are given in Table 6. The values of D_1 are given in reference 2, as are the combinations of $D_{fp}(t)$ and i_{fp} for the response of the AN/PDR-T1B to the ionization rate at a height of 3 feet above a uniformly distributed source of U^{235} fission products.

The value of $r_{fp}(t)$, for t = H + 1 hr, can be estimated from

$$r_{fp}(1) = \frac{z^{o}_{fp}\, e^{k_z x}}{1 + z^{o}_{fp}\, e^{k_z x}}$$

where, from empirical correlations of data,

$$z^{o}_{fp} = 0.32\, W^{0.086}$$

and

$$k_z = 4.1 \times 10^{-5}\, W^{-0.20}\ \mathrm{ft}^{-1}$$

for land shots. For seawater fallout from large yields (> 1 MT), r_{fp} is one; for yields less than 1 MT only rare gas daughter products are considered.

The average value of q was determined, from Operation REDWING data, to be 0.80 for the islands of Bikini atoll. The average value of q for the Nevada Test Site (area 2), from Operation PLUMBBOB data, was found to be 0.75. The values ranged from 0.5 to 1.0 and include the assumption that no sample-collector bias occurred when the calculated q value was less than about 1.0.

An empirical curve for α_λ (Fig. 3) was used to correct the data to equivalent surface detonations for correlating the observed data of $M_r(1)$.

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From correlations of $M_r(1)$ data from Operations JANGLE, CASTLE, and REDWING, empirical equations for K(x,W) were determined; these are

$$K(x,W) = 2.2 \times 10^{-10}\, W^{0.21}/x^{1/2},\quad W = 1 \text{ to } 12\ \mathrm{KT}$$
$$= 4.0 \times 10^{-10}\, W^{-0.003}/x^{1/2},\quad W = 12 \text{ to} > 10^4\ \mathrm{KT}$$

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for detonations near the surface of land, and

$$K(x,W) = 0.34 \times 10^{-10}$$

for detonations near the surface of the sea. The mass considered in these equations is that of the material removed from the crater. No wind corrections were applied to the data prior to correlation; hence an average wind speed somewhere between 10 and 20 mph is associated with the equation constants.

The mass contour ratio is useful in establishing the fallout mass from fallout contour maps in r/hr at 1 hr and in estimating the r/hr at 1 hr from the decontamination data given in terms of the mass of particles per unit area remaining after decontamination. The fraction-of-device contour is useful in summing the total activity (or fraction of the weapon) in fallout contour maps in r/hr at 1 hr and in estimating (especially for seawater fallout) the surface density of the radioactive elements (say, atoms/sq ft) for a given r/hr at 1 hr. The specific activity of the fallout is simply $2b\alpha_{\lambda}/6.0 \times 10^{23}\ K(x,W)$ moles (of fission products) per mg of fallout.

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TABLES

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FIGURES

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

In Part I of this series of reports,[1] decontamination equations were presented in which the decontamination effectiveness was shown to depend upon the initial level of fallout. The initial level of fallout deposited on surfaces was given in terms of mass per unit area, atoms per unit area, or in arbitrary C-Level units. These generalized units of the initial level of contamination were used as independent variables in the equations without direct reference to a gamma radiation level. In order to relate the generalized or real contamination level to radiation levels, conversion factors, such as the mass contour ratio, were introduced to indicate a conversion of the basic units of measure to gamma ionization rates at 3 feet above an extended contaminated surface. The effect of the detonation conditions on the decontamination ratio presented in Part I of this series will be discussed in Part III.

In this report, the dependence of the conversion factors (called contour ratio scaling functions) on the conditions of detonation such as yield, height or depth of burst, type of weapon, and other parameters are discussed. If these are known, then the dependence of the decontamination ratios on the same parameters, in turn, can be determined.

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Note: The author wrote this report before he left this Laboratory on 11 August 1960.

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Knowledge of the effect of detonation conditions on the decontamination effectiveness should aid in interpreting data obtained in the field, in correlating data from different tests, in correlating laboratory and field data, and in extrapolating data from one detonation condition to another.

1.2 OBJECTIVES

The specific objectives of this report are (1) to discuss the major parameters that can influence the radiochemical and chemical composition of fallout, (2) to develop empirical contour ratio scaling relationships, evaluate the scaling equation constants from available data, and illustrate the use of the scaling functions in estimating realistic fallout compositions for past decontamination experiments, and (3) to present information that will be useful in preparing synthetic fallout.

1.3 SCOPE

This report discusses the effect of detonation conditions on the contour ratio scaling functions and how the detonation conditions can influence the composition of fallout from land, harbor, and sea bursts. The data used in evaluating the empirical scaling constants were obtained from previously reported and evaluated field test data; in most cases this included data from field operations up to and including Operation PLUMBBOB.

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SECTION 2

GENERAL CONCEPTS

2.1 TYPE OF INFORMATION REQUIRED FOR EXPERIMENTAL INVESTIGATIONS

A most important consideration in the design of a reliable decontamination investigation is a precise definition of a contaminated system consisting of fallout debris and a contaminated surface. In this report, past data are summarized and used to develop scaling relationships that may aid in estimating the composition and amount of fallout per unit surface area required to produce a given ionization rate from fallout that would originate from the detonation of various types of weapons near the surface of land, water, or in a harbor.

2.2 BASIC UNITS AND GENERAL DEFINITION OF THE CONTOUR RATIOS

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For the kinds of detonations mentioned, the fallout is produced from three general source materials: (1) the bomb products or device products, (2) soil or solids, and (3) seawater or liquid. The possibility of rain water in the fallout from atmospheric sources, seawater from a base surge in underwater detonations, and extraneous dusts from wind or blast waves will not be considered. The overall composition of fallout which might be found at a given point in a fallout area from shots on land or at sea can be given in terms of two quantities: (1) the mass contour ratio, M_r, defined as the ratio of the mass per unit area to the radiation intensity in r/hr, and (2) the device contour ratio, FD_r, defined as the ratio of the fraction of the device per unit area to the radiation intensity in r/hr. The mass contour ratio is an inverse function or measure of the specific activity of the fallout material. The fraction of device contour ratio is a measure of the dispersion of the device as well as a measure of the radiation dosage potential of the radioactive composition.

For purposes of scaling the mass contour ratio with weapon yield and other parameters, the mass considered must be a "scalable" mass. This means, generally, that the mass of the fallout needs to be related to the original material thrown up by the detonation. In seawater detonations, the scalable mass is the seawater thrown up; any loss of water from the fallout droplets during their travel through the atmosphere has to be accounted for. The mass of coral fallout requires correction for loss of carbon dioxide. Other factors which are not scalable but which could influence the value of the mass contour ratio include: (1) dilution of seawater- and harbor-burst fallout with rain from atmospheric sources and with seawater from a base surge in underwater detonations, and (2) the dilution of land fallout by extraneous dusts from winds and the blast wave from the explosion itself.

Thus, either in deriving empirical scaling relations from available data, or in confirming theoretical scaling relations with data, the measured mass must be corrected to a "scalable" mass. The unscalable quantities can then be treated separately on a case basis depending on the probability of occurrence and effect on the value of the decontamination ratio itself.

Since a single decontamination operation will cover only a rather small amount of area and many individual separate operations would be required to decontaminate a large area in a reasonable time, the scaling functions for the contour ratios should be point functions. That is, the function should describe the contaminated system at individual points in the fallout area. Although most of the useful available data is in the form of point data, the point coverage has been small. In such a case, the function cannot be related to a point or region in the fallout area and degenerates to a "grand" average function for the entire area. The treatment of the data throughout the following sections will tend to show the degree to which the various parameters are point functions or an averaged function for the whole fallout area.

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SECTION 3

IDEALIZED CONTOUR RATIO SCALING FUNCTIONS

3.1 GENERAL DISCUSSION

The idealized scaling functions are presented first to introduce a simple working model that can be tested and modified in a consistent manner by use of available data. The model detonation will be a surface land detonation in which all of the radionuclides produced are retained by the total mass (clay soil) removed from the crater. The fallout thus produced will then deposit over an ideal smooth plane. A mathematical derivation of the contour ratio scaling functions for the idealized case follows.

3.2 DEFINITION OF THE MASS CONTOUR RATIO

At any point in the fallout area, the mass contour ratio is defined by

$$M_r(t) = m/I(t) \tag{1}$$

in which m is the mass of fallout per unit area, and I(t) is the radiation intensity (say, at 3 ft above an extended plane source of radioactivity) at the time, t, after detonation. The mass contour ratio, defined as a grand average function is

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$$\overline{M_r(t)} = M_F/I_F(t) \tag{2}$$

in which M_F is the integrated value of m over the whole fallout area and $I_F(t)$ is the integrated value of I(t) over the same area. Evaluation

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of Eq. 2 requires contour maps of m and $I(t)$ for the whole fallout area. In the ideal case, M_F would be essentially equal to the mass of material removed from the crater.

3.3 DEFINITION OF THE FRACTION OF DEVICE CONTOUR RATIO

The fraction of the device contour ratio at any point in the fallout area is defined by

$$FD_r(t) = \frac{a}{a_T I(t)} \tag{3}$$

in which a is the radioactivity (or measure of it) per unit area and a_T is the total radioactivity (or measure of it) produced by the device. The ratio, a/a_T is the fraction of the device per unit area and can be defined and measured in many ways. One fairly common unit of measure of the activity is in terms of the number of fissions for the radioactivity from the fission process. The advantages of using this unit are that its value is independent of time and that it is also used in determining weapon yields. The disadvantage of using the unit is that it is quite often related to a single fission product tracer nuclide and its fission yield, and is not a reliable measure of the true number of fissions in a given sample of fallout when the radionuclides are fractionated.

Excepting for fractionation or alteration of the radionuclide composition at various points in the fallout area from that produced by the device, the fraction of the device contour ratio for an extended plane surface should be a grand average function. Even with the occurrence of fractionation, the point variation of this contour ratio will not be large for areas where the pattern of fractionation is the same. Other parameters that effect the value of this contour are discussed in some of the following sections.

3.4 THE IDEALIZED CONTOUR RATIO SCALING FUNCTIONS

For the idealized model function, it will be assumed that, in the detonation, induced (neutron capture) radionuclides are produced as well as fission products. The induced products have no effect on the value of a or a_T in terms of fissions but do effect the value of I(t) in both contour ratios and on a and a_T in other units of measure such as disintegrations per unit time. For a given composition of radionuclides deposited uniformly over an extended area of the ideal plane, the radiation intensity over the plane (say, at 3 ft) is given by

$$I(t) = G_{\infty}^{O}(t)\ a\ (t) \qquad (4)$$

in which $G_{\infty}^{O}(t)$ is a conversion coefficient for a(t) on a smooth infinite plane and whose value depends on the units of a(t). If a(t) is in d/s per sq ft, then $G_{\infty}^{O}(t)$ has the units r/hr/(d/s per sq ft). If a(t) is in fissions per sq ft then G_{∞}^{O} has the units r/hr/(fiss/sq ft); in the latter units the parameter a does not depend on t. Values of $G_{\infty}^{O}(t)$ for the fission products from several kinds of fission have been calculated as a function of time after fission.[2,3,4] Keeping the fission products and induced activities (capture products) separate allows the separation of $G_{\infty}^{O}(t)$ into two parts so that

$$G_{\infty}^{O}(t) = i_{fp}(t) + i_{cp}(t) \qquad (5)$$

in which $i_{fp}(t)$ is the value of the (r/hr)/(fission/sq ft) for the fission products and $i_{cp}(t)$ in (r/hr)/(fission/sq ft) for the capture products is given by

$$i_{cp}(t) = \Sigma_j\ c_j i_j(t) \qquad (6)$$

in which c_j is the number of neturon captures to form the jth radionuclide per fission (radioactive atoms produced per fission) and $i_j(t)$ is the radiation rate (r/hr) at time, t, after detonation from one radioactive atom (corrected to zero time) per sq ft. The total radioactivity produced by the device is given by

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$$a_T = KbW \qquad (7)$$

in which W is the total nuclear yield of the device, b is the ratio of fission to total yield and K is a constant depending on the units of a_T

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and W. For W in KT (kilotons equivalent TNT) and a_T in fissions, the value, 1.45×10^{23} fissions/KT, will be used for K. Combination of Eqs. 3, 4, 5, and 7 gives, for $FD_r^o(t)$

$$FD_r^o(t) = \frac{1}{1.45 \times 10^{23} bW \left[i_{fp}(t) + i_{cp}(t)\right]} \tag{8}$$

in which $FD_r^o(t)$ is the idealized plane value of the fraction of device contour ratio. It may be noted that Eq. 8 has the units $(r/hr\ sq\ ft)^{-1}$; this function has been given previously in a report[5] which discussed the CASTLE Shot Bravo fallout pattern and fallout pattern summations in general.

The expected specific activity, from a uniform mixing of all the radionuclides produced, a_T, with all the mass of soil removed from the crater, M_o, is a_T/M_o. On an ideal plane, each fission/sq ft would give rise to $G_\infty(t)$ r/hr, hence the mass contour ratio would be given by

$$M_r(t) = \frac{M_o}{a_T\ G_\infty^o(t)} \tag{9}$$

The variation of M_o with yield for surface detonation on clay-type soils may be estimated from

$$M_o = 1.79 \times 10^{13}\ W^{0.962} \tag{10}$$

for M_o in mg and W in KT.[6] Substituting for M_o, a_T, and $G_\infty(t)$ in Eq. 9 gives, for the idealized plane value of $M_r(t)$,

$$M_r^o(t) = \frac{1.23 \times 10^{-10}\ W^{-0.038}}{b\left[i_{fp}(t) + i_{cp}(t)\right]} \tag{11}$$

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For fallout in which the radionuclides are fused within or mixed uniformly throughout all the particles and in which the fractionation is also uniform, the mass contour ratio is a grand average function. However, if the specific activity of the fallout and the fractionation of the radionuclides changes from point-to-point, $M_r(t)$ becomes a point function.

If some knowledge of $G_\infty(t)$ is available, $M_r(t)$ can be evaluated from specific activity data. If the average value of the specific activity of the particles at a given location in the fallout area is $\overline{a_p/m_p}$ where a_p is the activity and m_p is the mass of single particles, then

$$M_r^o(t) = \frac{1}{G_\infty^o(t)\,(\overline{a_p/m_p})} \qquad (12)$$

The value of $\overline{a_p/m_p}$ will be sensitive to changes in the radioactive content of the particles and to any variation in the radioactive content per particle with particle size. And since the size of the fallout particles changes with downwind distance from ground zero, any variation of the radioactive content of the particles with size will be reflected in a variation of $M_r^o(t)$ with downwind distance from ground zero. When such variations occur, $M_r^o(t)$ becomes a point function.

To illustrate how $M_r(t)$ could be a point function, consider particles that arrive at a distance, x, from the point of detonation and that have fallen from a height, h, directly above the detonation. Let V_w be the average velocity of the wind that transported the particles the distance, x. Two cases may be considered: for the first case, it will be assumed that the average radioactive concentration varies with the surface area of the particle (i.e. is proportional to the square of the particle diameter, d); for the second case, it will be assumed that the concentration is proportional to the volume (or mass) of the particle.

For the first case, the average specific activity is

$$a_p/m_p = k_1/\bar{d} \qquad (13)$$

in which $\bar{d}$ is the average diameter of the particle group and k_1 is a constant. For the larger particles, the falling velocity is approximately proportional to the particle diameter so that the distance at which the particles of diameter $\bar{d}$ are deposited is

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$$x \simeq V_w h/(k_2\bar{d}) \qquad (14)$$

in which k_2 is a constant. Combination of Eqs. 12, 13, and 14 gives, for these particles

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$$M_r^o(t) = \frac{V_w h}{k_1 k_2 G_\infty^o (t) x} \qquad (15)$$

Equation 15 suggests that, for the stated assumptions, $M_r(t)$ should vary inversely with distance. For small particles where the falling velocity is proportional to the square of the diameter, the mass contour ratio for those particles is given by

$$M_r^o(t) = \frac{1}{k G_\infty^o} \left(\frac{V_w h}{k_3 x} \right)^{1/2} \qquad (16)$$

in which k_3 is a constant. For these assumed conditions, $M_r^o(t)$ decreases with the square root of the distance.

For the second case, the average specific activity is given by

$$\overline{(a_p/m_p)} = k_4 \qquad (17)$$

in which k_4 is a constant. For this case where the specific activity is independent of the particle diameter, $M_r^o(t)$ is independent of the distance and is given by

$$M_r^o(t) = \frac{1}{k_4 G_\infty^o} \qquad (18)$$

Although Eq. 18 does not contain a distance term and in that sense is not a point function, the region of its applicability is, of course, restricted to the area within which the particles with a constant specific activity fall.

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In addition to the distance, x, Eqs. 15 and 16 suggest that the value of $M_r^o(t)$ depends on the wind velocity and the height from which the particles fall. The latter depends on weapon yield. If the bottom of the clouds is used as a reference point with respect to the measure of h, use of the empirical functions from reference 5 in Eqs. 15 and 16 gives, for constant V_w,

$$M_r^o(t) = \frac{k_5\ W^{0.58}}{G_\infty^o\ x}\ ,\ W = 1 \text{ to } 12 \text{ KT} \tag{19a}$$

$$= \frac{k_6\ W^{0.16}}{G_\infty^o\ x}\ ,\ W = 12 \text{ to} > 10^4 \text{ KT} \tag{19b}$$

$$M_r^o(t) = \frac{k_7\ W^{0.29}}{G_\infty^o\ x^{1/2}}\ ,\ W = 1 \text{ to } 12 \text{ KT} \tag{20a}$$

$$= \frac{k_8\ W^{0.08}}{G_\infty^o\ x^{1/2}}\ ,\ W = 12 \text{ to} > 10^4 \text{ KT} \tag{20b}$$

in which k_5, k_6, k_7, and k_8 are constants.

This rather simple treatment of how the value of $M_r(t)$ may depend on weapon yield, downwind distance, wind speed, particle fall rates, and on the mode of fallout particle formation indicates at least the scope of the information required in the development of a reliable scaling function from observed data.

3.5 MEASUREMENT OF CONTOUR RATIOS AND PARAMETERS EFFECTING THE OBSERVED VALUES OF THE CONTOUR RATIOS

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There are two methods for determining the mass contour ratio; each requires a radiation measurement and a fallout sample. The most direct method is to collect samples and weigh them (with appropriate analyses for correction to a scalable mass). The second method is to obtain sufficient pure fallout to determine the specific activity of the fallout and to determine, by soil sampling in the fallout area, the activity per unit area. The fraction of device contour ratio can be determined from the same samples of fallout and radiation measurements; radiochemical analyses of the samples are required.

Real differences between observed values of the contour ratios and those predicted from the idealized contour ratio functions are expected to occur. The major causes of variation in the functions, including those that cause variance from the idealized function, are:

1. Weapon type and yield
2. Fractionation
3. Effect of terrain roughness on fallout deposition patterns and on the radiations delivered at a point from a given radiation source
4. Instrument response to the radiations
5. Depth or height of detonation
6. Activity and mass particle size relations
7. Type of environmental material at shot point
8. Degree of mixing of crater material with the radioactive nuclides
9. Meteorological factors
10. Nonscalable or extraneous debris.

In the measurement of the observed values, there will be discrepancies due to sampling bias, recovery losses, analytical error, and instrument error.

The weapon type will mainly influence the values of the fraction of fission yield, b, and the values of the neutron capture ratios, C_j; it may indirectly influence other factors such as fractionation. The idealized mass contour ratio functions suggest that the yield itself should not influence the value of the mass contour ratio as much as other factors.

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The absence of the more volatile radionuclides in fallout particles results in fractionation. When certain of the fission product tracer nuclide or nuclides are used in determining the value for the number of fissions, and other radionuclides are not present in the proper amount, the true values of i_{fp} and i_{cp} are lower than given in the idealized scaling functions for the unfractionated fission products and the observed value of the contour ratios will be larger. If the reduction of a given radionuclide from its normal percentage (say, for U^{235} fission products) is given by the radiochemical "R" value, r_j, for the jth radionuclide, then the gross reduction in the value of $i_{fp}(t)$ may similarly be defined by the gross fission product "R" value, $\bar{r}_{fp}(t)$, from gross ionization-rate measurements or from knowledge of the r_j values of all the important radionuclides. Since "R" values for a given radionuclide may vary with particle size, $r_{fp}(t)$ may vary with distance (i.e. be a point function). The contour ratio scaling parameter sensitive to fractionation is $G_\infty(t)$; in terms of $r_{fp}(t)$ and r_j, it is given by

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$$G_\infty(t) = r_{fp}(t)\ i_{fp}(t) + \Sigma_j r_j c_j i_j(t) \qquad (21)$$

As a generalized point function, Eq. 21 would have $G_\infty(t,x)$, $r_j(x)$, and $r_{fp}(x,t)$ with the latter two given as explicit functions of the distance.

The effect of terrain and instrument response to radiations generally will tend to give lower values of $i_{fp}(t)$ and $i_j(t)$ than those calculated for an infinite smooth plane surface. These factors will also influence the value of $G_\infty(t)$ to give larger observed values of the contour ratio. As with fractionation, these factors would be easiest to apply as gross multiplying factors to $G_\infty(t)$ although detailed calculation of the dependence of the factors on the photon energies and photon abundances may be required to obtain the multiplier. The terms to be used are given by

$$G = q\ D_{fp}(t)\ r_{fp}(t)\ i_{fp}(t) + \Sigma_j\ D_j r_j c_j i_j(t) \qquad (22)$$

in which D is the relative response of the instrument and q is the "terrain factor". The data treated in Section 4 consists of radiation measurements taken at 3 ft above extended plane sources (or corrected to such a geometry). In addition, all radiation measurements were taken with or converted to the AN/PDR-39(T1B) survey instrument. The value of $D_j i_j$ for each individual nuclide for this instrument are given in Reference 2.

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The size of the crater and the amount of earth or debris thrown upward by a detonation of a given yield decreases with the height of the zero point. For subsurface explosions, the crater size increases as the depth of the zero point increases up to a given depth. Beyond this given depth, the amount of crater material thrown up decreases until such depth of detonation where no crater material is ejected.

In the model explosion where all the radioactivity produced is mixed with all the crater material, the variation of $M_r^o(t)$ with depth of burst can be expressed as

$$M_r^o(t) = \frac{M_r^s(t)}{\alpha_\lambda} \qquad (23)$$

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in which $M_T^S(t)$ is the value of the mass contour ratio for a surface detonation, α_λ is the ratio A_0/A_λ where A_0 is the crater mass scaling coefficient for surface detonations (see Eq. 10) and A_λ is the crater mass scaling coefficient for detonations at the scaled depth, λ (λ = depth of burst in ft/(yield in lbs of TNT)$^{1/3}$); the ratio, α_λ, is the mass correction factor to a surface detonation; for air bursts, α_λ has values that are greater than 1.00; and, for underground bursts, α_λ has values that are less than 1.00.

Possible effects of the particle size and specific activity on the mass contour ratio were mentioned in Section 3.3. The ratio, as defined, is concerned only with the total activity per unit area and the total particle mass per unit area at a given location. These can be estimated by use of fallout model computations if both the activity and mass distributions are known as a function of particle size.

The particles that carry the radioactive material back to earth are composed essentially of the environmental materials at the shot point. For near-surface bursts, the types of materials of most interest are native soils (to several hundred feet in depth), seawater, and mixtures of the two for harbor detonations. If the mass of the original material is scalable with weapon yield, then the equivalent mass of the original material must be used in the contour scaling functions. For example, the fallout from detonations in seawater will consist originally of seawater which, as drops or ice particles, will change in size during their fall time due to evaporation or condensation of the water. If they dry completely, the final residual mass would be about 3 % of the original seawater mass. In this case the original composition may be determined on the basis of the seawater mass and, if the contour ratios are point functions, the value of the ratio at a location will depend on how the evaporation takes place in space and time.

Meteorological factors are of major importance in the distribution of the fallout from the time that it is formed. Although the scaling functions discussed in this report are only concerned with the contaminated system after the fallout has been deposited, the discussion in Section 3.3 showed that the wind speed was involved when the activity was taken as varying with the square of the particle diameter. Thus the factors that influence the distribution of the fallout may indirectly influence the value of the contour ratios if the latter are point functions.

The effect of the inclusion of nonscalable or extraneous debris in fallout on the mass contour ratio, as previously mentioned, would result in high apparent observed values of the mass contour ratio.

Although the quantity of debris may not be scalable with other detonation parameters, knowledge of its effect on the contour ratio and its frequency and conditions of occurrence is necessary in considering whether or not it is sufficiently important to warrant separate treatment and inclusion for consideration in decontamination investigations and operations.

Of the several measurement errors, the one least amenable to treatment or reduction by careful analytical techniques is that due to sampling bias. It will depend on type of sampler, sampling location, sample size, and many other factors. The parameters most seriously affected by this bias are m and a; the value of a_p/m_p should not be very sensitive. For most collecting devices and sampling locations, the amount of fallout collected with respect to the local terrain (average) will be low. However, this generalization is not valid for the island collecting stations at Operation CASTLE where the collectors were at grade level and were not recovered for several days after shot. In the meantime, both inert coral and fallout particles drifted into the collectors by action of the wind.

Combining the various correction factors which, if known, would provide a more reliable scaling function for each of the contour ratios than those for the idealized fallout model gives

$$M_r(t) = \frac{K\,(X,W)}{bq\,\alpha_\lambda \left[D_{fp}(t) r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]} \tag{24}$$

and

$$FD_r(t) = \frac{6.89 \times 10^{-24}\ W^{-1}}{bq \left[D_{fp}(t) r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]} \tag{25}$$

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For the idealized model function, K(X,W) is equal to $1.23 \times 10^{-10}\ W^{-0.038}$ for all values of x. The only terms in Eq. 25 that depend on distance are $r_{fp}(t)$ and r_j.

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Although the quantity of debris may not be scalable with other detonation parameters, knowledge of its effect on the contour ratio and its frequency and conditions of occurrence is necessary in considering whether or not it is sufficiently important to warrant separate treatment and inclusion for consideration in decontamination investigations and operations.

Of the several measurement errors, the one least amenable to treatment or reduction by careful analytical techniques is that due to sampling bias. It will depend on type of sampler, sampling location, sample size, and many other factors. The parameters most seriously affected by this bias are m and a; the value of a_p/m_p should not be very sensitive. For most collecting devices and sampling locations, the amount of fallout collected with respect to the local terrain (average) will be low. However, this generalization is not valid for the island collecting stations at Operation CASTLE where the collectors were at grade level and were not recovered for several days after shot. In the meantime, both inert coral and fallout particles drifted into the collectors by action of the wind.

Combining the various correction factors which, if known, would provide a more reliable scaling function for each of the contour ratios than those for the idealized fallout model gives

$$M_r(t) = \frac{K\,(X,W)}{bq\,\alpha_\lambda \left[D_{fp}(t) r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]} \qquad (24)$$

and

$$FD_r(t) = \frac{6.89 \times 10^{-24}\ W^{-1}}{bq \left[D_{fp}(t) r_{fp}(t) i_{fp}(t) + \Sigma_j D_j r_j c_j i_j(t)\right]} \qquad (25)$$

DOE/NV

For the idealized model function, $K(X,W)$ is equal to $1.23 \times 10^{-10}\ W^{-0.038}$ for all values of x. The only terms in Eq. 25 that depend on distance are $r_{fp}(t)$ and r_j.

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SECTION 4

THE EVALUATION OF CONSTANTS AND PARAMETERS FOR THE CONTOUR RATIO SCALING FUNCTIONS

4.1 SUMMARY OF AVAILABLE CONTOUR RATIO SCALING DATA

Values of the mass contour ratio (evaluated at 1 hr after detonation), the specific activity of the fallout and activity per unit area for several test detonations are given in Table 1 along with the distance from zero point and the 1 MT scaled distance from GZ. The 1 MT scaled distances were calculated from[2]

$$X = 9.79\ W^{-0.58}\ x,\ W = 1 \text{ to } 12 \text{ KT} \tag{26a}$$

and

$$X = 2.92\ W^{-0.16}\ x,\ W = 12 \text{ to } > 10^4 \text{ KT} \tag{26b}$$

where X is the 1 MT scaled distance and x is the measured distance. Ideally, x would be the downwind distance along the center line of the fallout pattern or an average distance on the ground along the path of the particles for those arriving at a given location under similar meteorological conditions. Corrections in x for these factors were not made in the data of Table 1.

The values of the mass contour ratios for the several shots range generally from about 2 to 200 (mg/sq ft)/(r/hr at 1 hr) with the values for the underground detonation (JANGLE "U" Shot) and the detonation D[redacted] (REDWING Navajo) being the largest and the above surface detonations (PLUMBBOB Diablo and Shasta) being the smallest.*

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*The discrepancy in the two $M_T(1)$ values for both Diablo and Shasta results from calculation of the first $M_T(1)$ value from the gross sample weight including the desert sand blown into the collector by the blast wave (or settled down afterward). The lower values were obtained after the fallout particles were separated from the gross sample by a magnet. The fallout particles contained about 5 % Fe by weight.

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TABLE 1

Summary of Observed Values of the Mass Contour Ratio, Activity per Unit Area, and Specific Activity of Fallout

Station	Distance From GZ (ft)	$M_r(1)$ (mg/ft^2)/(r/hr at 1 hr)	1 MT Scaled Distance (ft)	I(1), obs (r/hr at 1 hr)	a/m (f/mg)	a (f/sq ft)	$M_r(1)^b$ $\frac{mg/ft^2}{r/hr\ at\ 1\ hr}$
			1. JANGLE, "S" Shot				
D1	900	32,000	5,200				
E2	900	6,100	5,200				
E3	900	24,000	5,200				
F1	900	815	5,200				
G1	1,800	105	10,400				
G3	2,015	565	11,700				
H1	2,700	22.5	15,600				
H3	2,850	22.9	16,500				
H5	3,240	47.8	18,750				
I1	3,600	31.8	20,800				
I3	3,710	25.0	21,500				
I5	4,030	37.1	23,300				
N4	7,500	17.3	43,400				
N3	9,000	17.3	52,100				
N1	12,000	13.6	69,400				
			2. JANGLE, "U" Shot				
D1	900	5,600	7,300				
E2	900	1,480	7,300				
F1	900	676	7,300				
D2	1,175	1,270	9,500				
D3	1,175	842	9,500				
F2	1,175	205	9,500				
F3	1,175	586	9,500				
E4	1,800	400	14,600				
E5	1,800	806	14,600				
G1	1,800	86.6	14,600				
G2	2,015	176	16,300				
G3	2,015	161	16,300				
G4	2,550	169	20,700				
G5	2,550	336	20,700				
H1	2,700	110	21,900				
H2	2,850	106	23,100				
H3	2,850	154	23,100				
H4	3,240	417	26,200				
H5	3,240	342	26,200				
I1	3,600	87.8	29,200				
I2	3,710	135	30,000				
I3	3,710	64.0	30,000				
I4	4,030	82.3	32,600				
I5	4,030	107	32,600				
I6	4,500	231	36,500				
I8	5,090	58.8	41,200				
N5	6,000	52.9	48,600				
N4	7,500	60.0	60,800				
N3	9,000	40.7	72,900				
N1	12,000	20.8	97,200				

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TABLE 1 (Cont'd)

Summary of Observed Values of the Mass Contour Ratio, Activity per Unit Area, and Specific Activity of Fallout

Station	Distance From GZ (ft)	$M_r(1)$ (mg/ft^2)/(r/hr at 1 hr)	1 MT Scaled Distance (ft)	I(1), obs (r/hr at 1 hr)	a/m (f/mg)	a (f/sq ft)	$M_r(1)^b$ $\frac{mg/ft^2}{r/hr\ at\ 1\ hr}$
			3. CASTLE, Bravo				
250.04	59,500	33.6	39,200				
250.05	73,900	78.3	48,700				
250.06	77,400	44.1	51,000				
250.17	58,600	2.1	38,600				
250.22	91,500	19.4	60,200				
250.24	69,800	58.0	46,000				
250.25	61,800	44.2	40,700				
Fox	47,700	8.9	31,400				
Fox	50,600	-	33,300	1,200	8.18×10^{10}	7.40×10^{12}	0.075
How	101,000	14.3	66,500	270	7.90×10^{10}	3.05×10^{14}	14.3
How	101,000	-	66,500	270	8.56×10^{10}	8.02×10^{14}	34.7
Love	110,000	800	72,400				
Nan	120,000	1.2	79,000				
Oboe	83,200	178	54,800				
Uncle	77,100	226	50,800				
Victor	62,500	-	41,200	9.1	17.5×10^{10}	5.13×10^{13}	32.2
William	62,400	148	41,100				
Zebra	51,200	389	33,700				
Mean					9.93×10^{10} (46 %)		
			4. CASTLE, Romeo				
A4	227,000	235	157,000				
A5	274,000	181	190,000				
Q4	179,000	75.5	124,000				
R4	191,000	20.2	132,000				
T4	227,000	21.0	157,000				
			5. CASTLE, Koon				
250.05	65,100	37.1	90,900				
250.05	65,100	94.0	90,900				
250.07	45,800	68.8	64,000				
250.07	45,800	95.6	64,000				
Fox	72,300	48.9	101,000				
Coca Head	32,700	28.9	45,700				
			6. CASTLE, Union				
YAG 39	120,000	80	84,800				
			7. REDWING, Zuni				
How F	74,500	18.2	61,400	59	1.92×10^{11}	2.07×10^{14}	18.3
How F	74,500	13.8	61,400	59	2.54×10^{11}	2.07×10^{14}	14.5
How K	77,200		63,600	46		1.87×10^{14}	
George	71,800		59,100	227		4.96×10^{14}	
William	35,000		28,800	87		2.21×10^{14}	
YFNB 13	66,800		55,000		1.56×10^{11}	4.19×10^{14}	
YFNB 13	66,800		55,000		3.03×10^{11}	4.19×10^{14}	
YFNB 29	55,300		45,500		1.76×10^{11}	6.10×10^{14}	
YFNB 29	55,300		45,500		1.50×10^{11}	6.10×10^{14}	
YAG 39	553,000		455,000		$^{a}0.258 \times 10^{11}$	2.74×10^{12}	
YAG 39	553,000		455,000		$^{a}0.369 \times 10^{11}$	2.74×10^{12}	
YAG 40	318,000		262,000		1.90×10^{11}	3.67×10^{14}	
YAG 40	318,000		262,000		5.33×10^{11}	3.67×10^{14}	
					$a/m \cong 6.3 \times 10^{9}\ x^{0.32}$		

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TABLE 1 (Cont'd)

Summary of Observed Values of the Mass Contour Ratio, Activity per Unit Area, and Specific Activity of Fallout

Station	Distance From GZ (ft)	$M_c(1)$ (mg/ft²) (r/hr at 1 hr)	1 MT Scaled Distance (ft)	I(1), obs (r/hr at 1 hr)	a/m (f/mg)	a (f/sq ft)	$M(1)^b$ mg/ft² / r/hr at 1 hr
			8. REDWING, Flathead				
How F	55,200	-					
How K	56,700	-					
George	15,070	-					
William	78,100	-			DELETED	DELETED	
YFNB 13	33,400	-					
YFNB 29	28,400	-					
YAG 39	153,000	-					
YAG 40	321,000	-					
LST 611	259,000	-					
			9. REDWING, Navajo				
How F	54,600	690					
How K	56,000	-					
Charlie	37,800	-					
George	15,970	-					
YFNB 13	39,800	-					
YFNB 29	43,600	-			DELETED	DELETED	
YAG 39	111,000	-					
YAG 40	238,000	-					
LST 611	229,000	-					
Mean							
			10. REDWING, Tewa				
How F	70,800	5.18	55,200	5.5	9.12×10^{11}	2.61×10^{13}	5.20
How K	72,240	-	56,400	3.5		1.53×10^{13}	
Charlie	31,700	-	15,900	1510		5.82×10^{14}	
George	31,700	-	24,700	540		1.02×10^{15}	
YFNB 13	39,800	-	31,000		15.0×10^{11}	3.79×10^{14}	
YFNB 29	41,400	-	32,300		5.96×10^{11}	2.70×10^{15}	
YAG 39	121,000	-	94,700		4.94×10^{11}	1.11×10^{15}	
YAG 40	224,000	-	175,000		5.03×10^{11}	4.70×10^{14}	
LST 611	313,000	-	244,000		15.1×10^{11}	9.48×10^{13}	
Mean					8.20×10^{11} (68 %)		
			11. PLUMBBOB, Diablo				
A1	5,300	798	9,500	17	7.1×10^{11}	1.83×10^{14}	15.2
A2	5,300	347	9,500	18	7.1×10^{11}	2.04×10^{14}	16.0
A3	5,500	296	9,900	17	7.2×10^{11}	1.58×10^{14}	12.9
A4	5,300	132	9,500	16	7.1×10^{11}	1.55×10^{14}	13.6
A5	5,500	186	9,900	16	7.2×10^{11}	1.38×10^{14}	12.0
			12. PLUMBBOB, Shasta				
A1	13,300	32.7	24,500	41	1.13×10^{12}	2.84×10^{14}	6.13
A3	13,500	17.2	24,800	39	1.14×10^{12}	2.37×10^{14}	5.33
A4	13,300	27.4	24,500	43	1.13×10^{12}	2.79×10^{14}	5.74
A6	13,600	13.1	25,000	37	1.15×10^{12}	2.58×10^{14}	6.06
A7	10,700	84.8	19,700	28	1.01×10^{12}	1.48×10^{14}	5.24
A8	14,700	20.4	27,100	57	1.19×10^{12}	3.94×10^{14}	5.81
A9	17,400	14.1	32,000	71	1.30×10^{12}	4.39×10^{14}	4.76
A10	20,400	11.5	37,600	87	1.41×10^{12}	6.89×10^{14}	5.62
A11	22,800	8.2	42,000	82	1.49×10^{12}	5.64×10^{14}	4.62
A12	21,300	11.0	39,200	117	1.44×10^{12}	6.56×10^{14}	3.89
					$a/m \cong 6.8 \times 10^{9}\, X^{0.51}$		

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a. Not used in calculating mean or equation constants.
b. Calculated from a, a/m, and I(1), obs; all a values are based on Mo^{99} analyses.

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TABLE 2

Summary of Observed Values of the Fraction of Device Contour Ratio, Fraction of Device Per Unit Area, and H+1 Ionization Rates

Station	Distance From GZ (ft)	$FD_r(1)$ (r/hr at 1 hr-ft^2)$^{-1}$	1 MT Scaled Distance	FOD/ft^2	I(1) obs (r/hr at 1 hr)	I(1) calc (r/hr at 1 hr)
			1. CASTLE, Bravo			
How	101,000	1.00×10^{-15}	66,500	2.70×10^{-13}	270	114
	101,000	2.62×10^{-15}	66,500	7.08×10^{-13}	270	300
Fox	50,600	5.45×10^{-18}	33,300	6.54×10^{-15}	1200	2.8
Victor	62,500	4.98×10^{-15}	41,200	4.53×10^{-14}	9.1	19
Mean		2.36×10^{-15} (125 %)				
			2. CASTLE, Romeo			
Able		2.16×10^{-17}		4.43×10^{-14}	2050	-
			3. CASTLE, Koon			
Victor	28,400	1.34×10^{-13}	39,700	1.88×10^{-13}	1.4	-
			4. REDWING, Zuni			
How F	74,500	4.73×10^{-14}	61,400	2.80×10^{-12}	59.2	69.5
How K	77,200	5.50×10^{-14}	63,600	2.53×10^{-12}	46	62.8
Charlie	78,100	-	64,300	-	203	-
George	71,800	2.95×10^{-14}	59,100	6.70×10^{-12}	227	166
William	35,000	3.44×10^{-14}	28,800	2.99×10^{-12}	87	74.2
YFNB 13	66,800	-	55,000	5.66×10^{-12}	-	140
YFNB 29	55,300	-	45,500	8.24×10^{-12}	-	204
YAG 39	553,000	-	455,000	3.70×10^{-14}	-	0.92
YAG 40	318,000	-	262,000	4.96×10^{-12}	-	123
Mean		4.03×10^{-14} (33 %)				
			5. REDWING, Flathead			
How F	55,200	DELETED		DELETED		DELETED
How K	56,700					
Charlie	36,800					
George	15,070					
William	78,100					
YFNB 13	33,400					
YFNB 29	28,400					
YAG 39	153,000					
YAG 40	321,000					
LST 611	259,000					
Mean						
			6. REDWING, Navajo			
How F	54,600	DELETED		DELETED		DELETED
How K	56,000					
Charlie	37,800					
George	15,970					
William	75,300					
YFNB 13	39,800					
YFNB 29	43,600					
YAG 39	111,000					
YAG 40	238,000					
LST 611	229,000					
Mean						

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TABLE 2 (Cont'd)

Summary of Observed Values of the Fraction of Device Contour Ratio, Fraction of Device Per Unit Area, and H+1 Ionization Rates

Station	Distance From GZ (ft)	$FD_r(1)$ (r/hr at 1 hr-ft^2)$^{-1}$	1 MT Scaled Distance	FOD/ft^2	I(1) obs (r/hr at 1 hr)	I(1) calc (r/hr at 1 hr)
			7. REDWING, Tewa			
How F	70,800	9.31×10^{-15}	55,200	5.14×10^{-14}	5.52	7.7
How K	72,240	8.55×10^{-15}	56,400	3.02×10^{-14}	3.53	4.5
Charlie	20,400	[a]0.766×10^{-15}	15,900	1.15×10^{-12}	1510	172
George	31,700	3.72×10^{-15}	24,700	2.01×10^{-12}	540	301
William	59,400	-	46,300	-	253	-
YFNB 13	39,800	-	31,000	7.46×10^{-13}	-	112
YFNB 29	41,400	-	32,300	5.32×10^{-12}	-	798
YAG 39	121,000	-	94,700	2.19×10^{-12}	-	328
YAG 40	224,000	-	175,000	9.26×10^{-13}	-	139
LST 611	313,000	-	244,000	1.87×10^{-13}	-	28
Mean		6.67×10^{-15} (66 %)				
			8. PLUMBBOB, Diablo			
A1	5,300	3.95×10^{-12}	9,500	6.75×10^{-11}	17.1	18.5
A2	5,300	4.19×10^{-12}	9,500	7.54×10^{-11}	18	20.7
A3	5,500	3.40×10^{-12}	9,900	5.82×10^{-11}	17	16.0
A4	5,300	3.58×10^{-12}	9,500	5.72×10^{-11}	16	15.7
A5	5,500	3.20×10^{-12}	9,900	5.11×10^{-11}	16	14.0
Mean		3.64×10^{-12} (12 %)				
			9. PLUMBBOB, Shasta			
A1	13,300	2.90×10^{-12}	24,500	1.19×10^{-10}	41.0	44.6
A3	13,500	2.54×10^{-12}	24,800	9.92×10^{-11}	39.0	37.1
A4	13,300	2.69×10^{-12}	24,500	1.17×10^{-10}	43.4	43.8
A6	13,600	2.88×10^{-12}	25,000	1.08×10^{-10}	37.4	40.4
A7	10,700	2.17×10^{-12}	19,700	6.18×10^{-11}	28.5	23.2
A8	14,700	2.89×10^{-12}	27,100	1.65×10^{-10}	57.0	61.8
A9	17,400	2.58×10^{-12}	32,000	1.84×10^{-10}	71.2	68.9
A10	20,400	3.32×10^{-12}	37,600	2.88×10^{-10}	86.7	108
A11	22,800	2.88×10^{-12}	42,000	2.36×10^{-10}	82.0	88.4
A12	21,300	2.35×10^{-12}	39,000	2.74×10^{-10}	117	103
Mean		2.67×10^{-12} (13 %)				
			10. PLUMBBOB, Coulomb C			
1	2,100	7.10×10^{-11}	21,800	2.84×10^{-8}	400	302
1	2,100	10.0×10^{-11}	21,800	4.00×10^{-8}	400	426
2	2,600	9.94×10^{-11}	27,000	3.48×10^{-8}	350	371
2	2,600	9.85×10^{-11}	27,000	3.45×10^{-8}	350	367
3	9,500	10.5×10^{-11}	98,600	6.95×10^{-9}	66	74
3	9,500	9.40×10^{-11}	98,600	6.18×10^{-9}	66	66
Mean		9.39×10^{-11} (16 %)				

a. Not used in calculating means.

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Observed values of the fraction of device contour ratio are given in Table 2.

Before these data can be correlated to test some of the assumptions described by Eqs. 11 through 20, appropriate values for b, c_j, G, D, and q for the various detonations are required along with generalizations for obtaining appropriate values of these parameters for other detonation conditions. Also, the effect of fractionation and depth (or height) of burst on the contour ratios for land and seawater detonations is required for correlation of the data as well as for a general determination of the scaling relations.

4.2 SELECTION OF VALUES OF b AND c_j FOR USE IN THE CONTOUR RATIO SCALING FUNCTIONS

The values of b and c_j depend on the type of weapon that is detonated. In analyzing decontamination data obtained at weapons tests, values of b and c_j are usually available from radiochemical analysis of cloud and (preferably) fallout samples. Some data sources for data on b and c_j as well as other parameters for test devices and detonations are summarized in Table 3.

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TABLE 3

Device Shot Conditions and Data Sources

Shot	Total Yield (KT)	b	λ ft/(lb)$^{1/3}$	Environmental Material	Depth of Water (ft)	References
JANGLE, "S"	1.1			Soil	-	7
JANGLE, "U"	1.2			Soil	-	7
CASTLE, Bravo	14,500			Coral	-	5,8,9, 10,11
CASTLE, Romeo	10,500			Seawater	200	5,8,9
CASTLE, Koon	116			Coral	-	5,8,9, 10,11
CASTLE, Union	7,000			Seawater	160	9
REDWING, Zuni	3,500	DELETED	DELETED	Coral	-	12
REDWING, Flathead	DELETED			Seawater	114	12
REDWING, Navajo				Seawater	215	12
REDWING, Tewa	5,000			Coral and Seawater	25	12
PLUMBBOB, Diablo	18			Soil	-	13,14, 15,16
PLUMBBOB, Shasta	16			Soil	-	13,14, 15,16
PLUMBBOB, Coulomb C	0.6			Soil	DOE/NV	17

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TABLE 4

Summary of Capture-to-Fission Values From Fallout and Cloud Sample Analysis

Shot	Yield W(MT)	Capture Ratios $C(U^{239})$	$C(U^{237})$	$C(U^{240})$	Type of Fallout	Type of Sample
		1. Operation, CASTLE				
Bravo	14.5				Coral	Cloud
					Coral	Fallout
Romeo	10.5				Seawater	Cloud
Koon	0.110		DELETED		Coral and Seawater	Cloud
Union	7.0				Seawater	Cloud
Yankee	13.5				Seawater	Cloud
Nectar	1.7				Coral	Cloud
		2. Operation, REDWING				
Cherokee	DELETED				Air Burst	Cloud
Zuni	3.5				Coral	Cloud
					Coral	Fallout
Dakota					Coral	Cloud
Navajo	DELETED		DELETED		Seawater	Cloud and Fallout
Flathead					Seawater	Cloud and Fallout
Tewa	5.0				Coral	Cloud
					Coral	Fallout

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TABLE 6

Summary of b, c_j, and f_T Values for Test Thermonuclear Devices

Shot	W(MT)	b	$c(U^{239})$	$c(U^{237})$	$c(U^{240})$	$c_T(U^{238})$	$f_T(U^{238})$	$c(U^{239})/c_T$	$c(U^{237})/c_T$	$c(U^{240})/c_T$
Bravo	14.5									
Romeo	10.5									
Koon	0.110				DELETED					
Union	7.0									
Yankee	13.5									
Nectar	1.7									
					2. Operation REDWING[a]				DELETED	
Cherokee	DELETED									
Zuni	3.5									
Dakota										
Navajo	DELETED				DELETED					
Flathead										
Tewa	5.0									
					Operation PLUMBBOB[b]					
Diablo	0.018								-	-
Shasta	0.016				DELETED				-	-
Coulomb C	0.0006								-	-

a. Cloud samples only.
b. Fallout samples only.

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4.3 EFFECT OF FRACTIONATION ON CONTOUR RATIO SCALING FUNCTIONS DOE/NV

Data from references 12, 13, and 17 were used to derive the r_{fp} and r(c) values plotted in Figs. 1 and 2, respectively. These curves indicate that r_{fp} (or r(c)) increases with downwind distances so that there is less fractionation of the radionuclides in the smaller particles. Comparison of the Diablo-Shasta curve with Coulomb C curve

(NTS soil) and the Tewa curve with Zuni curve (coral) indicates also that the gross fractionation decreases with yield. No comparison can be made between the coral and NTS soil from these curves because of the large differences in yield and distances.

A summary of corrected "R" values (i.e. corrected for mass chain yield from U^{235} to the fuel actually used) is given in Table 8 for some Operation REDWING data.[12] A general increase in the "R" values with distance is shown for all the radionuclides in the Zuni and Tewa fall-out. In Shot Flathead only the radionuclides with rare gas precursors were fractionated. In Shot Navajo, there was no fractionation in the fallout (within experimental error).

Rough correlations of the "R" values of Table 8 with distance and also those of References 19 and 20 with particle size (with aid of Eq. 14) can be made if a fractionation parameter, z, is defined as

$$z_j = \frac{r_j}{1-r_j} \tag{29}$$

where r_j is the "R" value for the jth mass number (or nuclide) and, further, that

$$z_j = z_o(j)e^{k_z x} \tag{30}$$

Although the data of Table 8 are somewhat scattered with respect to a continuous change in r_j or z_j, they all can be adjusted, within about the same degree of error, to Eq. 30 with the same value of k_z for a given shot. Substituting 1/d (inverse particle diameter) for x and using the data of Reference 20 gives an even better fit for a constant k_z.

If z_{fp} is defined as the sum of all the z_j of fission product mixture, then

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$$z_{fp} = e^{k_z x} \Sigma_j z_o(j) \tag{31a}$$

$$= z_{fp}^o e^{k_z x} \tag{31b}$$

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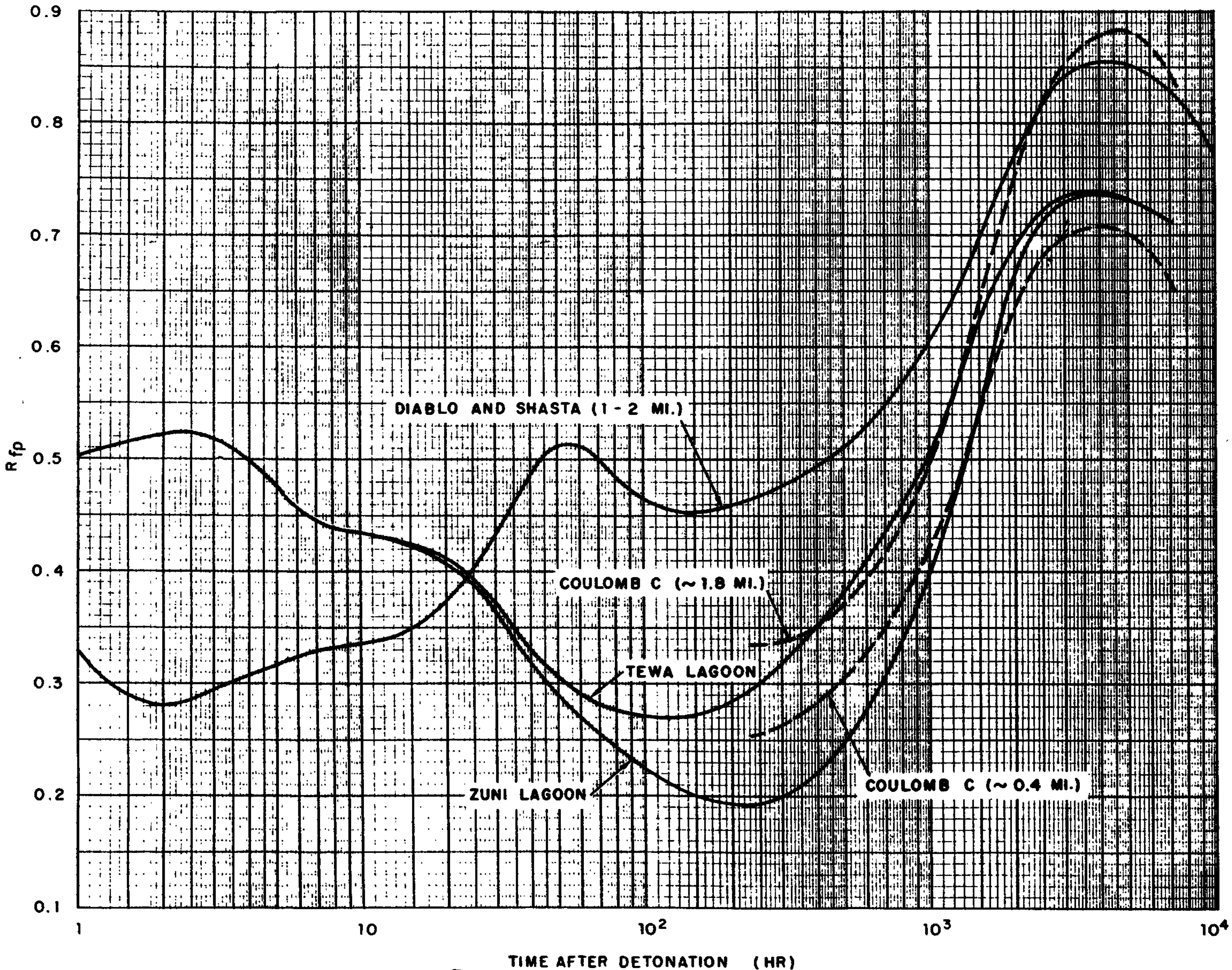

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Fig. 1 Gross Fission Product "R" Values for Some Fallout Samples

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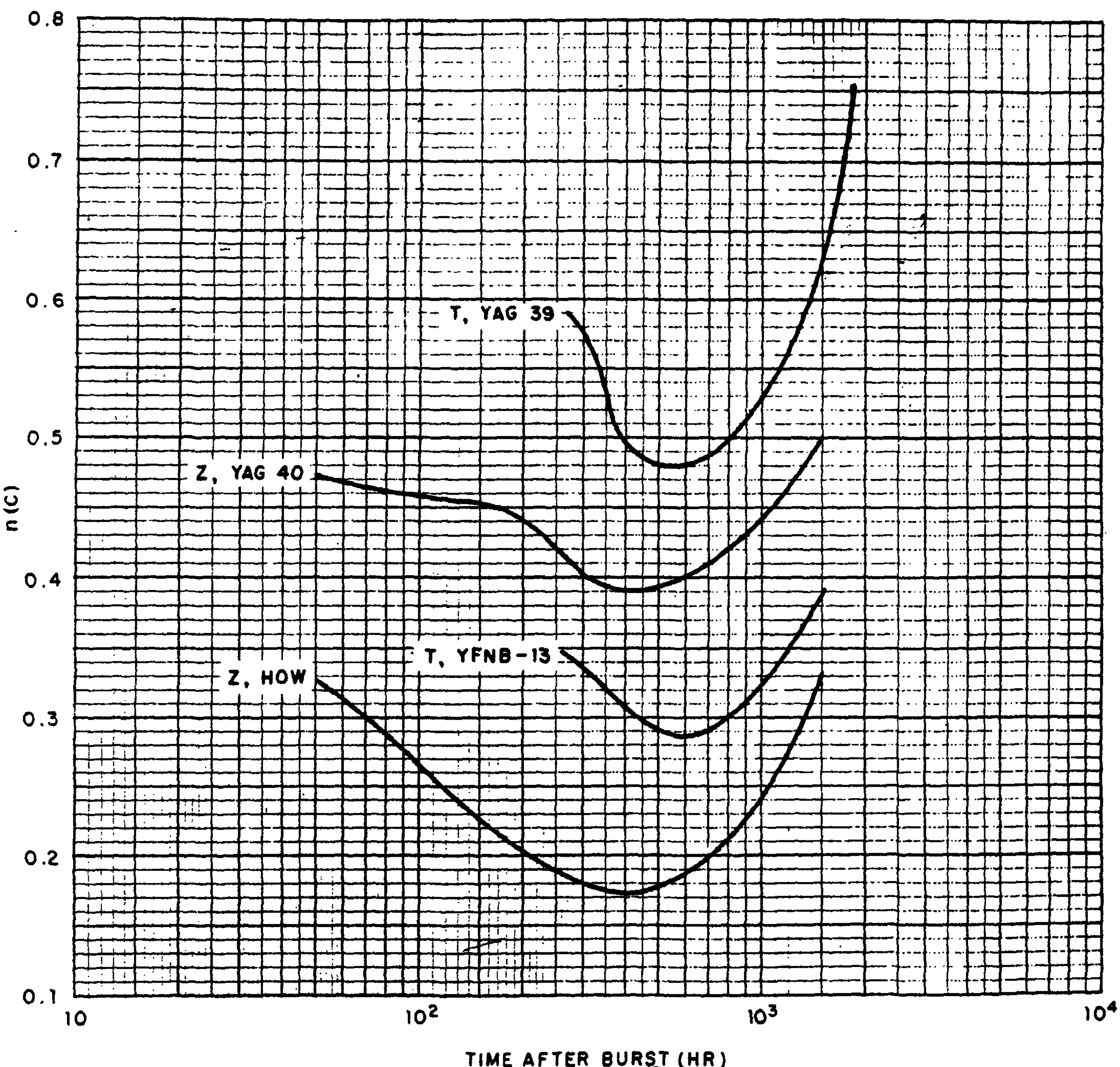

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Fig. 2 Ratio of Decay Curves: Fallout Sample/Cloud Sample Based on Mo^{99} Analysis

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TABLE 8

Summary of Corrected "R" Values for Fallout Collected During Operation REDWING

Station	Sr^{89}	Sr^{90}	Zr^{95}	Te^{132}	Cs^{137}	Ce^{144}
			1. Shot, Zuni			
YFNB 29	0.0524	0.0956	1.00	0.152	0.0461	0.590
YFNB 29	0.0524	0.0907	0.662	0.173	0.0133	0.576
YFNB 13	0.119	0.243	0.825	0.518	0.0461	0.820
How-F	0.0292	0.0794	0.941	0.142	0.0205	0.778
YAG-40	0.354	0.437	1.00	0.792	0.215	0.892
YAG-39	0.770	0.972	1.63	1.52	-	1.44
			2. Shot, Tewa			
YFNB 13	0.109	0.178	0.837	0.406	0.0615	0.705
YFNB 29	0.216	0.340	0.814	0.569	0.133	0.792
YFNB 29	0.231	0.389	0.860	-	0.164	0.806
How-F	0.0770	-	0.511	0.320	-	0.605
YAG-39	0.354	0.486	0.918	0.965	0.133	0.892
YAG-40	0.616	0.745	1.51	1.52	0.195	1.58
LST-611	0.400	0.567	1.09	1.12	0.369	1.21
			3. Shot, Flathead			
YFNB-29	0.277	0.551	1.14	1.12	-	1.17
YFNB-29	0.128	0.551	1.16	0.864	-	1.12
YFNB 13	0.462	0.486	1.08	1.02	0.205	1.04
YAG-39	0.416	0.454	1.28	0.975	-	1.17
LST-611	0.724	0.745	0.942	0.874	0.380	0.994
YAG-40	0.662	-	1.00	1.12	0.420	1.20
			4. Shot, Navajo			
YFNB-13	1.64	1.18	1.08	1.12	-	1.06
YFNB-29	1.03	1.25	1.07	1.22	-	1.70
YFNB-29	0.772	1.08	1.90	0.989	-	1.44
How-F	0.526	0.801	1.75	1.02	-	1.24
YAG-39	0.901	0.939	1.09	0.999	1.00	1.14
YAG-40	0.959	0.927	1.20	0.949	0.412	1.04
LST-611	1.16	0.989	1.31	1.02	-	1.44

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It may be noted that z is defined as the ratio of the fraction of the nuclide contained in the particles to that not contained in the particle (i.e. lost from the particle) assuming r_j for the reference nuclide (usually Mo^{99}) is unity. With this definition, Eq. 31 has no real significance except for the cases where all r_j are either 1 or 0 or where z^o_{fp} is taken to be proportional to the average value of $z_o(j)$ for the mixture. With the latter of the two views of z^o_{fp}, the data of Table 1 and Fig. 1 were used to obtain values of k_z for Shots Zuni, Tewa, and Coulomb C, and z^o_{fp} for Shots Shasta, Tewa and Zuni for application at H + 1 hr. The respective k_z values are 8.1×10^{-6}, 9.6×10^{-6}, and 4.5×10^{-5}; the respective z^o_{fp} values are 0.41, 0.65, and 0.73. Since Shot Tewa was detonated in 25 feet of water, the values of k_z for only the Zuni and Coulomb C Shots were used for obtaining constants for an assumed dependence of k_z on weapon yield and the z^o_{fp} values for Shasta (Diablo) and Zuni were used for a scaling function for z^o_{fp}. The two assumed empirical functions are

$$k_z = 4.1 \times 10^{-5}\, W^{-0.20} \tag{32}$$

and

$$z^o_{fp} = 0.32\, W^{0.086} \tag{33}$$

in which the respective values apply only to determining r_{fp} at H + 1 hr where

$$r_{fp} = \frac{z^o_{fp}\, e^{k_z x}}{1 + z^o_{fp}\, e^{k_z x}} \tag{34}$$

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By Eq. 34 r_{fp} can approach unity as the distance increases. Equation 32 indicates that r_{fp} approaches unity at shorter distances as the yield decreases, and Eq. 33 indicates that the fractionation decreases as the yield increases. These trends in fractionation correspond to the observed data. The constants are adjusted to r_{fp} values with respect to Mo^{99} and assume no difference between coral and NTS soil.

The values of z^o_{fp} and k_z for the fallout from some of the test devices are given in Table 9. The fallout from the surface water (barge) shots of yield 5 MT and larger is assumed to be unfractionated.

TABLE 9

Summary of Values for z^o_{fp} and k_z for Fallout From Test Shots at H + 1 hr

Shot	z^o_{fp}	$k_z (10^{-5}$ ft)
JANGLE, "S"	0.32	4.0
JANGLE, "U"	0.32	4.0
CASTLE, Bravo	0.73	0.60
CASTLE, Koon	0.48	1.62
REDWING, Zuni	0.65	0.81
REDWING, Flathead	[redacted] DELETED	[redacted]
REDWING, Tewa	0.73**	0.97*
PLUMBBOB, Diablo	0.41	2.3
PLUMBBOB, Shasta	0.40	2.3
PLUMBBOB, Coulomb C	0.30	4.5

* From data of Table 8.

** For rare gases only which contribute very nearly 1/3 of the H + 1 intensity for unfractionated fission products, the remaining 2/3 of i(1) is taken to be unfractionated at all distances.

4.4 EFFECT OF HEIGHT OF BURST ON THE CONTOUR SCALING FUNCTIONS

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The ratio of the crater volume or crater mass for a surface detonation to that for detonations at other scaled depths is plotted as a function of the nuclear scaled depth in Fig. 3 as taken from Reference 6. The nuclear scaled depth is defined as the charge depth divided by the cube root of the nuclear yield in lbs of TNT. There is a difference in the values of the scaled depth in Fig. 3 from those given in Reference 6. In that report, the equivalent blast yield (in TNT units) of nuclear explosions was found to be only 28 % with respect to the chemical explosives; conversion was made therefore in Fig. 3 to account for this decrease, in comparison to TNT explosions.

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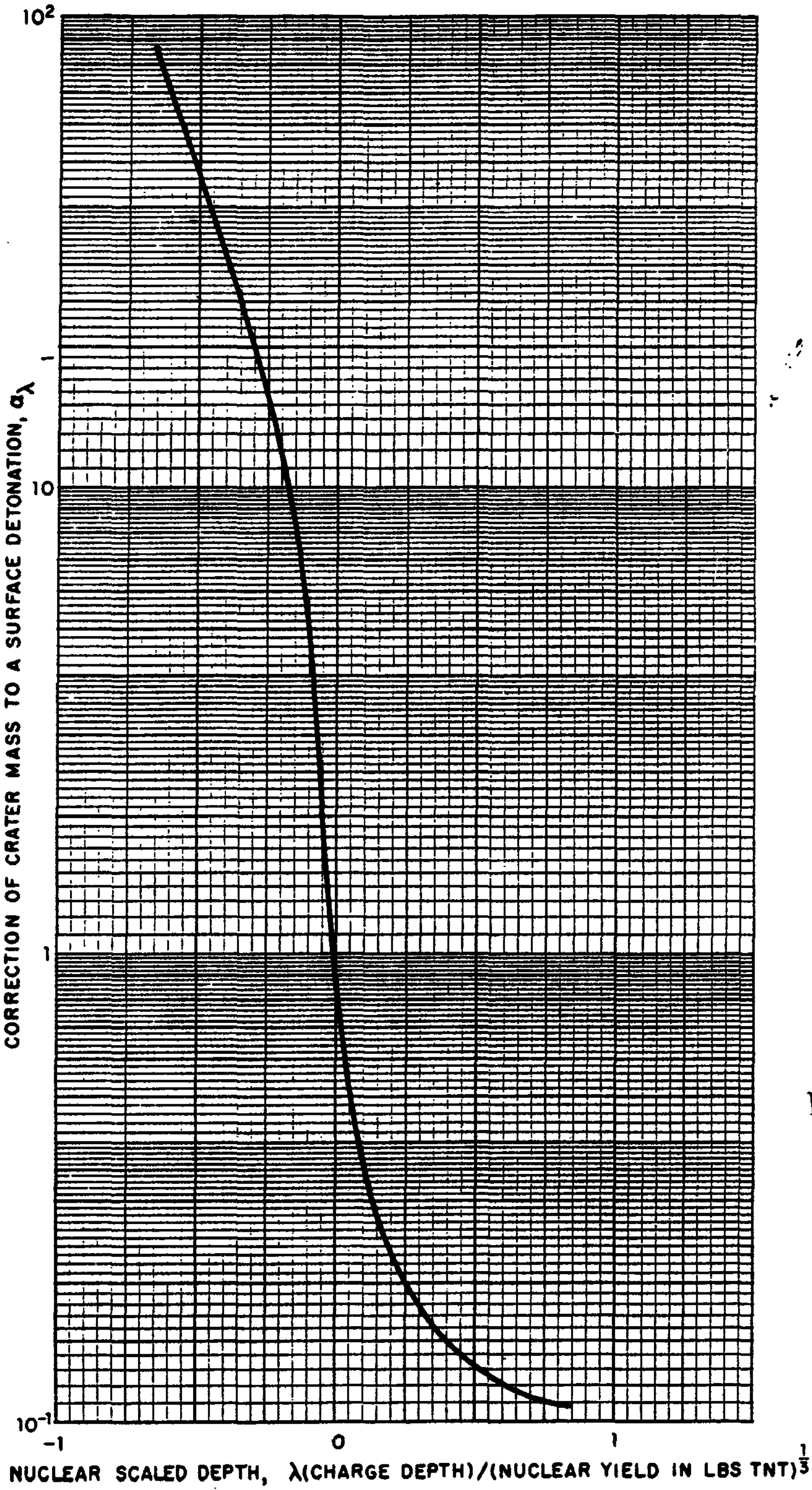

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Fig. 3 Variation in α_λ With Nuclear Scaled Depth

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If the curve of Fig. 3 is applied to the idealized mass contour ratio scaling functions, where the total crater mass is mixed with all the radionuclides, the value of the contour ratio would decrease as the scaled height increases and would increase as the scaled depth increases (up to a maximum). In a real detonation, the pressure and density of the confined vapors at larger values of the scaled depth could result in condensation and particle formation processes that differ markedly from surface and above-surface detonations, resulting in significant deviations from the idealized model. It may be noted that the curve of Fig. 3 has no inflection at zero charge depth and that it is very steep near zero charge depth. Therefore if Eq. 23 is valid in terms of the α_γ given in Fig. 3, the value of $M_T(t)$ is extremely sensitive to the height or depth of burst.

In Reference 7, some of $M_T(1)$ values for the JANGLE "S" and "U" Shots were averaged. For the "S" Shot, the average value of $M_T(1)$ was 23.6 (mg/sq ft)/(r/hr at 1 hr) and for the "U" Shot it was 85.9. The value of α_γ for the "S" Shot with a λ of -0.02 is 1.45; this correction gives a $M_T^s(1)$ value of 34.2. The value of α_γ for the "U" Shot with a λ of 0.13 is 0.32; this correction gives a $M_T^s(1)$ value of 27.6. The two $M_T^s(1)$ values for the 1.2 KT yield thus obtained are within the experimental and computational errors involved in obtaining the average values. Thus Fig. 3 can be used as a guide in adjusting the $M_T^s(1)$ values for detonations with λ values between -0.02 and 0.13. When the data from Operation TEAPOT ESS Shot and others are reduced, it may be possible to derive a better scaling function for α_γ than that given in Fig. 3.

The fraction-of-device contour ratio is not expected to be sensitive to the height or depth of burst unless the fractionation of the radioactive components changes with the height or depth of burst. In the underwater burst, for example, the rare gas daughter products are enriched with respect to the other fission products.[21] No conclusions can be made at the present time regarding the relative degree of fractionation in the two JANGLE Shots.[19] This effect was not considered in the treatment of the data in this report.

The values of α_γ and $b\alpha_\gamma$ for some test shots are summarized in Table 10. The α_γ values for PLUMBBOB Shots Diablo and Shasta would not be valid because of the heavy towers for those shots.

TABLE 10

Summary of α_γ and $b\alpha_\gamma$ Values for Some Test Shots

Shot	α_γ	$b\alpha_\gamma$
JANGLE "S"	1.45	1.45
JANGLE "U"	0.32	0.32
CASTLE Bravo	1.0	0.54
CASTLE Romeo	1.0	0.65
CASTLE Koon	1.40	1.40
CASTLE Union	1.0	0.81
REDWING Zuni	1.0	0.15
REDWING Flathead	DELETED	
REDWING Navajo		
REDWING Tewa	1.0	0.66
PLUMBBOB Coulomb C	1.30	1.30

4.5 COMPUTATION OF THE TERRAIN FACTOR FROM FRACTION-OF-DEVICE DATA

The computation of q was carried out by use of Eq. 25. The values of $D_{fp}(1)i_{fp}(1)$ and D_j were taken from Reference 2 for U^{235} fission products which were also used to determine the r_{fp} values in Section 4.3. The values of $D_j r_j c_j i_j(1)$ are given in Table 11. The $r_j c_j$ values were taken from Table 6 and the text of Section 4.2. The calculated values of the terrain factor, q, are summarized in Table 12.

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The terrain factors calculated from fallout sample analytical data by means of Eq. 25 contains sampling bias errors and errors in all the input terms to Eq. 25 as well as the true terrain factor (i.e. error in W, differences in the true fission yield factor per KT from 1.45 x 10^{23}, error in α_γ, b, and the gross fractionation factors). Many of these errors are constant for a given shot. The sampling error is probably one of major contributors to errors which are not constant for a given shot. The average values of q and $\overline{q/q}$ in Table 12 were calculated on the basis that the sampling error was the major contributing factor where values of q greater than one were obtained. This assumes that, for the data used in Table 12, the sampling bias is most likely to be on the negative side - i.e. the sampling devices used would tend to

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TABLE 11

Contribution of Induced Activities to the H + 1 Reference Intensity for Fallout From Some Test Shots

Shot	U^{239}	Np^{239}	U^{237}	Np^{240}	Sum
	(values in 10^{-13} r/hr per fission/sq ft)				
- i(1) =	0.1799	0.0227	0.00957	0.2097	-
JANGLE, "S"	0.106	0.013	-	-	0.119
JANGLE, "U"	0.106	0.013	-	-	0.119
CASTLE, Bravo	0.101	0.013	0.001	0.030	0.145
CASTLE, Romeo	0.119	0.015	0.001	0.048	0.183
CASTLE, Koon	0.130	0.016	0.001	-	0.147
CASTLE, Union	0.079	0.010	0.002	0.015	0.106
REDWING, Zuni	0.055	0.007	0.002	0.001	0.065
REDWING, Flathead			DELETED		
REDWING, Navajo					
REDWING, Tewa	0.064	0.008	0.002	0.019	0.093
PLUMBBOB, Diablo	0.018	0.002	-	-	0.020
PLUMBBOB, Shasta	0.018	0.002	-	-	0.020
PLUMBBOB, Coulomb C	0.005	0.001	-	-	0.006

be less efficient collectors than the surrounding terrain (all stations used in Table 12 are land stations) and that q for a non-biased collection should not be greater than about 1.0. The $q/\bar{q}$ values are separated by Operation Because different collectors or collecting platforms were used in each.

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The values of (1.0) of $q/\bar{q}$ indicate the station values used to calculate $\bar{q}$. This is not done for the PLUMBBOB Shots since all the values except 2 were used in calculating $\bar{q}$. In taking the respective $\bar{q}$ values as the estimate of q for the two different terrains (EPG and NTS), the assumption is implied that there was no collecting bias at the stations involved. The ratio of the average q value for all the stations to that for the no-bias stations (i.e. where q is less than about 1.0) is the average station collecting bias factor. This is 1.88 for the Operation CASTLE collectors (Chemical Corps, CWL) and 1.55 for the Operation REDWING collectors (NRDL). For the PLUMBBOB shots, the sampling bias was assumed to be absent for the collectors

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TABLE 12

Summary of the Calculated Values of the Terrain Factor From Fraction-of-Device Contour Ratio Values

Station	r_{fp}	$r_{fp}\, i_{fp}(1)$ (10^{-13} r/hr at 1 hr)	$i(1)$ (10^{-13} r/hr at 1 hr)	q	$q/\bar{q}$
			1. CASTLE, Bravo		
Fox	0.50	2.665	2.810	670	-
How	0.57	3.037	3.182	2.77	3.33[a]
How	0.57	3.037	3.182	1.06	(1.0)[a]
Victor	0.52	2.772	2.917	0.606	(1.0)[a]
			2. CASTLE, Koon		
Victor	0.45	2.398	2.545	1.836	2.21[a]
			3. REDWING, Zuni		
How F	0.54	2.877	2.942	0.943	(1.0)[b]
How K	0.55	2.932	2.997	0.800	(1.0)[b]
George	0.54	2.877	2.942	1.51	1.90[b]
William	0.46	2.478	2.543	1.50	1.88[b]
			4. REDWING, Flathead		
George	DELETED	DELETED		DELETED	
			5. REDWING, Navajo		
How F					
How K					
Charlie		DELETED			
George					
			6. REDWING, Tewa		
How F	0.59	3.144	3.237	0.693	(1.0)[b]
How K	0.59	3.144	3.237	0.755	(1.0)[b]
Charlie	0.47	2.505	2.598	10.5[c]	13.2[b]
George	0.50	2.665	2.758	2.04	2.56[b]
			7. PLUMBBOB, Diablo		
A1	0.32	1.705	1.725	0.562	
A2	0.32	1.705	1.725	0.530	
A3	0.32	1.705	1.725	0.654	
A4	0.32	1.705	1.725	0.621	
A5	0.32	1.705	1.725	0.694	
			8. PLUMBBOB, Shasta		
A1	0.37	1.972	1.992	0.746	
A3	0.37	1.972	1.992	0.844	
A4	0.37	1.972	1.992	0.804	
A6	0.37	1.972	1.992	0.751	
A7	0.34	1.812	1.832	1.085[c]	1.42
A8	0.36	1.919	1.939	0.768	
A9	0.38	2.026	2.046	0.817	
A10	0.39	2.078	2.098	0.618	
A11	0.40	2.132	2.152	0.695	
A12	0.41	2.186	2.206	0.832	
			9. PLUMBBOB, Coulomb C		
1	0.25	1.333	1.339	1.21[c]	1.63
1	0.25	1.333	1.339	0.858	
2	0.26	1.386	1.392	0.830	
	0.26	1.386	1.392	0.837	
3	0.32	1.705	1.711	0.640	
	0.32	1.705	1.711	0.714	

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Ave (EPG) = 0.797(4)
= 1.236(12); q(12)/q(4) = 1.55
Ave (NTS) = 0.746(19)

a. Relative to q for CASTLE Shots: $\bar{q}(2) = 0.83$, $\bar{q}(4)/\bar{q}(2) = 1.88$
b. Relative to q for REDWING Shots.
c. Not used in calculating averages.

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used in Shots Diablo and Shasta.[14] The Coulomb C samples were surface soil samples which, by definition, had no sampling bias.

The sample bias factors, $q/\bar{q}$, are used in the next section, where applicable, to increase the values of a (fissions/sq ft) for calculation of $M_r(1)$ from I(1) and a/m values. For the stations at which I(1) was not observed, the average value of the ratio, $q/\bar{q}$, was used to increase the FOD (fraction of device) per sq ft values and, by use of Eq. 25, to give estimates of I(1).

4.6 COMPUTATION OF K(x,W) FROM MASS CONTOUR RATIO DATA

The values of K(x,W) can be determined by means of Eq. 24 and the observed or estimated values of $M_r(1)$. In order to increase the number of data points in determining the dependence of K(x,W) on x, the I(1) values were estimated for the stations at which observed values were not available (i.e. mainly the floating stations for Operations CASTLE and REDWING) by the method described in Section 4.5. In addition, correlations were made of the variation of the specific activity of the fallout with distance from the data of Table 1. These are shown in Fig. 4. The data are quite scattered with respect to variation with distances; in the calculations, the empirical equations for Zuni and Flathead were used but for Tewa and Navajo, the geometric means were used.

Activity-particle size data and specific activity data from PLUMBBOB Shot Shasta are given in Figs. 5 through 7. The mean values of the sizes and specific activities are summarized in Table 13 for each station; these values and an extrapolated value were used in Table 1 for the calculated values of $M_r(1)$. The very small amounts of activity in small sizes (Figs. 5 and 6), if neglected, would result in distribution curves with a fairly small particle size range for each station. In Fig. 7, it may be noted that, for the range of distances given, the specific activity is nearly proportional to $x^{1/2}$.

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The values of K(X,W)/q are summarized in Table 14. For the JANGLE and CASTLE data (except for Stations How and Victor), no correction was applied for sampling bias since no estimate was available to apply to the collectors used. No bias was assumed for the PLUMBBOB data. The K(X,W)/q values are plotted against the 1 MT Scaled Distance in Figs. 8, 9, and 10; the 1 MT Scaled Distance was used to adjust the numerical values of the distances for each shot to a convenient common range for plotting.

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TABLE 13

Specific Activity for PLUMBBOB Shasta Fallout

Station	Geometric Mean Radioactive Particle Size (μ)	Specific Activity of Mean Size (f/mg)	1 MT Scaled Distance (ft)
A1	830[b]	[c]1.13×10^{12}	24,500
A3	780[a]	[b]1.15×10^{12}	24,800
A4	830[b]	[c]1.13×10^{12}	24,500
A6	780[b]	[c]1.15×10^{12}	25,000
A7	1010[a]	[b]1.01×10^{12}	19,700
A8	680[a]	[b]1.24×10^{12}	27,100
A9	620[b]	[c]1.30×10^{12}	32,000
A10	570[a]	[b]1.35×10^{12}	37,600
A11	470[a]	[b]1.49×10^{12}	42,000
A12	500[b]	[c]1.43×10^{12}	39,200

a. From Fig. 5.
b. From Fig. 6.
c. From Fig. 7.

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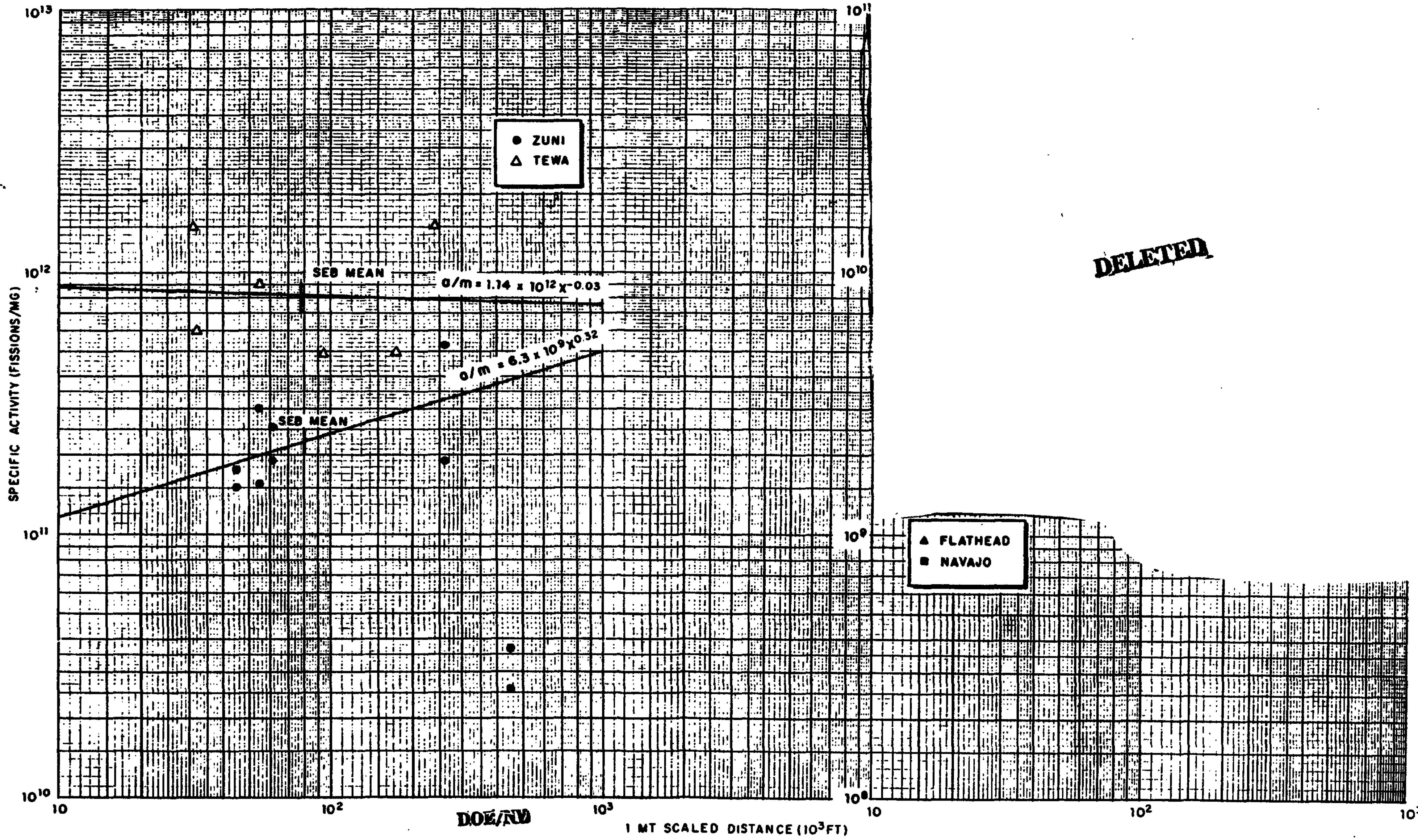

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Fig. 4 Variation of Specific Activity With Distance for Operation REDWING Shots

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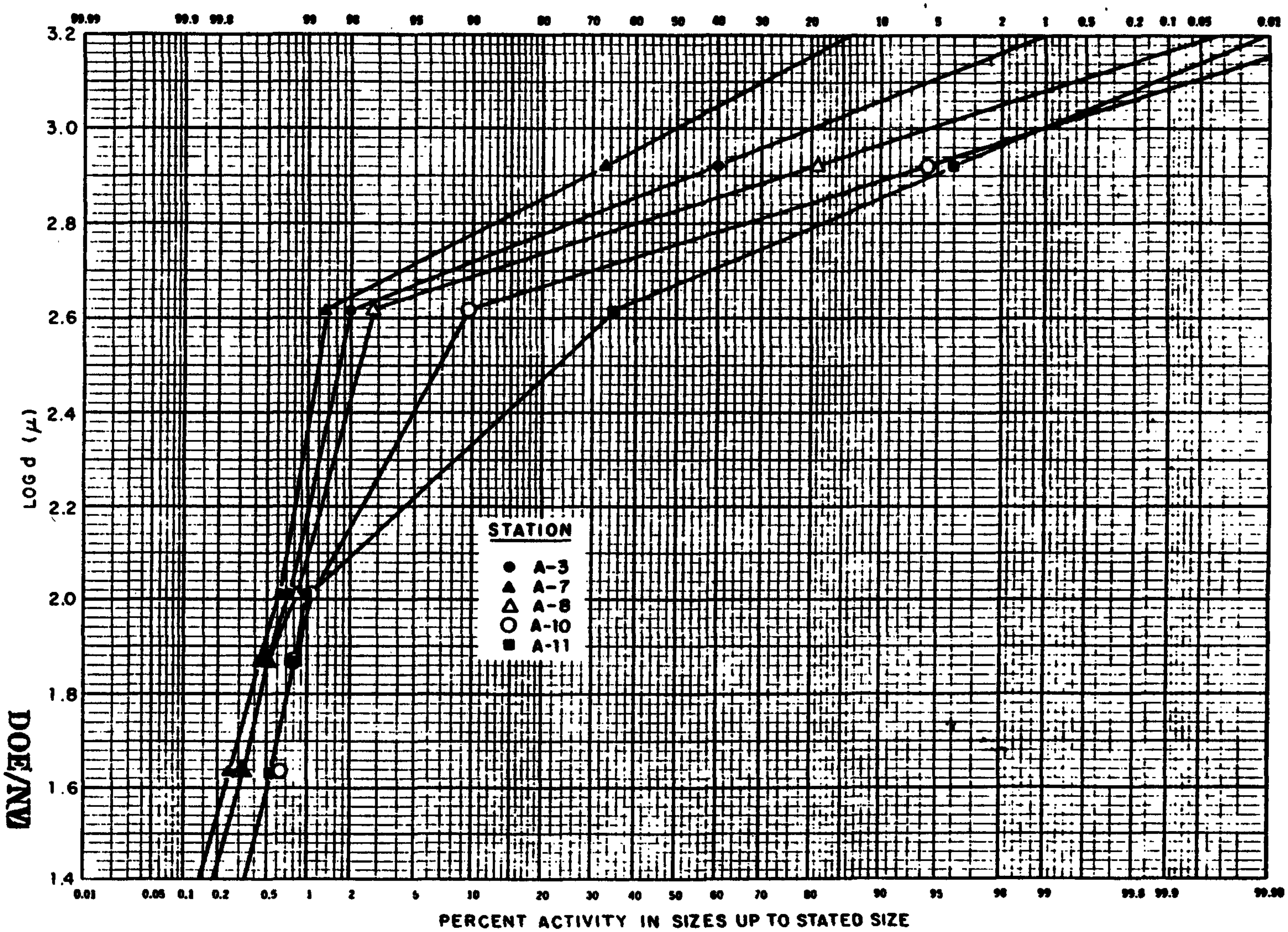

Fig. 5 Activity Size Distribution of PLUMBBOB Shasta Fallout

TABLE 14

Summary of Values of K(X,W)/q

Station	$M_r(1)$ (mg/sq ft)/(r/hr at 1 hr)	$r_{fp}(1)$	$r_{fp}(1)\,i_{fp}(1)$ (10^{-13} r/hr at 1 hr)	$i(1)$ (10^{-13} r/hr at 1 hr)	$\frac{K(X,W)}{q}$ (10^{-12} mg/f)
		1. JANGLE "S" Shot			
D1	32,000	0.248	1.322	1.441	6,680[a]
E2	6,100	0.248	1.322	1.441	1,270[a]
E3	24,000	0.248	1.322	1.441	5,020[a]
F1	815	0.248	1.322	1.441	170[a]
G1	105	0.257	1.370	1.489	22.6
G3	565	0.258	1.375	1.494	122[a]
H1	22.5	0.263	1.402	1.521	4.96
H3	22.9	0.263	1.402	1.521	5.04
H5	47.8	0.267	1.423	1.542	10.7
I1	31.8	0.271	1.445	1.564	7.21
I3	25.0	0.271	1.445	1.564	5.67
I5	37.1	0.273	1.455	1.574	8.47
N4	17.3	0.302	1.610	1.729	4.34
N3	17.3	0.314	1.674	1.793	4.50
N1	13.6	0.341	1.834	1.953	3.86
		2. JANGLE, "U" Shot			
D1	5,600	0.250	1.333	1.452	260[a]
E2	1,480	0.250	1.333	1.452	68.8[a]
F1	676	0.250	1.333	1.452	31.4[a]
D2	1,270	0.252	1.343	1.462	59.5[a]
D3	842	0.252	1.343	1.462	39.4[a]
F2	205	0.252	1.343	1.462	9.60[a]
F3	586	0.252	1.343	1.462	27.4[a]
E4	400	0.257	1.370	1.489	19.1[a]
E5	806	0.257	1.370	1.489	38.4[a]
G1	86.6	0.257	1.370	1.489	4.13[a]
G2	176	0.259	1.380	1.499	8.45
G3	161	0.259	1.380	1.499	7.71
G4	169	0.262	1.397	1.516	8.19
G5	336	0.262	1.397	1.516	16.3[a]
H1	110	0.264	1.407	1.526	5.38
H2	106	0.264	1.407	1.526	5.18
H3	154	0.264	1.407	1.526	7.52
H4	417	0.268	1.429	1.548	20.6[a]
H5	342	0.268	1.429	1.548	16.9[a]
I1	87.8	0.269	1.434	1.553	4.35
I2	135	0.269	1.434	1.553	6.72
I3	64.0	0.269	1.434	1.553	3.18
I4	82.3	0.273	1.455	1.574	4.16
I5	107	0.273	1.455	1.574	5.38
I6	231	0.276	1.471	1.590	11.7[a]
I8	58.8	0.281	1.498	1.617	3.04
N5	52.9	0.288	1.535	1.654	2.80
N4	60.0	0.302	1.610	1.729	3.33
N3	40.7	0.314	1.674	1.793	2.34
N1	20.8	0.340	1.812	1.931	1.29

Continued

TABLE 14 (Cont'd)

Summary of Values of K(X,W)/q

Station	$M_r(1)$ (mg/sq ft)/ (r/hr at 1 hr)	$r_{fp}(1)$	$r_{fp}(1)\ i_{fp}(1)$ (10^{-13} r/hr at 1 hr)	$i(1)$ (10^{-13} r/hr at 1 hr)	K(X,W) (10^{-12} mg/f)
			3. CASTLE, Bravo		
250.04	33.6	0.51	2.717	2.862	5.19
250.05	78.3	0.53	2.825	2.970	12.6
250.06	44.1	0.54	2.878	3.023	7.18
250.17	2.1	0.50	2.665	2.810	0.32[a]
250.22	19.4	0.56	2.985	3.130	3.28
250.24	58.0	0.53	2.825	2.970	9.29
250.25	44.2	0.52	2.772	2.917	6.96
Fox	8.9	0.50	2.665	2.810	1.35[a]
Fox	-	0.50	2.665	2.810	-
How	47.8(14.3)	0.57	3.037	3.182	8.18(2.46)
How	34.7	0.57	3.037	3.182	5.96
Love	800	0.59	3.144	3.289	142[a]
Nan	1.2	0.60	3.197	3.342	0.22[a]
Oboe	178	0.55	2.932	3.077	29.6[a]
Uncle	226	0.54	2.878	3.023	36.9[a]
Victor	32.2	0.52	2.772	2.917	5.07
William	148	0.52	2.772	2.917	23.3[a]
Zebra	389	0.50	2.665	2.810	58.8[a]
			4. CASTLE, Romeo		
A4	235	1.00	5.330	5.513	84.5
A5	181	1.00	5.330	5.513	64.8
Q4	75.5	1.00	5.330	5.513	27.0
R4	20.2	1.00	5.330	5.513	7.22
T4	21.0	1.00	5.330	5.513	7.54
			5. CASTLE, Koon		
250.05	37.1	0.58	3.092	3.239	16.8
250.05	94.0	0.58	3.092	3.239	42.7
250.07	68.8	0.50	2.665	2.812	27.0
250.07	95.6	0.50	2.665	2.812	37.6
Fox	48.9	0.60	3.198	3.345	23.0
Coca Head	28.9	0.45	2.398	2.545	10.3[a]
			6. CASTLE, Union		
YAG 39				5.436	35.2
			7. REDWING, Zuni		
How F	18.3	0.54	2.877	2.942	0.807
How F	14.5	0.54	2.877	2.942	0.639
How K	19.4	0.55	2.932	2.997	0.871
George	20.7	0.54	2.877	2.942	0.912
William	30.0	0.465	2.478	2.543	1.14
YFNB 13	27.1	0.53	2.825	2.890	1.17
YFNB 13	14.0	0.53	2.825	2.890	0.606
YFNB 29	25.4	0.50	2.665	2.730	1.04
YFNB 29	29.8	0.50	2.665	2.730	1.22
YAG 39	6.0	0.98	5.224	5.289	0.375[a]
YAG 40	14.4	0.90	4.796	4.861	1.05[a]
YAG 40	5.1	0.90	4.796	4.861	0.372[a]

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TABLE 14 (Cont'd)

Summary of Values of K(X,W)/q

Station	$M_r(1)$ (mg/sq ft)/ (r/hr at 1 hr)	r'_{fp}	r_{fp}	$r_{fp}(1)\ i_{fp}(1)$ (10^{-13} r/hr at 1 hr)	i(1) (10^{-13} r/hr at 1 hr)	$\frac{K(X,W)}{q}$ (10^{-2} mg/fiss)
8. REDWING, Flathead						
How F						
How K						
George						
William				DELETED		
YFNB 13						
YFNB 29						
YAG 39						
YAG 40						
LST 611						
9. REDWING, Navajo						
How F						
How K						
Charlie						
George				DELETED		
YFNB 13						
YFNB 29						
YAG 39						
YAG 40						
LST 611						
10. REDWING, Tewa						
How F	5.20		0.59	3.144	3.237	1.11
How K	5.33		0.59	3.144	3.237	1.14
Charlie	6.22		0.47	2.505	2.598	1.06
George	5.90		0.50	2.665	2.758	1.08
YFNB 13	3.09		0.52	2.772	2.865	0.584
YFNB 29	7.78		0.52	2.772	2.865	1.47
YAG 39	7.02		0.70	3.730	3.823	1.77
YAG 40	5.58		0.87	4.637	4.730	1.74
LST 611	1.74		0.94	5.010	5.103	0.585
11. PLUMBBOB, Diablo[b]						
A1	15.2		0.32	1.705	1.725	2.62
A2	16.0		0.32	1.705	1.725	2.76
A3	12.9		0.32	1.705	1.725	2.22
A4	13.6		0.32	1.705	1.725	2.35
A5	12.0		0.32	1.705	1.725	2.07
12. PLUMBBOB, Shasta[b]						
A1	6.13		0.37	1.972	1.992	1.22
A3	5.33		0.37	1.972	1.992	1.06
A4	5.74		0.37	1.972	1.992	1.14
A6	6.06		0.37	1.972	1.992	1.21
A7	5.24		0.34	1.812	1.832	1.36
A8	5.81		0.36	1.919	1.939	1.13
A9	4.76		0.38	2.026	2.046	0.974
A10	5.62		0.39	2.078	2.098	1.18
A11	4.62		0.40	2.132	2.152	0.994
A12	3.89		0.41	2.186	2.206	0.858

a. Not used in computing means or equation constants.
b. Values are for $K(X,W)/\alpha_\lambda q$ in last column.

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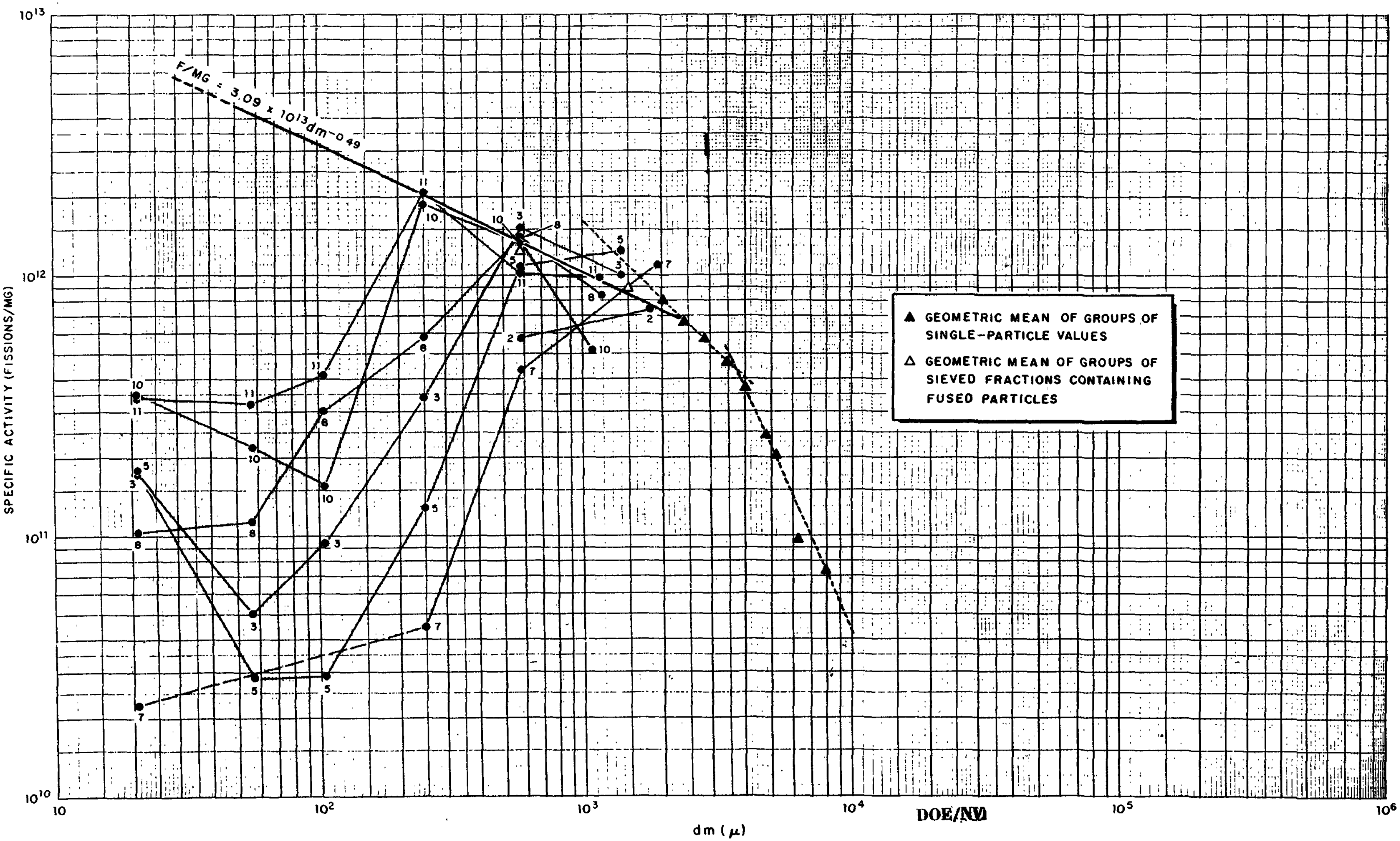

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Fig. 6 Variation of Specific Activity of PLUMBBOB Shasta Fallout With Particle Size

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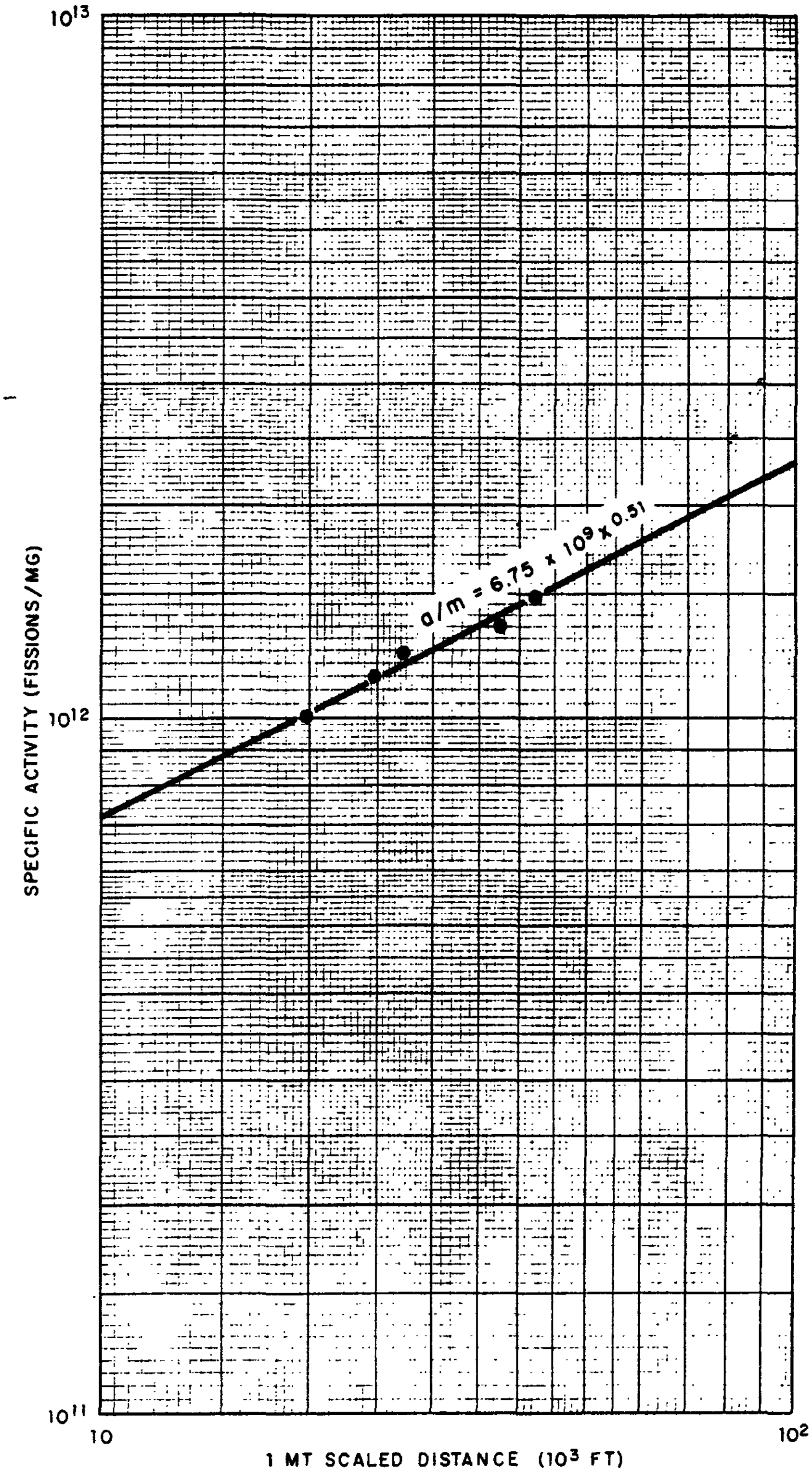

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Fig. 7 Variation of Specific Activity of PLUMBBOB Shasta Fallout With the 1 MT Scaled Distance

TABLE 15

Summary of Equation Constants for K/q

1. Land Shots

JANGLE "S"	$1.62 \times 10^{-7}\ X^{-1}$ (± 54 %)	$1.04 \times 10^{-9}\ X^{-1/2}$ (± 47 %)
JANGLE "U"	$1.43 \times 10^{-7}\ X^{-1}$ (± 24 %)*	$0.794 \times 10^{-9}\ X^{-1/2}$ (± 35 %)
CASTLE Bravo	$3.32 \times 10^{-7}\ X^{-1}$ (± 54 %)	$1.48 \times 10^{-9}\ X^{-1/2}$ (± 49 %)*
CASTLE Koon	$22.5 \times 10^{-7}\ X^{-1}$ (± 44 %)*	$8.28 \times 10^{-9}\ X^{-1/2}$ (± 55 %)
REDWING Zuni	$0.468 \times 10^{-7}\ X^{-1}$ (± 27 %)	$0.206 \times 10^{-9}\ X^{-1/2}$ (± 24 %)
REDWING Tewa	1.09×10^{-12} (± 47 %)*	$0.257 \times 10^{-9}\ X^{-1/2}$ (± 87 %)
PLUMBBOB Diablo[a]	$0.231 \times 10^{-7}\ X^{-1}$ (± 9.3 %)*	$0.235 \times 10^{-9}\ X^{-1/2}$ (± 11 %)
PLUMBBOB Shasta[a]	$0.318 \times 10^{-7}\ X^{-1}$ (± 19 %)	$0.188 \times 10^{-9}\ X^{-1/2}$ (± 9.7 %)*

2. Seawater Shots

CASTLE Romeo	24×10^{-12} (± 220 %)
CASTLE Union	35×10^{-12}
REDWING Flathead	
REDWING Navajo	

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a. For $K/\alpha_{\lambda}\ q$.

*Constants with smallest percent standard deviation in the product, KX or $KX^{1/2}$.

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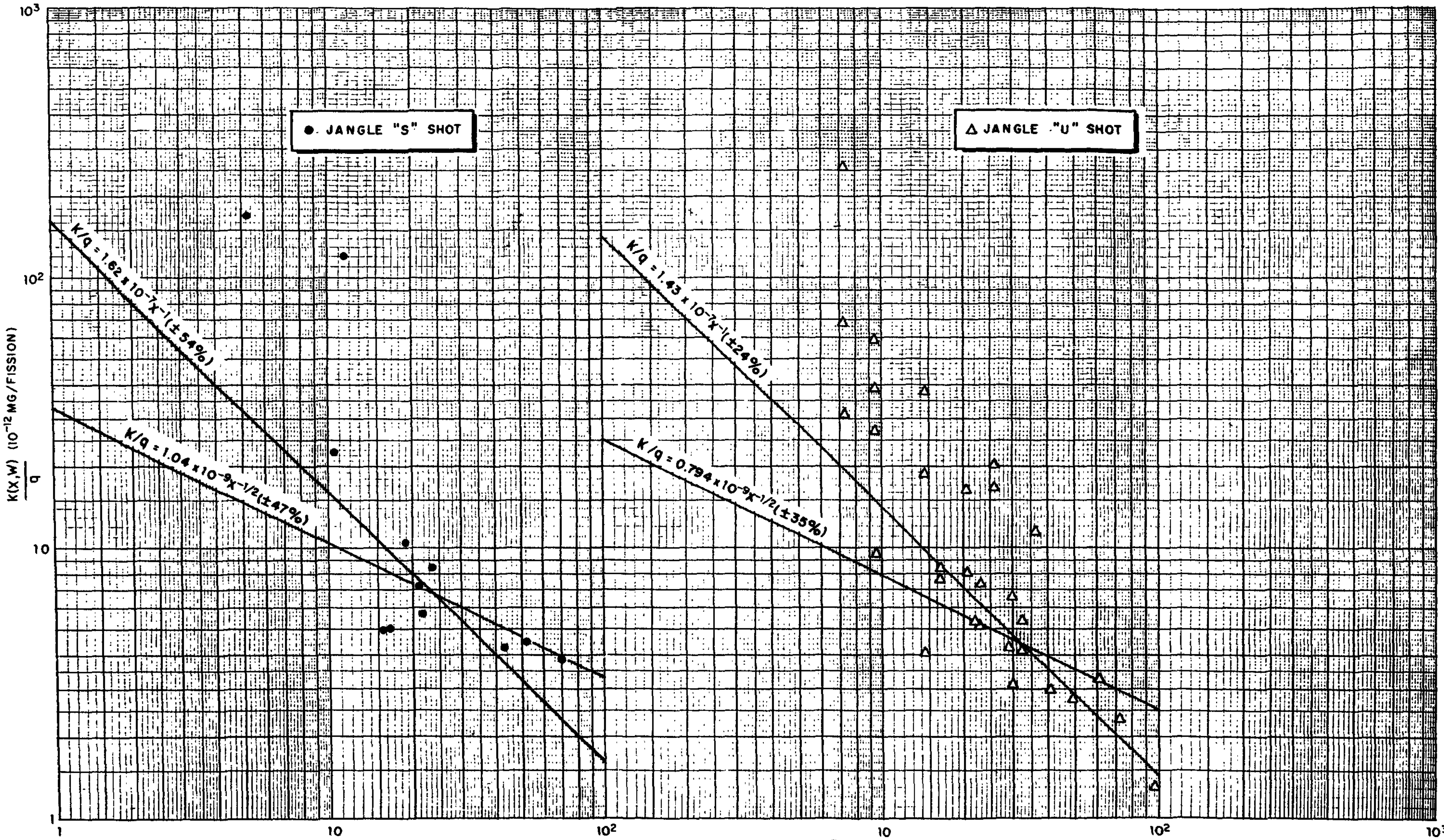

Fig. 8 Variation of $K(X,W)/q$ With the 1 MT Scaled Distance

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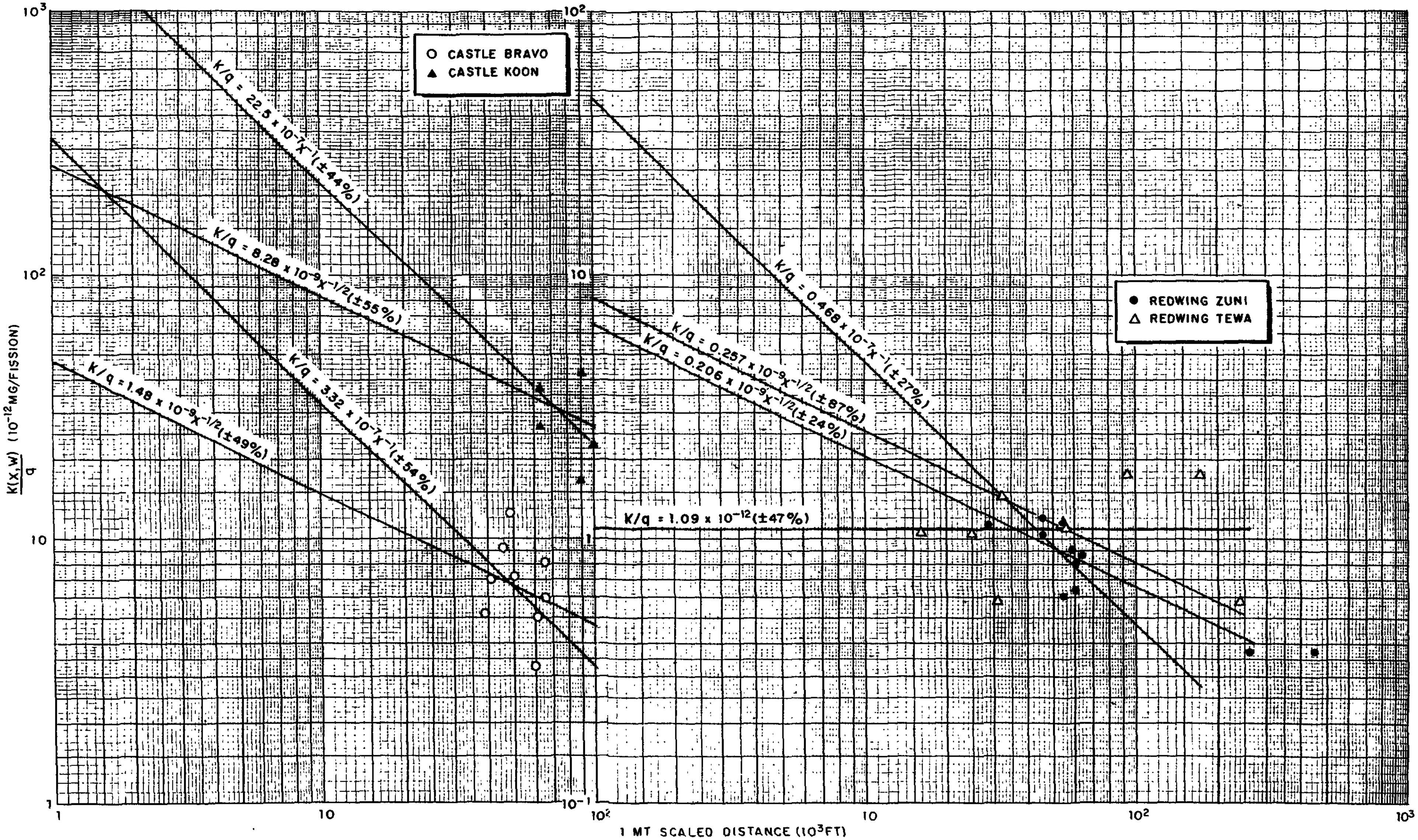

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Fig. 9 Variation of the 1 MT Scaled Distance With Yield

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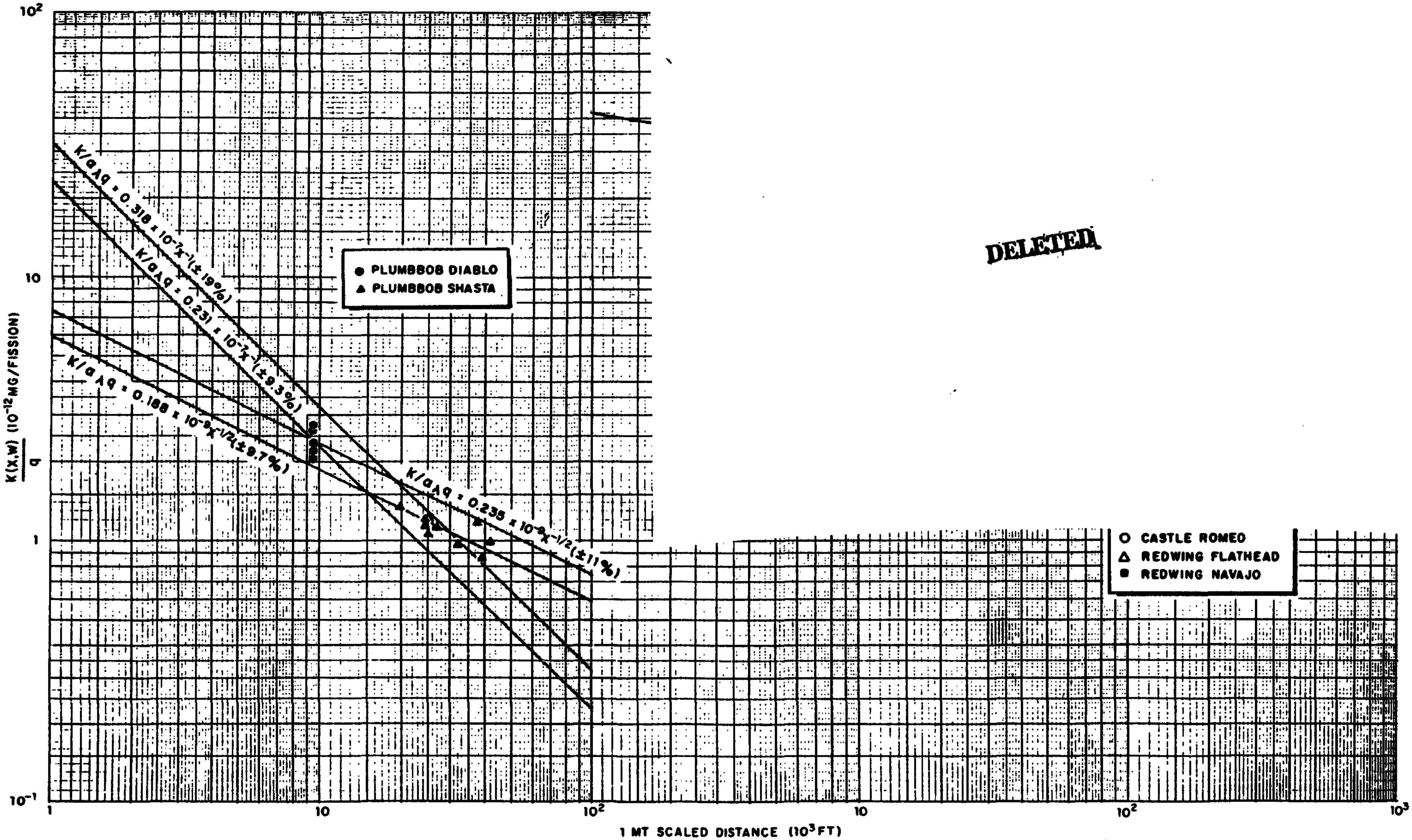

Fig. 10 Variation of K(X,W)/q With the 1 MT Scaled Distance

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The data for the land shots were fitted to equations of the forms const/X, and const/$X^{1/2}$ as suggested by the form of Eq. 19 and 20 since no other form was apparent from the plots of the data (exception is for Shot Tewa). The variation of K(X,W)/q with distance for the water shots was indeterminate for the Romeo data, did not occur for the Navajo data, and was determined from an empirical fit of the data to an equation of the form aX^n for the Flathead data.

The close-in samples from the two JANGLE Shots were known to contain a large amount of inert crater material, a surface desert sand raised by the blast wave. This extraneous debris was greater on the "S" Shot for some locations than for the "U" Shot. It may be noted that the higher values of K(X,W)/q from the "U" Shot data between the 1 MT scaled distances of 10 x 10^3 and 40 x 10^3 are for stations on the left side of the pattern (with respect to the downwind direction) where a high ridge of activity in the fallout pattern occurred. The excess soil must have originated from material blown out asymmetrically from the crater in that direction.

The difference in the fit of the Zuni and Tewa data to the assumed functions is due either to large errors in sampling and analysis of the Tewa data (large scatter) or to the presence of a larger amount of water in the Tewa fireball and cloud (it was detonated over water 25 ft deep).

The equation constants for the assumed dependence of K/q on X are summarized in Table 15. The best fit of the data, where values occurred over a range of X, is for the PLUMBBOB Shasta Shot and K/q inversely proportional to $X^{1/2}$. The JANGLE "U" Shot data was best fitted by the equation of K/q proportional to X^{-1}. No explanation is available for the high values of K/q for CASTLE Koon.

Since the most reliable sampling data are, in order of reliability, from Shot Shasta, Shot Zuni, and the two JANGLE Shots, and since preference of the two equations by measure of the percent standard deviation in the product KX or $KX^{1/2}$ is for the latter, it was retained for use in the mass contour scaling function. However, on the basis of the JANGLE "U" Shot results, the variation of K/q with X as X^{-1} may be considered for use with the fallout from underground shots.

The data for the water shots do not show a consistent trend in K/q with distance for all weapon yields. Within the large percentage standard deviations indicated, a constant value independent of X appeared to be the appropriate selection.

Many of the K/q values given in Table 14 were derived values that were obtained by means of a set of correlations to increase the amount of data for evaluating and selecting the functional dependence of K/q on X. However, for the determination of the final estimate of the equation coefficient and its dependence on the yield, W, it appeared that the most reliable method would be to select only those values of $M_r(1)$ and K/q that were obtained from direct measurements. These include the JANGLE "S" and "U" Shot data as given in Table 15; the remainder are summarized in Table 16. The data from PLUMBBOB Diablo and Shasta cannot be used to determine the yield dependence of K/q because α_λ is unknown. The one point from CASTLE Koon (Station Fox) was not used; its value of $KX^{1/2}/q$ is 7.3×10^{-9} which is about a factor of 17 to 40 times larger than those given in Table 16.

The values from Table 16 of $KX^{1/2}/q$ for the surface land shots and K/q for the surface water shots are plotted against yield in Fig. 11. The average values of $KX^{1/2}/q\alpha_\lambda$ for Shots Diablo and Shasta and the K/q values (average for Romeo) are also plotted for comparison. Since the indicated rapid increase in $KX^{1/2}/q$ with yield for Shots Zuni, Tewa and Bravo, seemed to be extremely unlikely, a geometric mean value of $KX^{1/2}/q$ for the three shots was taken. There is some justification for decreasing the value for the Bravo Shot in that the r/hr at 1 hr values given in reference 5 are probably low because the decay curve used to correct the observed intensities back to H + 1 appear to be too flat between 1 and 4 days after burst (compared with those of Reference 12 and the estimated r_{fp} values given in this report). Also, the $M_r(1)$ values for Zuni and Tewa are probably somewhat low due to difficulties in sample recovery and inconsistencies in the Ca and other analyses (described in Reference 13). Whether these two combined causes could account for the factor of 5 difference shown is not known. Although the two values of $KX^{1/2}/q$ for the JANGLE shots may be high because of extraneous inert desert sand, there appears to be a method of treatment or data available at present by which the amount of this excess weight can be estimated. There is no reason to assume that $KX^{1/2}/q$ would have a minimum between 10 and 1000 KT.

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Substitution of the appropriate values of q in the two geometric values of $KX^{1/2}/q$, solving for the constants of an assumed scaling function of the form $a_o W^n$, and replacing X with Eq. 26 gives

$$K(x,W) = 2.19 \times 10^{-10}\ W^{-0.21}/x^{1/2}, \quad W = 1 \text{ to } 12 \text{ KT} \qquad (35a)$$

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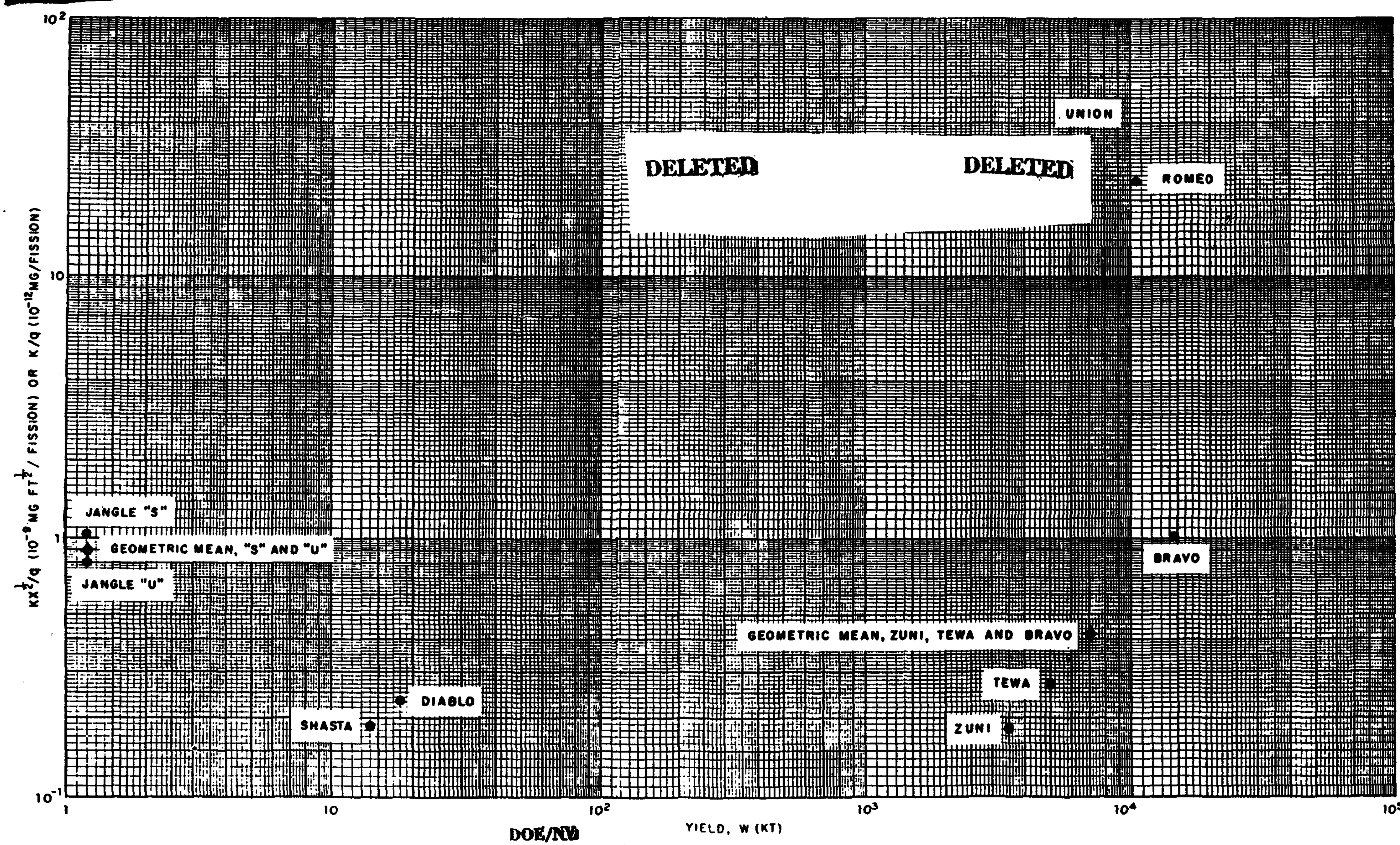

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63 Fig. 11. Plot of K/q and $KX^{1/2}/q$ With Total Yield for Surface Detonations

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TABLE 16

Summary of K(X,W)/q Values Used to Determine Final Values of Equation Constants

Station	K(X,W)/q (10^{-12} mg/fission)	Mean Value of Equation Constant ($KX^{1/2}/q$) (10^{-9} mg ft$^{1/2}$/fission)
	1. CASTLE, Bravo	
How	2.46	
How	5.96	
Victor	5.07	1.00
	2. REDWING, Zuni	
How F	0.807	
How F	0.639	0.178
	3. REDWING, Tewa	
How F	1.11	
How K	1.14	0.265
	4. REDWING, Flathead	
George	DELETED	-
	5. REDWING, Navajo	
How F		-

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and

$$K(x,W) = 4.00 \times 10^{-10}\, W^{-0.003}/x^{1/2},\ W = 12 \text{ to } > 10^{4} \text{ KT} \qquad (35b)$$

for detonations on land.

The single value of K/q for each of the two water shots is the same indicating no variation in K(x,W) with yield for the water shots. Good agreement is shown with the two CASTLE shot values. Substitution of 0.797 for q gives

$$K(x,W) = 0.34 \times 10^{-10} \qquad (36)$$

for detonations on seawater.

It may be noted that the general range in the 1 MT scaled distance from which these relationships were derived was from 10^4 ft (JANGLE "S" and PLUMBBOB Diablo) to 4×10^5 ft (REDWING Zuni and Flathead).

The mass contour ratio scaling function, given by Eq. 24, becomes a point scaling function when Eq. 35 is substituted for K(x,w). No direct comparison can be made with the idealized scaling of Eq. 11 without integration of $M_r(1)$ over the whole fallout area. When Eq. 35 is substituted in Eq. 24, the latter is a grand average function. If it is assumed that the mass of seawater thrown up by a surface burst on seawater is the same as the mass of soil removed from the crater on a surface land burst then the ratio

$$\frac{M_r(1)}{M_r^o(1)} = 0.276\, W^{0.038} \qquad (37)$$

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suggests that from 50 to 70 % (W = 1 to 15,000 KT) of the water thrown out is uniformly mixed with the radioactive elements.

The calculated variation of the mass contour ratio values $M_r^s(1)$, for land surface detonations at given downwind distances (assumed wind speed ~ 15 mph) and yields are shown graphically in Figs. 12 and 13. The values of the parameters used were:

(1) W = 1 to 100 KT; $\alpha_\lambda = 1.0$, b = 1.0, q = 0.8, $i_{cp} = 0.119$

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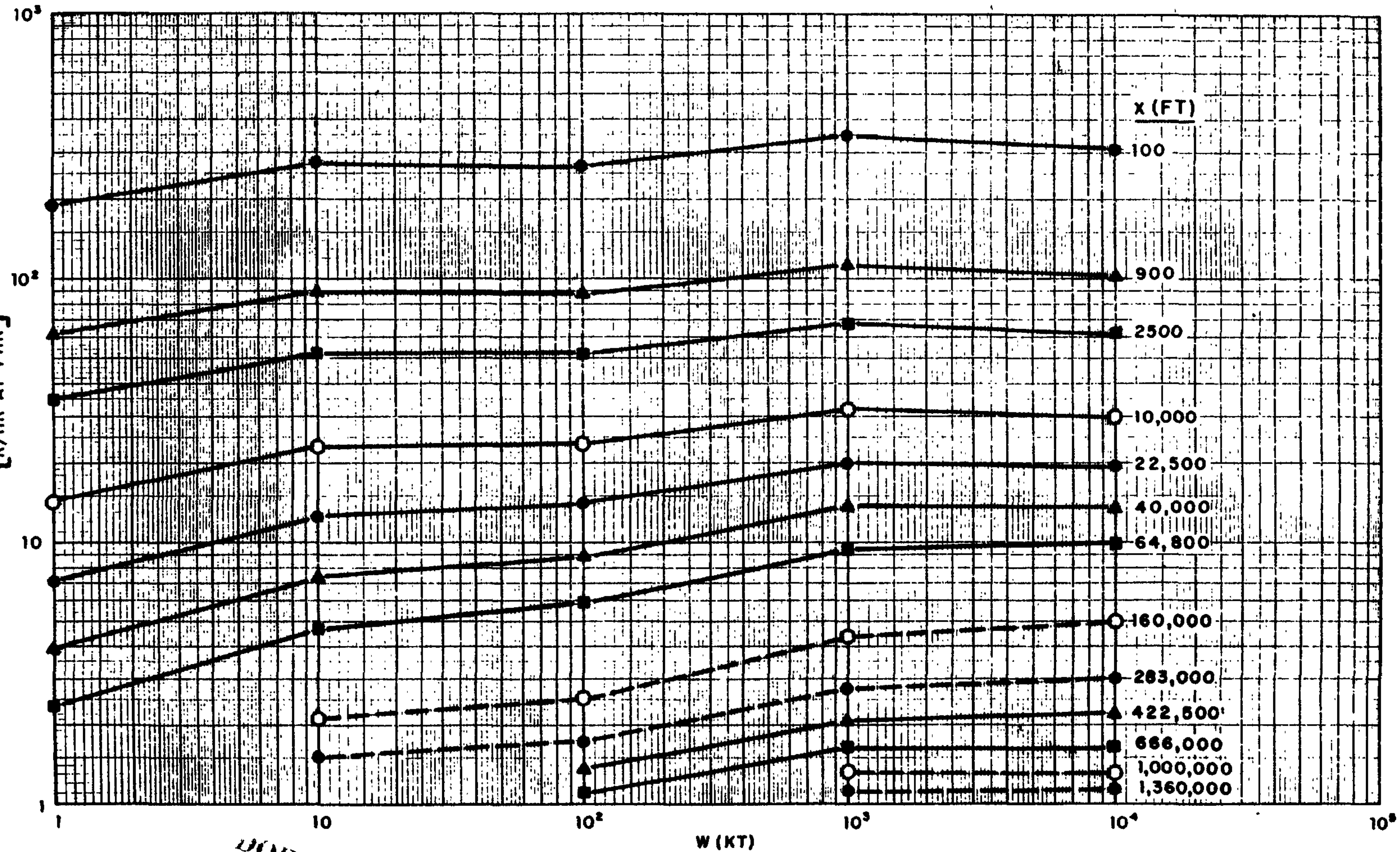

Fig. 12 Calculated Variation of $M_r^S(1)$ as a Function of Weapon Yield for Given Values of x

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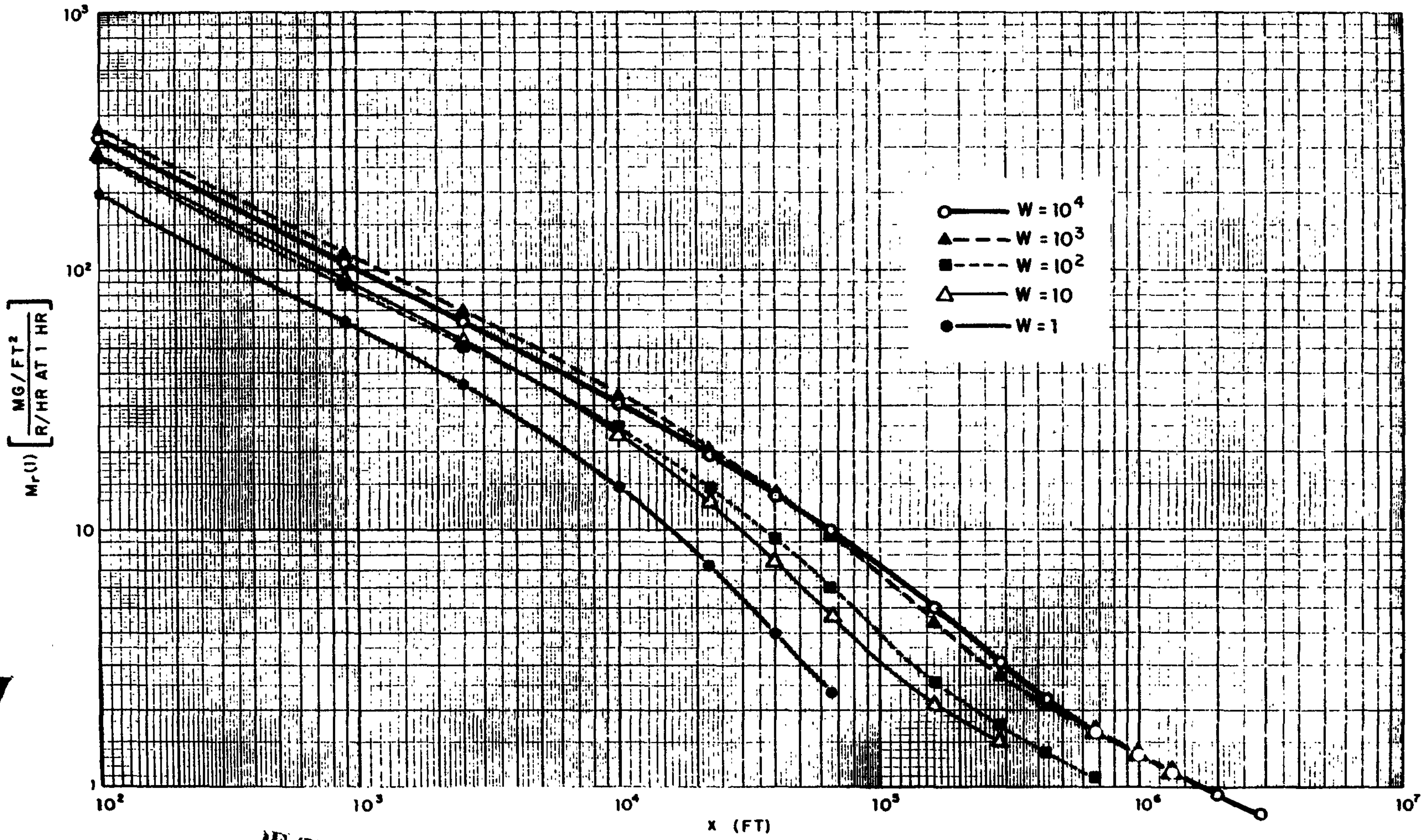

Fig. 13 Calculated Variation of $M_r^S(1)$ as a Function of Downwind Distance for Given Values of W

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(2) W = 1000 to 10,000 KT: α_λ = 1.0, b=0.7, q=0.8, i_{cp}=0.145

The curves, of course, show more variability with distance than with yield as would be expected from use of Eq. 35 in Eq. 24. The computations were extended to include somewhat greater distances than those used in obtaining the empirical equation coefficients to investigate the shape of the curves at distances where r_{fp} approached the value 1.0.

With fallout pattern data in r/hr at 1 hr, curves for other assumed weapon types and likely heights or depths of burst can be calculated to obtain possible ranges in the fallout mass deposited per unit area. This information can then be used directly in operational evaluations of decontamination methods and in establishing the experimental conditions for investigating the efficiency of the methods.

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