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SPECIAL REPORT

# CML C RADIOLOGICAL DISCUSSION PAPERS PREPARED FOR TENTH TRIPARTITE MEETING (U)

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## SPECIAL REPORT

## CML C RADIOLOGICAL DISCUSSION PAPERS PREPARED FOR TENTH TRIPARTITE MEETING (U)

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Typed: 4 October 1955
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Control no:

5025-580

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## INTRODUCTION

The papers comprising this report were prepared by personnel of the Cml C Research and Engineering Command. These were presented for discussion at the Tenth Tripartite Meeting at Ottawa, Canada, September 1955.

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# PROTECTION OF EYES AND FACE AGAINST THERMAL RADIATION (U)

## Object

To investigate troop requirements for eye and face shields for protection of the eyes and face against thermal radiation.

## Definitions

The following definitions will be helpful in reading the report:

| | |
|---|---|
| Adaptometer - | An instrument used to measure the state of adaptation to light of the human eye. |
| Fovea - | The anatomical area of the eye which is the site of the visual end organs capable of giving the individual acute vision. |
| Fundus - | Part of the eye opposite the pupil. |
| Nyctometer - | An instrument designed to measure the dark adaptation rates of the cones in the central area of acute vision. |
| Paracentral Vision - | Vision peripheral to the central area of very acute vision made possible by the fovea. |
| Scotoma - | A blind area in the visual field. It may be partial or complete; temporary or permanent. |

## Introduction

One of the recommendations of the recent 9th Tripartite Conference on Toxicological Warfare included the suggestion that each country investigate service requirements for the protection of the face and eyes against thermal radiation with a view to initiating a coordinated program.

Only a limited amount of research has been conducted to determine whether (1) the flash accompanying an atomic explosion can produce blindness of tactical significance; (2) actual visual impairment results from excessive exposure to the light. A requirement for eye shields for tactical troops must therefore be based on a consideration of both visual effects and actual physical damage to the eyes.

A considerable amount of research has been conducted on the effects of thermal radiation on the human skin. From these results a definite requirement has evolved.

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Visual Impairment

An unpublished report by the Opthalmalogical Survey Group indicated that in a group of 1000 persons within 2000 yards of ground zero in Hiroshima and Nagasaki no lesions were found in the fundus which were thought to have been directly related to the atomic bomb, and only one case of possible infrared burn of the retina was discovered. 3/ The thermal flux at 2000 yards, as given by the Effects of Atomic Weapons, *is 9 cal/sq cm for a 20 KT weapon. A critical energy of 3 cal/cm*$^2$ is sufficient to produce a moderate skin burn. Thermal radiation burns to exposed areas of the skin were recorded at a distance of 2500 yards from ground zero at Hiroshima and as far as 1300 yards at Nagasaki. The absence of any evidence to indicate actual eye damage among the Japanese people receiving thermal burns is qualitative evidence of the shielding afforded by the physical location of the eye, the blink reflex, and the property of the eye itself in being able to withstand a higher thermal flux without being damaged.

During Operation SNAPPER the USAF School of Aviation Medicine in cooperation with Army Medical Center conducted a project to determine the effect of the flash of atomic detonations at night upon the ability of military personnel to carry out their assigned tasks. As a result of direct exposure to the flash under conditions simulating night time, two of the subjects developed blanched areas of the retina. Only one of these men showed an impairment of vision and complained of a scotoma. This man showed a small area of retinal edema with a central blanched area. However, no actual discomfort was experienced and his visual acuity remained normal. Visual fields in this case revealed a small absolute paracentral scotoma about 2 degrees in diameter in the area corresponding to the site of the retinal lesion. The paracentral vision and the retinal lesion gradually improved and recovery was complete.

Examination of the retina of the second individual revealed a small area of retinal edema. Neither of these individuals had any visual impairment, visual field defect, or change in the fundus of the eye. Their injuries were minimal and both subjects completely recovered. The fact that two of the subjects developed retinal burns indicated that becuase the dilated pupil admits approximately 50 times the light which is admitted by the daylight constricted pupil, the flash of an atomic detonation presents a real danger to the retina of an individual whose eye is adapted for night vision and who is looking in the direction of the flash. It was also stated in this report that the size of the retinal burn and not its intensity (with the exception of attenuation by the atmosphere and degradation of the retinal image by optical defects) will be decreased with distance. Further, it was stated that in spite of the occurance of a retinal burn, in most cases the injury would not incapacitate the individual, and unless he were looking at the point

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of detonation, the small scotoma produced would not in itself constitute any significant disability. 2/

The Air Force has recently made a study of the problem of retinal burns caused by an atomic bomb. 5/ They have exposed the eyes of rabbits to the thermal radiation from an atomic bomb at distances 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 27, 28 and 42.5 miles. Rentinal burns were found in the rabbits out to and including 42.5 miles when the eyes were oriented within a 15° cone of the point of the detonation. Lesions of the type produced would not be disabling to the victim unless they involve the mocular area of the optic nerve head.

As yet, however, they have not been able to relate this data on the rabbit eyes to an effect on the human eye. There is as yet no conclusive evidence as to which form of radiation, i.e., ultraviolet, visible, or infrared, gives the main contribution to the burning effect. The time required for a person to blink is so long compared to the time required for the radiation to be formed and reach the eye that the blink reaction can afford no protection to the individual.

Based on the above studies it would appear that there is at the present time a limited possibility of visual impairment caused by an atomic bomb. Complete protection from this effect would be afforded by a predetonation warning to allow troops to shield their eyes for the few seconds required to prevent the occurance of actual eye damage. The effect of daylight exposure would be less than that during the hours of darkness. Atomic weapons detonated by the enemy could possibly cause eye damage to troops facing the detonation. However the present evidence does not indicate that the injuries would be of the casualty producing type and would not affect the ability of the soldier to carry out his assigned mission.

## Flash Blindness

The evaluation of the visual handicap which might be expected in military personnel exposed, during daylight and during darkness, has also been investigated. It is important to know whether the field soldier exposed to the atomic flash would be unable to see for a period of time that would prevent carrying out an assigned mission or render him more vulnerable to enemy attack.

A brief experimental program was carried out by ORO using Mazda No. 22 photoflash bulbs to learn some of the effects of night flashes on human vision. Except for the fact that the fireball diameter of an atomic detonation subtends a very small angle at a long distance from the bomb and thus concentrates on a smaller area of the retina, it can be shown that the total luminous energy reaching the retina at 10,000 yards from the first flash of a 20 KT atomic bomb is about the same as that from the No. 22 flash bulb at 3 feet. The measurements made in this fashion, together with the data obtained at BUSTER, indicate that recovery from daylight exposure to the flash takes only 15-30 seconds. 2/3.

During Operation SNAPPER, observations were made to determine to what degree the flash of an atomic detonation reduces the efficiency of military personnel during night operations. The nyctometer tests showed that the average time required for the unprotected individual to regain good mesopic vision was 132 seconds. Using adaptometers as measuring devices it was found that the average of the unprotected individuals tested regained vision for distinguishing form at 0.001 foot-candle of illumination (approximately that of moonlight) in 310 seconds; and at 0.0001 foot-candle of illumination (approximately that of a clear starlit night) in 671 seconds. Personnel protected by red filters regained vision in 11, 245, and 325 seconds for the three cases mentioned. 1/ In the case of tactical troops unprotected by filters it is felt that recovery time is sufficiently rapid to preclude the necessity for using an eye shield. If vision was reduced for a period as long as 15 minutes where form could not be distinguished, or approximately three times the length of time actually required to distinguish form, some further consideration for eye shielding for combat troops might be necessary. Shielding of the eyes by physical means prior to the detonation removes any possibility for reduced vision.

## Face Burns

It is felt that this effect is so well known that there is little advantage in a discussion of the effect in this report. It is necessary only to state that in this case there is a major requirement for protection. The requirement is proposed that there be developed a device or devices which are integral parts of the combat soldier's uniform, which will not impare his ability to maneuver, and which, with no advanced warning, will give him no more than a 1st degree burn from radiation equivalent to 10 cal/cm$^2$ from a 30KT equivalent bomb. At the time of this writing this requirement is not official doctrine; however, it is expected to be in the near future.

The ultimate goal to be reached is the same protection from radiation equivalent to 30 cal/cm$^2$ from a 30KT equivalent bomb.

## Thermonuclear Detonations

The previous discussion has been limited to the case of atomic weapons. Data now available indicate that the conclusions reached as a result of the research on nominal type devices would hold for the detonation of a so-called "Super Weapon". There appears to be even less danger from this type weapon due to the delay in the thermal pulse allowing the body reflexes time to act.

Present concepts of employment of atomic weapons probably do not include thermonuclear devices as suitable for tactical targets. In any case the use of eye shielding would apply only to the prevention of casualties or loss of vision to troops outside the areas which would result in casualties from the immediate effects of blast, thermal and radiation.

## Conclusions and Recommendations

Based on the available information summarized in this paper the following conclusions seem valid:

1. From information presently known there is an indication that any retinal damage to the eyes of individuals accidently looking directly at the point of detonation is not of tactical significance; however, further information is required to verify this.

2. Shielding tactical troops from the flash of atomic weapons to prevent reduced vision presents no particular problem in as much as recovery time is relatively short.

3. There is definitely a requirement for protection of the face by some means if no pre-warning is given.

4. Physical shielding of the eyes and face by turning the head from the point of detonation provides sufficient protection of the eyes and face of the field soldier, provided pre-warning is given.

In conclusion it should be noted that the field soldier has been primarily considered. For those individuals who are required to observe instruments at all times, such as pilots, some form of protection is required.

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# DETECTION OF RADIOACTIVE CONTAMINANTS IN POTABLE WATERS (U)

## Introduction:

Various techniques for monitoring radioactive waters have been reported. Special procedures are required to determine whether the maximum permissible level for drinking water has been exceeded.

Ordinary end window GM tubes are not very satisfactory (1) for estimating low activities even under optimum counting conditions. Their geometry and window absorption limit their sensitivity to beta activity levels which exceed the permissible levels for long term use. Internal proportional counters on the other hand have been found quite satisfactory (2). These instruments can detect both alpha and beta activity at levels as low as one-half to one-tenth of the long term drinking tolerance level, $10^{-7}$ µc/ml, with a precision of ± 10% for alpha emitters and ± 20% for beta emitters.

In using this counting technique a considerable volume (about a liter) of the water is evaporated to dryness in a special counting planchet and the activity measured with an internal flow counter. Corrections are made for the absorption of some of the radiation by solid matter present. The geometry is 50%, but because of backscattering, from 50-52% of the alpha disintegrations and from 50-75% of the beta disintegrations are counted. An internal flow counter is the most practical instrument for monitoring low activity levels.

Under emergency conditions, and for short periods, drinking water tolerances may be set considerably higher (4) than the accepted values (3). Non-technical personnel may be impressed to serve in surveying teams using portable and rugged, although perhaps not highly accurate, instruments.

It has been calculated that in the first thirty days after the burst of an atomic weapon, water which is safe from the beta hazard standpoint is also safe with respect to alpha contamination. Consequently, any instrument which is sensitive enough to detect and measure the beta activity levels in water can be calibrated for water monitoring, and the alpha activity may be neglected.

Survey meters with thin-walled GM tubes can be calibrated to detect $10^{-3}$ to 1 µc/ml (± 25%)(4, 7) of fresh fission products. The sample to be tested is poured into a shallow pan of prescribed size to a depth of about one centimeter. The GM tube is held above the pan at a specified distance and the scale is read. Reference to a calibration chart indicates the beta activity in µc/ml.

In another procedure (7) the water sample is monitored with a survey meter and the reading compared to those of two standards, one corresponding to the emergency "safe" level and the other to the emergency "acceptable risk" level. This procedure immediately indicates the value of the water for drinking purposes.

Another survey procedure, the Landsverk Analysis (7) uses an ionization chamber as the radiation-sensitive element, and is capable of detecting from $10^{-4}$ to 1 µc/ml of activity. The ionization chamber is charged and placed over the sample. By calibrating its rate of discharge against known standards, the activity of the water sample can be determined.

Still another procedure for water surveying uses the dip-type liquid counter. British instrument(5) can detect from $5x10^{-4}$ to 0.6 μc/ml ± 25%. The sample o be tested is poured into a cell and its activity is read off a scale. Although his instrument cannot count the soft beta activities, it can be calibrated for ission products. The instrument is rugged and very easy to operate.

A continuous water survey unit has been designed (8) which consists of a GM ube surrounded by an ion exchange column. The water sample is run through the ion xchange column which absorbs the active ions from solution. The build-up of activty on the column is followed by an automatic recorder. From the rate of build-up f activity on the column and the flow rate of the water through the column, the ctivity per unit volume is determined.

imitations of Assaying Techniques:

The various methods described suffer from the drawback that they require a ormal radioactive background. If a relatively high radioactive field is present ue to fall-out, the results obtained by the methods described might be questionble. However, a sample of the water could be removed for testing to a remote area r to a well-shielded laboratory.

Under certain conditions, the measured activity levels might indicate the resence of a greater hazard than actually exists, as when short-lived induced acivities (e.g. $Na^{24}$) are present. High level activity water may eventually become afe owing to decontamination by a natural process, such as selective adsorption n river sediments. In many cases the hazard will be greatly reduced by natural ilution; partial decontamination is also effected by certain aquatic plants and nimals. Artificial methods for purifying water are, of course, well known(6, 9).

lerance Levels for Drinking Waters:

Since exposure to water contamination must be considered from the standpoint life-time ingestion, the acceptable tolerances are very small. Therefore, rvey instruments, except under emergency conditions, must be quite sensitive. r either alpha or beta emitters the maximum permissible concentration is approxitely $10^{-7}$ μc per ml(3). This value is conservative since radioactive spring waters ntaining higher levels of activity have been consumed regularly with no apparent rmful effects. The following higher emergency tolerances have been proposed by the omic Energy Commission (4).

| pe of itter | Days of Use | Tolerance Levels, (μc/ml) "Safe" | "Acceptable Risks" |
|---|---|---|---|
| pha | 10 | $2.0x10^{-4}$ | $5.0x10^{-3}$ |
| | 30 | $6.7x10^{-5}$ | $1.7x10^{-3}$ |
| ta | 10 | $3.5x10^{-3}$ | $9.0x10^{-2}$ |
| | 30 | $1.1x10^{-3}$ | $3.0x10^{-2}$ |

The British Medical Research Council gives the following tolerances (5) as rmissible levels at different times after a nuclear burst, assuming the nsumption of 2.5 liters per day for up to 10 days:

| Time after burst | Permissible tolerances ($\mu$c/ml) |
|---|---|
| 12 hours | 0.18 |
| 1 day | 0.06 |
| 2 days | 0.024 |
| 10 days | 0.01 |

Summary:

A number of methods, and a variety of instruments are available for measuring the radioactive contamination in drinking water. Because of the presence of short-lived induced activities and of the natural removal of contamination, these methods tend to overestimate the immediate and future hazards.

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# POTENTIAL OF INDUSTRIAL SMOKES AS SHIELDS AGAINST THERMAL RADIATION (U)

## I. Introduction

Industrial smokes were used in the last war to augment the screening effect of fog oil smokes put out by generators and smoke pots. The concentrations of smoke used were at obscuration levels, but it has frequently been suggested that in many cities the industrial smoke output may be high enough to afford substantial protection against the thermal radiation from a nuclear detonation (1).

The feasibility of setting up protective screens of industrial smokes depends on the probability of encountering inversion conditions over cities. This probability may be relatively high, particularly over industrial areas. Over San Francisco, for example, a deep inversion layer with a lapse condition below it permits wide lateral spreading of a cloud(2). Similar results have been reported for built-up areas in England(3). An extensive study of the feasibility of establishing screening clouds over a number of American cities has been carried out by Stanford Research Institute(4). The cities of Los Angeles, Chicago, and St. Louis, for example, show high feasibility at night throughout the year (75%-86%) and lower (34%-64%) feasibility during the day, with marked seasonal variation.

The screening properties of smokes depend on their ability to absorb or scatter light. The variables involved are the complex refractive index of the smoke material, the size of the smoke particles, and the wavelength of the incident light. For light smokes the obscuring power has been calculated on a simple exponential law(5) but for the concentrations required for thermal screening the theory becomes much more complicated.

Industrial smokes may contain, besides carbon, water; certain acids, e.g., $CO_2$, HCl, $SO_2$, $SO_3$, etc.; and also silica in some form. The refractive indices of the various forms of silica range up to about 1.55, depending on the crystalline structure and on the wavelength of the light. The refractive indices of the acids in this region may range from about 1.35 to about 1.45 for strong solutions in water.

In industrial smokes these constituents are mixed in random proportions. Theory indicates that the scattering coefficient, K, is not strongly dependent on the refractive index, and that for a mixture such as is found in many such smokes a mean value of the refractive index may be used over the entire thermal spectrum (about 0.2 µ to about 3µ.)(6). On the other hand, the scattering coefficient is markedly dependent on the ratio of the circumference of the smoke particles to the wavelength of light (i.e. on $K = d/\lambda$ ) when this ratio is less than about 7. At higher values of the ratio the dependence is slight.

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According to the Mie Theory(7) the scattering coefficient is given by the relation:

$$K = \frac{2}{\alpha^2} \sum_{\nu=1}^{\infty} \frac{(a_\nu^2 + b_\nu^2)}{2\nu + 1} \qquad (1)$$

The $a_\nu$'s and $b_\nu$'s are complicated functions of $\alpha$ and the refractive index. Values of K are available in published tables(8). The theory applies to individual particles. To estimate the potential of industrial smokes for the attenuation of the thermal radiation from an atomic burst, a theory is required that considers multiple scattering from an assembly of many particles.

## The Six-Flux Theory of Multiple Scattering

A theory useful for this purpose is the Six-Flux method developed for the Chemical Corps by the Engineering Research Institute of the University of Michigan(9). A brief description of this theory is given below.

### a. Geometrical Representation

For a point source and a plane parallel medium, the geometric relationships and dimensions may be described by t, h, z and θ, as shown in figure 1. Theoretical considerations indicate that the problem may be greatly simplified if these variables are expressed in the form of the following dimensionless parameters:

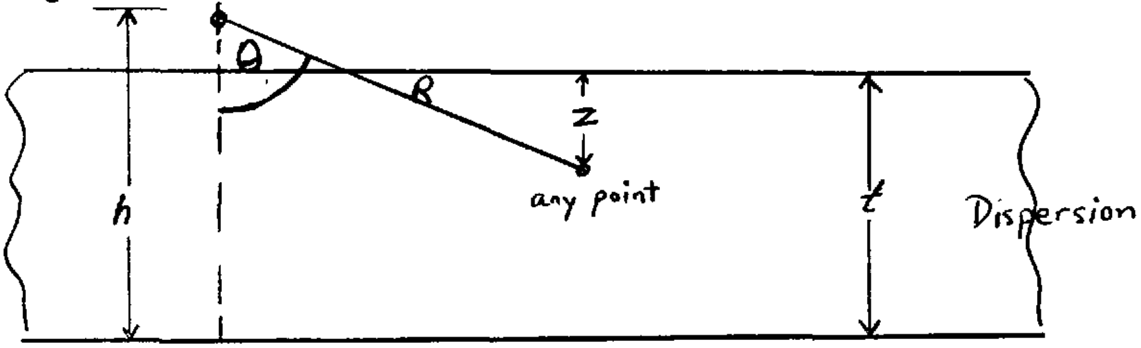


Fig. 1 - Diagrammatic Representation for a Point Source and a Parallel Plane Dispersion

$T = nqt$, where n is the particle concentration (number per unit volume) and q is the product of the scattering coefficient, K, defined above, and the geometrical cross-section of the individual particle. T is the number of mean free paths in the distance t.

$Z = nqz$, the number of mean free paths into the dispersion.

M = Xm/d, the dimensionless mean distance between particles.

Xm is the mean distance between particles.

Other variables required are $\alpha$, defined before, m* (m—jk) the complex index of refraction of the particles, and k, the extinction coefficient.

Since K and m* are complex functions of the wavelength, and $\alpha$ and M depend on the size of the particles, theoretical and experimental studies can only be made for uniform dispersions for particular wavelengths.

b. Spatial Distribution of Energy

The angular distribution of energy scattered by a single particle depends on $\alpha$, m* and M. At the concentrations of interest the effect of interference by adjacent particles does not seem to be important, and as mentioned before the effect of the refractive index is relatively small. Consequently the variation of the angular distribution of energy may be discussed qualitatively in terms of $\alpha$ alone. An important function in the theory is the angular energy distribution function, $f_1(\vec{\Omega}, \vec{\Omega}')$, which is the fraction of energy intercepted by a particle from an incident beam with direction $\vec{\Omega}'$ which is scattered into a unit solid angle in the direction $\vec{\Omega}$. Hartell(10) suggested expanding this function in an infinite series of Legendre polynominals, in which the coefficients, $a_n$, are functions of $\alpha$ and m* alone:

$$f_1(\vec{\Omega}, \vec{\Omega}') = f_1(\theta) = \frac{1}{4\pi} \sum_{0}^{\infty} a_n P_n(\cos\theta) \qquad (2)$$

where $\theta$ is the angle between $\vec{\Omega}$ and $\vec{\Omega}'$.

The angular energy distribution of scattered radiation is complex. To simplify this problem Theissing(11) assumed a two flux (forward and backward) distribution. However, in three dimensional space a reasonable division of the flux is into six components along a set of three orthogonal axes, one of which coincides with the direction of the incident beam. This Six-Flux distribution includes forward and backward components and four equal sidewise components. The choice of a weighting function for the forward and backward components is critical and somewhat arbitrary. A cosine law resolution is inadequate because of violation of energy conservation for the case of isotropical scattering. Instead, a cosine square resolution is used:

$$F = 2\pi \int_0^{\frac{\pi}{2}} \cos^2\theta \sin\theta \, f_1(\theta)\,d\theta \qquad (3)$$

$$B = 2\pi \int_{\frac{\pi}{2}}^{\pi} \cos^2\theta \sin\theta \, f_1(\theta)\,d\theta \qquad (4)$$

$$X = (1-F-B)/4 \qquad (5)$$

where F, B, and X refer, respectively, to the forward, backward and sidewise components. Use of the Hartel coefficients permits intergration of these expressions.

### c. Spatial Distribution of the Intensity

When an industrial smoke is widely enough dispersed it may be considered, in effect, a continuous medium. Assuming such a medium and considering an energy balance for a differential volume of unit cross section and length $dS_{\Omega}$ in the $\vec{\Omega}'$ direction, the following form of the Transport Equation can be obtained.

$$\frac{di(\vec{R},\vec{\Omega})}{dS} = -i(\vec{R},\vec{\Omega}) + w\int_{\Omega} i(\vec{R},\vec{\Omega}')\, f_1(\vec{\Omega},\vec{\Omega}')\, d\Omega' \qquad (6)$$

where $d\Omega'$ is the differential solid angle in the direction $\vec{\Omega}'$, w is the albedo for single scattering, and i is the intensity at the position R and in the direction $\vec{\Omega}$. $\vec{\Omega}'$ is any direction other than $\vec{\Omega}$. The distribution intensity is also represented by six components, a forward component, a backward component, and four sidewise components which may not be equal.

A rigorous solution of equation (6) can be written formally in integral form, but the integration cannot be performed analytically, After attempting several approximate methods of solution, a procedure based on the six-flux method of representing the angular distribution function was selected. This permits reduction of the transport equation into six simultaneous ordinary differential equations. For the special case of a point source and a plane, parallel dispersion, the boundary conditions permit reduction of the problem to the solution of four simultaneous, non-linear differential equations, since two of the six components are linearly dependent on the other four.

By introducing a geometric simplification, the above four non-linear equations may be linearized and the final numerical solutions are obtained from these. In the linearized equations, the substitution of a relative intensity, e.g. $I_1$ for $i_1$, simplifies the procedure somewhat. The relative intensity, $I_1$, is defined by

$$I_1 = \frac{i_1}{Q_s/4\pi\,{}^{2}} \qquad (7)$$

where Qs is the source intensity and R the distance of the source to the receiver. $I_1$ is therefore the ratio of the measured intensity in the smoke to that which would exist at the same point, and in the same direction, if no dispersion were present.

The final equations whose solutions give the required six components of the flux at any point in the smoke are:

$$\frac{dI_1}{dz} = -\left(-F-\frac{X}{2}\right) \text{Sec}\,\theta\, I_1 + I_2 \left(B+\frac{X}{2}\right) \sec\theta + \frac{3X}{2}(I_3+I_4)\,\text{Sec}\,\theta \quad (8)$$

$$\frac{-dI_2}{dz} = -\left(1-F-\frac{X}{2}\right) \text{Sec}\,\theta\, I_2 + I_1 \left(B+\frac{X}{2}\right) \text{Sec}\,\theta + \frac{3X}{2}(I_3+I_4)\,\text{Sec}\,\theta \quad (9)$$

$$\frac{dI_3}{dZ} = -\left(1-F-\frac{X}{2}\right) \csc\theta\, I_3 + I_4 \left(B+\frac{X}{2}\right) \csc\theta + \frac{3X}{2}(I_1+I_2)\csc\theta \quad (10)$$

$$-\frac{dI_4}{dZ} = -\left(1-F-\frac{X}{2}\right) \csc\theta\, I_4 + I_3 \left(B+\frac{X}{2}\right) \csc\theta + \frac{3X}{2}(I_1+I_2)\csc\theta \quad (11)$$

$$I_5 = I_6 = \frac{1}{4}(I_1 + I_2 + I_3 + I_4) \quad (12)$$

If the position of the point at which the intensities received from the various directions is represented in spherical coordinates (R,θ,d), $I_1$, $I_4$, $I_5$ represent the relative intensities in the directions of increasing R, θ, d, respectively; and $I_2$, $I_3$, $I_6$, the relative intensities in the opposite directions.

The boundary conditions are:

$$\left.\begin{array}{l} I_1 = 1 \\ I_3 = 0 \end{array}\right) \text{at } Z = 0;\; I_2 = I_4 = 0 \text{ at } Z=T \quad (13)$$

It is possible to show(9b) that the Six-Flux method degenerates to a Two-Flux distribution for a normally incident wave or when the sidewise component, X, is assumed equal to zero. On the latter assumption the two-flux distribution can be applied to obtain a first approximation of the scattered intensity.

Comparison of Experimental Results With Calculations by the Six-Flux Method

a. Experimental results are conveniently expressed in terms of the concentration (mass of smoke over a unit area) and the total relative intensity received at a point. If C is the concentration in mass units per unit volume, Ct = concentration in mass units per unit area for a dispersion of height t above the ground. If ρ is the density of the smoke,

$$\frac{3}{2}\,\frac{Ct}{\rho d} = n.\frac{\pi}{4} d^2 t = \frac{T}{K} = \frac{nqt}{K} \quad (14)$$

This relation, together with the backward and sidewise scattering coefficient of a single smoke particle yields the important scattering properties require for the six-flux solution.

This solution pertains to a single wavelength, and to obtain the intensities due to all wavelengths in the thermal region an integration is carried out between the limits (about 0.2 $\mu$ and about 3.0$\mu$) of interest. The energy striking surfaces normal to the six directions can be found by multiplying by $Q_s/4\pi R^2$. For a plane parallel to the boundary the reception is estimated by assuming that the components are collimated in their respective directions. The total intensity received at a point in the smoke is E ( $\lambda$ ). For the plane Z = T (fig. 1) the intensity received at a point on an arbitrarily oriented plane is

$$E(\lambda) = I_1 \cos\theta + I_3 \sin\theta \qquad (15)$$

If J ( $\lambda$ ) is the monochromatic power of the source, the point source strength is

$$Q_s = \int_0^\infty J(\lambda)\, d\lambda \qquad (16)$$

and consequently the normalized integral intensity, $\frac{I}{I_0}$, is

$$\frac{I}{I_0} = \frac{\int_0^\infty E(\lambda)\, J(\lambda)\, d\lambda}{Q_s} \qquad (17)$$

Assuming a blackbody source of equivalent temperature, T,

$$J(\lambda, T) = \frac{C_1 \qquad 4R^2}{\lambda^5 \left(\frac{C_2}{e^{\lambda T} - 1}\right)} \qquad (18)$$

by Plancks law, and using the method of Jahnke and Emde(12), $\frac{I}{I_0}$ can be calculated from (18) and (17).

Fig. 2 illustrates the theoretical relations between $\frac{I}{I_0}$, the relative total intensity received at a point, Ct, the concentration of particles in the smoke, and θ, the angle of reception (cf. fig. 1) for a 6000° K black body source and a smoke of mean refractive index about 1.5, a value within the range to be expected for industrial smokes. The strong dependence of $\frac{I}{I_0}$ on $\theta\ C_t$ is apparent.

b. In a laboratory series of experiments dispersions of polystyrene and polyvinyl toluene latices in water were used(13) to test the theoretical results, using a General Electric Neon 69 glow lamp as a monochromatic source. Four different dispersions, each containing particles of very uniform diameter (less than 2% standard deviation) were used. The diameters were 0.236, 0.333, 0.514 and 1.18 μ.

Fig. 3 compares a set of typical results obtained in this way, with calculated values for the same conditions. In this and in other cases, the theoretical values of E ( λ ) is low (about 20%) for values of tan $\theta < 3$, and slightly high above tan $\theta = 3$. Above tan $\theta = 3$ the agreement in general is much better and the experimental values range from about 20% below to about 20% above the theoretical prediction.

c. In another series(14) of larger-scale experiments the attenuation of the radiation from an uncollimated carbon arc source was measured after passing through a variety of smokes, e.g., fog oil, carbon (made by burning naphthalene), and several acid smokes made by hydrolyzing in moist air chlorosulfonic acid, silicon tetrachloride with ammonia, and titanium tetrachloride. Figure 4 illustrates some of the results obtained for the case of tan $\theta = 0$. A "Theoretical curve" (solid curve) shows the agreement between theory and experiment. The theoretical curve was calculated for a non-absorbing smoke of refractive index 1.5 and for particles of 0.9 μ diameter.

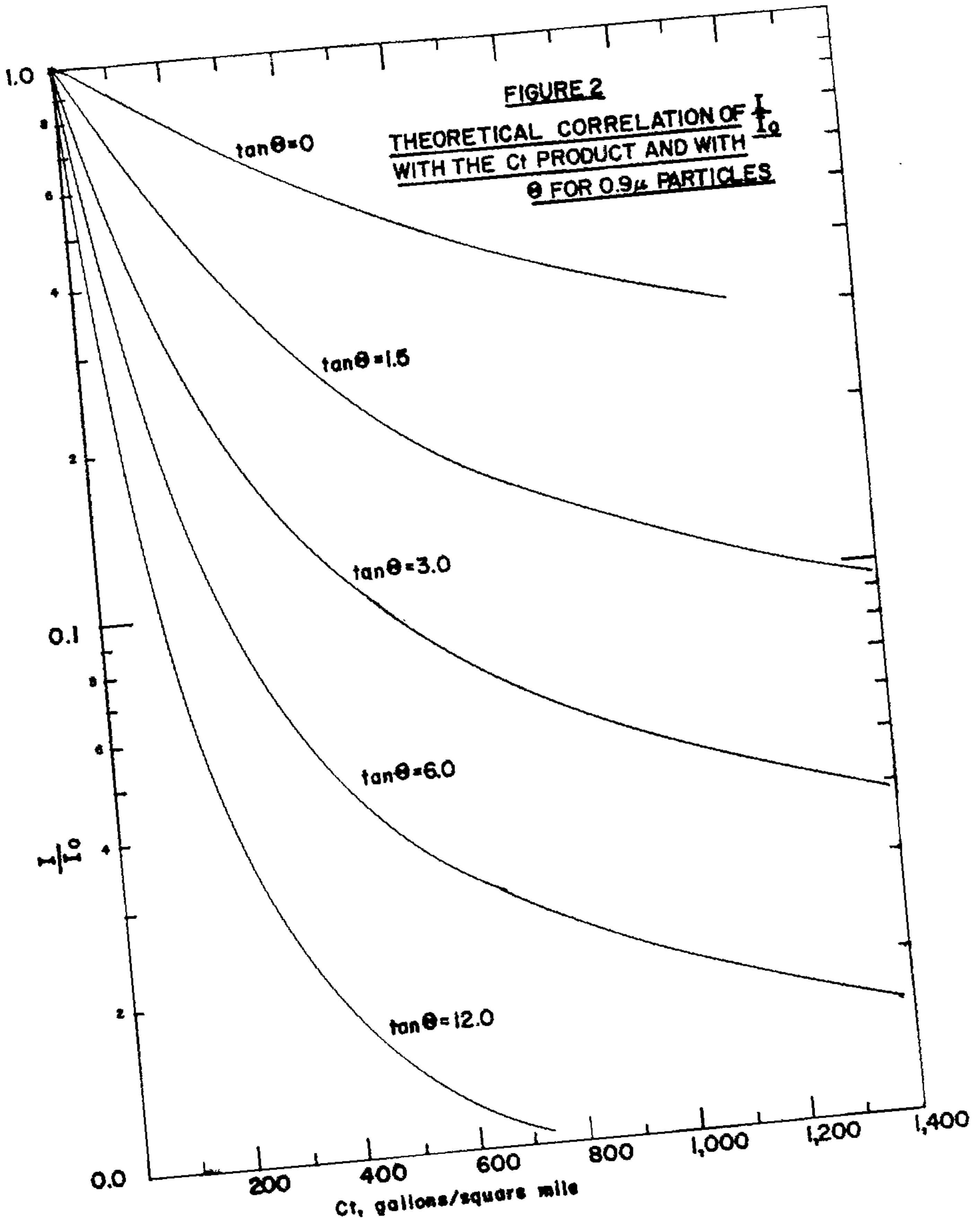
Deviations from the theory in the case of the acid smokes are in the direction to be expected if the particles tended to increase rapidly in size during the measurements owing to continuous absorption of water from the humid atmosphere. Deviations of the fog oil from theory are much less. In the thermal region the acid smokes would appear to behave largely as scatterers. In the absence of acceptable values of the refractive index of carbon, no theoretical curve has been included for this element.

## Conclusions;

The Six-Flux model described appears to be sufficiently accurate for the estimation of the potential of industrial smokes as screens against the thermal radiation from atomic detonations.

The possible acid constituents of industrial smokes other than carbon are about as effective as fog oil as thermal screens, but they are less stable owing to the tendency of the particles to increase in size by absorption of water. Carbon, owing to its absorbing properties, is much more effective than any of these.

Although a theoretical curve has been presented in the figures for only a pure scatterer (albedo unity) the theory can also take absorption into consideration by bringing in the complex index of refraction and an appropriate value of the albedo. A theoretical curve for carbon could be calculated if suitable values of the complex refractive index of this element were available.



## FIGURE 2

THEORETICAL CORRELATION OF $\frac{I}{I_0}$ WITH THE Ct PRODUCT AND WITH θ FOR 0.9μ PARTICLES

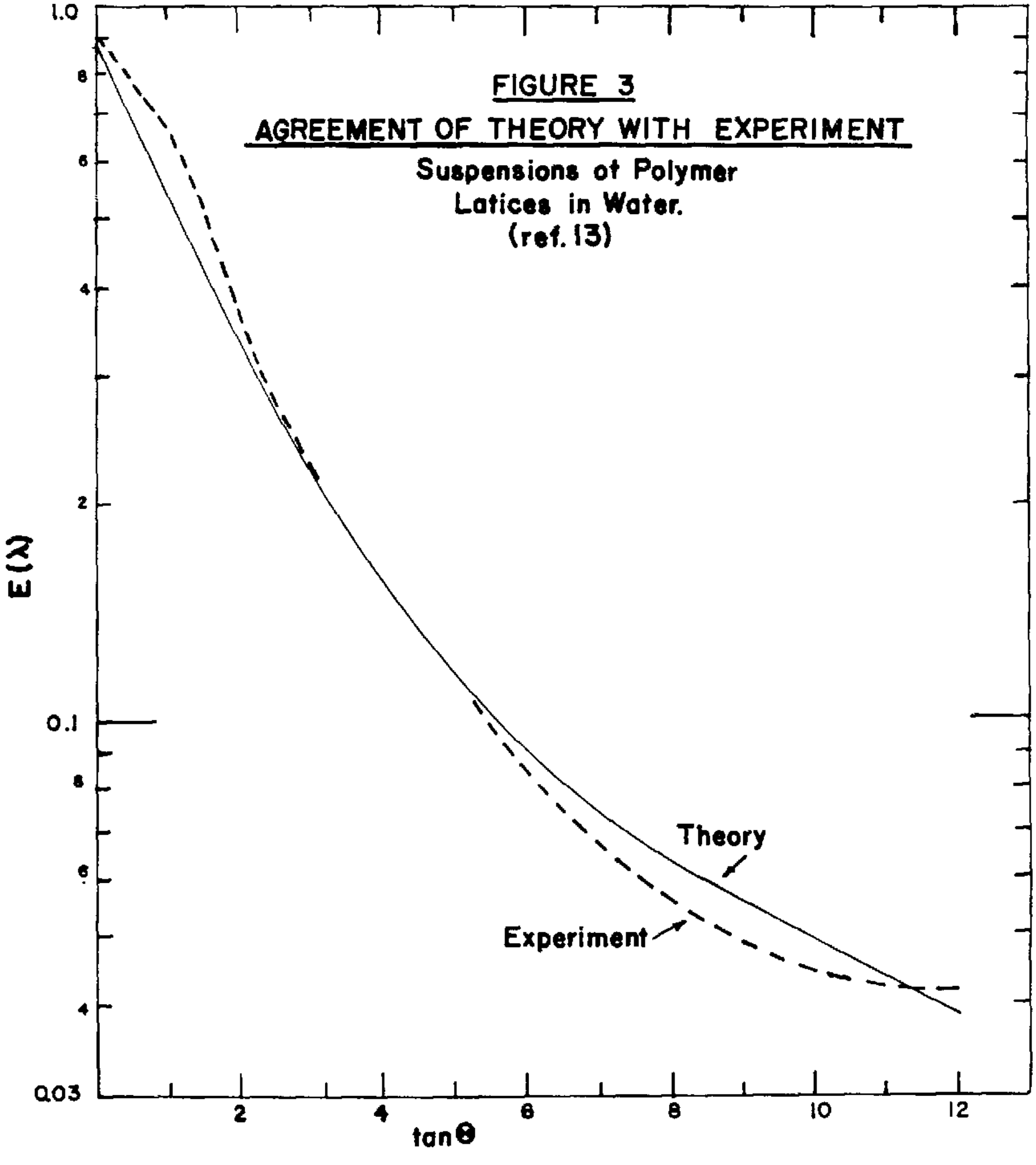


FIGURE 3

AGREEMENT OF THEORY WITH EXPERIMENT

Suspensions of Polymer Latices in Water.

(ref. 13)

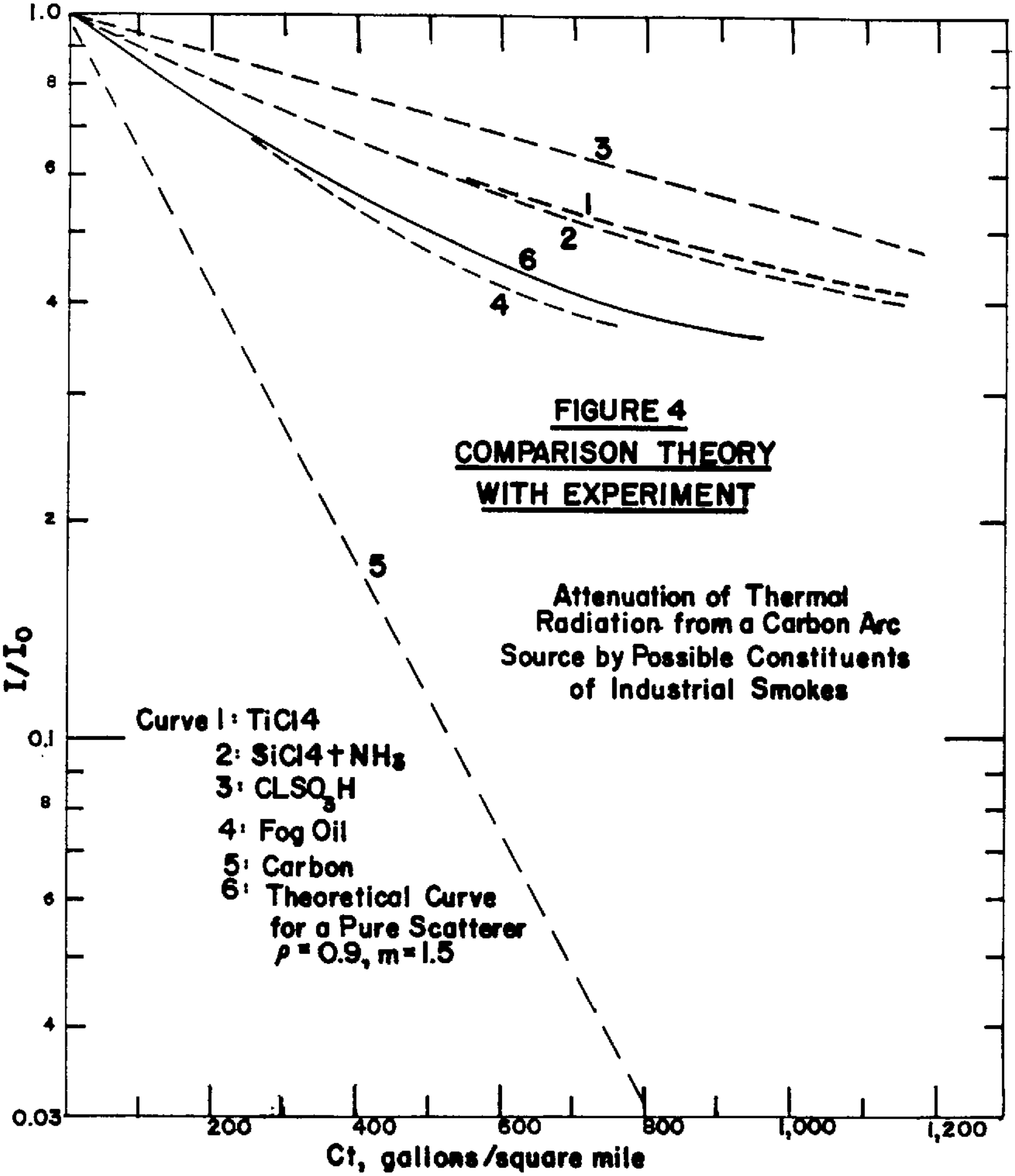


FIGURE 4
COMPARISON THEORY WITH EXPERIMENT

Attenuation of Thermal Radiation from a Carbon Arc Source by Possible Constituents of Industrial Smokes

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# APPLICATION OF THE RECIPROCITY THEOREM IN GAMMA SHIELDING STUDIES (U)

## Introduction

The Shielding characteristics of structures are often obtained experimentally by spreading about them on the ground uniform ("infinite") contaminated fields of gamma-emitting materials (fission products, etc.). The integrated dose rate is found inside the structure as a function of the field strength and the energy spectrum of the contaminating field. It has also been reported (1) that studies of this kind have been carried out by moving a large source in a definite pattern around a structure and summing the weighted contributions to the dose rate measured in the structure.

Either method of measuring the shielding properties of structures would be much simplified, on the basis of the Reciprocity relation, if a suitable source could be placed inside a structure and the integrated dose rate determined by measurements over the surrounding field, using the same pattern. This integrated dose rate would then be the same as that which would be obtained if the detector were placed inside the structure and the source spread out in a uniform way over the surrounding terrain to a distance corresponding essentially to an infinite field, i.e., to 100-200 feet from the detector, if the field is continuous, and the grid is dense enough.

## The Reciprocity Theorem

The Reciprocity Theorem is well known in electromagnetic theory and has previously been frequently applied in a variety of fields, as in the domains of radio and radar(3) in circuit and antenna theory(2). It has also been applied to neutron shielding(3). A general formulation is given by Chandrasekhar(4) who also considers polarization. These applications involve no change in the energy of the particles concerned.

For the practical application to shielding from gamma rays, the theorem may be stated as follows:

Let P and Q be two points in a scattering space, and let an isotropic $(4\pi)$ source be placed at P. Reciprocity exists if the radiation detected at Q by an isotropic $(4\pi)$ detector is the same as that which the detector would measure at P if the same source were at Q.

The Reciprocity relation does not take into account possible changes in energy of gamma rays passing through a shield, and in the absence of compensating effects deviations from reciprocity may be expected in such cases.

## Application of the Theorem to Shielding

For practical purposes the theorem is conveniently applied by the use of the following mapping technique.

If the field about a structure is uniform enough, the continuous distribution may be replaced by an array of isolated point sources of adequate density. This array is conveniently represented by the Cartesian coordinates of the centers of individual squares, the centers being the positions where the source (or, in the reciprocal case, the detector) is placed to obtain the experimental data. If the field strength at x,y,o is $\rho(x,y,o)$ the strength of the point source at this position is:

$$E = \rho(x,y,o) \cdot dA\ (x,y,o) \qquad (1)$$

where $dA\ (x,y,o)$ is the small area of the square whose center is at x,y,o, referred to any convenient origin on the ground. For a finite rectangle at $x = x_l$, $y = y_m$, $Z = 0$,

$$E_{l,m} = \rho_{l,m} A_{l,m} \qquad (2)$$

since $\rho$ is constant over this area.

If $E_{l,m}$ is the strength of the source at the point $x_l$ $y_m$, 0, and if $x_j$, $y_k$, z is a point inside a structure, the intensity at this point is:

$$I\ (\text{detector} \mid \text{source}) = I\ (x_j,\ y_k,\ z \mid x_l,\ y_m,\ 0).$$

This is the contribution to the intensity due to a single square. Superposition of the contribution of all the squares gives the total intensity:

$$I(x_j,\ y_m,\ z) = \sum_l \sum_m I\ (x_j,\ y_k,\ z \mid x_l,\ y_m,\ 0) \qquad (3)$$

The fact that there is no inter term connection suggests that instead of actually having sources at each of the points, only one source need be used. The source may be moved over successive points, being careful to weight the intensities to account for variations in the field strength. The intensity measured is directly proportional to the source strength, so that if the available source has a strength E and if the intensity measured at $x_j$, $y_k$, z is $G(x_j,\ y_k,\ z \mid x_l,\ y_m,\ 0)$

$$I\ (x_j,\ Y_k,\ z \mid x_l,\ y_m, 0) = \frac{E_{l,m}}{E} \cdot G(x_j,\ Y_k,\ z \mid x_l,\ y_m, 0) \qquad (4)$$

so that in (3), using (2),

$$I\ (x_j,\ Y_k,\ z) = \frac{1}{E} \sum_l \sum_m (x_j,\ y_k,\ z \mid x_l,\ y_m,\ 0) \quad \rho \qquad (5)$$

If the field strength, $\rho$, is constant and if $A_{l,m}$ is a certain fraction $f_{l,m}$ of a frequently recurring area, A,

$$I(x_j,\ y_k,\ z) - \frac{A}{E}\rho \sum_l \sum_m G(x_j,\ y_k,\ z \mid x_l,\ y_m,\ o) f_{l,m} \qquad (6)$$

If Reciprocity is assumed, and the single source of strength E is used,

$$G(x_j, y_k, z \mid x_l, y \, , 0) = G(x_l, y_m, 0 \mid x_j, y_k, z) \qquad (7)$$

so that

$$I(x_j, y_k, z) = \frac{1}{E} \sum_l \sum_m G(x_l, y_m, 0 \mid x_j, y_k, z) \rho_{l,m} A_{l,m} \qquad (8)$$

If Reciprocity were found to hold for every set of points $x_j$, $y_k$, $z$ and $x_l$, $y_m$, $0$, equation (8) would hold exactly. However, it is found experimentally that this equation holds fairly closely for the structures tested under conditions where Reciprocity does not hold in detail (i.e., at all points) owing to scattering that results in a change in the source energy spectrum.

In shielding measurements it is the dose rate rather than the intensity that is the important quantity, and it is assumed here that the former varies linearly as the intensity, i.e., if reciprocity holds for intensity it will also hold for dose-rate.

It should be pointed out that the magnitude of the deviations from Reciprocity may be expected to depend also on the energy of the source. Fall-out may be more closely simulated, perhaps, by a $Cs^{137}$ source, or by a mixture of nuclides of which the energy spectrum approaches closely that of Fall-out.

Experimental Results:

In a continuing series* of experiments the protection afforded by two types of buildings has so far been studied by the method described. Building A was a sheet metal and woodworking shop 30' x 60', of 8" clay tile construction. The partitioning walls were of wood, and the various heavy machine tools were arranged in random fashion. Building B was a vacant, two-story army-type barracks, of the same dimensions, but of frame construction. The joists were faced with 1" x 8" boards. Building A was 200 feet from any neighboring structure, and building B more than 500 feet away from another building.

Building A was mapped on one quadrant which was divided into 4 yd$^2$ squares extending to 18 feet from the walls. Building B was also mapped in one quadrant divided into squares of the same area, but extending 36 feet from the walls.

The detector used was a Jordan(6) dose-rate meter, model AGB-10-SR, covering the range 0.01 to 1000 mr/hr, with two scales, and with a rated accuracy of 10%.

The source used in all the measurements was $Co^{60}$ with a strength of 0.6 curie.

Measurements on building A showed a deviation of 0.9% from "overall Reciprocity", although the theorem was not found to hold accurately in

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* In progress at Army Chemical Center, Maryland.

general. Deviations from "overall Reciprocity" of only 1.4% were found in building B at its center and three feet above the lower floor. The deviation in the center three feet above the upper floor was only 0.8% and the deviation 15 feet from the center (in the direction of the grid) and three feet above the upper floor was 0.1%.

With the source inside the buildings it was found that data could be obtained in about half the time required for the reciprocal case, with half the personnel and with only about one third of the radiation dosage incurred.

Conclusions:

1. Although individual points in a grid may show deviations, "overall Reciprocity" is closely followed in the cases of the buildings studied.

2. A considerable saving in time and personnel is realized by placing the source inside a structure, rather than outside on a grid, in determining the shielding properties of structures to gamma radiation, and the dose incurred in the operation is much less.

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## HELICOPTER TO GROUND RADIOLOGICAL SURVEYING (U)

### Introduction:

The desirability of checking ground radiological contamination from the air has resulted in the development of low altitude aerial surveying techniques using a helicopter with a suspendable radiation detector. The utilization of this equipment at altitudes up to 1000 feet above terrain has been found to be an effective method of determining gamma radiation intensities at specific points on the ground.

The ultimate objective of such an aerial survey would be to establish radiation iso-intensity lines as early as possible after an atomic explosion, especially in areas inaccessible to ground survey teams due either to terrain or to high radiation levels.

### Background:

The present **method** of using helicopter-to-ground equipment for low altitude aerial surveying has evolved after considerable experimentation.

In 1953, the U.S. Army Chemical Corps set up a radiation field at the Army Chemical Center, Md. for the purpose of testing different types of low-altitude aerial surveying equipment.

As a result of these and other tests, several conclusions were reached.

1. Aerial surveys performed near the ground (below 20 feet), proved to be more reliable than those performed from higher altitudes because of the inaccuracies in correcting high altitude data back to ground level and the difficulties encountered in locating the exact position over which each reading was taken.

2. The helicopter was found to be more suitable than fixed wing aircraft for carrying the survey instruments because of its inherent ability to fly safely at low survey heights and slow speeds. The slow response times of the instruments then available and the rapidly changing radiation intensities at low survey heights made slower flight speeds imperative. Slower flight speeds also made it easier to correlate aircraft position with intensity readings.

3. The method of recording data manually from a direct instrument reading proved to be more desirable than using a recording system because of the slower response time and additional inaccuracies introduced with the recorder.

4. Wide range logarithmic scales were found to be preferable to linear scales due to the time and data lost in switching the linear scales.

In view of the above points, the most satisfactory combination of equipment appeared to be a system developed by the Evans Signal Laboratory*, whereby a helicopter was used to carry a suspendable radiation detector. A probe was attached to a 540-foot cable wound on a reel which was operated manually from the helicopter to raise or lower the probe to the desired height. The probe contained an ion-chamber type detector which was wired through the cable to a meter inside the helicopter. Ground readings could thus be taken remotely as the helicopter was flying slowly over an area or hovering over a specific point.

Although considerable difficulty was encountered with the original equipment, this system formed the basis for aerial surveying equipment developed and used by the Chemical Corps in the 1955 series of atomic tests at the Nevada Proving Ground.

Description of Equipment:

The equipment used in the Nevada operation consisted of an ion-chamber type radiation detector mounted in a probe unit so that when the tip of the probe was touching the ground, the ion chamber would be at 3'. The probe was attached to 1000' of 7-conductor cable, (1/8" diameter), wound on a handoperated reel which was mounted on an aluminum frame carried inside the helicopter. The reel could thus be operated from the helicopter to lower the probe to the ground or to any desired position.

Also mounted on the aluminum frame was a control panel with meter and associated circuitry which was wired to the detector through the 7-conductor cable. An indicator light on the control panel was also wired through the cable to a microswitch on the tip of the probe to indicate when the probe was in contact with the ground.

The entire unit weighed approximately 70 pounds and was portable to facilitate ease of installation in the H-19 helicopter.

The radiac instrument used was a modified version of the ion-chamber type gamma monitor, Model AGB-10K-SR, manufactured by the Jordan Electronic Mfg. Co. of Pasadena, California. Briefly, the operation of this instrument is as follows:

The ionization chamber is the Neher-White type consisting of a metal shell with a subminiature tube sealed inside at 10 atmospheres of pure argon. A relatively high output current from the chamber flows directly to the indicating meter, eliminating the need for complex circuitry required in other types of radiation monitors. The response is logarithmic, which makes possible the wide range of 0.01 mr/hr to 10,00 r/hr in three scales. Accuracy is quoted at ±10% of applied dose rate anywhere on

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* Helicopter to Ground Radiological Survey Equipment by Robert H. Sugarman and Eric C. Ellstrom, Evans Signal Laboratories, Belmar, N.J.

scale. The spectral response of the instrument is made essentially flat between 75 Kev and 1.3 Mev by using a lead absorber on the outside of the steel chamber shell and an aluminum secondary emitter on the inside. A built-in source of $Sr^{90}$ insures a convenient and rapid calibration check.

Throughout the operation, the modified Jordan instrument proved to be reliable, stable and rugged.

Discussion of Operation:

During the Nevada operation, the helicopter-to-ground method of aerial surveying was used primarily in two fields of operation, viz., to check radiation intensities at specific points, and to make air attenuation studies.

The point checking operation was carried out after each detonation in conjunction with the Radiological Safety teams for the purpose of checking for radiological contamination in outlying work areas and at other specific points of interest. The general procedure was to take off from a control point immediately following passage of the shock wave, check the outlying areas first, then to proceed in toward ground zero, utilizing pre-established check points.

These checks were made by hovering over the point at sufficient altitude to afford safety from ground radiation, (usually around 500 feet), and lowering the probe until the control panel light indicated that the detector was 3 feet above the ground. A reading was then taken, recorded and radioed in to the control point from the helicopter. In moving from point to point, the operator reeled in a few feet of cable to prevent catching the probe on an obstruction, and relowered it at the next check point.

In addition to the two helicopter pilots, it was deemed necessary to carry a Radiological Safety officer, a probe operator and a radio operator on each mission. This team also used the equipment to make quick determinations of "hot spots" by flying over an area with the probe extended to within 25 to 50 feet of the ground.

Throughout the operation, positioning was accomplished visually, utilizing check points. An attempt was made to utilize Raydist positioning equipment, (a radio triangulation method). This equipment was satisfactory for determing position but did not lend itself to rapid surveys at that time due to the great amount of time required in interpreting the positioning data.

For air attenuation studies, the equipment was used to obtain gamma radiation intensities at various altitudes directly above a given point on the ground. To obtain this data, the helicopter hovered at 500 feet with the probe at ground level. Readings were then taken at 100 foot intervals as the helicopter ascended over the initial point. Since the helicopter usually could not hover above 1000 feet, this only gave readings up to 500 feet. To obtain the data from 500 feet to 1000 feet, the helicopter was returned to its original position at 500 feet and the probe was reeled in to approximately 15 feet below the helicopter, whose altitude was again increased in 100 foot increments. The altitude was determined at each point from the helicopter's barometric type altimeter.

The data obtained in this manner at the Nevada Proving Ground in 1955 is presented in condensed form on graph I of this report.

Considerable difficulty was experienced in obtaining this data, due mainly to the problems encountered in trying to hold a stationary position in the helicopter, and in ascending directly above the initial point on the ground.

The ability of a helicopter to hover is directly dependent upon the air density. Since Yucca Flat at the Nevada Proving Ground is approximately 4300 feet above sea level, it was necessary that the aircraft be operated at 4800 feet to 5300 feet MSL. Hovering in a stationary position at these altitudes can be extremely difficult for the H-13, especially in gusty winds. Ascending directly over a point further complicates the problem and makes it impractical to attempt air attenuation studies under gusty wind conditions. Point-check runs, however, are not quite so critical.

It should be noted that to hover between 100 feet and 400 feet above ground level is dangerous in that if a power failure occurs, there would not be sufficient altitude in which to "recover" and break the fall prior to striking the ground. Also, it is advisable to be able to quickly sever the cable in an emergency.

Certain limitations were also encountered concerning the equipment used. The manually operated reel was found to be much too slow for quick and efficient data taking. This slow operation was also responsible for much of the rough treatment received by the probe. On several occasions when the probe was being lowered near the ground, the helicopter suddenly changed position and the probe could not be reeled up fast enough by hand to prevent its being dragged and bounced across the ground.

It is expected that these difficulties will be alleviated in the future by incorporating an electro-mechanical reel system. It is also planned that this system will have a footage register to indicate the length of unwound cable.

At elevations above 500 feet, the probe unit became increasingly difficult to observe at ground level. It is, therefore, planned that in future operations, the probe unit will be painted a bright, contrasting color.

## Discussion of Data:

The plot of attenuation factor vs. altitude shows that the gamma radiation intensity decreases approximately logarithmically with altitude above any specific point.

The rate at which the intensity decreases with altitude is dependent upon the position within the fallout pattern. This is indicated by the fact that the curves have different slopes corresponding to the different positions over which the data were taken. There seems to be no simple relationship, however, between the slope of the curve and the position within the fallout pattern, due to the influence of radiation from surrounding areas. Theoretical studies have been initiated to study this effect.

It should be noted that in every case, the steeper slopes were associated with the readings obtained over ground zero.

Some of the curves are discontinuous at the 500 foot point. These discontinuities are due to positioning difficulties encountered in returning the helicopter to its exact original position at 500 feet at the beginning of the 500-1000 foot run. The data are still valid, however, since the slope of the curve is the same on either side of the break. The discontinuity merely indicates that data for the second portion of the curve were taken over a point slightly to one side of the initial point on the ground.

## Conclusions:

Experience gained in the 1955 Nevada operation has proved the effectiveness of helicopter to ground radiological surveying. It has also served to develop practical techniques in low altitude aerial surveying.

The utilization of a helicopter and a suspendable radiation detector has been found to be an effective and accurate method of rapidly determining gamma radiation intensities at specific points on the ground.

This equipment has also been found useful in quickly checking for and locating "hot spots" in contaminated areas.

In considering the ultimate use of aerial surveying, it would be most desirable to be able to make a rapid and accurate survey of ground contamination from a relatively high altitude. This suggests the use of fast, fixed-wing aircraft which, in turn, presents several major problems. Among these are:

1. Development of positioning equipment which would make possible the quick and accurate correlation of intensity readings with the position at which they were taken.

2. Development of a reliable method of correcting aerial survey data back to ground level values.

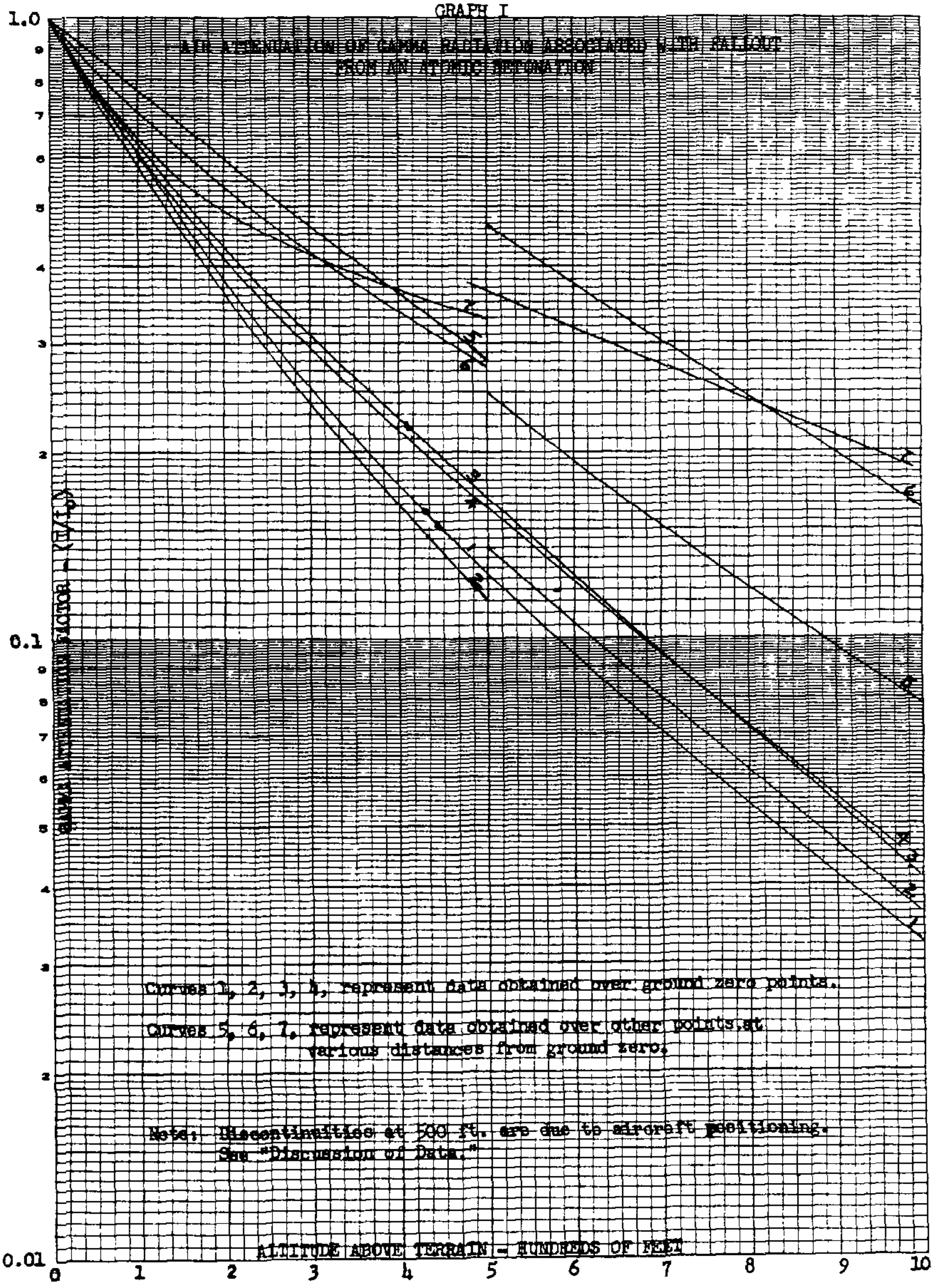
In dealing with this second problem the helicopter-to-ground survey system provides a valuable contribution by making it possible to obtain air-to-ground correlation data such as that obtained in the Nevada operation.

Indications are that much work remains to be done before aerial survey data can be corrected to indicate ground level values with a reasonable degree of accuracy.

It is expected that the improved equipment under consideration at this time will make it possible to carry out future air attenuation studies more efficiently.

Notes:

1. The 1953 work at ACC was by J. B. Graham and Donald Hamilton.
2. The 1955 work at Nevada was by Arthur Francis, John P. Johnson, and Harry I. West.



GRAPH I

AIR ATTENUATION OF GAMMA RADIATION ASSOCIATED WITH FALLOUT FROM AN ATOMIC DETONATION

Curves 1, 2, 3, 4, represent data obtained over ground zero points.

Curves 5, 6, 7, represent data obtained over other points at various distances from ground zero.

Note: Discontinuities at 500 ft. are due to aircraft positioning. See "Discussion of Data."

# TANK VULNERABILITY TO PROMPT IONIZING RADIATION (U)

## Introduction:

The object of this paper is to describe studies made to assess the dosages from prompt radiation to which tank crews may be exposed at ranges where tanks may sustain moderate blast damage. (Moderate blast damage is defined as that damage which is sufficient to prevent any military use until repairs are effected. Moderate damage to tanks may result, in many cases, with no accompanying blast injury to the crew.) The feasibility of incorporating additional shielding in tanks was considered in the study.

## Discussion:

The study covered the whole range of atomic weapons yields. Heights of bursts were selected for each yield to maximize the blast pressure required to produce moderate damage to the tanks, and the ranges of ionizing radiations which resulted, were calculated.

It was found, under these conditions, that particularly for the smaller yield weapons, the radiation hazard to tank crews, from both gamma and neutron radiation was overwhelming, at the range of moderate tank damage.

The study then went on to investigate the amount of shielding required and manner of application, to reduce the vulnerability of tank crews to ionizing radiation. It is well known that the materials which are efficient neutron shields are quite different from those which best attenuate gamma radiation. For the latter, high atomic weight, high density materials, like lead, are desired; for the former, low atomic weight materials, like water, paraffin, graphite, certain plastics and etc., are required to slow down the fast neutrons; materials, like boron, cadmium, and bismuth, with high capture cross-sections, are then required to absorb the slow or thermal neutrons.

The additional shielding desired might be applied in either of two ways. First, the shielding material can be applied as a liner throughout the vehicle. It was soon proved that this method would involve a tremendous increase to the weight of the tank, of the order of several tons. The second method involved applying the additional shielding to the individual members of the crew, either in the form of body armor, or by installing a shield in the form of a seat back extending from the neck of the individual to his buttocks, with an added chest plate hanging in front.

Considering only the gamma radiation, it was found that to reduce the dose to the individuals in the tank to approximately 150 r, at the range of moderate blast damage, it required of the order of 700 pounds of lead per individual when distributed in the form of body armor, and more than twice that amount in the form of seat and hanging chest shield.

Lack of satisfactory data on the neutron spectrum and attenuation factors, precluded the extension of the study to include estimates of the additional weight required to attenuate the neutron flux.

It appears obvious that any attempt to increase the protection afforded by tanks against ionizing radiation means additional weight. This must be weighed against current trends toward lighter and more mobile armored vehicles.

The problem posed here is similar in nature to that raised at the Eighth Tripartite Conference and further discussed at the Ninth Tripartite Conference meetings involving the so called "radiation gap", with respect to ships. Possible solutions in the latter case, such as relocation of personnel, machinery spaces etc. do not find ready application to the confined spaces within tanks.

# CALCULATION OF DOSE RATE FROM AN EXTENDED SOURCE OF FISSION PRODUCTS (U)

## Introduction:

In determing the dosage received by personnel in an open area that has been subjected to contamination by Fallout from a nuclear burst a number of factors enter, including the amount of contamination, the emitted gamma energy, the extent of shielding, the extent of the contamination area, etc. The calculation of the dose rate in some arrangements of shield and source becomes almost insurmountable.

Approximate calculatons were made early, assuming an infinite plane uniformly contaminated with fission products, and the whole body dose was assumed to be equal to that received at a height of three feet above the level of the plane. This simple geometry proved to be amenable to calculation on the basis of the exponential integral.(1). This type of calculation is only approximate, however, because it does not include the contribution of scattered radiation.

Recent theoretical work has indicated how the scattered radiation may be taken into account. A theory involving the application of the Moment Method to the solution of the Transport equation developed by Spencer and Fano(2) has been corroborated experimentally by White(3), Hayward(4), Kuper et al(5). Berger and Doggett(6) and Gates and Eisenhauer(7) have made calculations based on the theory for photon diffusion through air.

## Theoretical Dose Rate as a Function of Energy

The theory, as developed by Berger and Doggett (6) and by Gates and Eisenhauer leads to a general relation between dose rate and energy at unit field strength (figure 1). This relation, together with the concentrations of the various active nuclides present in the Fallout material permits estimating. The dose rate due to the Fallout on the assumption of an infinite smooth plane of uniform contamination, using the appropriate decay schemes. Actual soils are, of course, not smooth planes, nor is the contamination distributed uniformly. Consequently, the total dose rate calculated in this way will differ from the actual. Over a large area, however, regions of higher contamination density may compensate for low density regions, so that deviations from the theory may be due chiefly to characteristics of the soil, i.e., fineness of soil material, presence of rocks, protuberances, cracks in the soil, etc., which would result in greater attenuations than would be expected on a smooth plane.

The method may be understood more clearly by outlining the procedure to be used for a typical sample of Fallout. A radiochemical analysis provides information about the various active nuclides present; the counting rate of each nuclide is determined in the course of the analysis and the results correlated with the decay schemes of the various nuclides present. The number of photons emitted at each pertinent energy is obtained. If the sample of fallout was collected over a known area, the field strength (photons/cm$^2$-sec) can be calculated at these energies.

In figure 1 the theoretical infinite field dose rate is proportional to the field strength at each energy. Multiplication at each energy pertaining to the sample, of the dose rate by the field strength of the sample gives the dose rate contribution at that energy, and addition of all these contributions yields the total infinite field dose rate due to all the gamma emitting material in the fallout sample.

Time Dependence of the Dose Rate

The result calculated in this way is the infinite field dose rate of the sample at the time of the anlaysis. The fission products decay, and if an analysis were carried out on the same sample some time later, the data obtained might give by the above procedure an entirely different (lower) value of the infinite field dose rate. In fact, repeated analysis of the same sample and application of the method described to the data, would provide the information necessary to calculate the total dose received in any required time.

The gross decay of fission products has been treated by various authors. The problem was attacked from the statistical point of view by Way and Wigner(8); and Hunter and Ballou(9) have used a direct method based on Bateman(10) solutions for the various chains. Thornton and Houghton(11) obtained an exponential approximation to the Bateman solution for times greater than one hour which agrees closely with experiment.

The various nuclides present in fallout decay in a chain-like manner; sometimes the chain may include only one member, but they may be classified in this way. If decay takes place without the emission of a photon, the probability of emission of the photon is zero.

Let $N_i$ represent the amount of the isotope in a radioactive chain, so that $N_0$ represents the amount of the parent, $N_1$ the amount of the daughters, etc. At time t = o, the quantities of the various isotopes may be represented by $N_i^o$. Then the amount of the nth isotope present as a function of time is(10).

$$N_n(t) = \sum_{i=0}^{n} N_i^{\circ} \sum_{j=i}^{n} e^{-\lambda_j t} \frac{\prod_{n=i}^{n-1} \lambda_k}{\prod_{h=i} (\lambda_k - \lambda_j)(1-\delta_{jk}) + \delta_{jk}} \quad (1)$$

where the $\lambda_j$ and $\lambda_k$ are the decay constants of the jth and kth isotopes, respectively. $\delta_{jk}$ is the Kronecker delta,

$\delta_{jk}$ = 1 if j = k

= 0 if j = k

In order to obtain the gamma intensity, one needs to know the rate of change from the $n^{th}$ isotope to the $(n+1)^{th}$ isotope. This is given as: ${}_nI_{n+1} = \lambda_n N_n$; in which ${}_nI_{n+1}$ has been used rather than the deviative because

$$\frac{dN_n}{dt} = \lambda_{n-1} N_{n-1} - \lambda_n N_n$$

then

$${}_nI_{n+1} = \sum_{i=0}^{n} N_i^{0} \sum_{j=i}^{n} \frac{e^{-\lambda_j t} \prod_{k=i}^{n} \lambda_k}{\prod_{k=i}^{n} (\lambda_k - \lambda_j)(1-\delta_{jk}) + \delta_{jk}} \tag{2}$$

If decay occurs and a photon is emitted, it is necessary to know the probability that it is the $n^{th}$ gamma of the $(n+1)^{th}$ isotope. This probability is precisely the raltive intensity of this photon. Let $\rho_g^{n+1}$ be the probability that, in a transition from the $n^{th}$ isotope, a gamma particle of energy $E_q$ will be emitted. If $\sum_g \rho_g^{n+1} = 1$, a gamma particle is emitted at energy transition.

Figure I shows(12) (dotted line) that in the energy interval 0.07 to 3 MEV the dose rate at a point 3 feet above a plane infinite field contaminated by material emitting gamma particles of energy $E_q$ (MEV) is given to within 20% by:

$$D_q = 4.6 \times 10^{-3} E_q^{-0.915} \tag{3}$$

This gives the dose in mr/hr from a field emitting one photon (energy $E_q$) per square centimeter per second. The contribution to the total dose rate due to the decay of the $n^{th}$ isotope is:

$$D_n = \sum_g \rho_g^{n+1}\, 4.6 \times 10^{-3} (E_g^{n+1})^{-0.915}$$

If both sides of equation (2) are divided by the area of contamination, it may be combined with equation (3) to give the contribution to the total dose of the $n^{th}$ member of a chain as a function of the time:

$$D_n = \sum_{i=0}^{n} \rho_i^{0} \sum_{j=i}^{n} \frac{e^{-\lambda_j t} \prod_{k=i}^{n} \lambda_k}{\prod_{k=i}^{n} (\lambda_k - \lambda_j)(1-\delta_{jk}) + \delta_{jk}} \sum_g 4.6\times10^{-3} \rho_g^{n+1} (E_g$$

where $\rho_i^{0}$ is the number /cm² of the $i^{th}$ isotope at t = o.

The total dose-rate from all members of the $i^{th}$ chain is

$$D_i = \sum_n D_n^i$$

and the total dose rate due to all the chains is:

$$D = \sum_i D_i$$

In a formal way these relations, together with the plot in figure 1 (which is based on Transport Theory), permit calculating the dose rate, at any time after zero time, three feet above a uniform infinite plane of contamination due to a mixture of decaying nuclides, as, for example, fission products.

The Dose Rate for Branching Chains:

Equation (2) applies to the case where no branching occurs. If, after the g<u>th</u> term, the decay chain forms h branches,

$$\frac{dN_{g+1}^{\ell}}{dt} + \lambda_{g+1} N_{g+1}^{\ell} = F_1 \lambda_g N_g$$

where the superscript indicates the 1th branch, and the fraction of the decaying isotope going into this branch is $F_1$. By inspection the series can be represented by

$$N_n^{l} = \sum_{i=0}^{n} N_i^{0} \sum_{j=i}^{n} e^{-\lambda_j^{\ell} t} \frac{\prod_{K=i}^{n-1} \lambda_K^{\ell} \left[1+\delta_{jK}(F_\ell - 1)\right]}{\prod_{K=i}^{n} (\lambda_K^{\ell} - \lambda_j^{\ell})(1-\delta_{jK}) + \delta_{jK}} \qquad (5)$$

It is understood that if the superscript is numerically less than the branching number, the latter has no meaning. It simply refers to the chain before branching, so that symbols with the same subscript but different superscripts are the same.

If $k \leq g$, $\lambda^{\ell}_{k} = \lambda^{m}_{k}$

Relations can also be developed for the case of the convergence, after a number of terms, of a branch with other branches, etc.

Calculation of Total Dose.

The total dose received 3 feet above an infinite plane of uniform contamination by a mixture of nuclides, due to the n<u>th</u> member of a non-branching chain, is obtained by integrating equation (4).

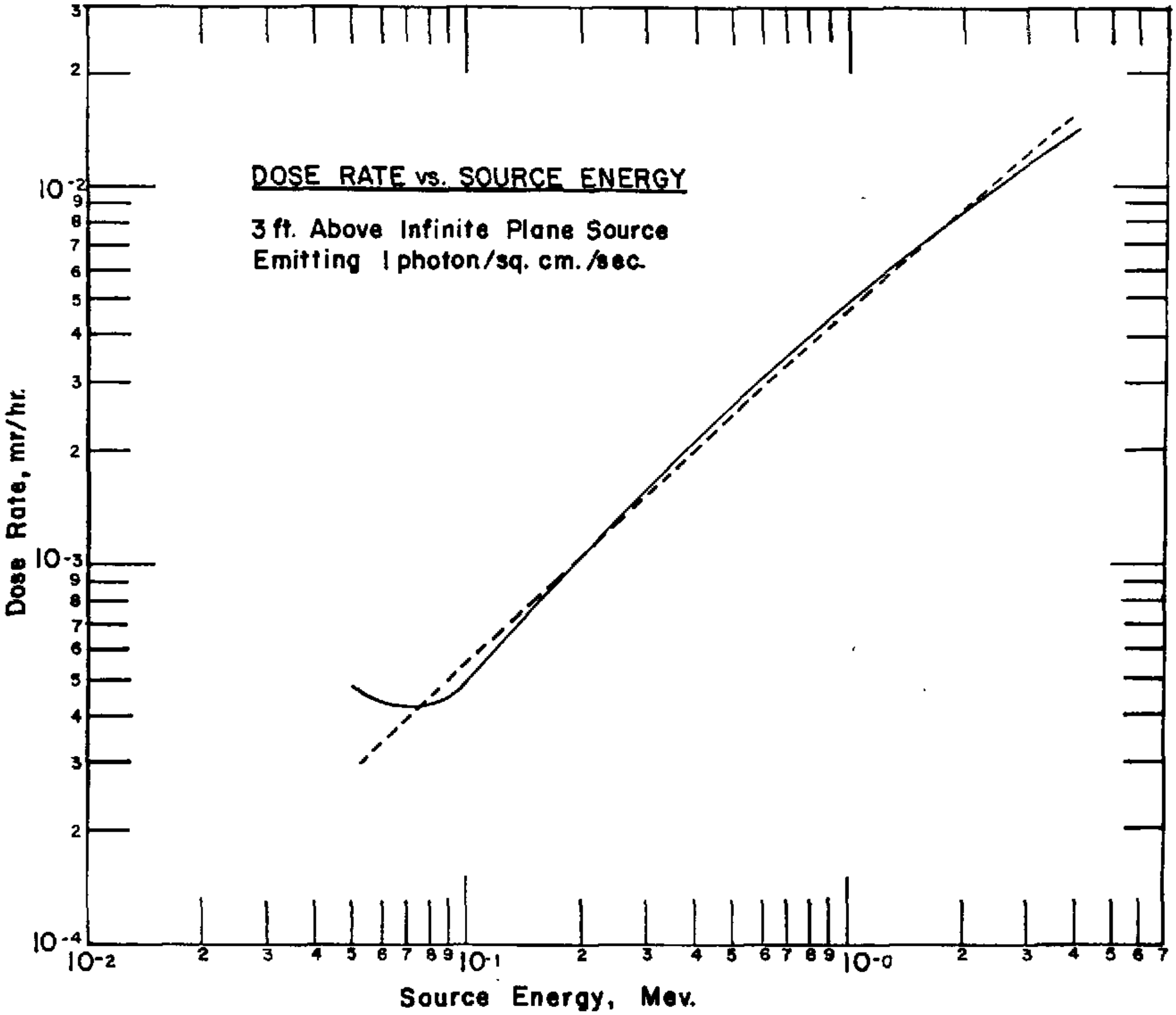
$$\int_0^t D_n dt = \sum_{i=0}^{n} P_i^{0} \sum_{j=i}^{n} (1-e^{-\lambda_j t}) \frac{\prod_{K=i}^{n} \lambda_K (1-\delta_{jK}) + \delta_{jK}}{\prod_{K=i}^{n} (\lambda_K - \lambda_j)(1-\delta_{jK}) + \delta_{jK}} \sum_{q} 4.6\times10^{-3} P_q^{n+1} (E_q^{n+1})^{-0.915} \qquad (6)$$

For a protracted stay in the contaminated field

$$\int_0^\infty D_n dt = \sum_{i=0}^{n} P_i^{0} \sum_{j=i}^{n} \frac{\prod_{K=1}^{n} \lambda_K (1-\delta_{jK}) + \delta_{jK}}{\prod_{K=i}^{n} (\lambda_K - \lambda_j)(1-\delta_{jK}) + \delta_{jK}} \sum_{q} 4.6\times10^{-3} P_q^{n+1} (E_q^{n+1})^{-0.915} \qquad (7)$$

Summary:

A procedure is outlined for calculating on the basis of Transport Theory the total dose at three feet above an infinite plane of uniform contamination due to a mixture of decaying nuclides, such as fission products. A Complete radiochemical analysis is required at one time and use of the pertinent decay schemes and decay constants permits calculation of the dose rate and the dose as a function of the time after or before analysis up to the time of formation.


DOSE RATE vs. SOURCE ENERGY
3 ft. Above Infinite Plane Source
Emitting 1 photon/sq. cm./sec.
Dose Rate, mr/hr.
Source Energy, Mev.
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-1}$
$10^{-0}$
2
3
4
5
6
7
8
9

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# THE EFFECT OF THERMAL UPDRAFTS OVER CITIES UPON THE DISPLACEMENT OF RADIOACTIVE FALL-OUT (U)

## INTRODUCTION:

Surface and underground bursts of large scale atomic weapons and high yield thermonuclear weapons result in lethal radiological contamination well beyond the areas damaged by blast and thermal effects. The hazardous areas are created by the radioactive fall-out from the atomic cloud as it moves downwind.

All radiation patterns obtained so far have been over either open desert area or a few islands and the ocean in the Pacific. Different patterns probably would occur in built-up areas due to the inherent thermal currents existing in and around cities. It may be possible that under certain weather conditions these generally upward thermal currents, perhaps aided by mechanical means, might be sufficient to displace fall-out to uninhabited areas where it would be relatively harmless during its decay process.

## THEORETICAL:

Before pursuing the meteorological aspects, it would be well to discuss the nature of the fall-out particulate. Considerable information is available on particle size distribution, specific activity, rate of fall, etc., but these data are primarily limited to areas less than 50 miles from ground zero. High radiation levels are found as far as 300-400 miles downwind, but particle size data in this region are quite limited. The hypothetical city under study could be anywhere in this area.

It has been established that about half of the fission product activity is associated with particles 100 microns and less in size. Calculations performed by meteorologists on the deposition of a 100 micron particle as a function of settling laws and weather conditions indicate a wide range of deposition downwind.[1] The rate of fall of a 100 micron particle from various altitudes was also calculated, treating the particles as irregular spheres subjected to the standard aerodynamic fall equation. For very small velocities this equation reduces to Stokes Law and for very high velocities to the law for the turbulent region. This results in a particle velocity of the order of $\frac{1}{2}$ m/sec.

Part of the objective of the proposed study is to determine the maximum particle size influenced by a thermal updraft. This does not imply, for example, that if all particles less than 100 microns were displaced, the radioactivity deposited by larger particles would be negligible. But, if the location of the city were sufficiently far downwind, the maximum particle size in the area would approach 100 microns and the displacement of these would result in a significant lowering of deposited

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activity in the city proper. However, the area surrounding the city would still be highly radioactive and probably contain some "hot spots."

At the present time the meteorological aspects of the problem are being investigated. Meteorological literature on such subjects as atmospheric pollution, urban influence upon city weather, vertical velocity (thermal updrafts), diffusion, and "heated islands", is being examined.

Meteorological data indicate a gradual horizontal temperature increase progressing to a maximum at a city built-up center. The increase in many cases is as large as 10°F. at the built-up center as compared to the surrounding urban area. Under inversion conditions, a vertical temperature increase is noted up to altitudes of 3000-4000 feet at which the gradient approaches the adiabatic lapse rate. Because the built-up area has a higher temperature than the surrounding urban and country area, it is sometimes referred to as a "heat island."[3] Associated with this condition is an upward air flow over the city and a corresponding downward flow near its outskirts. However, light winds and turbulence effects due to the surface roughness of the city change the flow pattern. The winds can produce a downward air flow downwind of the city or a turbulent condition throughout the area.

Vertical velocity, the air velocity of a thermal updraft, will directly affect the path of a fall-out particle. However, only a thorough examination of the local weather conditions will actually determine the final point of particle deposition. The calculation of vertical velocity is quite complex, and meteorological literature does not contain any reliable finite equation. The theories proposed include the estimation of vertical velocity from horizontal velocity differences normal to the sides of a square or triangle, but these averaged 1 m/sec and apparent divergence was inversely proportional to the length of a side. Other methods included kinemetic from pilot balloon runs and adiabatic from the temperature change of rising or sinking air. Both gave vertical velocities averaging 1 cm/sec.[4]

A study on the subject of buoyant air parcels rising through a turbulent air mass found that the observed properties of buoyant air parcels existing in super-adiabatic atmospheres agreed, within observational error, with combinations leading to extended survival of air bubbles as predicted by equations. The maximum vertical velocity experimentally encountered through a 100 m surface was 3 m/sec and the air temperature increase was 0.6°C. Slightly lower velocities and air temperatures were noted in one case at an altitude of approximately 2000 feet.[5]

The vertical velocities indicated in the previous studies can be compared to the particle fall velocity of $\frac{1}{2}$ m/sec. Equal velocities would indicate a state of equilibrium and probably some horizontal displacement. If these methods were used to estimate vertical velocity, the particle path and velocity could be analyzed vectorily and changes in either variable treated integrally.

A Chemical Corps contract which has studied the behavior of aerosol clouds within cities found evidence of thermal instability at night. The result of this condition was to lift the aerosol so that concentrations were higher at roof-top level than at ground level. During several day experiments it was indicated that the lifting effect was even higher, probably for the same reason. No additional information was presented on the magnitude of the thermal layer or any vertical components associated with it. The contractors have accumulated a great deal of meteorological data on several U.S. cities. Included for city, urban, and local countryside were horizontal and vertical temperature gradients, wind speed and direction with altitude, atmospheric pressure, geographical effects, and effects of weather systems.[6,7] These data will be useful in the computations involved in the application of most theories to the problem.

A theory was proposed for the effect of a heat source upon a stable atmosphere.[3] The example taken was that of a 5-10 km wide island as a heat source off the New England coast. A steady state was assumed in which the heat supplied by the source was continuously carried away downstream by the wind. It was found that the heat source obeyed an eddy-conduction equation and was established by turbulent eddying in the mixed ground layer. The wind streamline displacement was divided into two components, one obeying the equation for air flow over a mountain ridge and the other obeying a heat conduction equation. The complete streamline picture was constructed for several examples of an air stream whose properties remain unaltered to great heights. The basic current possessing a change in stability or wind speed at an upper level was also discussed.

The theory seems applicable to the study of an air flow stream over a city and we are presently studying it from that viewpoint. It is hoped that some of the meteorological data obtained on the U.S. cities for the contract previously mentioned can be utilized in this application.

Another subject which was originally thought to be related to the problem was FIDO (Fog Investigation Dispersal Of), the system whereby fog is dispersed by increasing the air temperature with oil burners.[8.9.10] Although the reports provided interesting reading, the results of theoretical and experimental studies and eventual practical use of the system did not indicate its application. The system provided sufficient heat to disperse fog by raising air temperature, but the mass vertical velocities were of negligible magnitude. Experimentation performed on calm days did result in small changes in horizontal air velocity, which probably corresponded to some vertical velocity and turbulence in the area of the heat source.

In addition to natural thermal updrafts there are those which occur as a result of the heat from smoke stacks. Rough calculations based on

Sutton's theory,[11] indicated that because of exhaust heat an average stack produces an updraft velocity of 4 m/sec. at 170 ft. and 1/5 m/sec. at 1500 ft. above the stack. Additional stacks in the same area will, in this example, increase either or both the updraft velocity and area affected.

The behavior of stack gases as a function of stack height, local building geometry, wind, etc., has been and still is being investigated by many agencies. Other than supplying additional heat to the atmosphere, it is not known at the present time whether stack gases will have any influence upon the displacement of fall-out. As with the calculation of natural vertical velocities, the information on the characteristics of stack gases will have to be more fully examined.

## CONCLUSIONS:

The many and complex aspects associated with just the micro-meteorological problems will require considerable study. The interpretation of its effect upon particle path and eventual deposition will also be a complex problem. The only conclusion reached at this time based upon the information accumulated is that the idea of fall-out displacement appears promising.

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