SC-RR-68-559

C. 3 UC-41
HEALTH AND SAFETY

SC-RR-68-559
December 1968

Research Report

THE DETERMINATION OF THE QUANTITY OF RADIOACTIVITY CONTAINED IN A GASEOUS EFFLUENT AT THE NEVADA TEST SITE USING GAMMA DOSE-RATE MEASUREMENTS

P. O. Matthews
Environmental Health and Medical Services Division 8263
Sandia Laboratories, Livermore

SANDIA LABORATORIES

OPERATED FOR THE UNITED STATES ATOMIC ENERGY COMMISSION BY SANDIA CORPORATION | ALBUQUERQUE, NEW MEXICO; LIVERMORE, CALIFORNIA

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation for the contributions, suggestions, and critical reviews of W. D. Burnett, Division 3311. Thanks are also extended to T. R. Crites, Division 3312, for his helpful comments.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

THE DETERMINATION OF THE QUANTITY OF RADIOACTIVITY CONTAINED IN A GASEOUS EFFLUENT AT THE NEVADA TEST SITE USING GAMMA DOSE-RATE MEASUREMENTS

I. Introduction

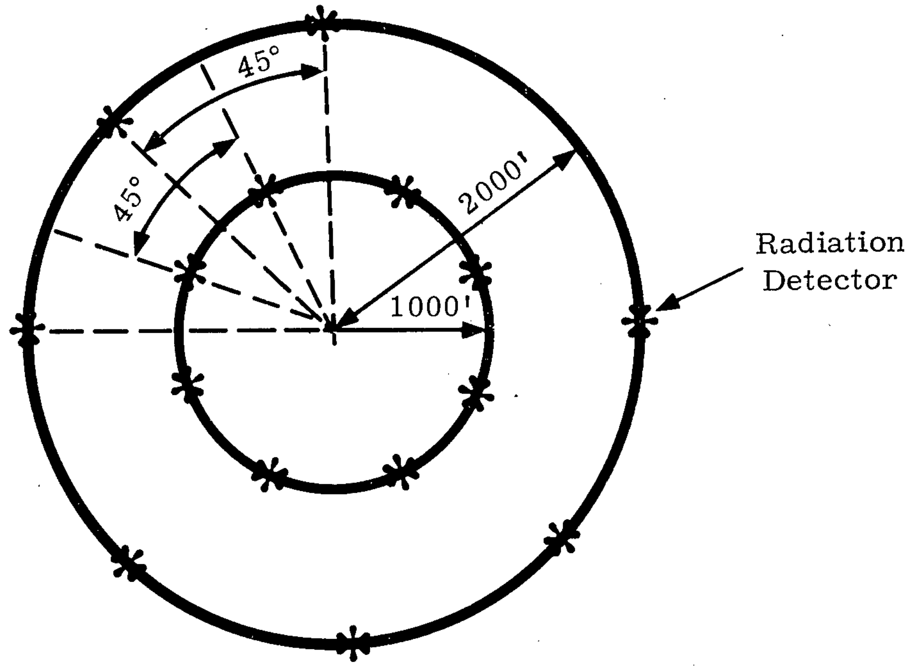
Effluent documentation may be simply stated as the determination of the radioactive materials contained in an effluent release. The quality of the effluent is usually determined by detailed laboratory analyses, whereas the quantitative determinations are the results of relatively simple calculations made at the time of release. This paper will concern itself only with the quantitative determinations presently used to arrive at effluent release estimates.

II. Methods

Several different geometric configurations of an effluent cloud are possible with respect to a radiation detector. These may be the result of different escape velocities, meteorological conditions, wind speeds and directions, relative distances, relative dimensions, and angles, etc.

Uncertainty as to possible time of appearance of an effluent and lack of knowledge of wind speed and direction which may possibly exist at the time of appearance make it judicious that preparations include a concentric array of radiation detectors equally spaced around the potential effluent release point(s).

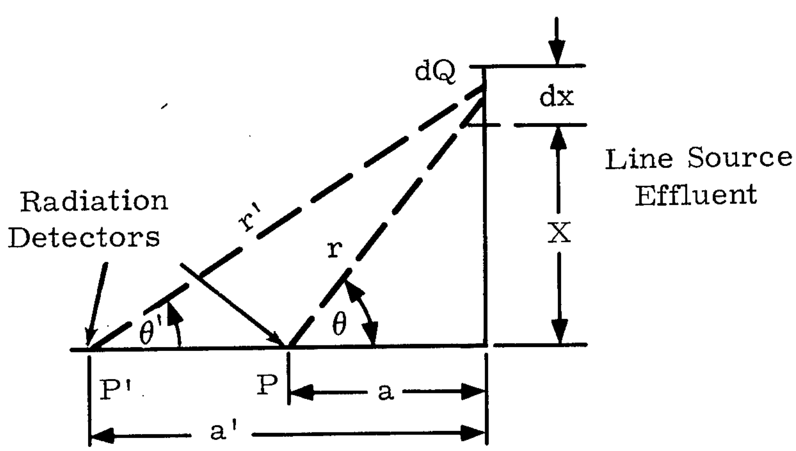
The distances and spacings of the radiation detectors are arbitrary. A typical array is shown below in which eight detectors are placed on a 1000-foot diameter circle and eight detectors are placed on a 2000-foot diameter circle around the central potential release point.



A. Line Sources

1. Vertical Line Source

If the gaseous effluent assumes a geometric configuration with respect to the array of selectors, similar to that shown in the diagram below, the applicable equations used to arrive at the quantity of effluent released may be derived as follows:



The differential photon flux at point P from differential source dx, is

$$d\phi = \frac{S_x \, Be^{-\mu r} dx}{4\pi r^2} \quad \text{(Reference 1)} \tag{1}$$

where

ϕ = flux at point of measurement P $\left(\frac{\text{photons}}{\text{cm}^2 \text{ sec}}\right)$

S_x = specific line source strength $\left(\frac{\text{photons}}{\text{cm sec}}\right)$

B(r) = build-up factor

r = slant distance from increment of x, dx, to point of measurement P (cm)

X = distance from ground to source increment, dx (cm)

μ = total attenuation coefficient (cm^{-1})

h = source height (cm)

If we assume a uniform line source strength, S_x is then constant, and

$$S\left(\frac{\text{photons}}{\text{sec}}\right) = S_x \left(\frac{\text{photons}}{\text{cm sec}}\right) \cdot h(\text{cm}) \tag{2}$$

For gross fission products,

(Reference 2)

$$S\left(\frac{\text{photons}}{\text{sec}}\right) = Q\ (\text{curies}) \cdot 3.7 \times 10^{10}\left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 1.19\left(\frac{\text{photons}}{\text{dis}}\right) \qquad (3)$$

For gross fission products at early times up to approximately H + 30 minutes, the average gamma photon energy used in these calculations is $\overline{E}_\gamma \sim 0.925 \frac{\text{mev}}{\text{photon}}$ (References 2, 4). Corrections may be easily made for any other energy desired. For this particular energy, 1 roentgen per hour is approximately $5.7 \times 10^5 \frac{\text{photons}}{\text{cm}^2\ \text{sec}}$ (Reference 3). However, the effluent release may be highly fractionated and obviously the composition of any release changes with time; therefore, the appropriate $\overline{E}_\gamma$ and conversion factor must be selected in each particular case.

Combining Equations 2 and 3, solving for S_x, and substituting Equation 1, we have:

$$d\phi\left(\frac{\text{photons}}{\text{cm}^2\ \text{sec}}\right) = \frac{3.7 \times 10^{10}\left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 1.19\left(\frac{\text{photons}}{\text{dis}}\right) \cdot B e^{-\mu r}\ Q(\text{curies})dx}{4\pi h\ r^2\ (\text{cm}^2)} \qquad (4)$$

Since we are assuming a uniform concentration, e.g., a constant linear source strength:

$$\frac{Q}{h} = \frac{dQ}{dx} \therefore dQ = \frac{Q\ dx}{h} \qquad (5)$$

$$d\phi\left(\frac{\text{photons}}{\text{cm}^2\ \text{sec}}\right) = \frac{3.7 \times 10^{10}\left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 1.19\left(\frac{\text{photons}}{\text{dis}}\right) \cdot Be^{-\mu r}\, dQ\ (\text{curies})}{4\pi\, r^2\ (\text{cm}^2)} \tag{6}$$

Converting the flux to a gamma dose rate:

$$dR\left(\frac{\text{roentgens}}{\text{hour}}\right) = \frac{d\phi\left(\frac{\text{photons}}{\text{cm}^2\ \text{sec}}\right)}{5.7 \times 10^5\left(\frac{\text{photons hour}}{\text{roentgens cm}^2\ \text{sec}}\right)} \tag{7}$$

$$dR\left(\frac{\text{roentgens}}{\text{hour}}\right) = \frac{3.7 \times 10^{10}\left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 1.19\left(\frac{\text{photons}}{\text{dis}}\right) \cdot Be^{-\mu r}\, dQ\ (\text{curies})}{4\pi\, r^2\ (\text{cm}^2) \cdot 5.7 \times 10^5\left(\frac{\text{photons hour}}{\text{roentgens cm}^2\ \text{sec}}\right)} \tag{8}$$

$$R\left(\frac{\text{roentgens}}{\text{hour}}\right) = 6.15 \times 10^3 \int \frac{Be^{-\mu r}\, dQ}{r^2} \cdot \left(\frac{\text{R/hr cm}^2}{\text{curies}}\right) \tag{9}$$

This general equation appears again and again in effluent release calculations. To estimate Q, the total release, from this integral equation, one must delineate the dimensions of the source cloud, and make assumptions about B, and μ, and how dQ varies with r. With these assumptions, it is then possible to relate Q to R.

From the diagram on page 6

$$r = a \sec\theta \qquad r^2 = a^2 \sec^2\theta$$

$$x = a \tan\theta \qquad dx = a \sec^2\theta\, d\theta$$

Substituting for dx and solving for dQ in Equation 4 and substituting for r and dQ in Equation 8, we have:

$$R\left(\frac{\text{roentgens}}{\text{hour}}\right) = 6.15 \times 10^3 \, B \int_{\theta=0}^{\theta_{max}} \frac{e^{-\mu \, a \sec\theta} Q \, a \sec^2 \theta d\theta}{ha^2 \sec^2 \theta} \tag{10}$$

where we have assumed B(r) to be slowly varying, i.e., essentially constant.

$$R\left(\frac{\text{roentgens}}{\text{hour}}\right) = \frac{6.15 \times 10^3 \, B \, Q \, (\text{curies})}{h(\text{cm}) \, a \, (\text{cm})} \int_{\theta=0}^{\theta_{max}} e^{-\mu a \sec\theta} \, d\theta$$

$$\cdot \left(\frac{R/\text{hr cm}^2}{\text{curies}}\right) \tag{11}$$

Thus

$$Q(\text{curies}) = \frac{R\left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot h \, (\text{cm}) \cdot a \, (\text{cm})}{6.15 \times 10^3 \cdot B \cdot \int_{\theta=0}^{\theta_{max}} e^{-\mu a \sec\theta} d\theta} \cdot \left(\frac{\text{curies}}{R/\text{hr cm}^2}\right) \tag{12}$$

where R is the dose rate reading of the gamma radiation detector at the time of measurement.

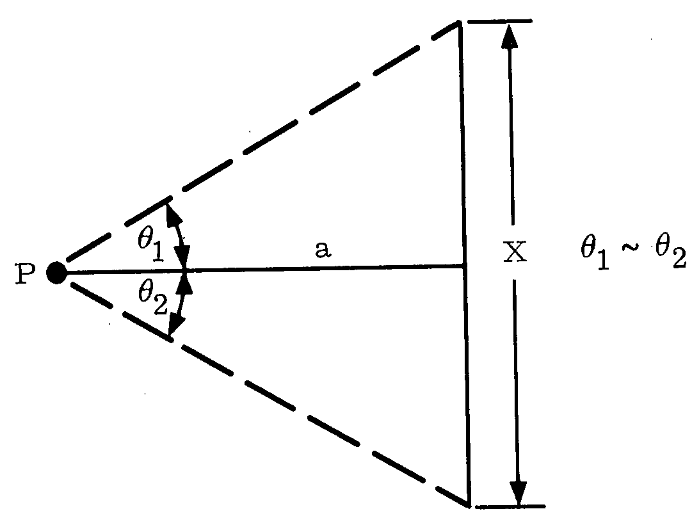
Converting from metric to English units Equation 12 becomes

$$Q(\text{curies}) = \frac{R\left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot h\ (\text{cm}) \cdot a\ (\text{cm})}{6.15 \times 10^{3}\ B \int_{\theta=0}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \cdot \left(\frac{\text{curies}}{\text{R/hr cm}^{2}} \cdot \frac{9.29 \times 10^{2}\ \text{cm}^{2}}{\text{ft}^{2}}\right) \quad (13)$$

$$Q(\text{curies}) = \frac{1.51 \times 10^{-1} R\left(\frac{\text{roentgens}}{\text{hr}}\right) \cdot h\ (\text{ft}) \cdot a\ (\text{ft})}{B \int_{\theta=0}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \cdot \left(\frac{\text{curies}}{\text{R/hr ft}^{2}}\right) \quad (14)$$

2. Symmetric Line Source

If the line source configuration is such that it is similar to the following diagram,



the expression used for the calculation is:

$$\phi \cong \frac{B\, S_x \int_0^{\theta_1 \text{ or } \theta_2} e^{-\mu a \sec\theta}\, d\theta}{2\pi a} \quad \text{(Reference 1)} \tag{15}$$

where

S_x = specific source strength $\left(\frac{\text{photons}}{\text{cm sec}}\right)$, assumed constant

x = source length (cm)

B = build-up factor

μ = total attenuation coefficient (cm^{-1})

a = perpendicular distance from source to point of measurement P (cm)

ϕ = flux at point of measurement P$\left(\frac{\text{photons}}{\text{cm}^2\text{ sec}}\right)$

3. Uniform Release Rate into a Line Source

If a uniform rate of release and a uniform concentration are assumed, the source length X can be thought of as the gaseous effluent being evenly distributed over a distance directly proportional to the wind speed and the time duration of effluent release; e.g., an increment of x, dx, contributes a given flux at the point of measurement P for a given time as it traverses the distance from the point of release to some distance beyond which its contribution to the total flux at point P is insignificant. This may be represented simply by:

$$X(\mathrm{cm}) = \overline{U}\left(\frac{\mathrm{cm}}{\mathrm{sec}}\right) \cdot T(\mathrm{sec}) \tag{16}$$

$$Q(\mathrm{curies}) = S_x\left(\frac{\mathrm{curies}}{\mathrm{cm}}\right) \cdot X(\mathrm{cm}) \tag{17}$$

$$\therefore Q(\mathrm{curies}) = \frac{\phi\left(\frac{\mathrm{photons}}{\mathrm{cm}^2\ \mathrm{sec}}\right) \cdot 4\pi a\ (\mathrm{cm}) \cdot \overline{U}\ \frac{\mathrm{cm}}{\mathrm{sec}} \cdot T(\mathrm{sec})}{B\int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \tag{18}$$

where

$\overline{U}$ = average wind speed $\left(\frac{\mathrm{cm}}{\mathrm{sec}}\right)$

T = time duration of effluent release (sec)

By the same reasoning and the same conditions as previously used,

$$Q(\mathrm{curies}) = \frac{5.7 \times 10^5\left(\frac{\mathrm{photons\ hour}}{\mathrm{roentgens\ cm^2\ sec}}\right) \cdot R\left(\frac{\mathrm{roentgens}}{\mathrm{hour}}\right) \cdot 4\pi a\,(\mathrm{cm}) \cdot \overline{U}\left(\frac{\mathrm{cm}}{\mathrm{sec}}\right) \cdot T(\mathrm{sec})}{3.7 \times 10^{10}\left(\frac{\mathrm{dis}}{\mathrm{curie\ sec}}\right) \cdot 1.19\left(\frac{\mathrm{photons}}{\mathrm{dis}}\right) \cdot B\int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \tag{19}$$

$$Q(\mathrm{curies}) = \frac{1.63 \times 10^{-4} \cdot R\left(\frac{\mathrm{roentgens}}{\mathrm{hour}}\right) \cdot a(\mathrm{cm}) \cdot \overline{U}\left(\frac{\mathrm{cm}}{\mathrm{sec}}\right) \cdot T(\mathrm{sec})}{B\int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \cdot \left(\frac{\mathrm{curies}}{\frac{R}{\mathrm{hr}} \cdot \mathrm{cm} \cdot \frac{\mathrm{cm}}{\mathrm{sec}} \cdot \mathrm{sec}}\right) \tag{20}$$

Converting from metric to English units, Equation 20 becomes

$$Q(\text{curies}) = \frac{1.63 \times 10^{-4} R \left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot a\,(\text{cm}) \cdot \overline{U}\left(\frac{\text{cm}}{\text{sec}}\right) \cdot T\,(\text{sec})}{B \int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta} \cdot \left(\frac{\text{curies}}{\text{R/hr cm}^2}\right)$$

$$\cdot \frac{4.47 \times 10^{1} \text{ cm/sec}}{1 \text{ mile/hour}} \cdot \frac{3.05 \times 10^{1} \text{ cm}}{\text{ft}} \cdot \frac{6 \times 10^{1} \text{ sec}}{\text{min}} \tag{21}$$

$$Q(\text{curies}) = \frac{13.2\, R \left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot a\,(\text{ft}) \cdot \overline{U}\, \frac{\text{miles}}{\text{hour}} \cdot T\,(\text{min})}{B \int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta}$$

$$\cdot \left(\frac{\text{curies}}{\text{R/hr} \cdot \text{ft} \cdot \frac{\text{miles}}{\text{hour}} \cdot \text{min}}\right) \tag{22}$$

Again if

$$|\theta_{min}| \approx |\theta_{max}| \,,$$

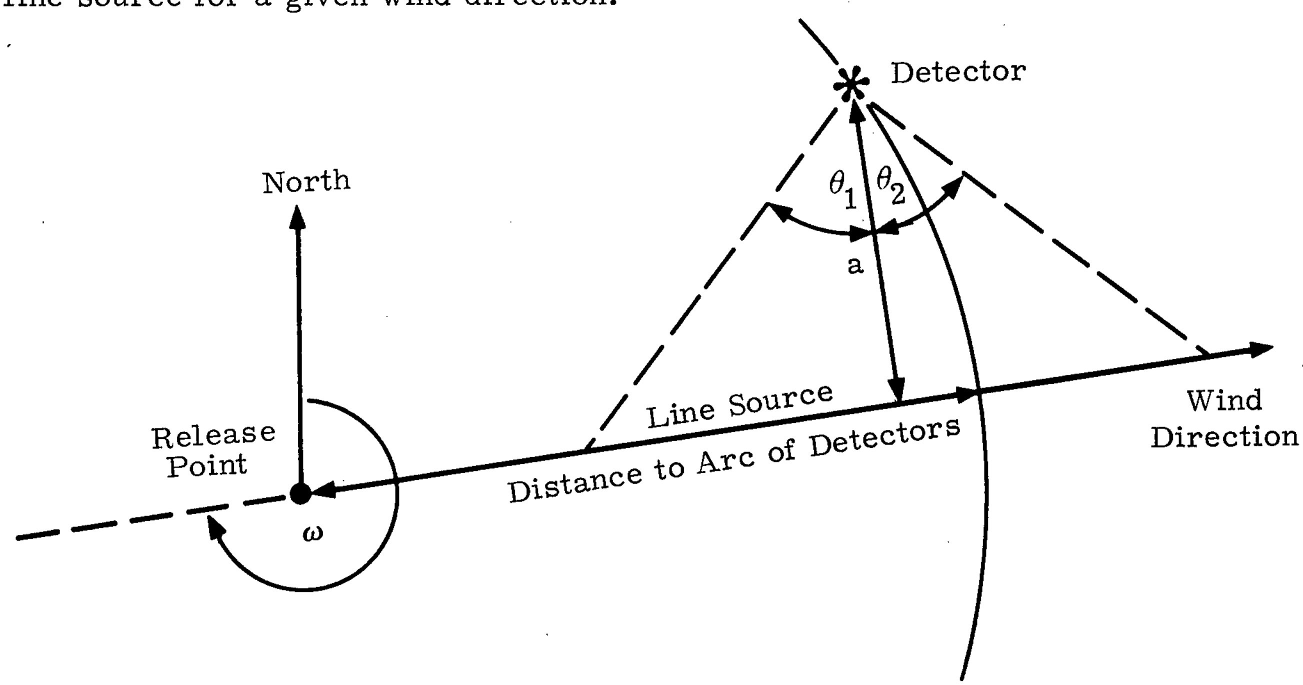
then

$$\int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta}\, d\theta \approx 2 \int_0^{|\theta_{min}| \text{ or } |\theta_{max}|} e^{-\mu a \sec\theta} d\theta$$

and the equation becomes

$$Q(\text{curies} \simeq \frac{6.6\ R\left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot a\ (\text{ft}) \cdot \overline{U}\left(\frac{\text{miles}}{\text{hour}}\right) \cdot T\ (\text{min})}{B \int_0^{|\theta_{min}|\ \text{or}\ |\theta_{max}|} e^{-\mu a \sec\theta}\, d\theta} \tag{23}$$

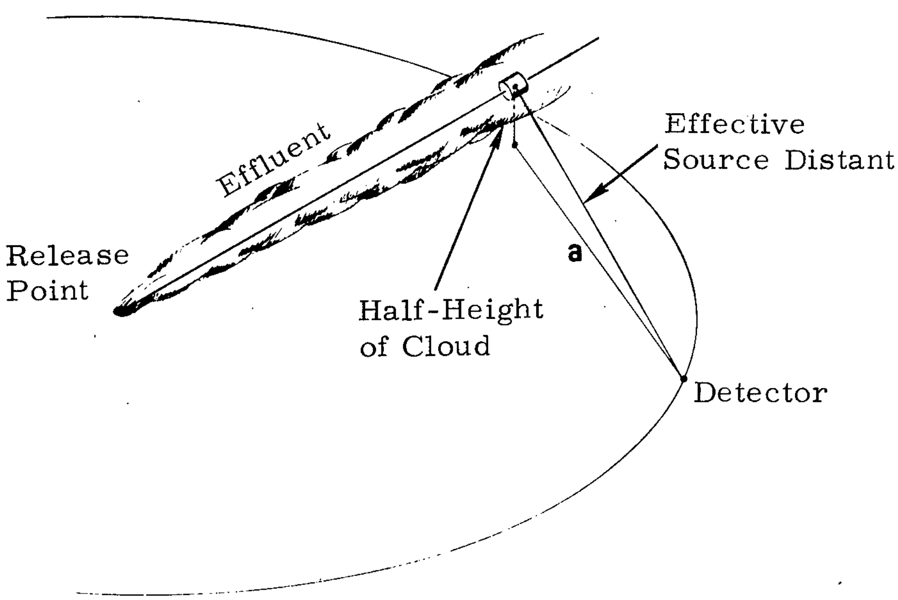
The factor a is determined by use of maps, drawn to scale, and the average value of the wind direction over the time period for which the calculations are made. The following diagram shows the relation of a detector to a line source for a given wind direction.



By use of ruler and protractor, the approximate position of the line source can be determined. The positioning of this line is arbitrary; however, the final values of Q determined by this method are usually an average of two or more detectors each having its own particular values for the parameters in the equation at the time the measurements are made.

Whenever possible optical measurements are obtained of the effluent cloud, thus giving more reliable values of dimensions and relative locations. However, the effluent is often not visible, nor does the visible cloud always necessarily correspond to the areas or locations of the radioactive effluent concentrations.

The a measured above may not necessarily be the effective source to detector distance. Diffusion of the effluent during the time of traversal of the distance from the point of release to the array of detectors may result in an effective source center of activity, assuming uniform concentration, and thus an effective source distance.

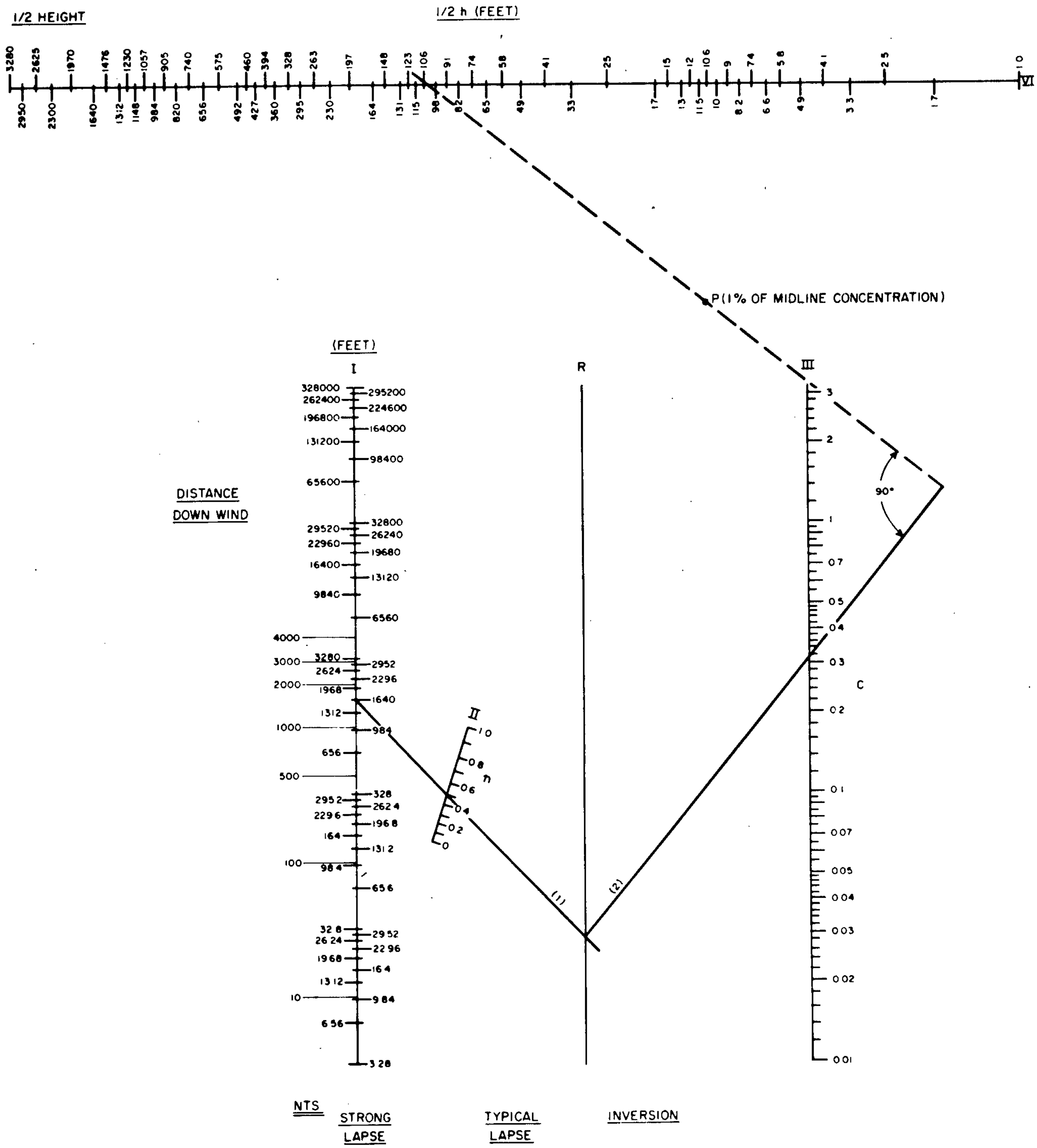


The extent of diffusion, of course, depends on the different meterological parameters. Figure 1 represents an attempt to simplify these determinations such that the effective source distance may be arrived at more rapidly.

The resultant figures are based entirely on theoretical considerations using those values for c and n for the Nevada Test Site shown on Figure 1.

The function $\int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta} d\theta$ must be evaluated for the different values of a and θ. These data are plotted in Figure 1-9, page 385 of Reference 1. Applying this function to a gaseous fission product effluent, using the average photon energy as 0.925 mev and a total attenuation coefficient of 8.19×10^{-5} cm^{-1}

MODIFIED FROM
METEOROLOGY AND ATOMIC ENERGY



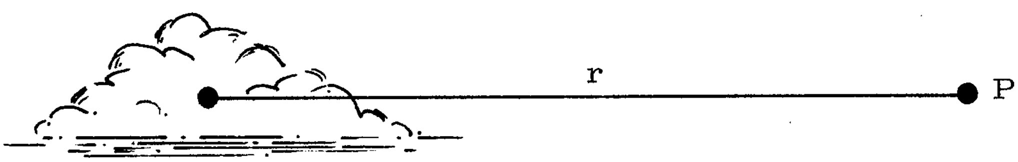
STRONG LAPSE	TYPICAL LAPSE	INVERSION
C = 0.5	C = 0.2	C = 0.05
n = 0.2	n = 0.25	n = 0.5

Figure 1. Nomograph for Determination of Half-Height of Cloud

(Reference 2), with the values of 1 meter $\lesssim$ a $\lesssim 10^3$ meters and $20° \lesssim \theta \lesssim 90°$, results in the data given in Table I. For convenience in its use for the solution of the preceding equations, $\dfrac{1}{\int e^{-\mu a \sec\theta} d\theta}$ is plotted versus θ for the selected values of a in Figure 2. In Table II, values are given for $\int e^{-\mu a \sec\theta}\, d\theta$ versus a for $\theta = 90°$. These data are plotted in Figure 3.

B. Point Source

For an isolated quantity of radioactivity in a geometrical configuration such that the dimension of the source is small compared to the distance from the source to the point of measurement, a point source equation may be used for the calculation.



(Cloud)

$$\phi = \frac{B\, S_o\, e^{-\mu r}}{4\pi\, r^2} \quad \text{(Reference 1)} \tag{24}$$

where

ϕ = flux at point of measurement P $\left(\dfrac{\text{photons}}{\text{cm}^2\ \text{sec}}\right)$

B = build-up factor

S_o = source strength $\left(\dfrac{\text{photons}}{\text{sec}}\right)$

μ = total attenuation coefficient (cm^{-1})

r = distance from source to point of measurement P (cm)

TABLE I

Values of $F(\theta, b) = \int_{\theta_{min}}^{\theta_{max}} e^{-\mu a \sec\theta} d\theta$, $b = \mu a$,

for selected values of a and θ

when $\mu = 8.19 \times 10^{-3}\ m^{-1}$

a	μa	$F(\theta, b)$ (θ = 20°)	$F(\theta, b)$ (θ = 40°)	$F(\theta, b)$ (θ = 60°)	$F(\theta, b)$ (θ = 90°)
10 m	8.19×10^{-2}	3.2×10^{-1}	6.4×10^{-1}	9.5×10^{-1}	1.3
25 m	2.05×10^{-1}	2.8×10^{-1}	5.6×10^{-1}	8.0×10^{-1}	1.0
50 m	4.1×10^{-1}	2.3×10^{-1}	4.4×10^{-1}	6.2×10^{-1}	7.2×10^{-1}
100 m	8.19×10^{-1}	1.4×10^{-1}	2.8×10^{-1}	3.8×10^{-1}	4.1×10^{-1}
200 m	1.64	6.4×10^{-2}	1.15×10^{-1}	1.4×10^{-1}	1.4×10^{-1}
300 m	2.46	2.8×10^{-2}	4.8×10^{-2}	5.6×10^{-2}	5.6×10^{-2}
400 m	3.28	1.23×10^{-2}	2.0×10^{-2}	2.2×10^{-2}	2.2×10^{-2}
500 m	4.10	5.3×10^{-3}	8.4×10^{-3}	9.2×10^{-3}	9.2×10^{-3}
600 m	4.91	2.3×10^{-3}	3.5×10^{-3}	3.8×10^{-3}	3.8×10^{-3}
800 m	6.55	4.3×10^{-4}	6.2×10^{-4}	6.4×10^{-4}	6.4×10^{-4}
1000 m	8.19	8.2×10^{-5}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}

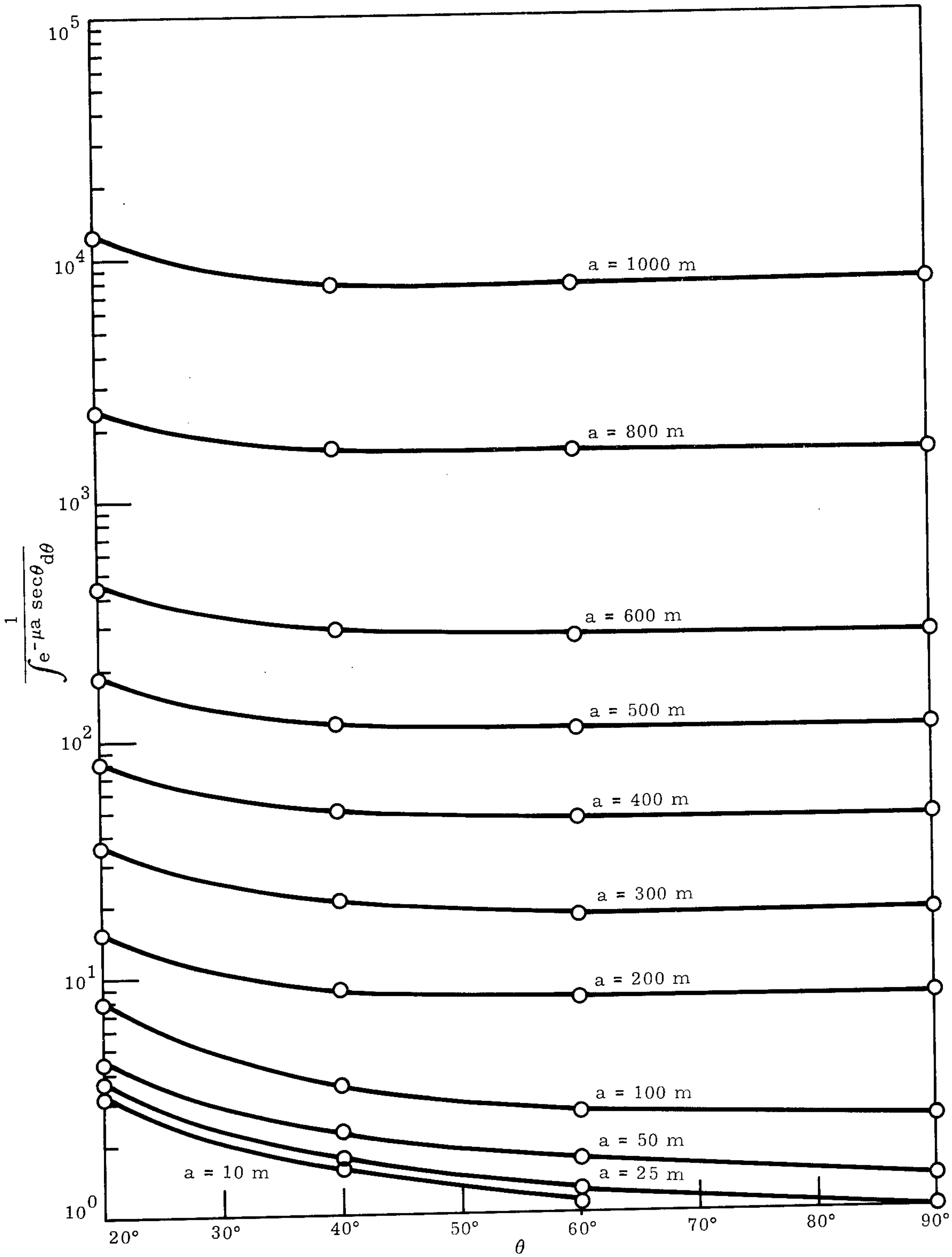


Figure 2. $\frac{1}{\int e^{-\mu a \sec\theta} d\theta}$ Versus θ for Selected Values of a

TABLE II

Values of $F(\theta, b) = \int e^{-\mu a \sec\theta} d\theta$, $b = \mu a$,

for selected values of a when

$\theta = 90°$ and $\mu = 8.19 \times 10^{-3} m^{-1}$

a (feet)	$F(\theta, b)$	a (feet)	$F(\theta, b)$	a (feet)	$F(\theta, b)$
1	1.5	1100	4×10^{-2}	2500	9×10^{-4}
25	1.35	1200	3.1×10^{-2}	2600	6.8×10^{-4}
50	1.18	1300	2.3×10^{-2}	2700	5.2×10^{-4}
75	1.08	1400	1.75×10^{-2}	2800	4×10^{-4}
100	9.4×10^{-1}	1500	1.35×10^{-2}	2900	3.1×10^{-4}
200	6.2×10^{-1}	1600	1.2×10^{-2}	3000	2.4×10^{-4}
300	4.5×10^{-1}	1700	7.8×10^{-3}	3100	1.8×10^{-4}
400	3.3×10^{-1}	1800	6×10^{-3}	3200	1.4×10^{-4}
500	2.35×10^{-1}	1900	4.5×10^{-3}	3300	1.05×10^{-4}
600	1.75×10^{-1}	2000	3.4×10^{-3}		
700	1.25×10^{-1}	2100	2.6×10^{-3}		
800	9.5×10^{-2}	2200	2×10^{-3}		
900	7×10^{-2}	2300	1.5×10^{-3}		
1000	5.4×10^{-2}	2400	1.15×10^{-3}		

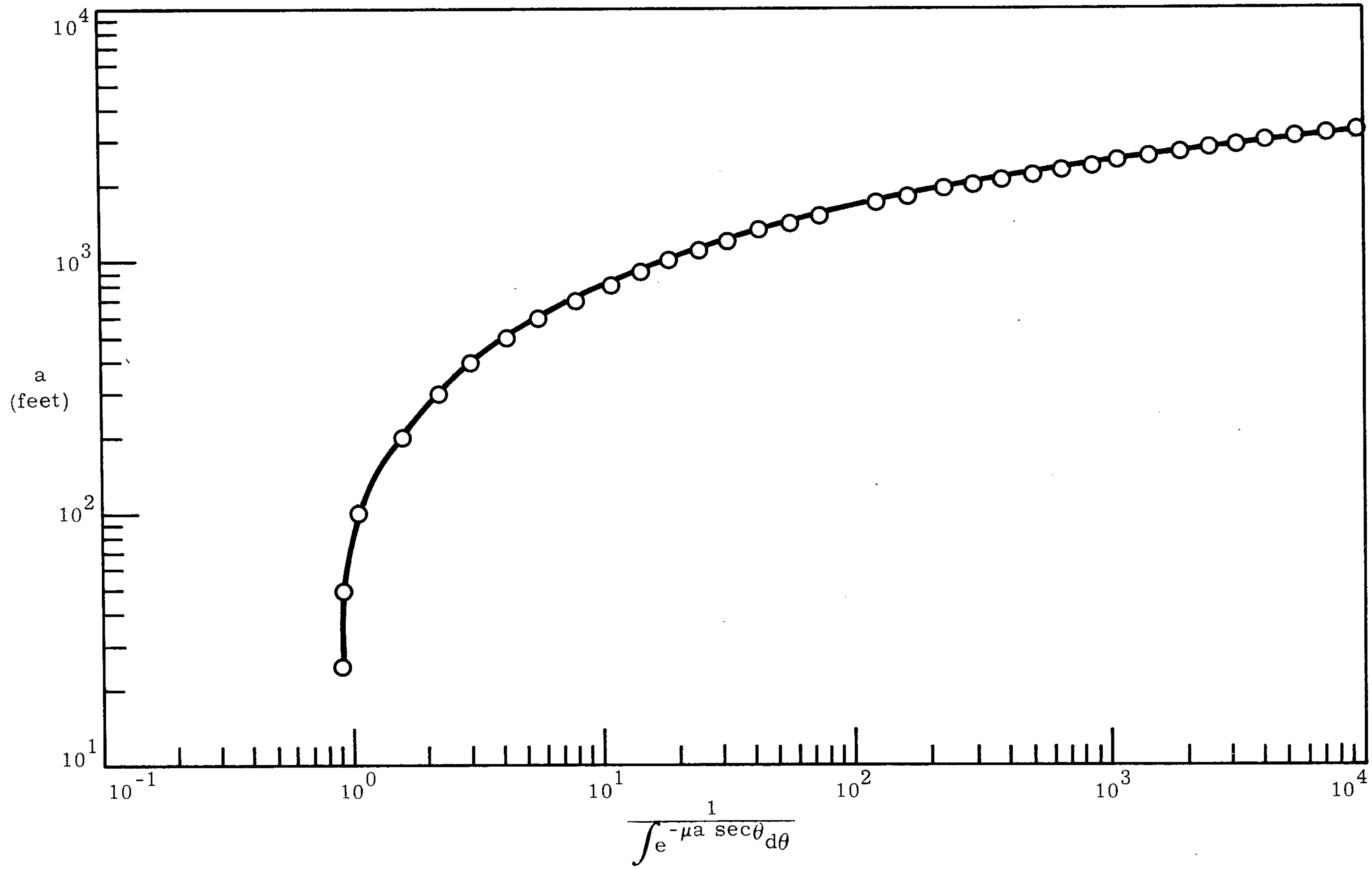


Figure 3. $\frac{1}{\int e^{-\mu a \sec\theta} d\theta}$ Versus a for θ = 90°

By the same reasoning and the same conditions as previously used,

$$Q(\text{curies}) = \frac{5.7 \times 10^5 \left(\frac{\text{photons hour}}{\text{roentgens cm}^2 \text{ sec}}\right) \cdot R \left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot 4\pi r^2 \ (\text{cm}^2)}{3.7 \times 10^{10} \left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 1.19 \left(\frac{\text{photon}}{\text{dis}}\right) \cdot B \cdot e^{-\mu r}} \tag{25}$$

$$Q(\text{curies}) = \frac{1.63 \times 10^{-4} \cdot R \left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot r^2 (\text{cm}^2)}{B \cdot e^{-\mu r}} \cdot \left(\frac{\text{curies}}{\text{R/hr cm}^2} \cdot \frac{9.29 \times 10^2 \text{ cm}^2}{\text{ft}^2}\right) \tag{26}$$

$$Q(\text{curies}) = \frac{1.51 \times 10^{-1} R \left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot r^2 \ (\text{ft}^2)}{B \cdot e^{-\mu r}} \cdot \left(\frac{\text{curies}}{\text{R/hr ft}^2}\right) \tag{27}$$

The function $\frac{1}{e^{-\mu r}}$ or $e^{\mu r}$ is plotted versus r in Figure 4 to facilitate the determination of Q.

The responses of selected detectors are continuously recorded such that average radiation dose rates over the time of effluent release may be obtained.

The wind speed and direction are also continuously recorded. In addition to this information, surveyors are also available to provide physical measurements of visible effluents. Cloud dimensions of height and width versus time are obtained and relayed via telephone, and this information often provides the basis for selection of the model used in arriving at the estimate of activity contained in the effluent.

Again, the values used in these equations apply only to gross fission products for a particular period of time. For fractional releases, the values

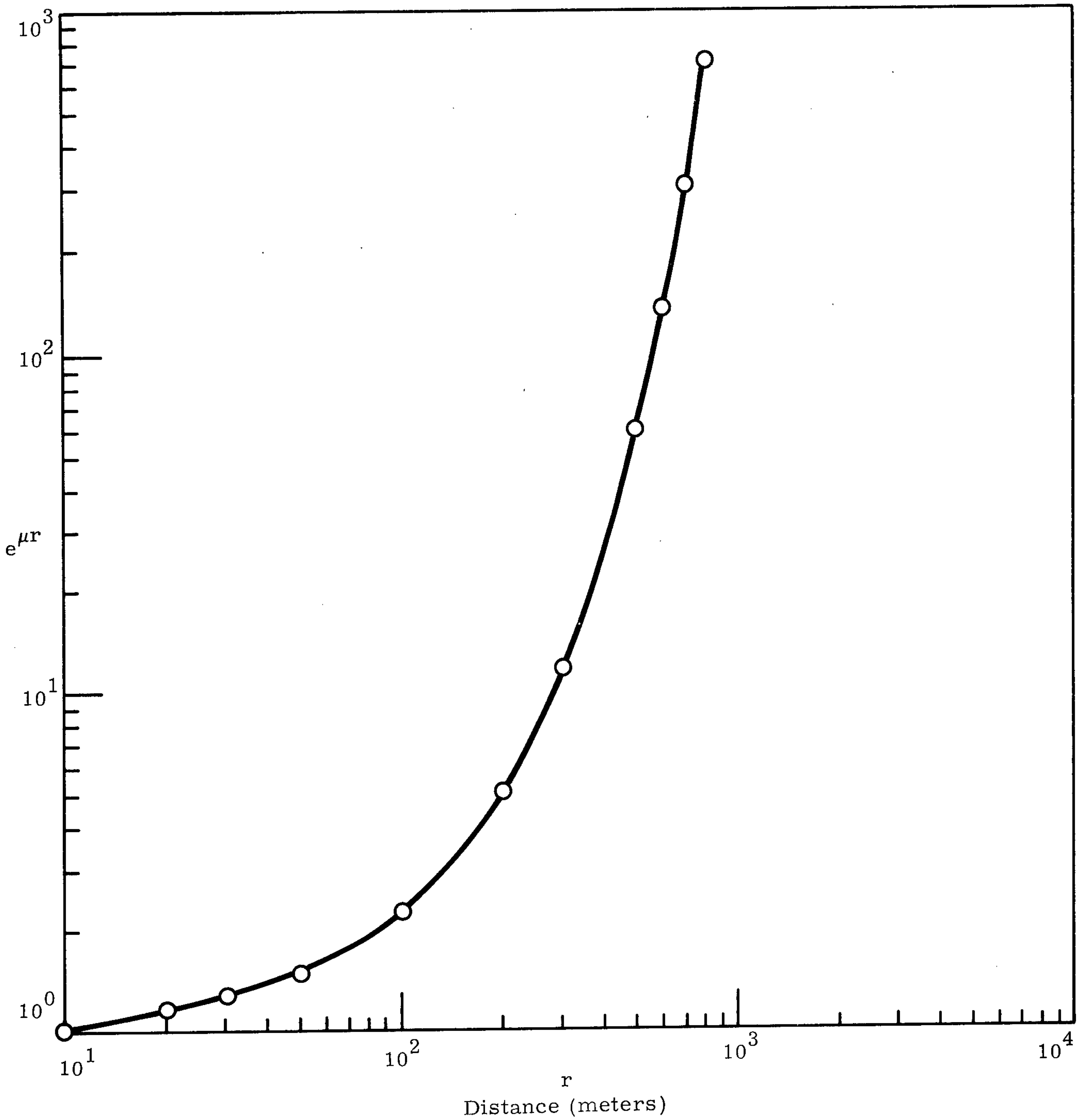


Figure 4. $e^{\mu r}$ Versus r for $\mu = 8.19 \times 10^{-3}\ m^{-1}$

used depend on the constituents of the effluent and these values will change with time.

III. Activities of Certain Effluent Constituents

The nuclides of frequent interest are the isotopes of iodine, xenon, and krypton. The activities of particular isotopes of these nuclides contribute predominantly to certain types of effluent release. Therefore, it is of importance to know the maximum possible activities which might possibly be present at a given time.

The activity curves for each of the nuclides shown in Figure 5 were derived from the data given by Bolles and Ballou (Reference 5). The listed activities as a function of time were converted to curies per kiloton as follows:

$$\text{Activity}\left(\frac{\text{curies}}{\text{kiloton}}\right) = \frac{\overset{\text{(Ref. 5)}}{\dfrac{\text{activity (dis/sec)}}{10^4 \text{ fissions}}} \cdot 1.45 \times 10^{23} \overset{\text{(Ref. 6)}}{\left(\dfrac{\text{fissions}}{\text{kiloton}}\right)}}{3.7 \times 10^{10}\left(\dfrac{\text{dis/sec}}{\text{curie}}\right)} \tag{28}$$

$$\text{Activity}\left(\frac{\text{curies}}{\text{kiloton}}\right) = 3.92 \times 10^8 \cdot \frac{\text{activity (dis/sec)}}{10^4 \text{ fissions}} \tag{29}$$

These data represent only those activities resulting from thermal fission of U-235. Frequently, comparisons of yields of these nuclides from other types of fission processes must be considered.

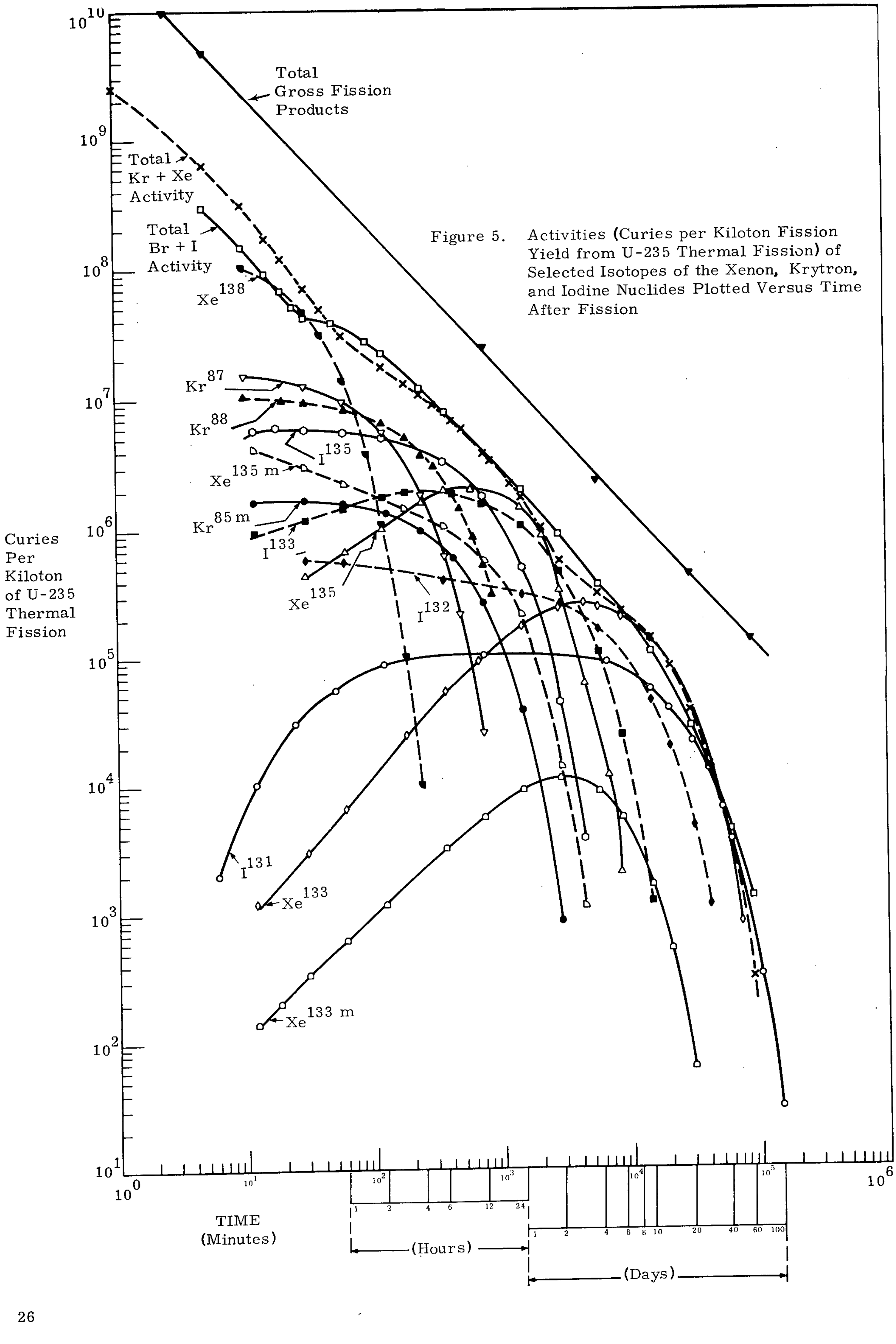


Figure 5. Activities (Curies per Kiloton Fission Yield from U-235 Thermal Fission) of Selected Isotopes of the Xenon, Krytron, and Iodine Nuclides Plotted Versus Time After Fission

Curves similar to those in Figure 5 may be prepared for the various fission processes. Presently, however, comparisons of total chain and independent fission yields may be made for the listed nuclides by use of Table III (Reference 7). This table gives the total number of atoms of each nuclide resulting from 10^4 fissions of each process.

IV. Ventilation Exhaust Calculations

When an effluent is discharged in a controlled manner, particulate and charcoal filters are employed. The resultant constituents of the gaseous discharge are the isotopes of xenon and krypton. The quantity of these gases which is released over a period of time may be determined by use of the following equations.

The radiation dose-rate reading of the detector is proportional to the energy fluence rate resulting from a given volume of radioactive gases emitting the radiations.

$$dR\left(\frac{\text{roentgens}}{\text{hour}}\right) = \frac{A\left(\frac{\mu c}{\text{cm}^3}\right) \cdot 3.7 \times 110^{10}\left(\frac{\text{dis}}{\text{curie sec}}\right) \cdot 10^{-6}\left(\frac{\text{curie}}{\mu c}\right)}{1} \cdot$$

$$\frac{1.19\left(\frac{\text{photon}}{\text{dis}}\right) \cdot 1\,\frac{\text{mev}}{\text{photon}} \cdot}{5.5 \times 10^5\left(\frac{\text{mev hour}}{\text{photons cm}^2\text{ sec}}\right)}\text{(Ref. 3)}$$

$$\frac{e^{-\mu r} \cdot dV\,(\text{cm}^3)}{4\pi\, r^2\,(\text{cm}^2)} \tag{30}$$

TABLE III

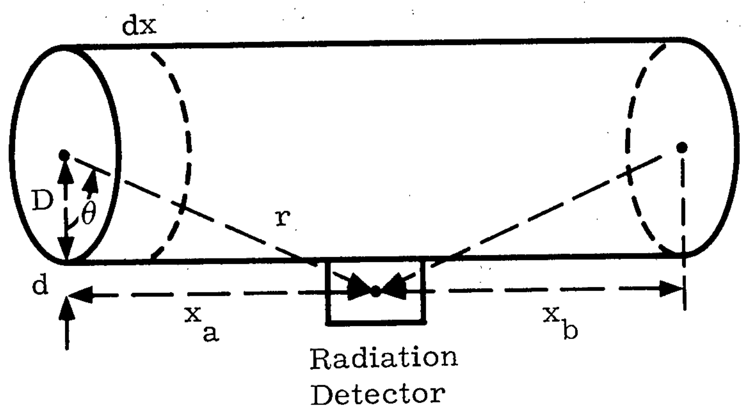
Total Number of Atoms of Selected Nuclides Resulting from 10^4 Fissions of Several Different Fission Processes (Reference 7)

	U^{235} (thermal)	Pu^{239} (thermal)	U^{235} (14 mev)	Pu^{239} (14 mev)	U^{235} (Fast)	Pu^{239} (Fast)
Xe^{133}		1.3036	3.1899	8.5891		1.0964
Xe^{135}	93.0372	135.3368	132.4311	165.6841	54.8015	125.8819
Xe^{138}	275.1100	288.5859	210.7298	210.4086	300.9506	280.1888
Kr^{85}	1.1104	1.3335	9.8598	6.1293	1.0371	1.7258
Kr^{87}	32.8131	18.8078	67.7622	36.0846	32.9419	29.1356
Kr^{88}	86.9348	43.1884	127.5979	68.3066	83.6765	44.0587
I^{131}	0.9454	4.6273	12.6631	17.8898	1.1794	5.6139
I^{132}	16.7067	29.8537	41.5660	50.4168	19.4194	29.8462
I^{133}	64.4258	91.6509	93.4751	107.7455	54.2931	76.8489
I^{135}	285.1140	329.3860	260.9957	263.2649	236.8970	304.5531

$$R\left(\frac{\text{roentgens}}{\text{hour}}\right) = 6.4 \times 10^{-3}\, A\left(\frac{\mu c}{cm^3}\right)\int \frac{dV}{r^2}\,(cm)\cdot\left(\frac{R/hr\ cm^2}{\mu c}\right) \tag{31}$$

The factor of $e^{-\mu r}$ is considered to be a relatively insignificant correction under these particular conditions since other uncontrollable factors contribute greater errors in the calculations. The value of $\overline{E}_{\gamma}$ = 1 mev was used purposefully in this expression. As the relative composition of the effluent changes with time, the effective energy changes and thus it is a simple matter to make the energy corrections when necessary.

A radiation detector is placed adjacent to a section of exhaust pipe as shown below:



An approximate solution to the function $\int \frac{dV}{r^2}$ in terms of this diagram is as follows:

$$V = \pi D^2 X \tag{32}$$

$$r^2 = (D + d)^2 + X^2 \tag{33}$$

$$dV = \pi D^2\, dx \tag{34}$$

$$\int \frac{dV}{r^2} = \int \frac{\pi D^2 \, dx}{(D+d)^2 + X^2} = \pi D^2 \int_{-x_b}^{x_a} \frac{dx}{(D+d)^2 + X^2} \tag{35}$$

$$\int \frac{dV}{r^2} = \pi D^2 \left[\left(\frac{1}{D+d} \text{ arc tan } \frac{x_a}{D+d} \right) + \left(\frac{1}{D+d} \text{ arc tan } \frac{x_b}{D+d} \right) \right] \tag{36}$$

$$\int \frac{dV}{r^2} = \frac{\pi D^2}{D+d} \left(\text{arc tan } \frac{x_a}{D+d} + \text{arc tan } \frac{x_b}{D+d} \right) \tag{37}$$

Equation 31 may be rearranged and converted to English units.

$$A\left(\frac{\mu c}{cm^3}\right) = \frac{\left(\frac{\text{roentgens}}{\text{hour}}\right)}{6.4 \times 10^{-3} \cdot \int \frac{dV}{r^2} \, (cm)} \cdot \left(\frac{\mu c \text{ cm}}{R/hr \text{ cm}^3} \cdot \frac{\text{curie}}{10^6 \mu c} \cdot \frac{2.8 \times 10^4 \text{ cm}^3}{ft^3} \right)$$

$$\times \left(\frac{ft}{3.05 \times 10^1 \text{ cm}} \right) \tag{38}$$

$$A\left(\frac{\text{curies}}{ft^3}\right) = \frac{1.45 \times 10^{-1} R \left(\frac{\text{roentgens}}{\text{hour}}\right)}{\int \frac{dV}{r^2} \, (ft)} \cdot \left(\frac{\text{curies}}{R/hr \text{ ft}^2} \right) \tag{39}$$

When effluent is being discharged, the activity exhausted is simply:

$$Q(\text{curies}) = \frac{1.45 \times 10^{-1}\ R\left(\frac{\text{roentgens}}{\text{hour}}\right) \cdot W\left(\frac{\text{ft}^3}{\text{min}}\right) \cdot T\ (\text{min})}{\int \frac{dV}{r^2}\ (\text{ft})} \cdot \left(\frac{\text{curies}}{R/\text{hr ft}^2}\right) \quad (40)$$

LIST OF REFERENCES

1. TID-7004, "Reactor Shielding Design Manual," Theodore Rockwell III.

2. USNRDL-TR-187, "Gamma Decay of Fission Products from the Slow Neutron Fission of U-235," C. F. Miller.

3. Radiological Health Handbook, "Gamma Flux Equivalent to One Roentgen Hour^{-1} as a Function of Gamma Energy," page 140.

4. "Nuclear Explosions and Their Effects," Jawaharlal Nehru, The Publications Division, Ministry of Information and Broadcasting, Government of India.

5. USNRDL-456, "Calculated Activities and Abundances of U-235 Fission Products," R. C. Bolles, N. E. Ballou.

6. "Effects of Nuclear Weapons," Samuel Glasstone, Ed., Revised Edition, 1964.

7. USNRDL-TR-633, "Estimated Total Chain and Independent Fission Yields for Several Neutron Induced Fission Processes," L. E. Weaver, P. O. Strom, P. A. Killeen.

DISTRIBUTION:
UC-41, TID-4500(53rd Ed.) (295)

Los Alamos Scientific Laboratory (2)
P.O. Box 1663
Los Alamos, New Mexico 87544
Attn: H. S. Jordan, H-8
J. E. Dummer, H-8

University of California
Lawrence Radiation Laboratory
P.O. Box 808
Livermore, California 94550
Attn: B. Rich

University of California
Lawrence Radiation Laboratory
P.O. Box 45
Mercury, Nevada 89023
Attn: B. King

REECo Radiological Sciences Dept.
Mercury, Nevada 89023
Attn: V. Milligan
A. Western

W. H. Kingsley, 3310
W. D. Burnett, 3311
H. L. Rarrick, 3312 (10)
H. D. Abbott, 3312
H. D. Christiansen, 3312
B. L. O'Neal, 3312
G. R. Wenz, 3312
J. Metcalf, 3312
C. S. Selvage, 8180
M. O. Jones, 8184
C. H. DeSelm, 8200
M. L. Glaze, 8260
P. K. Lovell, 8263 (3)
P. O. Matthews, 8263 (15)
B. F. Murphy, 9100
C. D. Broyles, 9110
W. D. Weart, 9111
A. D. Thornbrough, 9135
W. F. Carstens, 3410
Attn: R. S. Gillespie, 3411 (1)
W. J. Wagoner, 3413 (2)
B. R. Allen, 3421
B. F. Hefley, 8232
C. H. Sproul, 3428-2 (25)

r-d