

APPENDIX F

ESTIMATING ATMOSPHERIC ENVIRONMENTAL EFFECTS

Because the Savannah River Plant is a large nuclear complex engaged in varied activities, there are some continuous and intermittent releases of radioactive gases and particulates to the atmosphere. Although SRP has an extensive monitoring system, an environmental model is needed to estimate effects of radioactive releases to the environment and potential effects from postulated accidental releases. The modeling system is required for basically two reasons:

- Most releases lead to very low concentrations and may not be detectable.
- Accounting for all releases by environmental monitoring methods alone is difficult, even if the releases were detectable.

Mathematical models have been developed which provide estimates of the effect of radioactive releases to the environment. Some of the models can account for the effects of the very small continuous and intermittent releases of radioactive material to the atmosphere which are a consequence of routine production activity. Real time models (models which can provide immediate results and predictions) can be used to evaluate potential effects of accidental release of radioactive material to the atmosphere and to predict the distribution of the dispersed radionuclides. These models are based on measured meteorological parameters for determination of transport and diffusion of atmospheric pollutants and have been validated against information obtained during special tests and data collection exercises based at the Savannah River Plant.

ANNUAL RELEASES

The environmental model in use at SRP is diagrammatically presented in Figure F-1. The first objective in developing the model was to obtain a library of data representing an estimate of annually averaged azimuthal and radial distributions of released material. This library is based on air concentrations at ground level for each isotope considered and whole body dose estimates for discrete gamma energies that were spatially distributed.

The meteorological data were obtained from instrumentation installed on the WJBF-TV tower located approximately 30 km northwest of the geometric center of SRP. For modeling purposes, the data were assumed to be applicable to any release point of interest within the general area, including offsite release points. The meteorological data and calculational techniques are described more fully in DP-1163.¹ Additional analysis of the data and discussion of calculational techniques is given in DP-1341.²

Annually averaged concentrations in air were estimated for each isotope individually by processing the meteorological data assuming a unit release (1 curie) for each data period (15 minute averages). Ground-level concentrations were accumulated as a function of azimuth and radial distance from an arbitrary origin based on a grid overlay of SRP and environs. At the end of this procedure, i.e., after all meteorological data for the two-year period had been processed, the accumulated concentrations were divided by the total number of data periods represented. The result was a quantity representing a yearly integrated concentration associated with each grid point assuming a unit curie release over the year. These quantities were corrected for decay according to isotope and measured meteorology for each data period.

Whole body dose calculations were performed by processing the meteorological data in a similar fashion. However, the calculations were significantly more complex as the gamma dose to a receptor may be strongly dependent on the total spatial distribution about the receptor and may not be necessarily related to ground-level concentration. To minimize computations and at the same time have a library of data covering the usually encountered spectrum of gamma energies, the calculations were performed for discrete gamma energies rather than for specific isotopes. This also provided an efficient method of treating multiple energies from individual isotopes when desired.

Because the gamma calculations are isotope independent, the library data need not be corrected for decay, but a correction is made when the data are utilized later. The calculations are normalized to a unit curie release of discrete gamma energies over the range of 0.01 through 5.0 Mev.

At this point the library consists of isotope and gamma energy data originating from an arbitrary point. To relate these data to a specific population grid to facilitate man-rem calculations, the library data are reprocessed. In this processing, each source to be treated as a separate entity is assumed to be the origin of material distributions, and a population grid centered about SRP is assumed to be exposed. Thus, a new library is constructed that contains annually averaged data that is source specific, but always with respect to the same fixed population grid.

Man-rem calculations are performed by processing the library data according to source point and release magnitude; the results are applied to the population distribution (Figure F-2). Multiple source points may be considered within a single pass to estimate total man-rem exposure from sources separated by relatively large distances. In addition, multiple gamma energies may be input for individual isotopic species. Decay corrections are then applied to the gamma calculations. Some of the isotopes being considered from each source point, particularly tritium and ^{85}Kr , may be assumed for practical purposes to have infinite half-lives over the time intervals of interest, i.e., transport times out to a maximum of 150 km. For any particular isotopic species whose decay is significant, a decay correction for each grid point is simply determined as the ratio of ground level concentrations with respect to a long-lived isotope from the same source.

A glossary of terms used in this appendix is found in Table F-1.

MODELING EQUATIONS

All ground-level air concentration calculations are based on a sector-averaged Gaussian plume model with a finite mixing depth imposed

$$X/Q = \frac{2N}{(2\pi)^{3/2} \sigma_z \bar{u} x} \sum_{m=0}^{\infty} \left\{ \exp \left[- \left(\frac{2mH+h}{\sqrt{2} \sigma_z} \right)^2 \right] + \exp \left[- \left(\frac{2mH-h}{\sqrt{2} \sigma_z} \right)^2 \right] \right\} \quad (1)$$

where N = number of azimuthal subdivisions or sectors

σ_z = standard deviation of material distribution in the vertical, m

H = mixing depth, m

h = release height, m

X/Q = concentration per unit source, sec/m^3

x = downwind distance

\bar{u} = effective wind speed, m/sec

A plot of the annual average unit concentration (χ/Q) for an arbitrary center of distribution in the SRP Area and a 70-meter release height is given in Figure F-3; the plot shown is for long-lived isotopes, and assumes no radioactive decay.

An average mixing depth of 300 m was used in all these calculations. This value of the mixing depth provides good agreement between calculations and experimental tritium concentration measurements over 12 years but does not imply the actual existence of an average mixing depth of 300 m. If gravitational settling is assumed, there are no ground reflections, and the plume is assumed to be tilted downward from the horizontal according to settling velocity:

$$\chi/Q = \left(\frac{N}{(2\pi)^{3/2} \sigma_z \bar{u} x} \right) \left\{ \exp \left(- \frac{(h-xV_g/\bar{u})^2}{2\sigma_z^2} \right) + \exp \left(- \frac{(2H-h+xV_g/\bar{u})^2}{2\sigma_z^2} \right) \right\} \quad (2)$$

where V_g = gravitational settling velocity, m/sec

When chemical dry deposition is assumed, as for iodines, Equation 1 must be modified to account for depletion. Chemical dry deposition is generally assumed to result in plume depletion in a manner that leaves the remaining material distribution unaltered. Thus, Equation 1 must be multiplied by a fraction representing the material remaining in the plume as a function of distance. This can be accomplished by integrating total deposition out to the distance of interest to obtain the ratio of the material remaining to that from the original source. Due to the form of the integral expression, it has to be evaluated by numerical means for each new calculation. Rather than devoting a large amount of computational time in this manner, a simple approach was taken that depleted the source by radial increments. At each radial grid point of each sector, the estimated concentration is assumed to apply over an area represented by that point. The source term for each point is then determined as

$$Q'(x_i) = Q(0) - V_d \sum_{j=1}^{i-1} Q'(x_j) A_j, \quad i \geq 2 \quad (3)$$

where A_j = area represented by grid point j in m^2 and

$Q(0)$ = the original source which applies at the 1st ($i=1$) radial increment in each sector.

Calculations involving gamma photon emissions are complicated by the fact that a receptor need not be near the material to receive exposure. For an elevated source under stable meteorological conditions, significant exposure (at downwind distances of several kilometers) may be received from material passing overhead. A computer program, EGAD,³ was developed for the specific purpose of accounting for the spatial distribution of gamma photon emissions in the geometry required for this application. The expression solved in EGAD is

$$D = \frac{Q_y}{2\pi} \int_{z=0}^H f(z) \cdot \int_{y=0}^{\infty} \frac{G(\mu a)}{a} dydz \quad (4)$$

where D is related to total integrated dose from Q_y photons.

The first integral expression represents the spatial distribution with ground and inversion reflections. The second expression, which is an analytical integration with respect to x , accounts for attenuation and buildup in air where

μ = linear attenuation coefficient for air, m^{-1}

a = distance from spatial point to receptor = $\sqrt{x^2 + y^2}$, m

This program was used to generate the gamma library for incremental gamma energies from 0.01 to 5 MeV.

The SRP program considers many pathways to man resulting from atmospheric releases. All pathways, except whole body gamma doses, have dose conversion factors relating all dose calculations to estimated ground-level concentrations as contained in the library data. Results of these estimates are presented in Section III.

Results of current operations (1975 releases) indicate the total man-rem exposure to the local population out to 100 km is about 0.15% of that received from naturally occurring radioactivity.

POSTULATED ACCIDENTAL RELEASES

Consequences of accidental releases of radioactive material to the atmosphere are determined by using the same meteorological data base as described above. Because postulated accidents are being considered, it is necessary to provide estimates of consequences for the full spectrum of meteorological conditions that could occur. This is accomplished by assuming an accident occurs for each 15-minute averaged set of meteorological parameters constituting the data base and estimating the consequences for each set. After estimates are obtained for the entire two-year period, cumulative probability estimates are obtained that relate consequence magnitude to the frequency that the given magnitude would not be exceeded. The frequencies are given in terms of percentiles. For instance, the consequence magnitude at the 95th percentile would be a magnitude that would not be exceeded for 95% of the meteorological conditions under which the accident could occur.

In the case of a chemical explosion in a waste tank (page III-103) the material is assumed to be released instantaneously and influenced by gravitational settling. Under these conditions the governing equation is

$$\chi/Q = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp \left\{ \frac{-1}{2} \left[\frac{\left(H - \frac{xV}{\bar{u}} \right)^2}{\sigma_z^2} \right] \right\} \quad (5)$$

where σ_y is the standard deviation of material distribution horizontally.

If it is assumed that the material is released at a height such that the plume axis intersects the ground at the plant boundary the above equation reduces to

$$\chi/Q = 1/2\pi\sigma_y\sigma_z\bar{u} \quad (6)$$

which is equivalent to assuming a ground level release without gravitational settling or ground reflection.

Equation 6 was therefore used to provide a conservative estimate by maximizing χ/Q at the plant boundary irrespective of particle size and gravitational settling properties. A graph of this equation is shown in Figure F-4 for the 95th percentile as a function of distance.

In case of actual accidental release to the atmosphere, real-time meteorological data are available from sensors located throughout the plant. These data are used as input to models which allow rapid determination of the downwind concentrations of these atmospheric releases. Details of these accidental release models are to be found in DP-1412.⁴

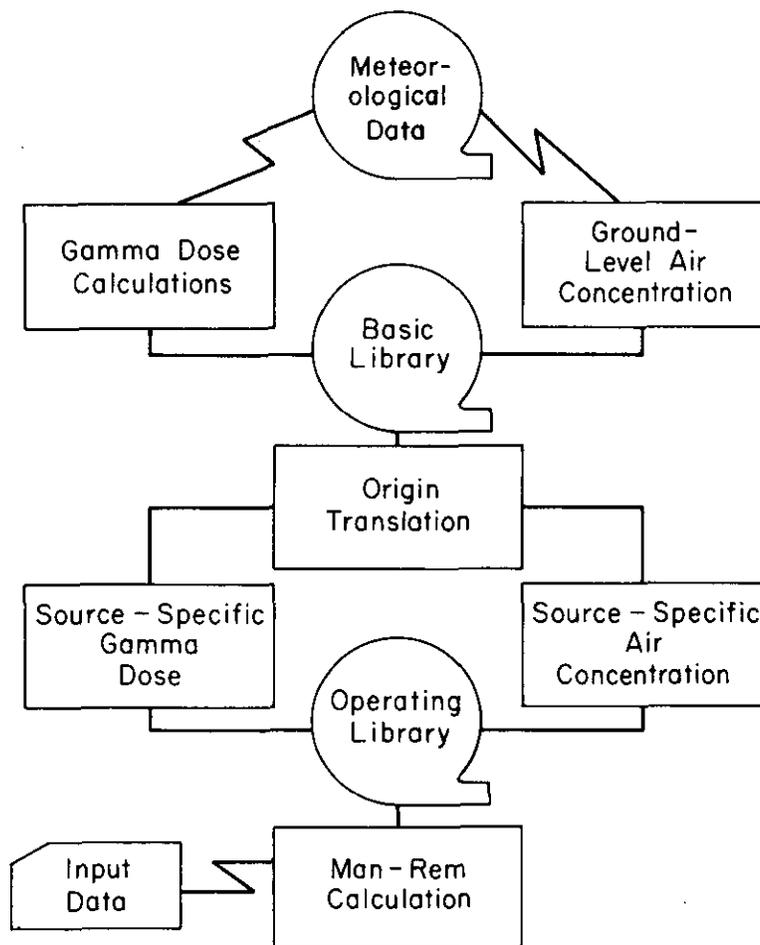


FIGURE F-1. Man-Rem Calculation Procedures

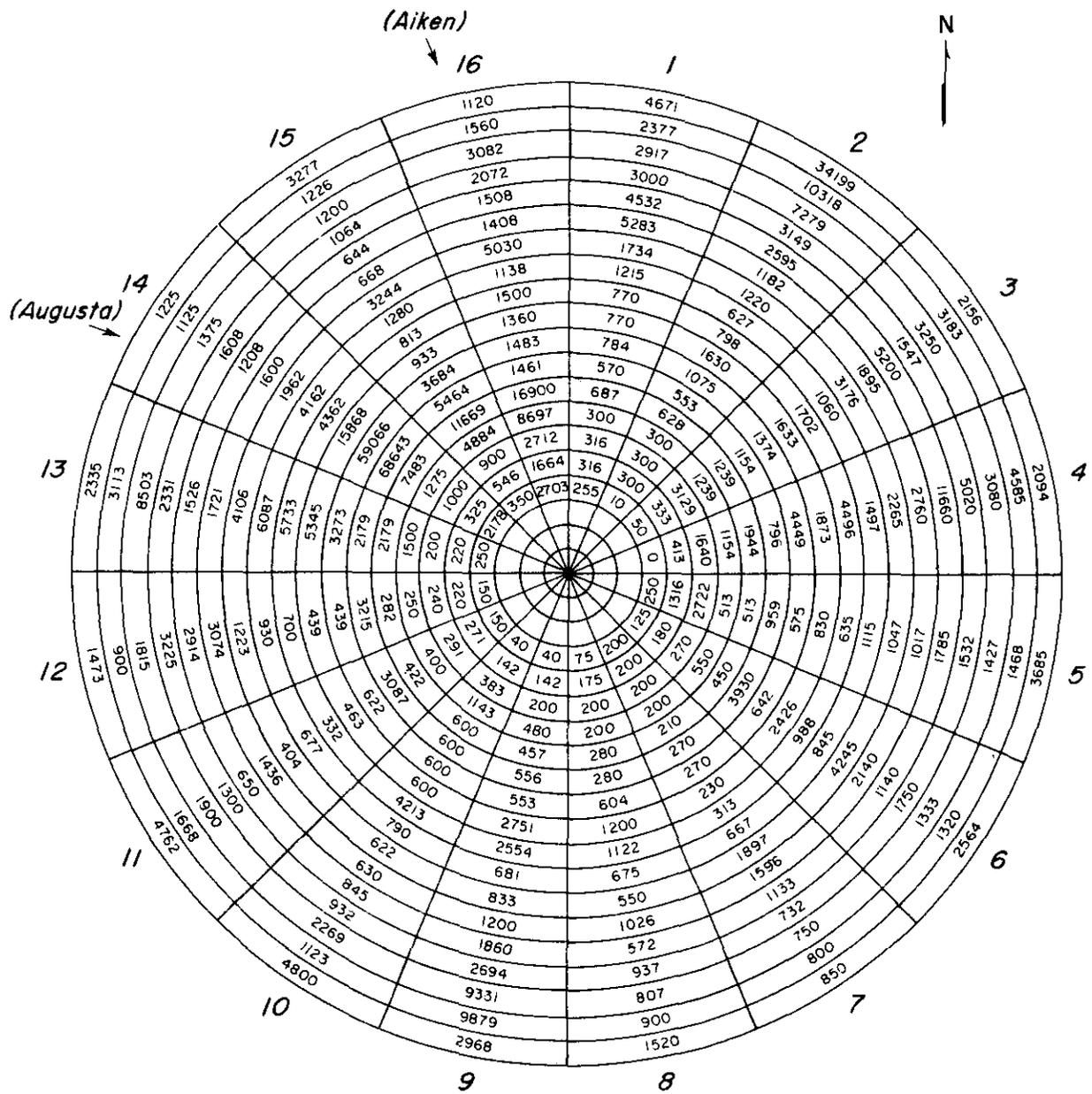


FIGURE F-2. Distribution of Population in Region Surrounding the Savannah River Plant (Radial Increments = 5 km, 22.5° Sector) 1970 Census

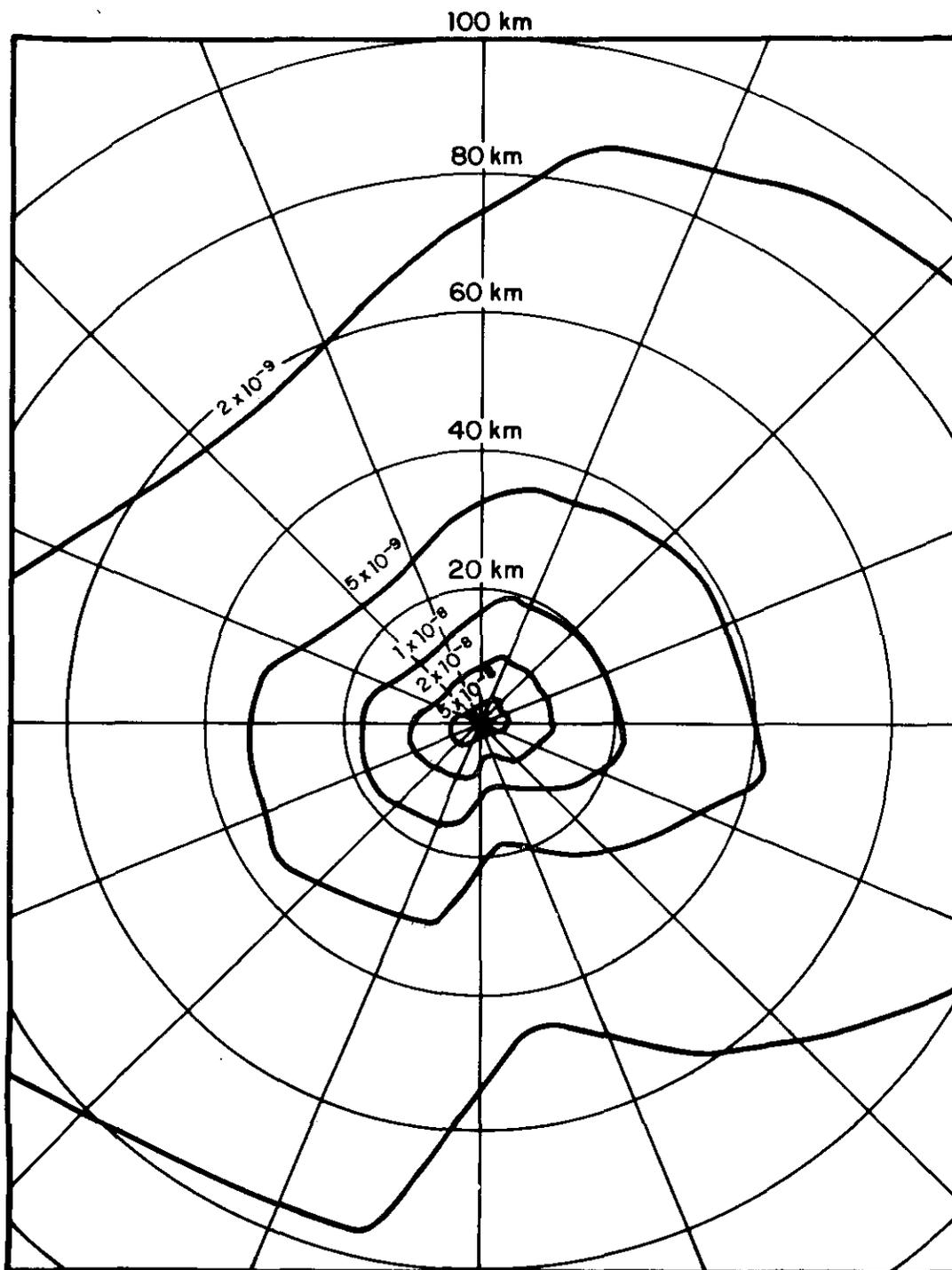


FIGURE F-3. Annual Average Unit Concentration (χ/Q), 70-meter release height with no radioactive decay.

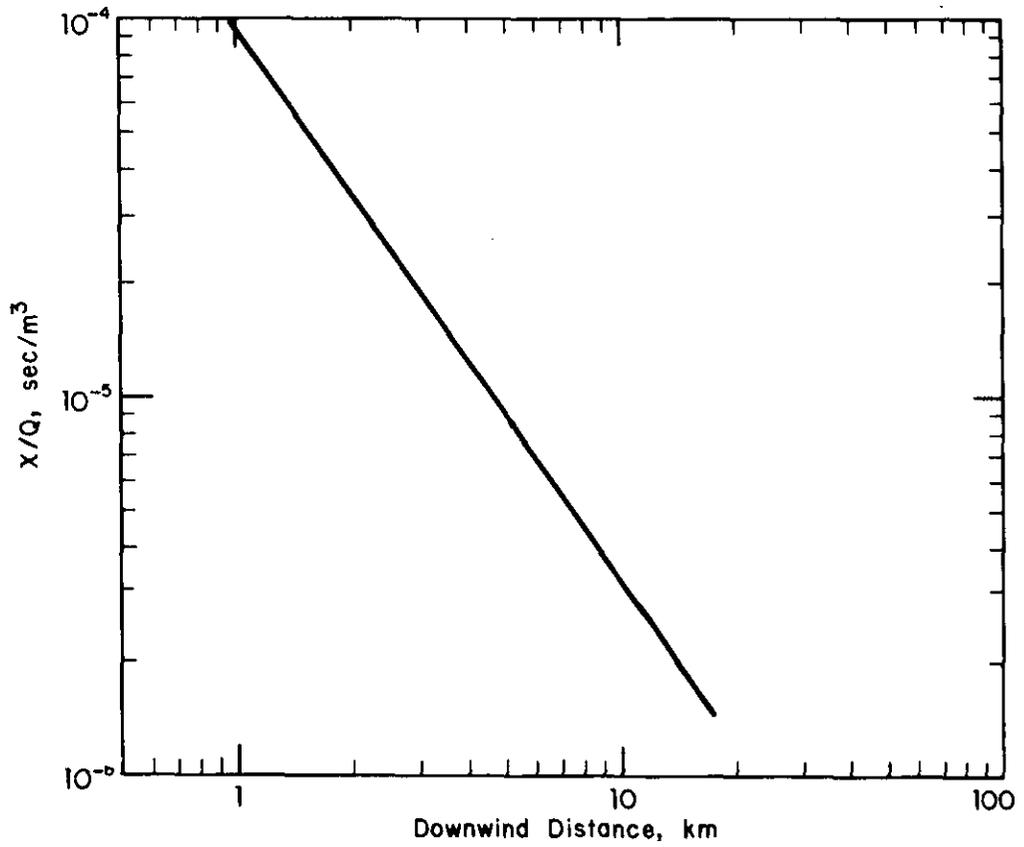


FIGURE F-4. Unit Concentration (χ/Q) vs Distance
Ground Level Release
95th Percentile Meteorology

TABLE F-1

Glossary of Terms Used in Modeling Equations

- a - distance from spatial point to receptor, m
- A_j - area represented by grid point j, m^2
- D - related to total integrated dose from Q_Y photons
- h - release height, m
- H - mixing depth, m
- m - integer counter to account for reflections
- N - number of azimuthal subdivisions or sectors
- $Q(0)$ - original source at first radial increment in each sector
- Q_Y - number of photons
- $\bar{\mu}$ - effective wind speed, m/sec
- V_g - gravitational settling velocity, m/sec
- x - downwind distance, m
- μ - linear attenuation coefficient for air, m^{-1}
- σ_y - standard deviation of material distribution in the horizontal direction, m
- σ_z - standard deviation of material distribution in the vertical direction, m
- χ/Q - concentration per unit source, sec/m^3

REFERENCES FOR APPENDIX F

1. R. E. Cooper and B. C. Rusche. *The SRL Meteorological Program and Offsite Dose Calculations*. USAEC Report DP-1163, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (1968).
2. T. V. Crawford. *Progress Report Dose-to-Man Program 1972*. USAEC Report DP-1341, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (1974).
3. R. E. Cooper. *EGAD - A Computer Program to Compute Dose Intervals from External Gamma Emitters*. USAEC Report DP-1304, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (1972).
4. T. V. Crawford. *Savannah River Laboratory Environmental Transport and Effects Research. Annual Report FY-1975*. USAEC Report DP-1412, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1976).