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REACTOR TECHNOLOGY MEMORANDUM - ATMOSPHERIC DIFFUSION MODELS

The enclosed RTM sets forth proposed guidelines for the atmospheric diffusion model to be used in the calculation of radiation doses from postulated accidents. I recommend that consideration be given to factoring these guidelines into our safety evaluations as soon as possible. Further, I would appreciate receiving any comments you care to make as a result of reviewing the RTM by September 9, 1968, in order that necessary revisions can be made promptly.

Saul Levine

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Enclosure:
RTM-Atmospheric Diffusion
Models

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REACTOR TECHNOLOGY MEMORANDUM NO.

ATMOSPHERIC DIFFUSION MODELS

INTRODUCTION

As a part of the evaluation of the doses resulting from the release of radioactivity from any reactor accident or incident, it is necessary to have a model which characterizes the movement of this activity in the atmosphere after it is released outside the facility structures. This model must conservatively account for the diffusive capacity of the atmosphere as a function of time and distance. It must also account for special effects which occur in the vicinity of the point of release. All of these requirements are fulfilled by the models which are described herein. It would also be desirable for the model to account for decreases in effective stack height due to terrain, for confinement of the plume in deep narrow valleys, and other such effects. However, these are so difficult to reduce to standard equations and models that this has not been done here. Such problems should be referred to Reactor Technology for treatment on a case-by-case basis.

Description of the models is divided into two parts, one for PWR's and the other for BWR's. Each part is discussed in detail separately below.

A. Pressurized Water Reactors

In this type of reactor, there is generally a single high-pressure containment barrier, which in the case of the DBA will have some low value of leak rate from a number of points in its surface and its penetrations. In the case of other accidents which may occur at times when this containment is not fully effective, such as during refueling, the initial point of release may be a roof vent or short stack. In any event, all such releases are caught into the turbulent wake on the lee side of the building, providing a large amount of dilution before the radioactivity reaches the site boundary. Equations are given which explain this aspect of the model, as well as provisions which are incorporated to describe the changes in diffusion conditions with time which are necessary in developing a reasonable model representing conditions which are possible as a function of time.

The basic equation for atmospheric diffusion from a ground level point source in terms of the gaussian parameters is:[1]

$$X/Q = 1/(\pi\, u\, \sigma_y\, \sigma_z) \qquad (1)$$

where:

X = the concentration at the receptor, units per cubic meter
Q = the source emmission rate, units per second
u = the ambient wind speed, meters/second
σ_y = the horizontal standard deviation (dimension) of the plume, meters
σ_z = the vertical standard deviation (dimension) of the plume, meters

This equation may be modified by an empirical expression to account for the additional diffusion occuring in the turbulent wake of a structure as follows:(1)

$$X/Q = 1/u\,(\pi \sigma_y \sigma_z + cA) \qquad (2)$$

where:

A = cross sectional area of the reactor building, square meters (other structures not included).
c = an empirical constant, which is assumed to be 1/2, with reservations as stated below.

1. The turbulent wake is assumed to have a cross-sectional area equal to half the projected area of the reactor containment building only, and can usually be conservatively approximated by curves (Figure 1) which have been generated for an area of 10,000 square feet or 930 square meters. The effects of the auxilliary building or the turbine building are not included, even though they may be connected to the reactor building, to avoid over-estimating the effect. In addition, the reduction factor given for the wake effect compared to a point source is limited to a factor of less than 4 at short distances (less than approximately 500 meters).(2)

2. For the first 8 hours following the accident, Pasquill Type F diffusion conditions are assumed to exist, with a non-varying wind direction and a wind speed of 1 meter per second.

3. From 8 to 24 hours after the accident, the same atmospheric conditions continue, but the plume is assumed to meander so as to spread uniformly over a 22-1/2 degree sector. The reduction factor below the diffusion calculated for the first 8 hours is limited to a factor of 5, to offset excessive effects at large distances (greater than 5000 meters).(3)

   The equation for plume centerline concentration is integrated in a cross-wind direction and divided by the arc length of the 22-1/2 degree sector at the desired distance. The resultant equation, in terms of gaussian parameters is:(1)

$$X/Q = (8/\pi) \quad 2^{1/2} \quad / \quad (\pi^{1/2} \sigma_z \quad u \quad x)$$

$$= 2.032/ (\sigma_z \quad u \quad x) \qquad (3)$$

where:

x = distance from the point of release to the receptor, and the other variables are defined in the plume centerline equation. Note that credit for the effect of the building wake is not included in this equation, since it is not considered to be appropriate under these conditions.

When taking credit for spread of the plume into a 22-1/2 degree sector, the topography must be studied to see that it will accommodate such a spread at all distances out to the point being considered. A graph has been prepared (Figure 2) to indicate the width of a valley at any distance which will accommodate the plume without interference. When this graph indicates that interference will occur, a "volumetric model" must be used, in which the plume assumes the cross-sectional area of the valley. The problem should be referred to Reactor Technology.

4. From 24 hours to 96 hours (4 days) "stagnation conditions", associated with low wind speeds and neutral to stable conditions, are assumed. Specifically, the conditions are assumed to be 60% of the time with Pasquill Type F and 2 m/sec, and 40% of the time with Pasquill Type D and 3 m/sec, uniformly spread in the same 22-1/2 degree sector used for the first 24 hours. A parameter study indicates that worse conditions can reasonably be expected to exist only if one has a higher frequency of stable conditions, which does not appear likely in combination with these low wind speeds, which average to 2.4 m/sec or 5.4 mph.

5. For the period from 4 to 30 days, Pasquill Type C, D and F conditions are assumed to occur equal portions of the time, with associated wind speeds of 3, 3, and 2 m/sec, respectively. The wind is also assumed to remain in the same 22-1/2 degree sector 1/3 of the time and to spread uniformly in all the other sectors for the remaining 2/3 of the time. The resultant average wind speed is 2.67 m/sec, or 6.0 mph.

If an applicant takes reliable data at his site for a significant period of time, and provides a proper and conservative analysis of this data to substanciate a less conservative model, it may be possible to give additional credit for atmospheric diffusion. However, because of the very large fusion Factors for Ground Rele

over Various Time Periods

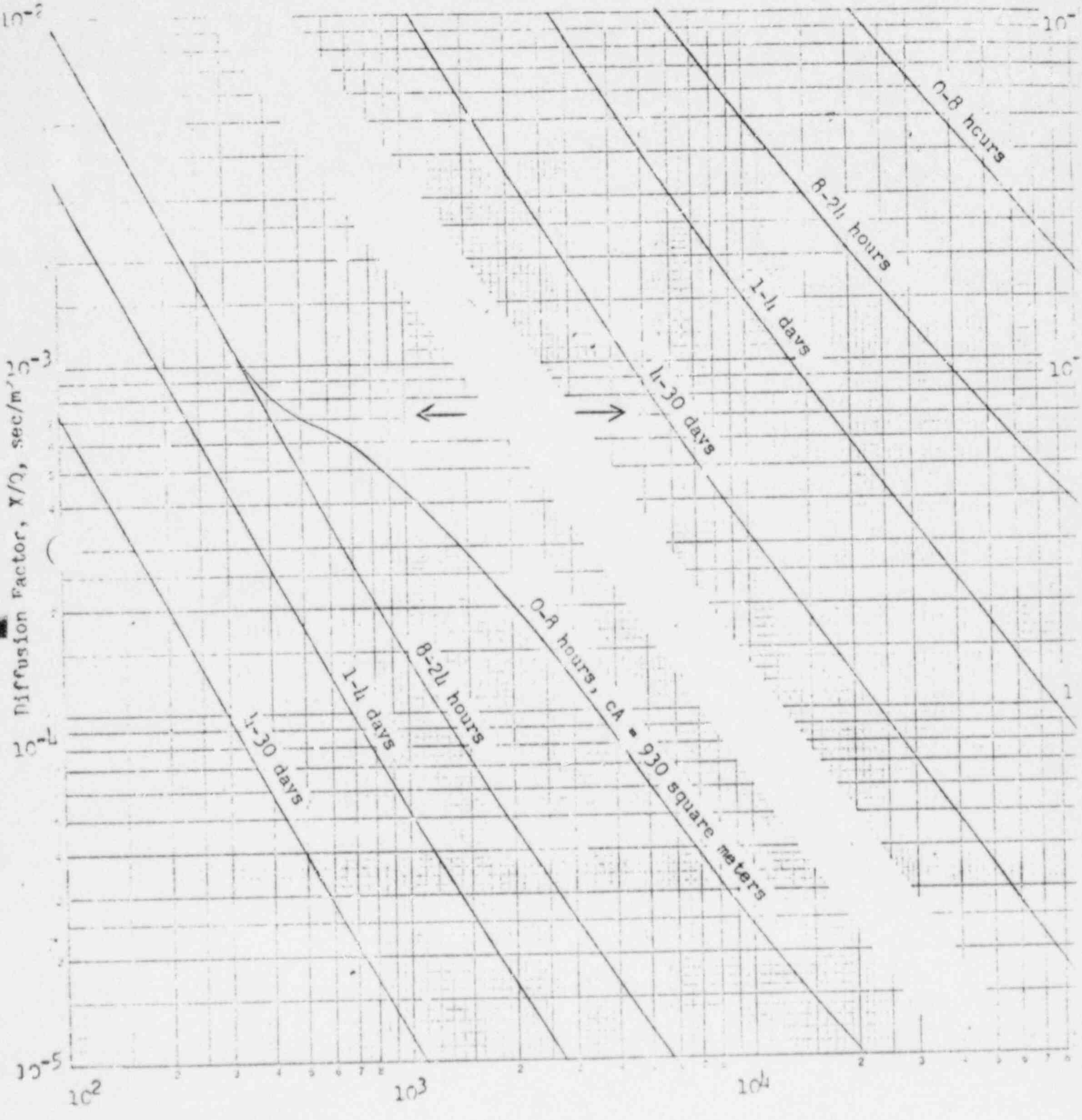

Figure 1

Plume and Sector Width
vs
Distance

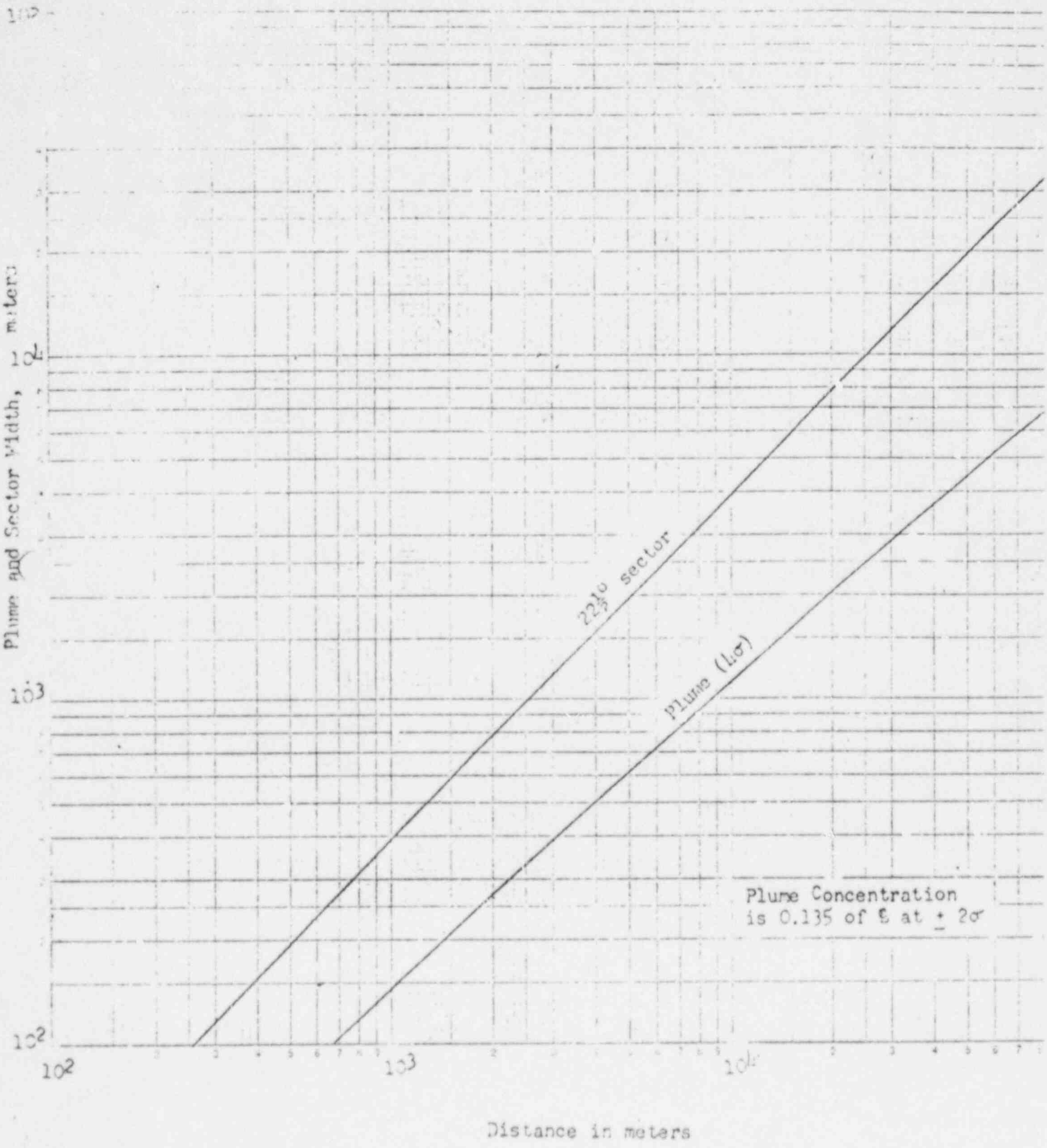

Figure 2

reduction factor which even this model gives below the doses which would be obtained assuming constant wind direction and stability conditions for the duration of the accident (which cannot be theoretically ruled out), we do not feel that it is appropriate to give a great deal of additional credit, nor to establish a probability level at which data and models will be acceptable.

This model is to be applied to any critical direction or distance from the reactor without regard to terrain, even though as a practical matter flow in such a direction may not be very likely.

B. Boiling Water Reactors

In this type of reactor, there is a primary containment system surrounded by a conventional building which collects the leakage and conducts it through a cleanup system and up a stack by virtue of emergency exhaust fans which maintain a negative pressure inside the building. There is some small fraction of the activity which will escape (by exfiltration) through the walls of this building due to local conditions where the negative pressure effects of the outside wind exceed those of the exhaust system. Since this activity is not filtered, and mixes into the wake of the building at ground level, it can produce 100 to 200 times as much dose per curie in the building as it would if it were released from the stack under the same atmospheric conditions. Diffusion conditions are assumed to vary with time during the course of an accident according to the model below. Conditions for release from the stack are described here. The exfiltration case will be treated in a future addendum to this RTM.

The basic equation for atmospheric diffusion from an elevated source in terms of the gaussian parameters is:(1)

$$X/Q = (e^{-h^2/2\sigma_z^2})/(\pi\ u\ \sigma_y\ \sigma_z) \qquad (4)$$

where h is the height of the stack, and the other variables are the same as defined for the ground level release.

1. The stack exhaust velocity and temperature are so low that no additional credit for plume rise above the top of the stack is given.

2. In general, better diffusion conditions bring the plume down to the ground closer to the stack and produce higher doses. Hence, the simplest way to arrive at the maximum atmospheric diffusion factor for any distance

is to utilize a curve which is the envelope for all possible atmospheric conditions based on a similar model, such as plume centerline or spread over a given sector (see Figure 3).

3. Due to lack of information concerning the ventilation system and air flow patterns in the reactor building, it is conservatively assumed that all leakage from the primary containment passes directly into the emergency exhaust system and up the stack.

4. For the first 8 hours following an accident, it is necessary to use separate models for inland and seacoast locations, but both models are for plume centerline concentrations.[4]

5. At the inland locations (more than 2 miles from the oceans or great lakes) it is assumed that a fumigation condition exists at the time of the accident, and continues for 1/2 hour. This is followed by an additional 7-1/2 hours of winds in the same direction with good diffusion conditions producing the maximum centerline concentrations at the site boundary, as determined from the envelope curve described above.

   The equation for atmospheric diffusion from an elevated source during fumigation conditions in terms of the gaussian parameters is obtained by integrating the basic elevated source equation (4) in the vertical direction, and dividing by the height over which the plume is distributed, which is here assumed to be the height of the stack, h.[1]

$$X/Q = 1/(2\pi)^{1/2} \quad \sigma_y \; u \; h = 0.3990/\sigma_y \; u \; h \qquad (5)$$

6. For coastal locations less than 2 miles from the shore, unless data is presented to the contrary, the fumigation condition should be assumed for the entire first 2 hours following an accident, for purposes of calculating doses at the site boundary only. This is due to the fact that it is possible to have a breeze coming inland off cold water, being heated by the warm land to produce a steady-state fumigation condition lasting all through the daylight hours. However, after the plume has traveled more than approximately 2 miles, the inversion condition is dissipated, and fumigation no longer occurs. Therefore, the long-term dose models for distances greater than approximately 2 miles include only the 1/2 hour fumigation condition associated with inland areas. A gradual transition from one condition to the other occurs between one and two miles (see Figure 3).

7. For the coastal locations above, during the period from 2 to 8 hours the same centerline diffusion conditions are assumed as were used from 1/2 to 8 hours for inland locations.

8. From 8 to 24 hours at all locations, it is assumed that the wind direction stays within the same 22-1/2 degree sector, but the plume is spread uniformly within this sector. However, the reduction factor below the diffusion calculated for the first 8 hour period is limited to a factor of 5, to offset excessive effects at large distances. This produces a discontinuity in this curve at a point near 20,000 meters.

   Although confinement of the plume in a narrow valley is not a frequent problem for elevated releases, some consideration should be given to the possibility of this, particularly if the valley is appreciably deeper than the height of the stack (see comments under item 3 for pressurized water reactors). Again the envelope of the curves for all types of diffusion conditions is used to assure that the worst diffusion condition for each distance is obtained.

   The equation for atmospheric diffusion from an elevated source spread over a 22-1/2 degree sector is obtained by integrating the basic elevated source equation (4) in the horizontal direction, and dividing by the arc length of the sector at the desired distance. The resultant equation, in terms of gaussian parameters is:[1]

$$X/Q = (8/\pi)\ 2^{1/2}\ (e^{-h/2\sigma_z^2})/(\pi^{1/2}\ \sigma_z\ u\ x)$$

$$= 2.032\ (e^{-h^2/2\sigma_z^2})/(\sigma_z\ u\ x) \qquad (6)$$

9. From 24 to 96 hours (1 to 4 days), the plume continues to be spread uniformly in the same 22-1/2 degree sector, but combinations of diffusion conditions, rather than a single condition, were assumed. These were chosen so that their envelope produces conservative estimates of diffusion for any distance. The general pattern of these combinations was to assume 50% occurrence for each of two diffusion types which were separated by one unit, such as A and C, B and D, etc., as well as 33-1/3% occurrence for each of 3 adjacent types, such as B, C, and D, or C, D, and E, etc. Wind speeds were assumed to be 2 m/sec for all types except for C and D conditions, which were assumed to have winds of 3 m/sec. Diffusion factors were calculated for all the combinations of conditions, at all distances. For the 100 meter stack height, envelope curves were constructed through the highest value obtained for each distance, and this value was used to represent the diffusion factor for this time period at any distance.

10. For the period from 4 to 30 days, the same conservative combinations of diffusion conditions were assumed, with the plume spread in the same 22-1/2 degree sector, but the wind direction was assumed to occur in this sector only 1/3 of the time. Hence all diffusion factors for this time period are reduced by a factor of 3 below those used for the period from 1 to 4 days. The wind is assumed to be spread uniformly in the remaining sectors for the other 2/3 of the time.

It is seen that this model follows very closely the one used for ground level releases, in that both use conservative combinations of stability conditions after 4 days as well as for the 1 to 4 day period. Both models also assume a 33% wind frequency in the critical sector after 4 days.

This model is to be applied to any critical direction from the reactor without regard to terrain, except for the forced fumigation conditions which occur at coastal locations.

11. In case elevated terrain is involved within approximately a few miles from the stack, the effective stack height for 2 hour exposures is taken to be the difference between the elevation of the top of the stack and that of the hilltop, and the distance is taken from the stack to the point in question. This same reduction in stack height should be used at distances beyond the hill to account for downwash effects on the lee side of the hill. There may also be special conditions where it is appropriate to consider a reduction in stack height for exposure times longer than 2 hours, but this will require careful study by the E&RSTB and ESSA. Ordinarily, for times longer than 8 hours it may be assumed that the plume will on the average follow the ups and downs of the terrain, without significant reduction in effective stack height.

Dif ion Factors for 100 Meter Rele Height

over Various Time Periods

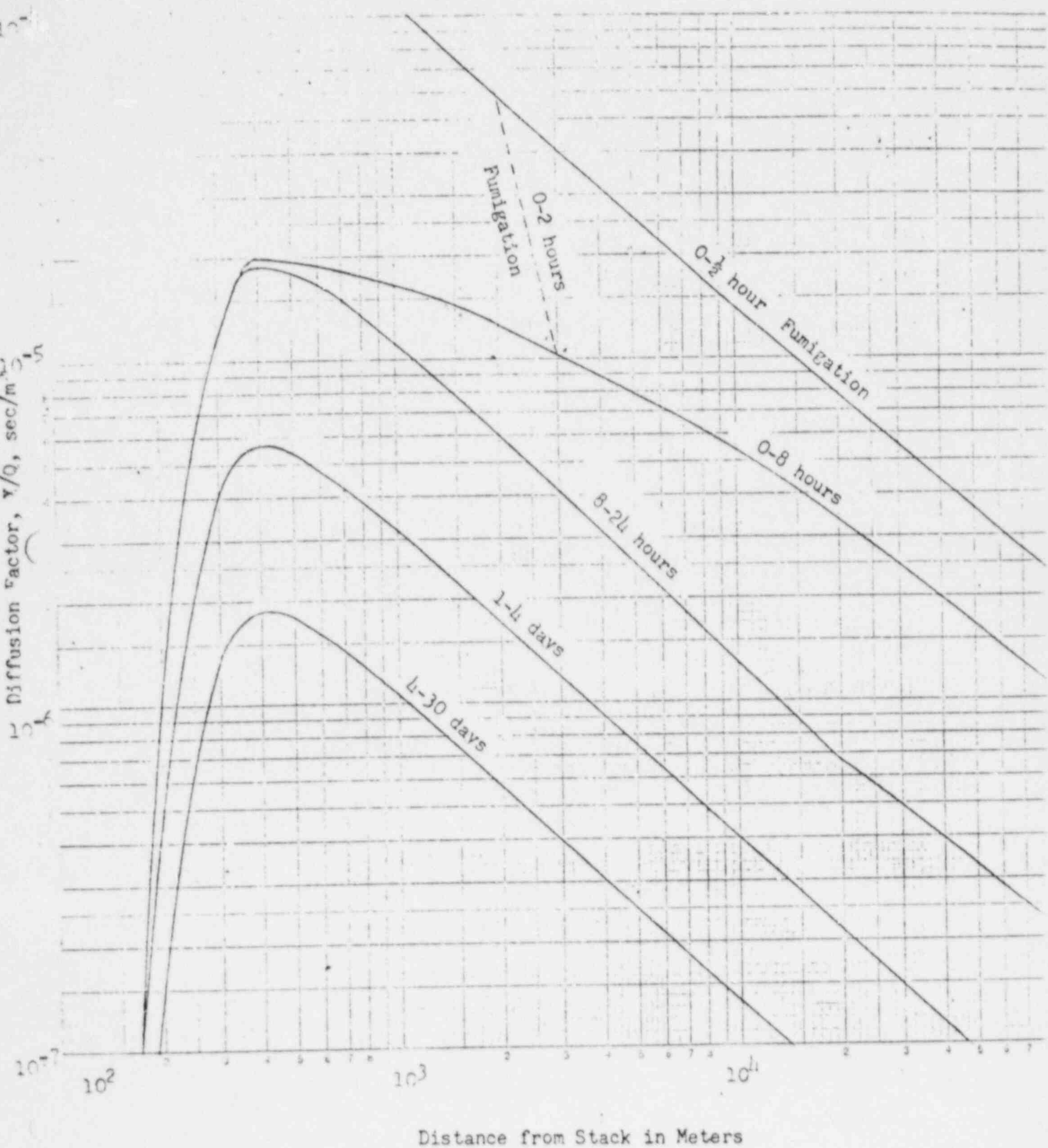

Figure 3

SUMMARY

The meteorological models described above may be summarized in tabular form for the two release situations as given below.

Time Period	PWR Ground Release	BWR Stack Release
0-2 hours	Pasquill Type F, 1 m/sec building wake effect	Fumigation, 1 m/sec plume centerline (only 1/2 hour fumigation inland)
2-8 hours	Pasquill Type F, 1 m/sec building wake effect	Pasquill Envelope, 1 m/sec plume centerline
8-24 hours	Pasquill Type F, 1 m/sec 22-1/2 degree sector spread	Pasquill Envelope, 1 m/sec 22-1/2 degree sector spread (max. factor 5)
24-96 hours	40% Pasquill Type D, 3 m/sec 60% Pasquill Type F, 2 m/sec 22-1/2 degree sector spread	Envelope of conservative conditions Average u = 2.3 to 2.7 m/sec 22-1/2 degree sector spread
96-720 hours	33.3% Pasquill Type C, 3 m/sec 33.3% Pasquill Type D, 3 m/sec 33.3% Pasquill Type F, 2 m/sec 33.3% Frequency in 22-1/2 degree sector	Envelope of same conservative conditions and wind speeds as 24-96 hr 33.3% frequency in 22-1/2 degree sector

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