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ASSUMPTIONS FOR EVALUATING THE HABITABILITY OF A NUCLEAR POWER PLANT CONTROL ROOM DURING A POSTULATED HAZARDOUS CHEMICAL RELEASE

A. INTRODUCTION

Criterion 4, "Environmental and missile design bases," of Appendix A "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that structures, systems, and components important to safety be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. Criterion 19, "Control room," requires that a control room be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions. Release of hazardous chemicals can potentially result in the control room becoming uninhabitable. This guide describes assumptions acceptable to the Regulatory staff to be used in assessing the habitability of the control room during and after a postulated external release of hazardous chemicals and describes criteria that are generally acceptable to the Regulatory staff for the protection of the control room operators. This guide does not consider the explosion or flammability hazard of these chemicals, which also must be addressed. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

The control room of a nuclear power plant should be appropriately protected from hazardous chemicals that may be discharged as a result of equipment failures, operator errors, or events and conditions outside the control of the nuclear power plant.

At present, there is no one standard design evaluation method in use for evaluating the habitability of control rooms during the course of all postulated hazardous chemical releases.[1] However, the "Accidental-Episode Manual"[2] prepared for the Environmental Protection Agency (EPA) in April 1972 presents a method for the evaluation and estimation of the area affected by the release of hazardous chemicals as a function of source strength, type of chemical, distance from source, and meteorology. The "Accidental-Episode Manual" rates accident potentials from both mobile and stationary sources and identifies some hazardous chemicals that may be released. Human tolerance for hazardous chemicals should be considered in the design stage of nuclear facilities.

For hazardous chemicals shipped on routes near the nuclear power plant, the shipment frequencies specified for consideration in this guide (Regulatory Position 2) reflect the relative accident probabilities for common modes of transportation. A discussion of accident rates for various transportation modes can be found in Appendix A, "Analysis of Transportation Accidents," of WASH-1238.[3] Consideration is also given to the quantity of hazardous chemical shipped.

The purpose of this guide is to identify those chemicals which, if present in sufficient quantities, could result in the control room becoming uninhabitable. The general design considerations that are used in assessing

[1] A regulatory guide is being developed to describe specific design provisions and procedures that are acceptable to mitigate hazards to control room operators from an onsite chlorine release.

[2] Office of Air Programs, Publication APTD-1114. Copies may be obtained from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

[3] WASH-1238, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants" December 1972. Copies may be obtained from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

the capability of the control room, as designed, to withstand hazardous chemical releases occurring either on the site or within the surrounding area are presented. Some of the chemicals specifically identified, such as helium and nitrogen, should generally not present a problem except when very large quantities are stored on the site. Asphyxiating chemicals such as these need not be considered unless a significant fraction of the control room air could be displaced as a result of their release.

Fire-fighting equipment used for fighting chemical and electrical fires should be considered as a potential source of hazardous chemicals.

This guide identifies chlorine as a potentially hazardous chemical. Chlorine is used in a majority of nuclear power plants for water treatment and is normally stored onsite as a liquified gas. A separate guide will be issued to describe the detailed design provisions which are considered adequate to protect control room operators from an onsite chlorine release.

C. REGULATORY POSITION

In evaluating the habitability of a nuclear power plant control room during a postulated hazardous chemical release the following assumptions should be made:

1. If major depots or storage tanks of hazardous chemicals such as the chemicals listed in Table C-1 of this guide are known or projected to be present within a five-mile radius of the reactor facility, these chemicals should be considered in the evaluation of control room habitability.[4] Whether a major depot or storage area constitutes a hazard is determined on the basis of the quantity of stored chemicals, the distance from the nuclear plant, the inleakage characteristics of the control room, and the applicable toxicity limits (see Regulatory Position 4 for definition). Table C-2 gives the criteria to be used in evaluating the hazards of chemicals to control rooms. A procedure for adjusting the quantities given in Table C-2 to appropriately account for the toxicity limit of a specific chemical, meteorology conditions of a particular site, and air exchange rate of a control room is presented in Appendix A of this guide.

Chemicals stored or situated at distances greater than five miles from the facility need not be considered because, if a release occurs at such a distance, atmospheric dispersion will dilute and disperse the incoming

[4] The list of chemicals given in Table C-1 is not all-inclusive but indicates the chemicals most commonly encountered. See also "Guide for Emergency Services for Hazardous Materials (1973)–Spills, Fires, Evacuation Areas" copies of which may be obtained from the U.S. Department of Transportation, Office of Hazardous Materials, Washington, D.C.

TABLE C-1

SOME HAZARDOUS CHEMICALS POTENTIALLY INVOLVED IN ACCIDENTAL RELEASES FROM STATIONARY AND MOBILE SOURCES[a]

Chemical	*Toxicity Limit*[b]		*Chemical*	*Toxicity Limit*	
	ppm[c]	*mg/m³*[d]		*ppm*	*mg/m³*
Acetaldehyde	200	360	Ethylene oxide	200	180
Acetone	2000	4800	Fluorine	2	4
Acrylonitrile	40	70	Formaldehyde	10	12
Anhydrous ammonia	100	70	Helium		asphyxiant
Aniline	10	38	Hydrogen cyanide	20	22
Benzene	50	160	Hydrogen sulfide	500	750
Butadiene	0.1%[e]	2200	Methanol	400	520
Butenes		asphyxiant	Nitrogen (compressed or liquified)		asphyxiant
Carbon dioxide	1.0%[e]	1840	Sodium oxide	–	2
Carbon monoxide	0.1%[e]	1100	Sulfur dioxide	5	26
Chlorine	15	45	Sulfuric acid	–	2
Ethyl chloride	10000	26000	Vinyl chloride	1000	2600
Ethyl ether	800	2400	Xylene	400	1740
Ethylene dichloride	100	400			

[a] This list is not all-inclusive but indicates the hazardous chemicals most commonly encountered.

[b] Adapted from Sax's "Dangerous Properties of Industrial Materials."

[c] Parts of vapor or gas per million parts of air by volume at 25°C and 760 torr (standard temperature and pressure).

[d] Approximate milligrams of particulate per cubic meter of air, at standard temperature and pressure, based on listed ppm values.

[e] Percent by volume.

TABLE C-2

EXAMPLES OF WEIGHTS OF HAZARDOUS CHEMICALS THAT REQUIRE CONSIDERATION IN CONTROL ROOM EVALUATIONS (FOR A 50 mg/m³ TOXICITY LIMIT AND STABLE METEOROLOGICAL CONDITIONS[a])

Distance From Control Room (miles)[b]	Weight (1000 lb)		
	Type A Control Room[c]	Type B Control Room	Type C Control Room
0.3 to 0.5	9	2.3	0.1
0.5 to 0.7	35	8.8	0.4
0.7 to 1.0	120	20	1.0
1 to 2	270	52	2.5
2 to 3	1300	280	13
3 to 4	3700	780	33
4 to 5	8800	1400	60

[a] For different toxicity limits as given in Table C-1 and different meteorological conditions, the weights should be proportionately scaled as described in Appendix A.

[b] All hazardous chemicals present in weights greater than 100 lb within 0.3 mile of the control room should be considered in a control room evaluation.

[c] Control room types (Appendix A illustrates the use of this table for other air exchange rates):

Type A – A "tight" control room having low leakage construction features and the capability of detecting at the fresh air intake those hazardous chemicals stored or transported near the site. Detection of the chemical and automatic isolation of the control room are assumed to have occurred. An air exchange rate of 0.015 per hour is assumed (0.015 of the control room air by volume is replaced with outside air in one hour). The control room volume is defined as the volume of the entire zone serviced by the control room ventilation system. The assumption that the air exchange rate is less than 0.06 per hour requires verification by field testing.

Type B – Same as Type A, but with an air exchange rate of 0.06 per hour. This value is typical of a control room with normal leakage construction features. The assumption that the air exchange rate is less than 0.06 per hour, requires verification by field testing.

Type C – A control room that has not been isolated, has no provision for detecting hazardous chemicals, and has an air exchange rate of 1.2 per hour.

plume to such a degree that there should be sufficient time for the control room operators to take appropriate action. In addition, the probability of a plume remaining within a given sector for a long period of time is quite small.

2. If hazardous chemicals such as those indicated in Table C-1 are known or projected to be frequently shipped by rail, water, or road routes within a five-mile radius of a nuclear power plant, estimates of these shipments should be considered in the evaluation of control room habitability. The weight limits of Table C-2 (adjusted for the appropriate toxicity limit, meteorology, and control room air exchange rate) apply also to frequently shipped quantities of hazardous chemicals. Shipments are defined as being frequent[5] if there are 10 per year for truck traffic, 30 per year for rail traffic, or 50 per year for barge rraffic.[5] If the quantity, per shipment, of hazardous chemicals frequently shipped past a site is less than the adjusted quantity shown in Table C-2 for the control room type being evaluated, the shipments need not be considered in the analysis.

3. In the evaluation of control room habitability during normal operation, the release of any hazardous

[5] For explosive hazards, a lower number of shipments would be considered frequent since the effects of an explosion would be independent of wind direction.

chemical to be stored on the nuclear plant site in a quantity greater than 100 lb should be considered. Any hazardous chemical stored onsite should be accompanied by instrumentation that will detect its escape, set off an alarm, and provide a readout in the control room.

4. The toxicity limits should be taken from appropriate authoritative sources such as those listed in the References section. For each chemical considered, the values of importance are the human detection threshold and the maximum concentration that can be tolerated for two minutes without physical incapacitation of an average human (i.e., severe coughing, eye burn, or severe skin irritation). The latter concentration is considered the "toxicity limit." Table C-1 gives the toxicity limits (in ppm by volume and mg/m^3) for the chemicals listed. Where these data are not available, a determination of the values to be used will be made on a case-by-case basis.

5. Two types of industrial accidents should be considered for each source of hazardous chemicals: maximum concentration chemical accidents and maximum concentration-duration chemical accidents.

a. For a maximum concentration accident, the quantity of the hazardous chemical to be considered is the instantaneous release of the total contents of one of the following: (1) the largest storage container falling within the guidelines of Table C-2 and located at a nearby stationary facility, (2) the largest shipping container (or for multiple containers of equal size, the failure of only one container unless the failure of that container could lead to successive failures) falling within the guidelines of Table C-2 and frequently transported near the site, or (3) the largest container stored onsite (normally the total release from this container unless the containers are interconnected in such a manner that a single failure could cause a release from several containers.)

For chemicals that are not gases at 100°F and normal atmospheric pressure but are liquids with vapor pressures in excess of 10 torr, consideration should be given to the rate of flashing and boiloff to determine the rate of release to the atmosphere and the appropriate time duration of the release.

The atmospheric diffusion model to be used in the evaluation should be the same as or similar to the model presented in Appendix B of this guide.

b. For a maximum concentration-duration accident, the continuous release of hazardous chemicals from the largest safety relief valve on a stationary, mobile, or onsite source falling within the guidelines of Table C-2 should be considered. Guidance on the atmospheric diffusion model is presented in Regulatory Guide 1.3, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Boiling Water Reactors," and Regulatory Guide 1.4, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Pressurized Water Reactors."

6. The value of the atmospheric dilution factor between the release point and the control room that is used in the analysis should be that value that is exceeded only 5% of the time.

When boiloff or a slow leak is analyzed, the effects of density on vertical diffusion may be considered if adequately substantiated by reference to data from experiments. Density effect of heavier-than-air gases should not be considered for releases of a violent nature or for released material that becomes entrained in the turbulent air near buildings.

7. For both types of accidents described in Regulatory Position 5 above, the capability of closing the air ducts of the control room with dampers and thus isolating the control room should be considered in the evaluation of control room habitability. In particular, the time required to shut off or redirect the intake flow should be justified. The detection mechanism for each hazardous chemical should be considered. Human detection may be appropriate if the buildup of the hazardous chemical in the control room is at a slow rate due to slow air turnover. The air flows for infiltration, makeup, and recirculation should be considered for both normal and accident conditions. The volume of the control room and all other rooms that share the same ventilating air, during both normal conditions and accident conditions, should be considered. The time required for buildup of a hazardous chemical from the detection concentration to the toxicity limit should be considered.[6] Table C-3 of this guide contains a sample list of the chemical and control room data needed for the evaluation of control room habitability.

8. In the calculation of the rate of air infiltration (air leaking into the control room from ducts, doors, or other openings) with the control room isolated and not pressurized, use of the following assumptions is suggested:

a. A pressure differential of 1/8 inch water gauge across all leak paths.[7]

[6] The time from detection to incapacitation should be greater than two minutes. Two minutes is considered sufficient time for a trained operator to put a self-contained breathing apparatus into operation, if these are to be used.

[7] This pressure differential accounts for wind effects, thermal column effects, and barometric pressure changes. It does not account for pressure differences resulting from the operation of ventilation systems supplying zones adjacent to the control room. It should be adjusted appropriately when the ventilation system supplies zones adjacent to the control room.

TABLE C-3

TYPES OF CHEMICAL AND CONTROL ROOM DATA FOR HABITABILITY EVALUATION

CHEMICAL

1. Name of hazardous chemical.
2. Type of source (stationary, mobile, or onsite).
3. Human detection threshold, ppm.
4. Maximum allowable two-minute concentration (toxicity limit as defined in Regulatory Position 4, ppm and mg/m³).
5. Maximum quantity of hazardous chemical involved in incident.
6. Maximum continuous release rate of hazardous chemical.
7. Vapor pressure, torr, of hazardous chemical (at maximum ambient plant temperature).
8. Fraction of chemical flashed and rate of boiloff when spilling occurs.
9. Distance of source from control room, miles.
10. Five percentile meteorological dilution factor between release point and control room for instantaneous and continuous releases.

CONTROL ROOM

1. Volume of control room, including the volume of all other areas supplied by the control room emergency ventilation system, ft³.
2. Normal flow rates for volume defined above, cfm:[a]
   - unfiltered inleakage or makeup air,
   - filtered makeup air,
   - filtered recirculated air,
3. Emergency flow rates for volume defined above, cfm[a] (as in item 2. above).
4. Time required to isolate the control room, sec.

[a] "Filtered air" refers to the air filtered through filters whose removal capability for the particular chemical being considered has been established.

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b. The maximum design pressure differential for fresh air dampers on the suction side of recirculation fans.

9. When the makeup air flow rate required to pressurize the control room is calculated, a positive pressure differential of 1/4 inch water gauge should be assumed in the control room relative to the space surrounding the control room.

10. To account for the possible increase in air exchange due to ingress or egress, an additional 10 cfm of unfiltered air should be assumed for those control rooms without airlocks. This additional leakage should be assumed whether or not the control room is pressurized.

11. If credit is taken in the evaluation for the removal of hazardous chemicals by filtration or other means, the experimental basis for the dynamic removal capability of the removal system for the particular chemical being considered should be established.

12. Concurrent chemical release of container contents during an earthquake, tornado, or flood should be considered for chemical container facilities that are not designed to withstand these natural events. It may also be appropriate to consider release from a single onsite container or pipe coincident with the radiological consequences of a design basis loss-of-coolant accident, if the container facilities are not designed to withstand an earthquake.

13. If consideration of possible accidents for any hazardous chemical indicates that the applicable toxicity limits may be exceeded, self-contained breathing apparatus of at least one-half hour capacity or a tank source of air with manifold outlets and protective clothing, if required, should be provided for each operator in the control room. Additional air capacity with appropriate equipment should be provided if a chemical hazard can persist longer than one-half hour. For accidents of long duration, sufficient air for six hours (coupled with provisions for obtaining additional air within this time period) is adequate. Each operator should be taught to distinguish the smells of hazardous chemicals peculiar to the area. Instruction should include a periodic refresher course. Practice drills should be conducted to ensure that personnel can don breathing apparatus within two minutes.

14. Detection instrumentation, isolation systems, filtration equipment, air supply equipment, and protective clothing should meet the single-failure criterion. (In the case of self-contained breathing apparatus and protective clothing, this may be accomplished by supplying one extra unit for every three units required.)

15. Emergency procedures to be initiated in the event of a hazardous chemical release within or near the station should be written. These procedures should address both maximum concentration accidents and maximum concentration-duration accidents and should identify the most probable chemical releases at the station. Methods of detecting the event by station personnel, both during normal workday operation and during minimum staffing periods (late night and weekend shift staffing), should be discussed. Special instrumentation that has been provided for the detection of hazardous chemical releases should be described including sensitivity, action initiated by detecting instrument and level at which this action is initiated, and Technical Specification limitations on instrument availability. Criteria should be defined for the isolation of the control room, for the use of protective breathing apparatus or other protective measures, and for orderly shutdown or scram. Criteria and procedures for evacuating nonessential personnel from the station should also be defined.

Arrangement should be made with Federal, State, and local agencies or other cognizant organizations for the prompt notification of the nuclear power plant when accidents involving hazardous chemicals have occurred within five miles of the plant

REFERENCES

1. "Matheson Gas Data Book," Fourth Edition, The Matheson Company, Inc., East Rutherford, New Jersey (1966).

2. N. Irving Sax, "Dangerous Properties of Industrial Materials," Third Edition, Reinhold Book Corp., New York, New York (1968).

3. "Hygienic Guide Series," published by the American Industrial Hygiene Association, William E. McCormick, Executive Director, 66 South Willer Road, Akron, Ohio 44313.

4. "Toxic Substances List, 1973 Edition," U.S. Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, Rockville, Maryland 20852 (June, 1973). Prepared for NIOSH under contract by Tracor Jitco, Inc., 1300 East Gude Drive, Rockville, Maryland 20852.

5. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1973).

APPENDIX A

PROCEDURE FOR CALCULATING WEIGHTS OF HAZARDOUS CHEMICALS NECESSITATING THEIR CONSIDERATION IN CONTROL ROOM EVALUATION

The weights presented in Table C-2 are based on the following assumptions:

1. A toxicity limit of 50 mg/m^3
2. Air exchange rates for the three control room types of 0.015, 0.06, and 1.2 per hour
3. Pasquill stability category F

These conditions are generally applicable to most of today's plants for a gas such as chlorine (toxicity limit of 45 mg/m^3). If the toxicity limit, air exchange rate, or meteorological conditions are significantly different from the assumptions used in Table C-2, simple corrections that result in only minor errors can be made.

Toxicity Limit

The weights presented in Table C-2 are directly proportional to the toxicity limit. If a particular chemical has a toxicity limit of 500 mg/m^3, the weights from the table (based on 50 mg/m^3) are increased by a factor of ten.

Air Exchange Rate

Table C-2 weights are inversely proportional to the air exchange rate. If a type C control room has an exchange rate of 2.4 per hour, the weights from the table (based on 1.2 per hour) are decreased by a factor of two. When adjustments of this type are made, the control room type (A, B, or C) that has an air exchange rate closest to that of the control room in question should be selected.

It should be noted that the use of an air exchange rate of less than 0.06 per hour for an isolated control room requires that the control room leakage rate be verified by periodic field testing.

For control rooms without automatic isolation capability, the weights given for Type C control rooms should be used, appropriately adjusted for the actual fresh air exchange rate. Weights for Type B control rooms should be used when the control room has automatic isolation. Weights for Type A control rooms, appropriately adjusted for the design isolated air exchange rate, should be used only when the control room has been designed specifically for low inleakage.

Pasquill Stability Category

The weights given in Table C-2 are based on stable atmospheric dispersion conditions equivalent to Pasquill Condition F. This represents the worst five percentile meteorology observed at the majority of nuclear plant sites and, for most cases, there will be no need to adjust the weights because of meteorology. If it is determined that the worst five percentile meteorology is better or worse than Condition F, the following adjustments should be made:

Five Percentile Dispersion Category	*Weight Multiplication Factor*
E	2.5
F	1.0
G	0.4

Appendix B provides additional discussion of atmospheric dispersion.

APPENDIX B

DIFFUSION CALCULATIONS FOR AN INSTANTANEOUS (PUFF) RELEASE

1. Diffusion Equation

The diffusion equation for an instantaneous (puff) groundlevel release with a finite initial volume is:[1]

$$\frac{\chi}{Q_I} = \left[7.87\left(\sigma_{x,y}^2 + \sigma_I^2\right)\left(\sigma_z^2 + \sigma_I^2\right)^{1/2}\right]^{-1}$$

$$\cdot \exp\left[-\tfrac{1}{2}\left(\frac{x^2}{\sigma_x^2 + \sigma_I^2} + \frac{y^2}{\sigma_y^2 + \sigma_I^2} + \frac{z^2}{\sigma_z^2 + \sigma_I^2}\right)\right]$$

where:

$\frac{\chi}{Q_I}$ = unit concentration at coordinates x, y, z from the center of the puff, m^{-3}

$\sigma_x, \sigma_y, \sigma_z$ = standard deviations of the gas concentration in the horizontal alongwind, horizontal crosswind, and vertical crosswind directions, respectively (assume $\sigma_x = \sigma_y$), m

7.87 = $2^{1/2}\pi^{3/2}$

σ_I = initial standard deviation of the puff, m^3

= $\left[\frac{Q_I}{7.87\chi_o}\right]^{1/3}$ where Q_I is the puff release quantity, g, and χ_o is the density of the gas at standard conditions, g/m^3.

x, y, z = distance from the puff center in the horizontal alongwind, horizontal crosswind, and vertical crosswind directions, respectively, m.

[1] G.R. Yanshey, E.H. Markee, Jr., and A.P. Richter "Climatography of the National Reactor Testing Station," IDO-12048, January 1966. Copies may be obtained from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

Windspeed does not enter into the determination of unit concentration per se, but does affect the time-integrated concentration since it determines cloud passage time. The variation of unit concentration at a specific stationary receptor location is determined by evaluating x in the exponential term in the above equation as follows:

$$x = D - ut$$

where D is the source-receptor distance, u is the windspeed, and t is the time after release.

2. Determination of Input Data

The following assumptions and methods should be applied when analyzing worst-case instantaneous source releases:

a. Select the appropriate stability category based on the worst five percentile meteorology observed at the site according to the ΔT method. Regulatory Guide 1.23 (Safety Guide 23), "Onsite Meteorological Programs," presents a classification of various atmospheric stability categories as a function of temperature change (ΔT) with height. Normally, this category will be Pasquill Condition F. In some cases, the worst case stability category may be either Pasquill Condition E or G. This occurs at sites having distinctly better or worse diffusion than is normally encountered. Figures 1 and 2 of this appendix include conditions E, F, and G and encompass the worst expected stability conditions at nearly all sites.

b. Determine the x, y, and z standard deviation values based on the Pasquill stability categories as presented in Figures 1 and 2.

c. Additional credit due to building wake or other dispersive phenomena may be allowed, depending on the properties of the released gas, the method of release, and the intervening topology or structures.

d. Windspeed should be selected to maximize the two-minute concentration within the control room.

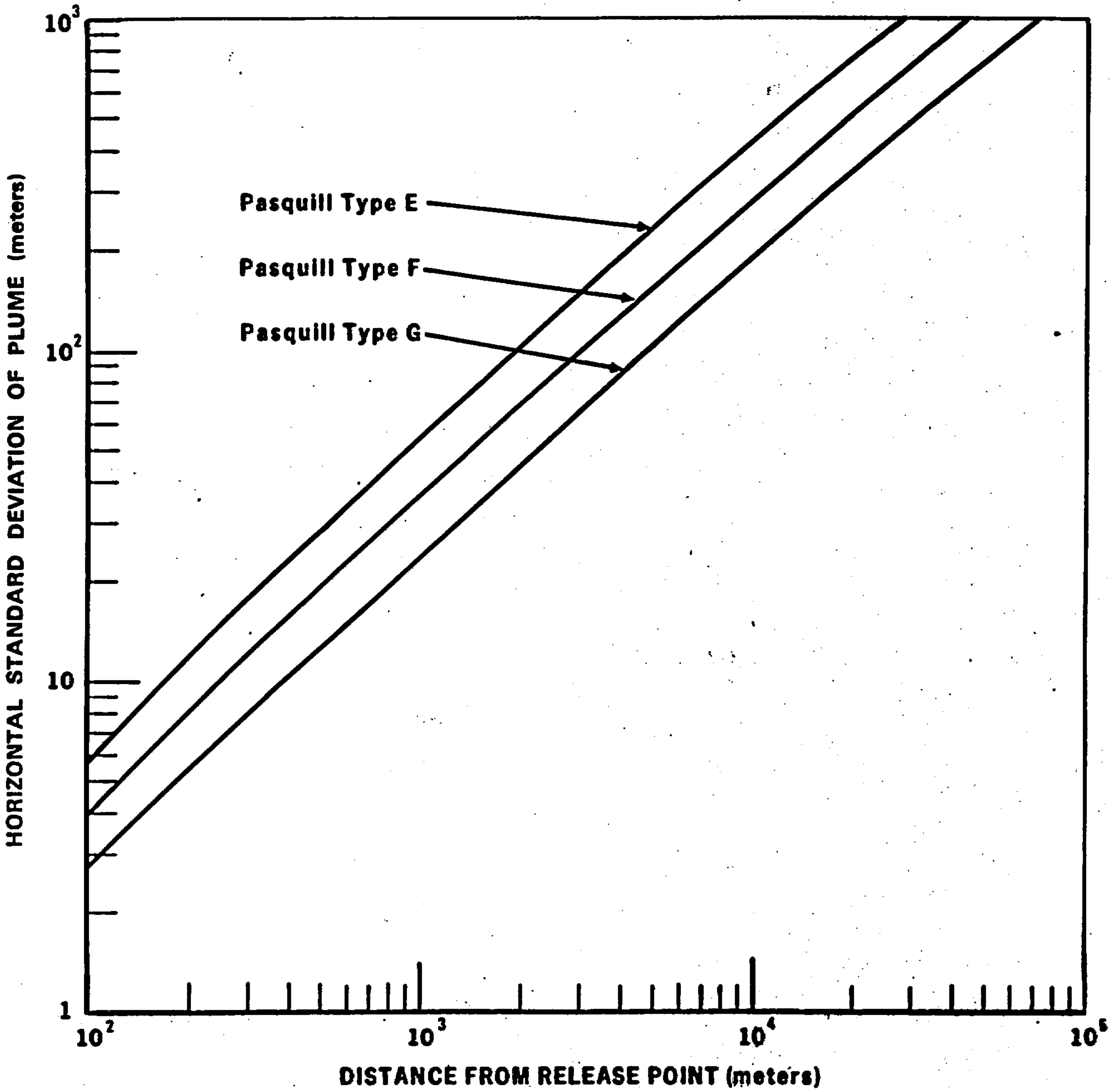

Figure 1. Horizontal Standard Deviation of Material in a Plume

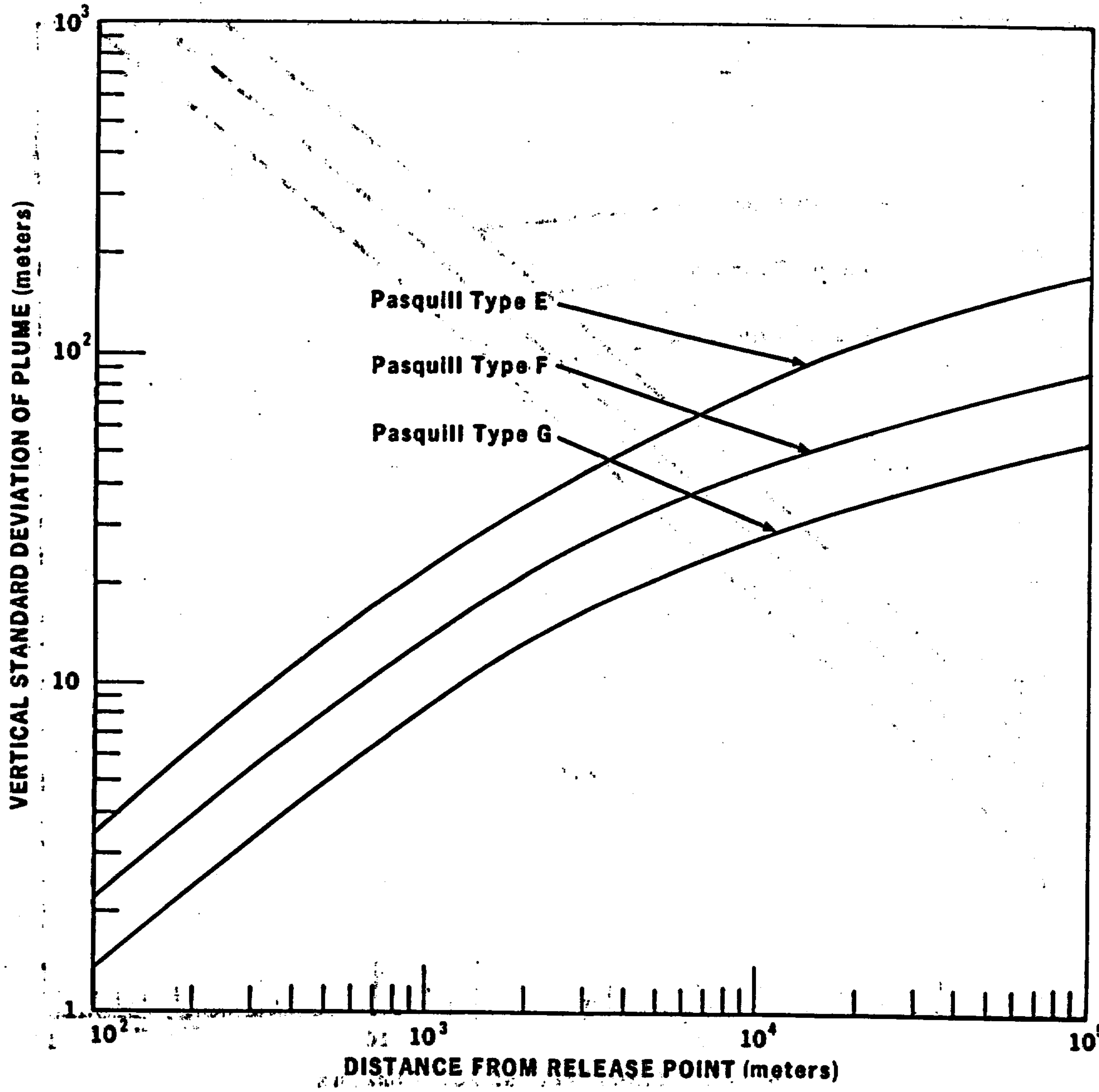

Figure 2. Vertical Standard Deviation of Material in a Plume