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EMERGENCY OPERATIONAL METEOROLOGICAL CONSIDERATIONS DURING AN ACCIDENTAL RELEASE OF HAZARDOUS CHEMICALS

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EMERGENCY OPERATIONAL METEOROLOGICAL CONSIDERATIONS DURING AN ACCIDENTAL RELEASE OF HAZARDOUS CHEMICALS

by Peter Mueller[1] and Jerry Galt[2]

ABSTRACT

The accidental release of toxic chemicals into the atmosphere has always been of great concern among local emergency response authorities. Evacuation of persons in and around the affected area, the amount of chemical spilled, and atmospheric conditions governing the downwind concentrations are among some of the more pressing issues confronting local hazardous materials (HAZMAT) personnel. Recently, the National Oceanic and Atmospheric Administration (NOAA) has embarked upon a program to provide chemical dispersion models to local HAZMAT groups. Greater public awareness of the dangers of toxic chemicals will likely mandate greater involvement by a number of government agencies, including the National Weather Service (NWS). HAZMAT personnel have not yet fully utilized the services of NWS meteorologists. In the future, NWS meteorologists and meteorological technicians may be asked to provide weather data as well as initial and short range weather forecasts (including trajectory forecasts) to emergency response managers responsible for protecting people from accidental releases of toxic spills. While a wide number of dispersion models exist, many are very similar when it comes to the type of meteorological input required to run them. This paper focuses on this input so that meteorologists may be better informed when they are called upon to provide assistance during a hazardous chemical spill in their area.

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[2]Dr. Jerry Galt is the head of the NOAA Hazardous Materials Response Branch in Seattle, Washington. He spearheaded the design of the NOAA "ALOHA-CAMEO" chemical dispersion model for use on a MacIntosh desktop computer and just recently released a PC version. This model is used by large number of HAZMAT response teams throughout the United States during a chemical emergency spill situation.

I. INTRODUCTION

During the mid to late 1960s, the issue of air pollution gained considerable interest among many government officials who were tasked to deal with increasing air pollution problems. More recently, the problem of pollutants mixing in the atmosphere has taken on renewed interest because of the Superfund legislation[3] which has established Local Emergency Planning Committees that are tasked with assessing the toxic chemical threats found in each community. This means that virtually every area of the country may need to seek meteorological information which NWS offices should be prepared to provide.

Most emergency management personnel have only a casual understanding of weather. Therefore, it is easy to understand why cloud cover, wind direction and speed, atmospheric stability classes, and temperature can be quite confusing to those who are not trained in their everyday use. It is for this reason that many emergency personnel have been trained to rely upon meteorological input from trained and qualified meteorologists. During a chemical spill, HAZMAT personnel could misinterpret or incorrectly communicate a variety of meteorological information which are key elements during any toxic spill.

II. CHEMICAL ACCIDENTS

The overall safety record of the chemical industry is very good, however, accidents do occur. Within the past six years, major chemical spills and radioactive accidents have taken place. For example:

- In Bhopal, India, an accidental release of 90,000 lbs of highly toxic methyl isocyanate gas in December 1984 killed approximately 2,500 people and injured many more.

- A rail accident in Miamisburg, Ohio, released 40,000 lbs of white phosphorous and caused the evacuation of 40,000 residents for five days.

- In San Francisco, a liquid and gaseous release of polychlorinated biphenyls (PCBs), natural gas, and oil resulted in the evacuation of 19 buildings containing 30,000 people[4].

- May 1988, in Henderson, Nevada, just south of Las Vegas, an explosion of ammonium perchlorate, an oxidizer making up 70 percent of the solid rocket fuel for space shuttles, rocked Henderson, Nevada. The blast measured 3.5 on the Richter scale. The blast and resultant cloud lasted over six hours, killed two people and damaged 4,000 buildings.

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[3]Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA) directed EPA to establish Local Emergency Planning Committees, Emergency Response Plans, list of hazardous substances, public right to information, Material Safety Data Sheets, and annual chemical inventory reporting.

[4]U.S. Environmental Protection Agency. Acute Hazardous Events Database Executive Summary, EPA-560-5-29(a) U.S. EPA Office of Toxic Substances, 1985.

- Several chlorine spills occurred in the Los Angeles Basin during the summer of 1988 which forced the evacuation of several hundred residents.

- On January 4, 1986, at the Kerr-McGee plant in Gore, Oklahoma, 27,000 lbs of radioactive Uranium Hexafluoride was released into the atmosphere. The material reacted with the atmosphere to form hydrogen fluoride and radioactive uranyl fluoride. The hydrogen fluoride then reacted with atmospheric moisture to form a deadly 18 mile toxic cloud of hydrofluoric acid. The net result was one dead and over 100 injured, not from the radiation but from the chemical reaction which produced hydrofluoric acid.

The above are a few examples of some of the more lethal accidents in recent history. In the U.S. alone, the Environmental Protection Agency (EPA) has recorded at least 6,928 accidents with acutely toxic chemicals in the last five years. These accidents killed 135 and injured nearly 1,500 people. Literally, thousands of chemicals and radioactive substances are used and transported each day. The most common chemical involved in accidents is chlorine which accounts for nearly 10 percent of all accidents.

Chlorine is heavier than air and is credited with causing two deaths and 382 injuries over the past 30 years. Ammonia is the second most common chemical involved in accidents and has been involved in 7 percent of all accidents. Its molecular weight is less than that of air, however, because it is stored in refrigerated containers, it is actually more dense. It is credited with 4 deaths and 271 injuries.

III. BRIEF HISTORY

Essentially all models and early research were based upon the basic GAUSSIAN[5] diffusion theories. This approach has origins in the classical Fickian theory of diffusion and represents solutions to the parabolic diffusion equation with constant coefficients (e.g., Sutton, 1953). These solutions are characterized by a mathematical Gaussian curve and are not considered to be numerical-type models. Some of the early pioneers in diffusion modeling were G. I. Taylor (1920's & 1930's) and O. G. Sutton (1930's-50's). More recently, Pasquill and Hay (1957), Pasquill (1961), Gifford (1959), Cramer (1957), and others made valuable contributions. They formed the basis and foundation of early research into air pollution meteorology. However, some of the early theory lacked sufficient physics and/or chemistry.

The culmination of theory and application were condensed into a nearly complete set of works when the U.S. Department of Health, Education, and Welfare published the Workbook of Atmospheric Dispersion Estimates. The workbook was authored by D. Bruce Turner (1969) and includes a number of important topics. The workbook contains 26 example problems dealing with binormal continuous plume dispersion models to estimate downwind concentrations of air pollutants.

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[5]The Gaussian model is based upon the assumption that the pattern of gaseous concentrations across a plume satisfies a normal statistical distribution in both the horizontal and vertical.

In addition, descriptions are given on how to determine effective stack height of emission, extension of concentration estimates to longer sampling intervals, inversion break-up fumigation concentrations, and concentrations from area, line, and multiple sources. A slightly more comprehensive introduction and review to atmospheric dispersion problems is also presented in the *Handbook on Atmospheric Diffusion* by Hanna, Briggs, and Hosker (1982). This work is, in many ways, an update to the original Turner workbook.

Nearly 20 years after its publication, the assumptions in the Turner workbook are still considered a valuable source of information and guidance. NOAA's hazardous materials section, located in Seattle, realized the potential of the Turner workbook and incorporated many of the equations and model assumptions into a desktop computer program.

IV. DISPERSION MODELS

Today, many dispersion models exist, none of which are excellent, some of which are good, and a significant majority have limited or highly specialized utility. Most air dispersion models are designed to run on mainframe computers. Renewed interest in both large-scale and small-scale toxic spills of hazardous materials has triggered a significant effort to place an increasing number of dispersion models on personal computers. At the present time, there are perhaps a dozen or more models which can run effectively on a personal computer.

Extensive model refinements and improvements were primarily a result of a number of empirical measurements both in the laboratory and in open field experiments. The use of wind tunnels has proven to be an excellent tool for modelers in refining and improving model performance. Many models today have incorporated the addition of empirical coefficients to the model to improve performance. For the most part, nearly all atmospheric diffusion models have incorporated improved and more comprehensive mathematics, physics, chemistry, and meteorology.

The Gaussian model has been broadened to accommodate a variety of chemicals. Differences in density, temperature, and composition severely complicate the physics and mathematical equations required, and have a direct bearing upon which of several models to use.

Today, models are trying to deal with seepage (both on and into the ground), evaporation, chemical reactions, buoyancy effects, momentum, and air infiltration rates. They are employing some of these techniques with not only one chemical but for a large number of chemicals. It is clear that models are increasing in complexity. For example, the NOAA model "ALOHA-CAMEO" has a database of 2,629 chemicals.

V. GAUSSIAN MODEL ASSUMPTIONS

Experimental diffusion studies provide an empirical justification for using a Gaussian model to estimate concentration distribution near the ground under certain conditions of distances of 1 km to 10 km from the source. For Gaussian models, the following assumptions are made.

1) The equation of continuity (or conservation of mass):

$$Q = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \chi \, u \, dy \, dz \qquad \text{Equation \#1}$$

is satisfied, none of the material emitted is removed from the plume as it moves downwind, and there is complete reflection at the ground.

2) The mean wind direction specifies the x-axis, and a mean wind speed representative of the diffusing layer is chosen.

3) With the exception of heavy gas dispersion models, it is assumed that the plume constituents are distributed normally in both the cross-wind and vertical directions.

4) The material diffused is a stable gas or aerosol which remains suspended. That is, the material remains non-depositing for a long period of time.

5) Total reflection of the plume takes place at the earth's surface.

6) Meteorological factors influencing plume rise are wind speed (**u**), temperature of the ambient air (**T_a**), shear of the wind speed with height (**du/dz**), and atmospheric stability.

The concentration, χ, at x, y, z, and height H, from a stationary point source is given by Equation #2 (Sutton, 1953). Z is taken to be the vertical in the coordinate system. H is the sum of both the physical stack height, h, and associated plume rise. The mean wind speed affecting the plume is given by 'u'. The source term, Q, is considered to be the uniform emission rate of pollutants from a stationary point or line source.

$$\chi(x,y,z;H) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z\,u}\, e^{\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]}\left(e^{\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]} + e^{\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]}\right)$$

Equation #2

The plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentrations distribution in the horizontal and vertical of σ_y and σ_z. The values of σ_y and σ_z are evaluated in terms of the downwind distance in the 'x' direction. For concentrations, χ, calculated at ground level (z = 0) with no effective cloud rise (H=0), <u>and</u> along the centerline of the plume (y = 0) equation 2 reduces to:

$$\chi(x,0,0;0) = \frac{Q}{\pi\sigma_y\sigma_z u} \qquad \text{Equation \#3}$$

VI. HEAVIER-THAN-AIR GASES

By and large, modelers have endorsed Gaussian-type models for a large number of applications. Gaussian models have become the accepted model of choice, due to their simplicity and exceedingly quick execution on computers. However, Gaussian dispersion models have several important limitations. They cannot deal satisfactorily with complex terrain, nor can they deal with light or calm winds. Experimental results have also found that they cannot deal with the transition from near-source density-dominated dispersion[6] to far-field passive dispersion[7].

Since the Gaussian model is essentially a steady state model, there has been little effort to include spatial and temporal variability into current dispersion models. In addition, the effects of hydrometeors are not handled well by any Gaussian-type model. The most important limitation is the fact that Gaussian models assume the dispersing gas will be neutrally buoyant[8].

Some of the assumptions of Gaussian dispersion were abandoned in the early 1970's as a result of field experiments which proved that heavy gases were significantly influenced by gravity. Much of the research in the recent past has been geared toward heavy gas modelling. It is an area which has evolved into a relatively sophisticated science.

Specifically, heavier-than-air gases (1) settle faster and closer to the source, (2) boil off (in the case of refrigeration) and then act as a Gaussian type-plume, and (3) are considered more serious because they tend to stay near the ground.

Several problems continue to plague heavy gas modelers. It has been found that the dispersion of heavy gases tends to be non-linear. In other words, what works for small spills may not necessarily work for large spills. Vertical mixing, because of the high density of heavy gases, is greatly inhibited and stratifies the gas into a dense layer near the surface, limiting dispersion[9].

Heavy gas models are largely dynamic numerical models, solving both heat and mass balances simultaneously. Most heavy gas models are 4-dimensional and employ partial differential equations which simulate the spatial and temporal dispersion process making them ideally

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[6]Density-dominated dispersion refers to chemical dispersions which are heavier-than-air.

[7]Far-field passive dispersion refers to chemicals which begin as heavier-than-air and transform into neutrally buoyant gases. Most chemicals stored cryogenically would fall into this category, initially acting as a heavier-than-air substance moving away from the source and gradually evaporate into the atmosphere and behave more Gaussian with time.

[8]Gaussian models were never intended to handle heavier-than-air gases.

[9]Heavier-than-air gases can pose a serious health problem because they tend to stay close to the ground and are inhaled or deposited by the local population. The most notable heavy gas accident occurred in Cameroon, West Africa in August 1986. A carbon dioxide (CO_2) "bubble" came out of Lake Nyos killing almost 1,700 people 25 kilometers (15 miles) from the source.

suited for handling topographic effects. Unfortunately, most 4-dimensional models require extensive computer time to run and many are being rewritten to accommodate PC-type machines. Many researchers agree that 4-dimensional conservation equation dispersion models are generally more useful for planning purposes or research tools.

VII. METEOROLOGICAL CONSIDERATIONS

All chemical dispersion models require the input of meteorological parameters in order to have at least a minimal amount of accuracy. To provide the proper input to these models and to make effective decisions, meteorologists must first determine the characteristics of the spill. There are many questions which should be asked to help determine the correct action to be taken:

- What chemical has been spilled? (This is frequently unknown and assuming the worst case chemical is generally most useful.)
- What is the source term? (What quantity of chemical has been or will be released?)
- Where is the chemical spill taking place?
  - Are there downwind obstacles which would disrupt the flow of a typical Gaussian plume dispersion model?
  - Will any part of the toxic cloud be over water?
  - Is the toxic cloud on or near a highway?
  - Are there any people in the affected area(s)?
- Is the toxic spill being released from a high pressure vessel, such as a chlorine container?
- Is the toxic chemical heavier than air?
- Is the toxic chemical stored as a liquid or gas?
- Is the toxic chemical stored cryogenically?
- Is the spilled chemical expected to leak for a period of time, or has all the available chemical been spilled?
- Are rescue workers planning to move damaged containers within a short time?
- Is there a fire at the site?
- Is the ground surface urban or rural?
- Is the meteorologist familiar with the topography in the region where the chemical accident has taken place?
- Are there any known chemical reactions taking place now or expected later?

While some questions are relatively easy to answer, most are not. Emergency personnel, dealing with life and death situations, are anxious to get quick results from a dispersion model. However, most HAZMAT personnel are likely to assume a "worst case" scenario. While this is a rather conservative but effective approach to a time-critical emergency, it could be a prescription for failure. Emergency HAZMAT personnel could recommend the evacuation of people several miles downwind, when in fact no evacuation would have been necessary. It is during the "heat of battle" that the meteorologist is needed to provide accurate information directly to the on-scene commander. Critical meteorological information such as atmospheric stability, wind, relative humidity, precipitation, and the forecast of these parameters are needed.

A seemingly minor misinterpretation of one meteorological parameter can significantly affect dispersions. For example, incorrect cloud cover estimation (generally on the high side) has the net effect of increasing atmospheric stability. NWS meteorologists can contribute this valuable information to emergency personnel, which can be used to make responsible decisions during and after an emergency like a chemical spill.

VIII. ATMOSPHERIC STABILITY

Atmospheric stability is an indication of how much stirring, or mixing, is going on in the atmosphere. Unstable conditions are more efficient at diluting a cloud of toxic gas. As a result, downstream toxic gas concentrations will not be nearly as high as it would under stable conditions. Unstable conditions generally mean less of a toxic plume problem, although the same processes that lead to unstable conditions also tend to make the wind direction more variable. This means that the threat zone associated with the plume may meander back and forth, expanding the problem area.

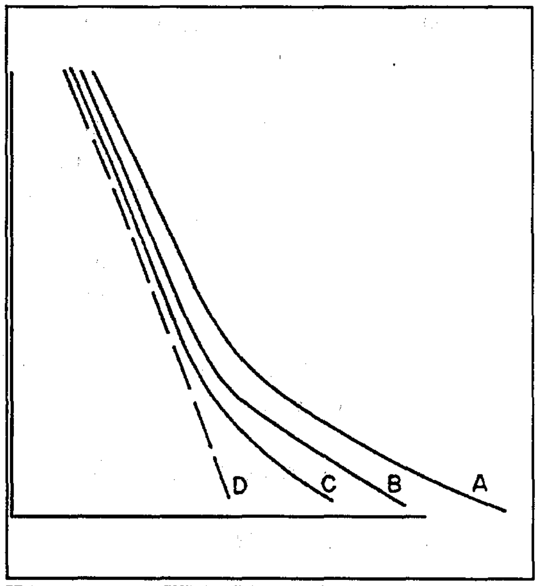


Figure 1 - UNSTABLE

From the onset of early research into air pollution meteorology, it was clear that atmospheric stability (or turbulence) played an important role in determining downwind concentrations. Pasquill (1961) and Gifford (1961) established six separate and distinct types of stability profiles for use in air pollution plume modelling. Figures 1 and 2 illustrate the Pasquill-Gifford atmospheric stability classes. The profiles range from highly unstable (A), to very stable (F). A description of each atmospheric stability class and their associated plume characteristics class can be found in Appendix 1. Appendix 2 is a helpful method in determining stability class. For purposes of the Pasquill stability values, night is defined to be the period from one hour before sunset to one hour after sunrise. The resultant stability is a derived value based largely upon the influences of wind speed at a height of 10 meters, amount of cloud cover, cloud height, and incoming solar radiation.

Atmospheric instability represented by stability class A is a result of super-adiabatic lapse rates (Figure 1 and Table 1) typically found on very hot summer days in the desert southwest.

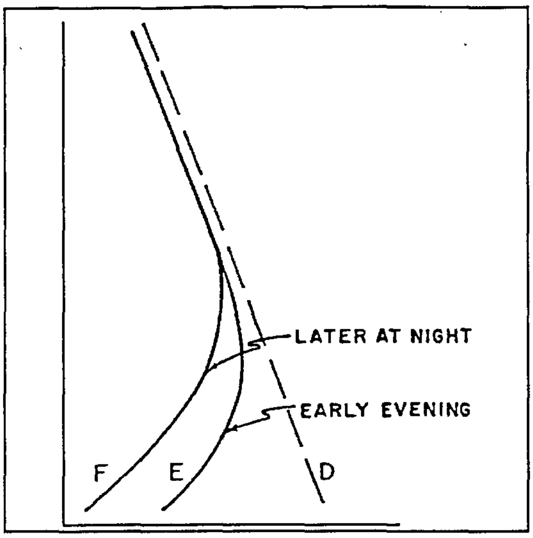


Figure 2 - STABLE

Stability classes B and C are typical of most cities during the daytime of hot summer months. The transition between A, B, and C to D can be very rapid. Typically, the A-type sounding is found during midday from the months of May through September with winds less than 7 mph and skies from clear to scattered (see Appendix 2, Figure 4, and Table 3).

Strong mechanical turbulence within the atmospheric boundary layer, under overcast skies, produces an atmosphere that is well mixed. The stability class associated with this condition is considered "neutral", or stability class D, and is due in large part to the strong winds.

Table 1

STABILITY CATEGORY	LAPSE RATES °C/m		
A		>	-.019
B	-.019	to	-.017
C	-.017	to	-.015
D	-.015	to	-.005
E	-.005	to	.015
F	.015	to	.040
G		<	.040

Figure 2 depicts two types of soundings with strong inversions (stability classes E and F). The E and F stability classes are indicative of very stable soundings and typically occur after sunset through early morning. In the winter, some regimes are favored for the existence of strong and persistent inversions (E & F type), and often have severe fog episodes due to the lack of mixing. These types of soundings most resemble the trapping-type plume.

Church (1949) has classified the behavior of smoke plumes into five classes. The five types of plumes are: FANNING, FUMIGATION, CONING, LOFTING, and LOOPING. Figure 3 illustrates the various types of plumes expected with different vertical temperature and wind profiles. Figure 3 also illustrates the vertical wind shear profile, **du/dz**, and the horizontal standard deviation of wind direction, σ_h, which play significant roles in determining the types of plumes. Hewson (1960) added a sixth class, TRAPPING (not shown) which takes into account inversions. Stability classes E & F are usually associated with the "trapping" plume.

The movement of cracked or damaged containers during the evening hours might seem like a sensible thing to do (less traffic). However, it is during this time of day when a temperature inversion is generally established near the ground. This stable layer traps pollutants and confines them to the lowest layer near the surface (stability class E or F).

Meteorologists can assist emergency personnel in scheduling times during the day (or night) which are best suited for the movement of damaged chemical containment vessels or railcars. This is especially important when determining the onset or destruction of an inversion layer.

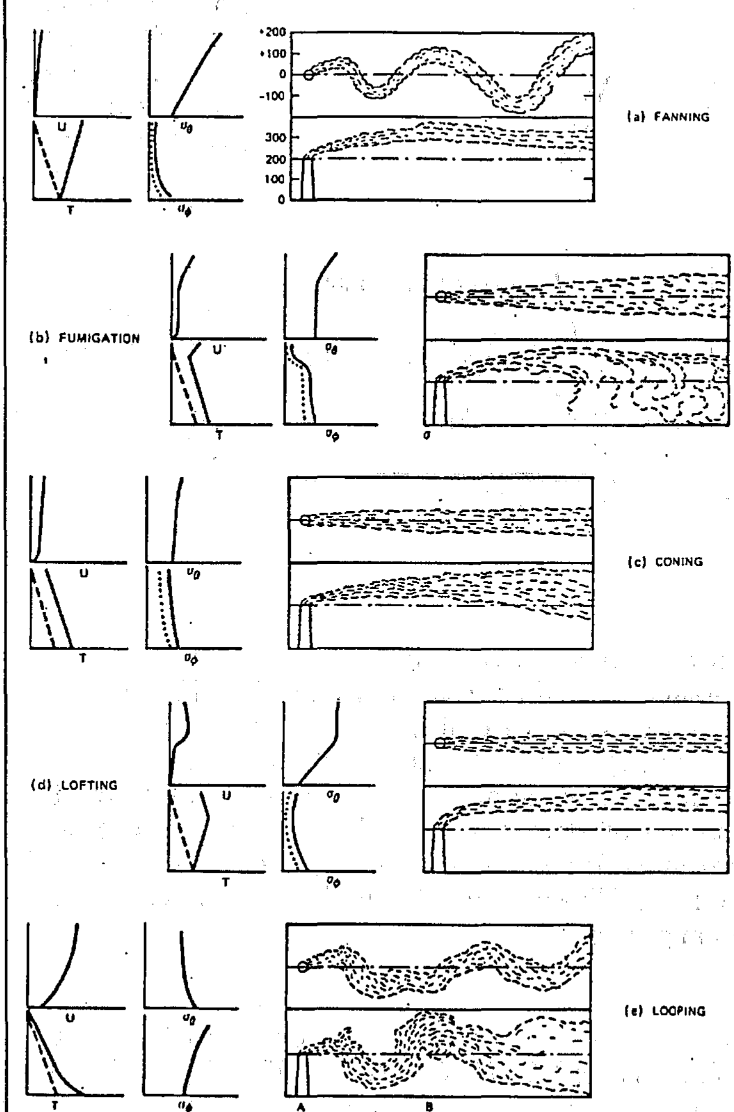
IX. WIND

Experienced weather forecasters with knowledge of local topography are aware of local wind flow patterns in and around bodies of water and/or mountains. HAZMAT personnel may or may not have such knowledge. Since wind speed and direction can be highly variable for any given location and at any given time, it is critical that frequent updates to the dispersion model be made. Nearly all chemical dispersion models are static models which do not routinely update toxic chemical corridors unless new and current wind velocities are manually added.

TABLE 2

KEY TO STABILITY CATEGORIES

Surface Wind Speed (at 10 m), m sec^{-1}	Day: Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥4/8 Low Cloud	≤3/8 Cloud
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D



Instantaneous position of pollution plumes released during periods of varying conditions.

FIGURE 3

Table 2, (Pasquill, 1961) illustrates typical stability classes as a function of both wind speeds and sky condition. During the day, an increase in wind speeds will lead to an increase in atmospheric stability. At night, the reverse may be true; if an inversion has formed, a subsequent increase in wind has the net effect of destabilizing the atmosphere near the surface. In addition, Table 2 indicates the effect of insolation upon the stability class. A bright sun in summer would result in an 'A' or 'B' type stability class, while a mostly cloudy day would likely reduce the stability one full level ('C' or 'D'). Table 2 assumes that a stability class of 'D' will be used under overcast sky conditions during day or night, regardless of wind speed.

Dispersion model output is designed to be as simple as possible. A "footprint" of the toxic cloud is overlaid on a condensed street map (using the same scale) at the point of the spill, without compensating for topographic features. The meteorologist, communicating directly with the on-scene commander, can help adjust the "footprint" to a more reasonable solution based upon known topographic effects and expected wind conditions in both the near- and long-term.

Adjustment of the "footprint" is often required for the effects of on-shore/off-shore winds or up-slope/down-slope winds. The wind channeling effects of both land-water interfaces and nearby mountains are very common in the western U.S. since many cities are located near these natural features. These winds can be highly variable within small spatial and temporal scales. The variability of wind velocity can have enormous consequences to life and property downwind of an accident scene. *Therefore, meteorologists must ensure that dispersion models are regularly updated with current winds and weather during an emergency*.

Forecasting the onset and demise of thunderstorms is of particular interest to HAZMAT teams. Thunderstorm activity in and around the affected area, because of the variability of winds and weather, would substantially alter expected winds. The gusty and erratic behavior of thunderstorm winds can cause great problems for HAZMAT personnel since no model has the capability to provide any reasonable output during such conditions. Thunderstorms bring not only disruptive wind patterns but the threat of precipitation as well. Dispersion model output is very unreliable during any precipitation event. Therefore, meteorologists communicating with HAZMAT teams should highlight thunderstorm activity.

X. SURFACE ROUGHNESS

Early research into air pollution made use of large open areas to validate models. While this worked well, it was soon realized that open fields are not representative of urban areas. To make model output more representative of the area in question, a factor representing either "urban" or "rural" conditions is applied to the models, depending on the location of the spill. Rural models apply a small correction due to friction caused by surface winds, while urban models apply a larger correction. In either case, downwind trajectories can be affected.

The structure of a city tends to increase the rate of diffusion due to increases in mechanical and thermal turbulence. Tall buildings and trees tend to increase the surface friction more than rural farm lands. The large paved surfaces and buildings heat up more rapidly during the day than rural farm fields. Rural, open country is less efficient at dispersing toxic plumes than urban areas because there is often less turbulence (mixing) and greater stability over these areas.

XI. ON-SCENE METEOROLOGICAL DATA

Many communities have regional response teams which are units of well-trained HAZMAT personnel. These teams are generally knowledgeable in all facets of chemical spills and can also offer the meteorologist some rudimentary meteorological observations. In addition, many of these regional response teams are equipped with automatic surface monitoring stations.

These self-orienting portable unit[10] are capable of providing a full spectrum of meteorological measurements. These state-of-the-art stations are generally equipped with the capability to determine sky cover, stability (as it relates to the Pasquill-Gifford classification scheme), temperature, relative humidity, wind speed, and direction. Siting of these weather sensors is critical to ensure that on-scene data are reliable. Meteorologists should provide whatever assistance may be required on the most appropriate placement of these on-scene instruments (both weather sensors and chemical or radiological sensors).

Naturally, these instruments can provide meteorologists with vital basic surface observations. Surface observations are the basic tools essential in making accurate weather nowcasts and forecasts during an on-scene emergency. In areas where automatic equipment is not available, meteorologists should solicit observations from the best qualified HAZMAT personnel at the scene. In addition, if the stability class is difficult to determine or unavailable, meteorologists can determine the stability class simply from the observation of the plume (see Appendix 1).

Because of the urgency surrounding a chemical emergency, meteorologists should retain phone numbers and/or radio call frequencies of HAZMAT personnel who would deal directly with the weather team. Emergency personnel will only have a limited amount of time to communicate weather data. A vast majority of hazardous chemical spills are over within 60 minutes. Those that last longer will require frequent weather updates and might require professional on-scene meteorological services. Several precedents have already been set as NWS meteorologists have provided on-scene weather support for chemical spill emergencies.

XII. CONCLUSIONS

The state and federal meteorologists' mission of public safety goes beyond routine forecasts and severe weather events. It must include mechanisms which give emergency HAZMAT people direct access to meteorologists and meteorologist technicians. The NWS shares in the high level of concern for public safety demonstrated by other proactive federal agencies such as Federal Emergency Management Agency (FEMA), Department of Transportation, U.S. Coast Guard, Environmental Protection Agency, Center for Disease Control, various agencies of the National Oceanic and Atmospheric Administration, as well as others. The NWS, with its contingent of weather offices located throughout the country, is ideally suited to provide expanded services to HAZMAT teams in the event of a toxic chemical spill. It is incumbent upon HAZMAT teams to utilize the best possible personnel in the mitigation of an accidental release of airborne toxic material. Federal and state meteorologists are a logical choice due to their expertise of local and regional meteorological factors.

The Weather Service Nuclear Support Office (WSNSO) in Las Vegas, Nevada, is now working directly with Clark County and surrounding local communities in southern Nevada to provide support in the event of a toxic chemical emergency. WSNSO meteorologists have been trained and are prepared to assist emergency response teams when asked to do so.

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[10]Quick deployed meteorological measurement systems are in use by a number of HAZMAT teams throughout the U.S. These instruments are designed to gather meteorological data with a minimum of effort. For example, some systems are capable of orienting automatically to magnetic north without intervention.

XIII. ACKNOWLEDGEMENTS

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APPENDIX 1

PLUME CHARACTERISTICS

The shape of the plume or toxic cloud is governed by the nature of the atmospheric turbulence. Mechanical and convective turbulence are caused by both wind and surface heating/cooling effects, respectively. Toxic clouds are affected by either wind or thermal influences singularly or in combination with one another. The various combinations create a variety of plume characteristics.

FANNING -- During inversion conditions, typically at night, the plume will not spread much in the vertical direction. With light winds, the plume will meander in the horizontal direction. To an observer on the ground on a moonlit night, the plume will often appear like a slender cylinder and be visible for up to 20 miles from the source. Fanning is associated with stable (E-, F-stability) atmospheric conditions.

FUMIGATION -- Strong diabatic heating, generally during the morning hours, causes an unstable layer to form near the ground. This unstable layer increases in depth until it replaces the stable air above it. The plume from a toxic cloud mixes downward toward the ground in the unstable layer. The resultant mixing of the plume to the ground can occur many miles from the source. Fumigation is associated with an E- or F- stability class over an A-, B-, C-, or D- stability class.

CONING -- If the sky is overcast and winds are strong, then generally only mechanical turbulence affects the plume. The plume spread in both horizontal and vertical directions is moderate. Coning is typically associated with neutral meteorological condition (D-stability) and is the most common.

LOFTING -- Sometimes, particularly in the early evening, the emissions take place above a shallow inversion layer where the neutral layer left over from daytime conditions still exists. The plume will disperse in the same manner as it does on cloudy days except that none will penetrate the inversion layer, and, therefore, none will reach the ground. Lofting is characterized by E- or F-stability at the surface and D-stability aloft.

LOOPING -- On warm sunny days, with light or no wind, the plume shows large vertical undulations which reflect the movement of thermals and downdrafts. The plume spread in both the vertical and horizontal direction can be quite large. Looping is associated with unstable (A-, B-, or C-stabilities) atmospheric conditions.

TRAPPING -- This condition is characterized by a strong inversion and light wind or no winds. Ground based releases of hazardous chemicals are trapped within the layer closest to the ground. Dispersion in the vertical is limited to the height of the inversion, thereby "trapping" hazardous chemicals close to the ground. This situation is potentially the most dangerous and is associated with very stable (E- or F- stabilities) atmospheric conditions.

APPENDIX 2

OUTLINE FOR σ_z and σ_y

To obtain σ_y, σ_z (spread of cloud in the y and z directions in meters) from Figures 5 and 6 at any given distance, you must first determine the appropriate stability class to be used. The following procedure is designed to assist in determining the appropriate stability class.

Having determined the stability class, one can evaluate the estimates of σ_y and σ_z as a function of downwind distance from the source, x, using Figures 5 and 6. These values of σ_y and σ_z are representative for a sampling time of about 10 minutes. Figures 5 and 6 apply strictly only to open level country and probably underestimate the plume dispersion potential from low-level sources in built-up areas. With very light winds on a clear night for ground-level sources free of topographic influences, frequent shifts in wind direction usually occur which serve to spread the plume horizontally. For elevated sources under these extremely stable situations, significant concentrations usually do not reach ground level until the stability changes.

DAYTIME

A) From Figure 4a, determine the appropriate Insolation Index Number, the "**IIN**".

B) Based upon the following cloud cover criteria, determine the necessary modification (if any) to be made with the IIN to derive the appropriate Net Radiation Index, the "**NRI**".

1) If total cloud cover is ten-tenths (overcast) and
   a) Ceiling less than 7000 feet above surface, use **NRI = 0.**
   b) Ceiling equal to or more than 7000' AGL, subtract 1 from the IIN to get the NRI.

2) If the total cloud cover is greater than five-tenths but less than ten-tenths and:
   a) Ceiling less than 7000' AGL, subtract 2.
   b) Ceiling equal to or more than 7000' AGL but less than 16,000' AGL, subtract 1.
   c) Ceiling equal to or greater than 16,000' AGL the IIN is not modified, i.e., **NRI = IIN.**

3) If the total cloud cover is equal to or less than five-tenths, the IIN is not modified, i.e., **NRI = IIN.**

4) If the **NRI** is computed to be less than 1 in the above three preceding steps, use **NRI = 1** with the exception of 1(a) where **NRI = 0** will be applicable.

C) From Figure 4b, determine the appropriate stability class using the derived NRI and the appropriate mean wind speed for the time interval of interest.

D) σ_y at any given distance is obtained from Figure 5 using the determined stability class.

E) σ_z at any given distance is obtained from Figure 6 using the determined stability class.

NIGHT-TIME

For night-time conditions, the appropriate NRI is based on the following three cloud cover criteria:

A) If the total cloud cover is ten-tenths (overcast) and
   1) Ceiling less than 7,000' AGL, use NRI = 0.
   2) Ceiling equal to or greater than 7,000' AGL, use NRI = -1.

B) If the total cloud cover is greater than five-tenths but less than ten-tenths, use NRI = -1.

C) If the total cloud cover is equal to or less than five-tenths, use NRI = -2.

The stability class used to obtain σ_y or σ_z from Figures 5 and 6 is determined from Figures 4a and 4b using the NRI and the appropriate mean wind speed.

THE INSOLATION INDEX

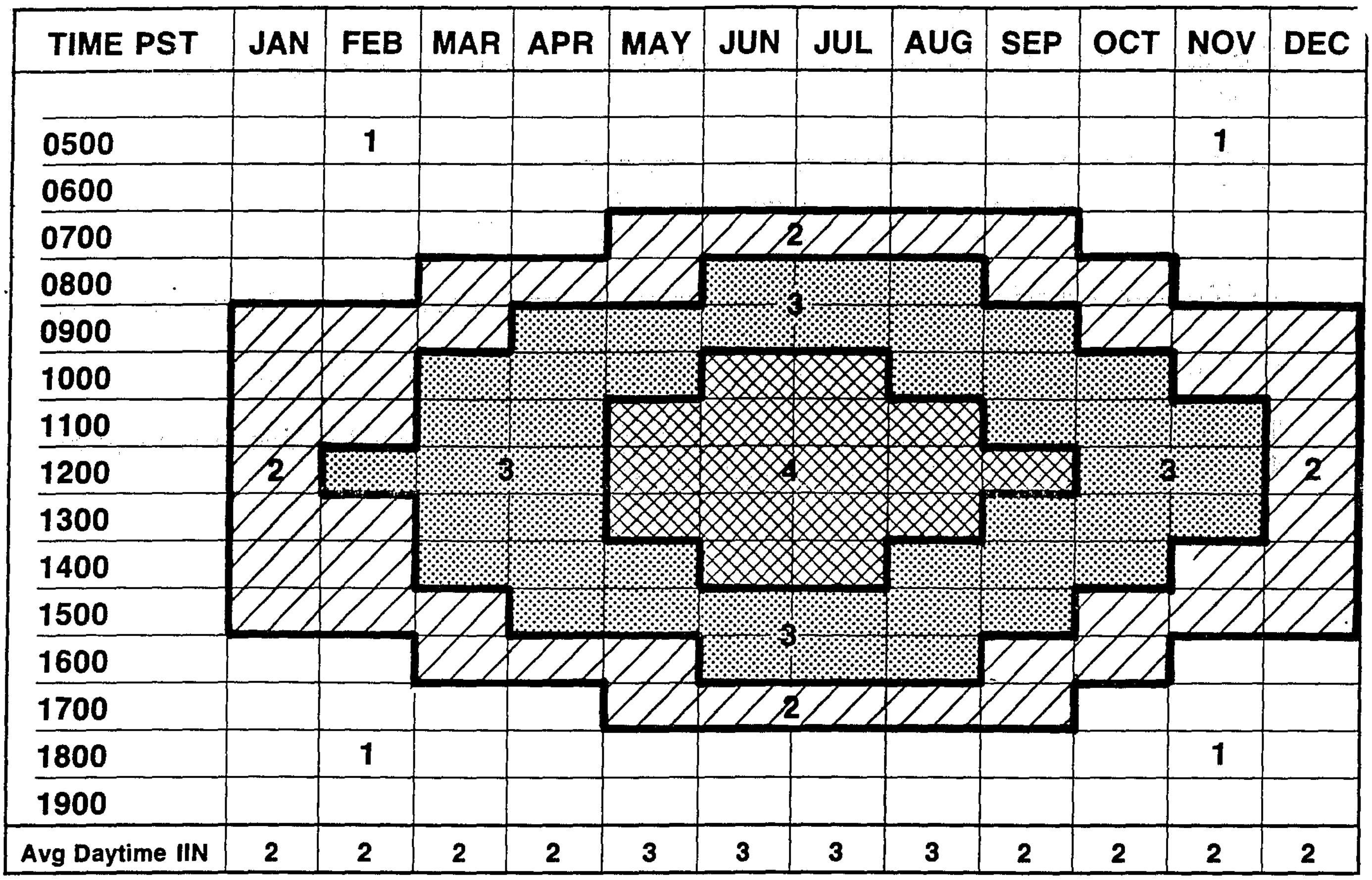
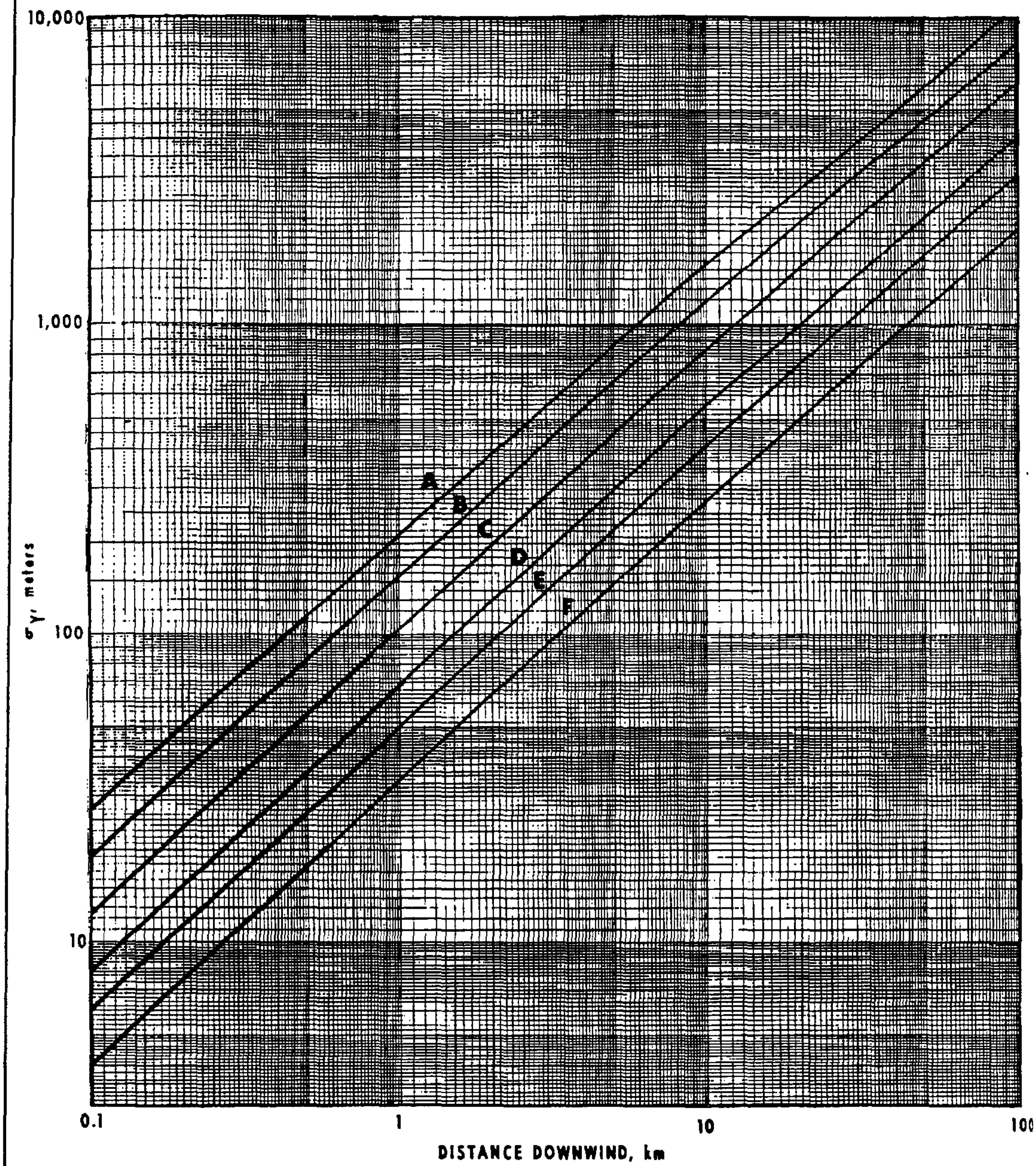


FIGURE 4A

STABILITY CLASS AS A FUNCTION OF THE NRI AND THE MEAN WIND SPEED

MEAN WIND SPEED, MPH	DAYTIME				DAY OR NIGHT	NIGHT TIME	
	4	3	2	1	0	−1	−2
4	A	A-B	B	C	D	F	F
4-7	A-B	B	C	D	D	E	F
7-9	B	B-C	C	D	D	D	E
9-11	B-C	C	C-D	D	D	D	E
11-13	C	C-D	D	D	D	D	D
13	C	D	D	D	D	D	D

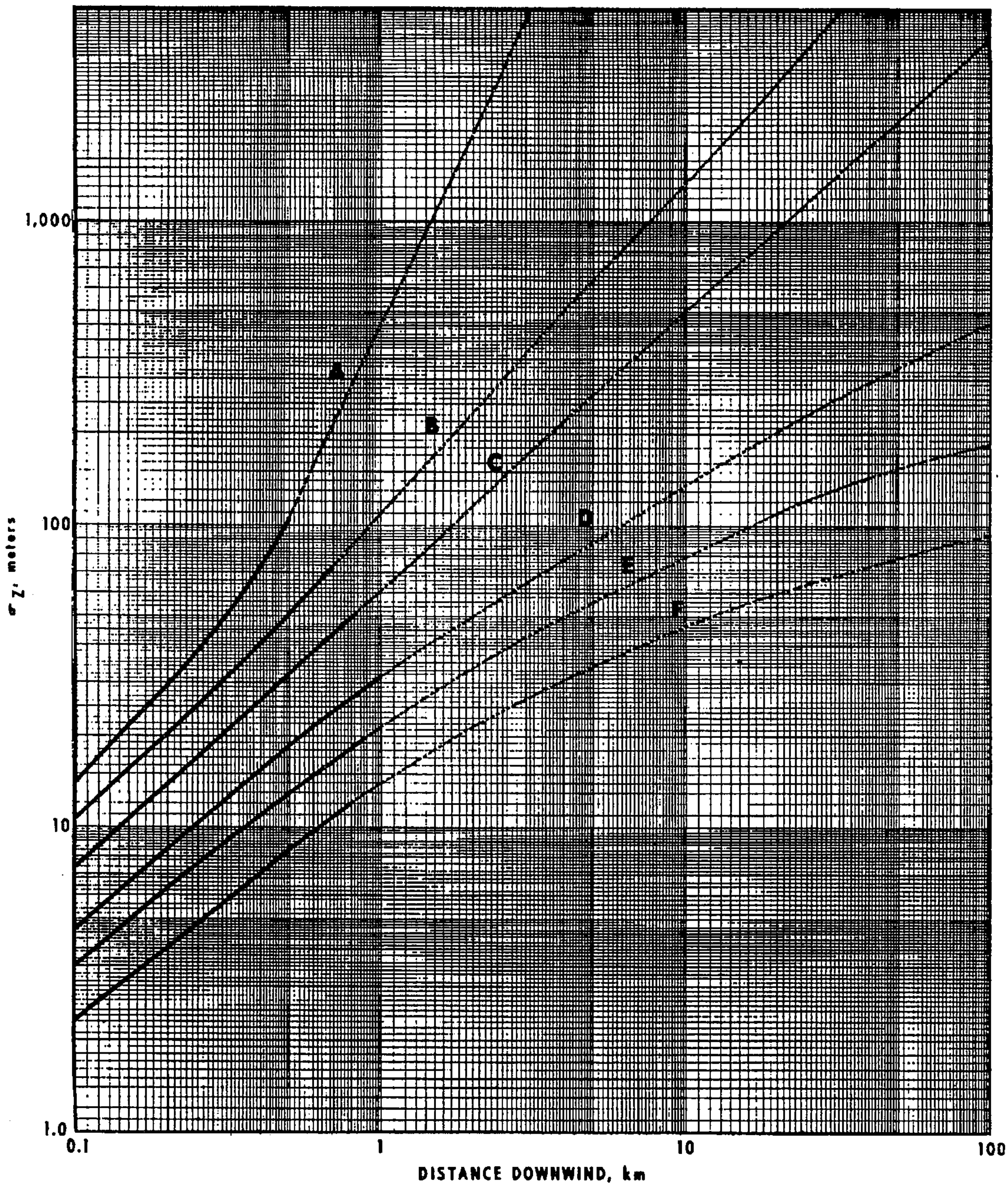
FIGURE 4B



Horizontal dispersion coefficient as a function of downwind distance from the source.

Figure 5

The above diagram should be used to compute the **HORIZONTAL DOWNWIND DISTRIBUTION** σ_y, of hazardous chemicals. It is necessary to first find the Pasquill-Gifford atmospheric stability condition. A simplified method for determining the stability can be found by following the procedure outlined in Appendix 2.



Vertical dispersion coefficient as a function of downwind distance from the source.

Figure 6

The above diagram should be used to compute the **VERTICAL DOWNWIND DISTRIBUTION** σ_z, of hazardous chemicals. It is necessary to first find the Pasquill-Gifford atmospheric stability condition. A simplified method for determining the stability can be found by following the procedure outlined in Appendix 2.

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