PSD quick

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Trinity Consultants
INCORPORATED
100 NORTH CENTRAL EXPRESSWAY
SUITE 600
RICHARDSON, TEXAS 75080
(214) 234-8567

8.18.0

PSD Permitting

August 6, 1985

It was pleasant meeting you and having the opportunity to have you in our workshop.

I've taken the liberty of enclosing a brief description of our firm, a description of our TRPUF model, and a revised attendence list.

Enclosed is an evaluation sheet. Could you please fill it out and return it to us in the enclosed envelope?

As I emphasized in the course, if you have any questions concerning toxic gas releases, please don't hesitate to call me or a member of our staff.

Sincerely,

TRINITY CONSULTANTS, INC.

Richard H. Schulze

RHS/pgl/C1201579

Enclosures

A

PRACTICAL PLANNING FOR TOXIC GAS RELEASES

REGISTRATION LIST

Houston, TX - July 31, 1985

Mr. Allen Jurisich
Senior Program Advisor, Environmental Service
Cigna Loss Control
139 West Livingston Place
Metairie, LA 70005
(504) 831-1617

Mr. John Brau
Employee Relations Manager
Sohio Chemical Company
Box 659
Port Lavaca, TX 77979
(512)552-8218

Mr. Joe Ledvina
Director of Environmental Activities
Vista Chemical Company
P.O. Box 19029
Houston, TX 77224
(713)531-3451

Ms. Ailleen Teng
Senior Environmental Health Specialist
Cigna Loss Control Service
12815 Leader
Houston, TX 77072
(713)933-1826

Mr. Ron Pertuit
Texas Eastman Company
P.O. Box 7444
Longview, TX 75607
(214) 236-5000 ext. 2760

Mr. Joe Woolbert
Texas Eastman Company
P.O. Box 7444
Longview, TX 75607
(214) 236-5000 ext. 2760

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A

SERVICES TO ESTIMATE AIR QUALITY

Trinity Consultants, Inc. has specialized in making estimates of air quality and in obtaining air pollution permits since 1974. All employees devote their time exclusively to this narrow area of the environmental field and they are unusually familiar with rules, regulations, and current practices. The client benefits in terms of reduced costs and quick response time. As a small firm with 7 employees and its own computer, overhead is low and individuals working on study deal directly with the client.

Dispersion Modeling Studies. These studies are performed to help clients evaluate the air quality either to pinpoint the sources of current problems or to evaluate the effect of proposed changes. Since 1978, Trinity Consultants has prepared over 300 dispersion modeling studies for clients in 40 states. Typical categories of work include:

- Trinity Consultants is a leading firm in preparing "Prevention of Significant Deterioration" (PSD) applications. Since 1977, 115 PSD reports have been prepared for nearly every type of industrial plant. Applications have been prepared for plants located in all 10 EPA regions and in 29 states.

- SIP Revisions - Since 1978 Trinity Consultants has helped 9 clients obtain permits to construct in non-attainment areas. In 15 other cases Trinity Consultants has been involved in State Implementation Plan revisions.

- Stack Heights - Trinity Consultants has conducted more than a dozen studies of stack design to optimize investment.

Training Seminars. Three courses are conducted: a two-day course on the fundamentals of dispersion modeling, a two-day laboratory applications course using dispersion models on an IBM-PC and a one-day seminar entitled "Permits Under the Clean Air Act". These courses have been taught a total of over 90 times and have been sponsored by professional associations for their members, major corporations for their employees and Trinity Consultants for the public.

Sale of Models and Met Data. Clients can purchase dispersion models and meteorological data in one of 3 ways: First, 21 firms currently use Trinity Consultants timesharing service devoted almost exclusively to air quality dispersion models. Second, over 70 customers have purchased IBM-PC versions of popular air pollution dispersion models. Third, since 1976 some 20 firms have purchased IBM mainframe version of the UNAMAP models. Trinity Consultants also processes and sells meteorological data from its extensive library. Delivery is generally overnight.

Toxic Gas Releases. 20 firms have been served with studies of the possible effects of a potential gas releases, estimated effects of actual releases, building ventilation studies and testimony in court. Both puff models and steady state models have been used in these analyses.

January 1, 1985

214/234-8567

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PARTIAL LIST OF CLIENTS

Firms Purchasing Dispersion Modeling Studies/Consultation

Petroleum/Refineries

Allied Materials Corp.
\+ American Petrofina, Inc.
Calumet Refining Co. Inc.
\+ Champlin Petroleum, Inc.
* Crystal Oil Company
Dorchester Refining Company
Getty Refining & Marketing Co.
\+ Gulf Oil Co. - U.S.
Kerr-McGee Corp.
Lake Charles Refining Co.
\+ Murphy Oil Corp.
\+ Pennzoil Oil Corp.
Plateau Refining Co.
Rock Island Refining
* Sigmor Refining Co.
\+ Standard Oil Co. (Indiana)(AMOCO)
Standard Oil Co. (Ohio)
\+ Sun Company
Union Oil Company
* Vidette Refining Co.

Petroleum/Production

\+ Aminoil U.S.A., Inc.
Arco Oil & Gas Co.
Mid-American Oil & Gas (Centex)
Cities Service Company
Delbi Gas Pipeline Co.
\+ Endevco, Inc.
Exxon Production Research
\+ Farmland Industries
\+ Getty Oil Co.
Haliburton Resource Management
* Hunt Energy Co.
Husky Oil Co.
\+ Kerr-McGee Corp.
Koch Hydrocarbon Co.
Leede Oil & Gas Inc.
Mesa Petroleum Co.
Moore McCormick Energy
\+ Pursue Gas Processing
\+ Shell Oil Co.
\+ Sun Exploration & Production
Texas Oil & Gas Corp.
Tipperary Corp.
* Tomlinson Interests
\+ Union Texas Petroleum

Pulp & Paper

\+ Boise-Cascade
\+ Bowater Southern Paper Corp.
Celotex
Container Corporation of America
\+ Fort Howard Paper Co.
Georgia-Pacific
* Hammermill Paper
\+ Owens-Illinois, Inc.
Temple Eastex, Inc.

Chemicals

\+ Airco Carbon
\+ Agrico, Inc.
\+ American Cyaminid
\+ CF Industries, Inc.
Cabot Corp.
Calgon Corporation
Chemische Werke Huls AG
\+ Chevron Chemical Co.
Colombian Chemical Co.
Conoco Chemical Co.
Cosden Oil - Chemical Co.
Coulton Chemical Co.
\+ Dow Chemical Co.
\+ E. I. DuPont de Nemours
\+ Ethyl Corp.
FMC Corporation
\+ Firestone Synthetic Rubber & Latex
\+ Freeport Chemical Co.
Georgia Pacific Co.
\+ Goodyear Tire & Rubber Co.
\+ W.R. Grace (Davidson Chemical Div.)
\+ Kerr-McGee Chemicals
Mississippi Chemical Corp.
\+ Monsanto Corp.
Olin Chemical
Petro United, Inc.
Procter & Gamble Co.
Rohm & Haas, Inc.
Sintech, Inc.
Stauffer Chemical
Sid Richardson Carbon & Gasoline
\+ Union Carbide Corp.
Vulcan Chemical Co.

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Coal and Mining

Energy Fuels Nuclear, Inc.
Kerr-McGee Corp.
Texas Industries
\+ Pittston Coal
* Sohio

Metals

* Arco Aluminum
\+ Blaw-Knox
Chaparral Steel (TXI)
Kaiser Aluminum & Chemical Corp.
LTV Steel
National Steel
* National Zinc
+* NL Industries
\+ RSR Corporation
* Ross Metals

Consultants

Argento, Vittorio
Benham Group, Inc.
Louis Berger & Assoc.
\+ Bovay Engineers, Inc.
Breisch Engineering Co.
Browning-Ferris Industries
Castel Consulting Service
CE-Maguire
Chittenden Engineering Co.
Clark, Dietz & Associates
Controls for Environmental Pollution
\+ Cooper Engineers
Daniel Construction Co.
Davis & Floyd Engineers, Inc.
Evergreen Environmental Management
F.E. Courtney & Associates
\+ Ford, Bacon & Davis
Gibbs and Hill
Kaiser Engineers
George E. McVehil
MITRE
Metro Environmental Application
\+ Moore Engineering
J.F. Mullen & Associates
Ortloff Corp.
Petro Project Engineering, Inc.
Petrochem Consultants, Inc.
R.W. Beck & Associates
Resource Consultants, Inc.
Rist, Frost Associates
\+ Scott Environmental
Simons Eastern
\+ Stanley Consultants
Steuver & Associates
\+ J.E. Thibault & Associates
Tippet & Gee
Trovillion, Al
TRW, Inc.
\+ Turner Engineering
\+ Turner, Mason & Associates
Roy F. Weston Co.

Attorneys

George R. Alexander, Jr.
Baker & Daniels
Greenberg, Traurig
Lynberg & Nelson
Millbank, Tweed
Popham, Haik, Schnobrick, Kaufman & Doty
Rooks, Pitts & Poust
Sewell, Junell & Riggs
\+ Thompson & Knight
Wachtell, Lipton, Rosen & Katz

Cement, Stone, Lime & Glass

Acme Brick
* B.L. Anderson
\+ Capitol Aggregates, Inc.
+* Chemical Lime
* Centex Corp.
Dal-Tex Cement
Englehard Minerals & Chemicals
\+ General Portland, Inc.
Genstar Building Materials Co.
Gifford Hill Portland Cement
Ideal Basic Industries
Lehigh Portland Cement
Libbey-Owens-Ford
* Lone Star Cement
Loomis Construction
* Nevada Cement
\+ Owens-Corning
Owens-Illinois, Inc.
\+ Southwestern Portland Cement
\+ Texas Industries, Inc.
+* U.S. Brick
\+ U.S. Gypsum

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Utilities/Energy

* Arizona Public Service, Inc.
* Brazos Electric Power Cooperative
+* Cajun Electric Power Cooperative
Foothills Pipeline, Ltd.
* Golden Valley Electrical Co-op, Inc.
+* General Electric Co.
\+ Hawaiian Electric Company
Louisiana Power & Light
Mississippi River Transmission Corp.
* Nebraska Power & Light
New Orleans Public Service, Inc.
\+ Panhandle Eastern Pipeline
* Oklahoma Gas & Electric Co.
\+ Southwestern Electric Power Co.
Tennessee Gas Transmission Co.
Transcontinental Gas Pipeline Co.
* United Gas Pipeline, Inc.
* Valley View Energy

Miscellaneous

Alexander & Baldwin
Amstar Corp.
Bunge Corp.
* City of Detroit
Dresser Industries

Ford Motor Co. (Boiler)
\+ Frito Lay, Inc.
Gearhart Industries
City of Indianapolis
\+ Intec, Inc.
* Iowa Beef Processors
Manville Building Corp.
McDonnell-Douglas Corp.
* City of San Diego
TD Mechanical
Texas Instruments
* University of Vermont
Varo, Inc.
* Warwick, Rhode Island

States in Which Studies Have Been Done

Alabama	Indiana	Montana	Rhode Island
Alaska	Iowa	Nebraska	South Carolina
Arkansas	Kansas	New Jersey	Tennessee
California	Kentucky	New Mexico	Texas
Colorado	Louisiana	Nevada	Utah
Connecticut	Maine	North Dakota	Vermont
Florida	Maryland	Ohio	Virginia
Georgia	Michigan	Oklahoma	West Virginia
Hawaii	Mississippi	Pennsylvania	Wisconsin
Illinois	Missouri	Puerto Rico	Wyoming

Countries in Which Studies Have Been Done

Brazil	Belgium	Canada	Gulf of Mexico
New Zealand	Netherlands	Saudi Arabia	Indonesia

Firms Purchasing Specialized Training Programs/Seminars

Air Pollution Control Association
American Cyanimid
American Society of Mechanical Engineers
Aramco Services Company
Ashland Chemical
City of Indianapolis
Damson Oil
IBM
Inland Steel Co.
Kerr-McGee Corp.
+Mobil Oil
PEDCO Environmental
Republic Steel
Standard Oil Co. (Indiana)(AMOCO)
Tennessee, State of
Texas Chemical Council
Timken Company
U.S.Environmental Protection Agency
Regions IV and VII
United Technologies
University of Texas (for EPA)

* Served through a consulting firm
\+ Performed more than one study

January 1, 1985 (84-62)

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EMPLOYEE QUALIFICATIONS

Richard H. Schulze — **President**

Mr. Schulze received a BSE degree in Mechanical Engineering from Princeton University in 1954 and a MBA degree from Northwestern University in 1958. Following 13 years of work in corporate long-range planning and product development, he joined Core Laboratories Inc. in 1971 as President of their environmental affiliate, Ecology Audits, Inc. He supervised activities in stack sampling, ambient air monitoring networks, water quality studies and preparation of environmental impact statements. In 1974, he founded Trinity Consultants, a firm responsible for over 300 dispersion modeling studies including over 115 PSD permits and 15 SIP revisions. In 1975 he started teaching a two-day short course on dispersion modeling. To date, there are over 1000 graduates of this course which has been offered 80 times throughout the world. Since 1978 he has taught all the Air Pollution Control Association (APCA) short courses dealing with the fundamentals of dispersion modeling as well as selected EPA courses. He is a registered Professional Engineer, a Diplomate of the American Academy of Environmental Engineers, the founder of the North Texas Chapter of APCA, the author of numerous papers on air pollution, and a member of more than 10 professional organizations. He is the sole owner of Trinity Consultants, Inc.

James C. Clary, Jr. — **Project Manager**

Mr. Clary has over 10 years experience in work as a consulting meteorologist. He holds both the BS and MS degrees in Meteorology from Florida State University. After completing his active military obligation as an officer, Mr. Clary joined Dames & Moore Consultants where he worked on meteorological and safety studies for nuclear power plants as well as on the dispersion of conventional pollutants, including preparation of several PSD permits. Mr. Clary has continued his work in meteorology since joining Trinity Consultants in 1978. He has served as project manager for over 28 PSD permit applications and over 50 other modeling studies. He is also the director of data processing and has installed two computer systems at Trinity. Mr. Clary has been responsible for converting most of EPA's UNAMAP models to be executable on IBM-PC or compatible computers and for developing a two-day Dispersion Modeling Laboratory course which he has now taught 6 times. Mr. Clary is a Certified Consulting Meteorologist of the American Meteorological Society. He taught a semester-length course on modeling of air pollutants at the University of Texas at Dallas.

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Deborah K. Fusselman — Project Manager

Ms. Fusselman graduated cum laude in Chemical Engineering from Texas A&M University in 1980. After graduation, she joined Trinity Consultants and became involved with the development of emission inventories and the preparation of state and federal permit applications. Subsequently, her work also included over 70 dispersion modeling studies. More than half of these dispersion modeling studies were performed for state and federal permit applications. The majority of the permit applications have focused on petroleum refineries, chemical plants, natural gas processing plants and compressor stations. Ms. Fusselman has also assisted timesharing customers with the use of the computer and with technical modeling advice. She has converted most of the EPA's UNAMAP models to execute on the IBM mainframes. She has satisfied the written requirements for registration as a Professional Engineer in the State of Texas. She is a member of the American Institute of Chemical Engineers and the Air Pollution Control Association.

Tammy S. Rippetoe — Project Meteorologist

Ms. Rippetoe graduated cum laude in Meteorology from Texas A&M University in 1983. She joined Trinity Consultants in July, 1984, and has become involved in preparing emission inventories, dispersion modeling and processing meteorological data. She is a member of the American Meteorological Society and the Air Pollution Control Association.

Scott R. Humphrey — Project Meteorologist

Mr. Humphrey graduated magna cum laude in Meteorology from Texas A&M in 1983 and received his Master of Science degree in Meteorology from Texas A&M in 1985. His graduate study was in the areas of atmospheric diffusion and boundary layer turbulence. He joined Trinity Consultants in March, 1985, and his duties include dispersion modeling, processing meteorological data, and aiding in the preparation of project reports. He is a member of the American Meteorological Society and the Air Pollution Control Association.

A

TRPUF

YOUR SOLUTION FOR EVALUATING TOXIC GAS RELEASES

INTRODUCTION

Trinity Consultants, a leader in the field of IBM-PC applications for the air pollution professional, has developed a software package for evaluating releases of toxic gases. This package consists of both the EPA Puff model and TRPUF, a puff model developed by Trinity Consultants. TRPUF is based upon the EPA Puff model. A graphics system is also included in this package.

System characteristics include:

- Simple data entry using interactive and menu-driven screens
- Complex input variables are not required
- Graphical output of concentration versus distance produced on your printer

EPA PUFF MODEL

This model is described in the EPA publication "Estimating Concentrations Downwind from an Instantaneous Puff Release" (PB82-261959), August 1982. The model is based upon the Gaussian Puff equation using the dispersion parameters presented in Meteorology and Atomic Energy.

This program has been converted for the IBM-PC with all of the features included in the original model. Verification test files are included.

TRPUF

TRPUF is based on the Puff EPA model. Several enhancements have been made to make the program easier to use in the PC environment.

All input parameters are specified with simple interactive commands. When TRPUF is started a screen of input items is presented. This screen contains the data used in the last run made. You simply enter the variable number you wish to modify. The computer will prompt you for the entry, verify the entry and then present the input screen again.

The input screen is shown in Figure 1. Notice that all of the entries are relatively simple. There are no complicated variables to define. You also have complete control of the output format from units through fixed or scientific presentations.

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When you select option zero from the input screen, TRPUF begins executing. The results are automatically printed on your printer as the model executes. Total execution times vary with different printers, but will be under two minutes for most printers.

An example of the output is shown in Figure 2. This compact output displays both instantaneous and average concentrations at several downwind distances. Concentrations are included for all three stabilities as well as the maximum concentrations. All input parameters are also shown.

GRAPHICS

The results of your TRPUF run are not only sent to the printer but are also placed in a disc file. Another program included in this package, PDIST, allows you to produce plots of concentration versus downwind distance. Again, you may design your output with simple interactive responses as shown in Figure 3. The output of PDIST is processed by the Golden Software package to produce high quality plots on your dot-matrix printer. Examples are included as Figures 4 and 5.

GOLDEN SOFTWARE GRAPHICS SYSTEM

This complete graphics system is included in the TRPUF package. This system, developed by Golden Software of Golden, Colorado, is used to produce the concentrations versus distance plots. However, this package contains many additional capabilities including contour and three-dimensional plots, XY, graphs, bar charts, pie charts, line graphs and scatter charts.

PRICE AND HARDWARE REQUIREMENTS

The complete TRPUF package is available for $995.00 for a single-use license. This package includes:

- Both source and executable versions of the EPA Puff model and test data files
- Both source and executable versions of TRPUF
- Executable version of PDIST
- Complete Golden Software Graphics System with all documentation
- EPA guide for the EPA Puff model and Trinity Consultants guide for TRPUF
- Telephone support services to help you get started.

Hardware requirements are an IBM-PC, PC/XT or AT, or compatible; two floppy disc drives or one floppy and one hard drive; 256 kb of RAM; and a dot-matrix printer. A math coprocessor will decrease execution time, but is not required.

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COMPANY-WIDE LICENSE

A company-wide license of the software. This license removes the restriction that only copies for backup purposes be made. The user is free to copy and distribute the software and manuals within a single company. The user is responsible for all reproduction. Questions about the software must be made by one person. The additional cost of this option is $500. You must have also purchased one copy of our single-use product.

```
                    TRPUF - MOD5

          COPYRIGHT 1985 TRINITY CONSULTANTS, INC.

1) TITLE - EXAMPLE OF TRPUF5
2) RELEASE AMOUNT (POUNDS) =          2.20500
3) MOLECULAR WEIGHT =  64.00
4) AMBIENT TEMPERATURE (DEGREES F) =  88.00
5) AMBIENT PRESSURE (MB) = 1013.00
6) RECEPTOR HEIGHT ABOVE GRADE (FEET) =    5.
7) AVERAGING TIME (SECONDS) =  300.
8) EXIT VELOCITY (FEET PER SECOND) (USE 0 IF NOT A VERTICAL RELEASE)   5.000
9) STACK DIAMETER (FEET) =   1.500
10) DISTANCE FACTOR (USE 1 FOR THE STANDARD DOWNWIND DISTANCES) =  1.0000
11) WIND SPEED (MPH)  =   5.0
12) STACK HEIGHT (FEET) =  60.00
13) CONCENTRATION UNITS = UG/M3
14) INITIAL PUFF CENTER CONCENTRATION (PPM)  5.00E+05
15) DISTANCE AT WHICH INITIAL PUFF SIZE IS KNOWN (FEET) =    0.
16) INITIAL HORIZONTAL STANDARD DEVIATION (FEET) =    .00
17) INITIAL VERTICAL STANDARD DEVIATION (FEET) =    .00
18) OUTPUT FORMAT - SCIENTIFIC

ENTER VARIABLE NUMBER TO BE MODIFIED, 0 TO RUN, 99 TO STOP
```

FIGURE 1 VAB.0001126438

TRPUF - MOD5
COPYRIGHT 1985 TRINITY CONSULTANTS, INC.
A PUFF MODEL DEVELOPED BY TRINITY CONSULTANTS, RICHARDSON, TEXAS 214/234-8567

EXAMPLE OF TRPUF5

RELEASE AMOUNT (POUNDS) = 2.20500 RECEPTOR HEIGHT ABOVE GRADE (FEET) = 5. INITIAL CONCENTRATION (PPM) = 5.00E+05
MOLECULAR WEIGHT = 64.00 EXIT VELOCITY (FEET PER SECOND) = 5.000 INITIAL HORIZONTAL SIGMA (FEET) = .00
AMBIENT TEMPERATURE (DEG F) = 88.00 STACK DIAMETER (FEET) = 1.50 INITIAL VERTICAL SIGMA (FT) = .00
AMBIENT PRESSURE (MB) =1013.00 WIND SPEED (MPH) = 5.0 DOWNWIND DISTANCE (FT) = 0.
STACK HEIGHT (FEET) = 60.00

COMPUTED VIRTUAL DISTANCES (FT) HORIZONTAL VERTICAL

UNSTABLE	3.3	3.3
NEUTRAL	16.4	16.4
STABLE	85.3	85.3

DOWNWIND DISTANCE (FEET)	PEAK INSTANTANEOUS CONCENTRATIONS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	AVERAGE CONCENTRATIONS FOR 300. SECONDS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	TRAVEL (MINUTES)	--- SIGMAS (FEET) --- UNSTABLE HOR	VER	NEUTRAL HOR	VER	STABLE HOR	VER
20	5.5409E-07	2.2128E-09	6.7703E-09	5.5409E-07	1.7591E-09	4.5425E-12	1.1093E-11	1.7591E-09	.045	3	7	2	3	1	1
40	2.0281E+01	7.2767E-10	4.4680E-09	2.0281E+01	1.1391E-01	2.2348E-12	8.5457E-12	1.1391E-01	.091	5	11	3	4	2	2
60	1.9562E+03	3.3662E-10	3.1362E-09	1.9562E+03	1.5583E+01	1.3668E-12	6.8435E-12	1.5583E+01	.136	7	15	4	4	2	2
80	1.2150E+04	1.8649E-10	2.3043E-09	1.2150E+04	1.2461E+02	9.3783E-13	5.6399E-12	1.2461E+02	.182	9	18	4	5	2	2
100	2.8975E+04	1.1553E-10	1.7539E-09	2.8975E+04	3.6224E+02	6.9102E-13	4.7519E-12	3.6224E+02	.227	11	22	5	6	2	2
120	4.5077E+04	4.2469E-10	1.3728E-09	4.5077E+04	6.6321E+02	2.9391E-12	4.0747E-12	6.6321E+02	.273	13	25	6	7	3	2
140	5.6339E+04	1.9488E-07	1.0993E-09	5.6339E+04	9.5187E+02	1.5296E-09	3.5444E-12	9.5187E+02	.318	15	27	7	7	3	2
160	6.2312E+04	1.7899E-05	8.9711E-10	6.2312E+04	1.1873E+03	1.5694E-07	3.1199E-12	1.1873E+03	.364	17	30	8	8	3	2
180	6.4114E+04	5.3571E-04	7.4386E-10	6.4114E+04	1.3586E+03	5.1847E-06	2.7738E-12	1.3586E+03	.409	19	33	8	9	3	2
200	6.3107E+04	7.4087E-03	6.2525E-10	6.3107E+04	1.4710E+03	7.8394E-05	2.4873E-12	1.4710E+03	.455	20	35	9	9	3	2
220	6.0408E+04	5.9064E-02	5.3177E-10	6.0408E+04	1.5350E+03	6.7793E-04	2.2469E-12	1.5350E+03	.500	22	38	10	10	4	3
240	5.6808E+04	3.1416E-01	4.5695E-10	5.6808E+04	1.5621E+03	3.8856E-03	2.0429E-12	1.5621E+03	.545	24	40	11	10	4	3
260	5.2823E+04	1.2322E+00	3.9622E-10	5.2823E+04	1.5620E+03	1.6331E-02	1.8680E-12	1.5620E+03	.591	26	43	12	11	4	3
280	4.8773E+04	3.8245E+00	3.4633E-10	4.8773E+04	1.5427E+03	5.4052E-02	1.7168E-12	1.5427E+03	.636	28	45	12	12	4	3
300	4.4843E+04	9.8854E+00	3.0491E-10	4.4843E+04	1.5103E+03	1.4836E-01	1.5848E-12	1.5103E+03	.682	30	47	13	12	5	3
320	4.1134E+04	2.2095E+01	2.7017E-10	4.1134E+04	1.4692E+03	3.5084E-01	1.4690E-12	1.4692E+03	.727	31	50	14	13	5	3
340	3.7693E+04	4.3934E+01	2.4079E-10	3.7693E+04	1.4228E+03	7.3567E-01	1.3666E-12	1.4228E+03	.773	33	52	15	13	5	3
360	3.4536E+04	7.9416E+01	2.1575E-10	3.4536E+04	1.3733E+03	1.3983E+00	1.2756E-12	1.3733E+03	.818	35	54	15	14	5	3
380	3.1659E+04	1.3271E+02	1.9424E-10	3.1659E+04	1.3225E+03	2.4508E+00	1.1942E-12	1.3225E+03	.864	37	56	16	14	5	3
400	2.9050E+04	2.0776E+02	1.7566E-10	2.9050E+04	1.2717E+03	4.0143E+00	1.1212E-12	1.2717E+03	.909	38	58	17	15	6	3
420	2.6688E+04	3.0788E+02	1.5949E-10	2.6688E+04	1.2215E+03	6.2112E+00	1.0553E-12	1.2215E+03	.955	40	60	18	15	6	4
440	2.4554E+04	4.3556E+02	1.4536E-10	2.4554E+04	1.1726E+03	9.1568E+00	9.9557E-13	1.1726E+03	1.000	42	62	18	16	6	4
460	2.2625E+04	5.9227E+02	1.3294E-10	2.2625E+04	1.1252E+03	1.2952E+01	9.4130E-13	1.1252E+03	1.045	44	65	19	16	6	4
480	2.0882E+04	7.7844E+02	1.2198E-10	2.0882E+04	1.0797E+03	1.7680E+01	8.9179E-13	1.0797E+03	1.091	45	67	20	17	6	4
500	1.9305E+04	9.9350E+02	1.1225E-10	1.9305E+04	1.0361E+03	2.3400E+01	8.4648E-13	1.0361E+03	1.136	47	69	21	17	7	4
520	1.7877E+04	1.2360E+03	1.0359E-10	1.7877E+04	9.9452E+02	3.0148E+01	8.0487E-13	9.9452E+02	1.182	49	71	21	17	7	4
540	1.6583E+04	1.5038E+03	9.5846E-11	1.6583E+04	9.5490E+02	3.7935E+01	7.6657E-13	9.5490E+02	1.227	51	72	22	18	7	4
560	1.5408E+04	1.7940E+03	8.8899E-11	1.5408E+04	9.1724E+02	4.6751E+01	7.3121E-13	9.1724E+02	1.273	52	74	23	18	7	4
580	1.4339E+04	2.1035E+03	8.2645E-11	1.4339E+04	8.8147E+02	5.6565E+01	6.9849E-13	8.8147E+02	1.318	54	76	24	19	7	4
600	1.3366E+04	2.4290E+03	7.6997E-11	1.3366E+04	8.4753E+02	6.7328E+01	6.6813E-13	8.4753E+02	1.364	56	78	24	19	8	4
620	1.2478E+04	2.7668E+03	7.1881E-11	1.2478E+04	8.1534E+02	7.8978E+01	6.3992E-13	8.1534E+02	1.409	57	80	25	20	8	4
640	1.1667E+04	3.1135E+03	6.7234E-11	1.1667E+04	7.8480E+02	9.1440E+01	6.1363E-13	7.8480E+02	1.455	59	82	26	20	8	4
660	1.0924E+04	3.4656E+03	6.3002E-11	1.0924E+04	7.5585E+02	1.0463E+02	5.8910E-13	7.5585E+02	1.500	61	84	26	21	8	4
680	1.0244E+04	3.8200E+03	5.9138E-11	1.0244E+04	7.2838E+02	1.1847E+02	5.6616E-13	7.2838E+02	1.545	62	86	27	21	8	5
700	9.6184E+03	4.1736E+03	5.5602E-11	9.6184E+03	7.0232E+02	1.3285E+02	5.4467E-13	7.0232E+02	1.591	64	87	28	21	9	5

FIGURE 2 VAB.0001126439

TRPUF - MOD5
COPYRIGHT 1985 TRINITY CONSULTANTS, INC.
A PUFF MODEL DEVELOPED BY TRINITY CONSULTANTS, RICHARDSON, TEXAS 214/234-8567

EXAMPLE OF TRPUF5

RELEASE AMOUNT (POUNDS) = 2.20500
MOLECULAR WEIGHT = 64.00
AMBIENT TEMPERATURE (DEG F) = 88.00
AMBIENT PRESSURE (MB) =1013.00

RECEPTOR HEIGHT ABOVE GRADE (FEET) = 5.
EXIT VELOCITY (FEET PER SECOND) = 5.000
STACK DIAMETER (FEET) = 1.50
WIND SPEED (MPH) = 5.0
STACK HEIGHT (FEET) = 60.00

INITIAL CONCENTRATION (PPM) = 5.00E+05
INITIAL HORIZONTAL SIGMA (FEET) = .00
INITIAL VERTICAL SIGMA (FT) = .00
DOWNWIND DISTANCE (FT) = 0.

COMPUTED VIRTUAL DISTANCES (FT) HORIZONTAL VERTICAL

UNSTABLE	3.3	3.3
NEUTRAL	16.4	16.4
STABLE	85.3	85.3

DOWNWIND DISTANCE (FEET)	PEAK INSTANTANEOUS CONCENTRATIONS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	AVERAGE CONCENTRATIONS FOR 300. SECONDS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	TRAVEL (MINUTES)	--- SIGMAS (FEET) --- UNSTABLE HOR	VER	NEUTRAL HOR	VER	STABLE HOR	VER
800	7.1553E+03	5.8462E+03	4.1752E-11	7.1553E+03	5.9044E+02	2.0986E+02	4.5504E-13	5.9044E+02	1.818	72	96	32	23	10	5
900	5.4742E+03	7.2158E+03	3.2330E-11	7.2158E+03	5.0321E+02	2.8807E+02	3.8755E-13	5.0321E+02	2.045	81	105	35	25	11	5
1000	4.2882E+03	8.2037E+03	2.5660E-11	8.2037E+03	4.3417E+02	3.6025E+02	3.3524E-13	4.3417E+02	2.273	89	113	39	27	11	6
1100	3.4273E+03	8.8252E+03	2.0786E-11	8.8252E+03	3.7870E+02	4.2249E+02	2.9373E-13	4.2249E+02	2.500	97	122	42	29	12	6
1200	2.7867E+03	9.1378E+03	1.7128E-11	9.1378E+03	3.3350E+02	4.7338E+02	2.6012E-13	4.7338E+02	2.727	105	129	45	31	13	6
1300	2.2997E+03	9.2101E+03	2.2435E-11	9.2101E+03	2.9620E+02	5.1310E+02	3.6422E-13	5.1310E+02	2.955	113	137	49	33	14	7
1400	1.9225E+03	9.1056E+03	3.2298E-10	9.1056E+03	2.6504E+02	5.4262E+02	5.5789E-12	5.4262E+02	3.182	121	145	52	34	15	7
1500	1.6255E+03	8.8774E+03	4.2657E-09	8.8774E+03	2.3874E+02	5.6329E+02	7.8081E-11	5.6329E+02	3.409	129	152	56	36	16	7
1600	1.3882E+03	8.5673E+03	4.0331E-08	8.5673E+03	2.1634E+02	5.7651E+02	7.7955E-10	5.7651E+02	3.636	137	160	59	38	17	7
1700	1.1962E+03	8.2069E+03	2.8638E-07	8.2069E+03	1.9709E+02	5.8361E+02	5.8267E-09	5.8361E+02	3.864	145	167	62	39	18	8
1800	1.0390E+03	7.8191E+03	1.6029E-06	7.8191E+03	1.8041E+02	5.8578E+02	3.4233E-08	5.8578E+02	4.091	152	174	66	41	19	8
1900	9.0896E+02	7.4205E+03	7.3509E-06	7.4205E+03	1.6587E+02	5.8401E+02	1.6438E-07	5.8401E+02	4.318	160	181	69	43	20	8
2000	8.0039E+02	7.0225E+03	2.8491E-05	7.0225E+03	1.5310E+02	5.7917E+02	6.6561E-07	5.7917E+02	4.545	168	188	72	44	21	8
2500	4.5860E+02	5.2344E+03	4.1562E-03	5.2344E+03	1.0768E+02	5.2927E+02	1.1757E-04	5.2927E+02	5.682	206	221	89	51	25	10
3000	2.8996E+02	3.9020E+03	9.5734E-02	3.9020E+03	8.0500E+01	4.6614E+02	3.1695E-03	4.6614E+02	6.818	244	252	105	58	29	11
3500	1.9643E+02	2.9558E+03	7.9806E-01	2.9558E+03	6.2828E+01	4.0661E+02	3.0201E-02	4.0661E+02	7.955	281	283	121	65	33	12
4000	1.4003E+02	2.2832E+03	3.6077E+00	2.2832E+03	5.0615E+01	3.5495E+02	1.5335E-01	3.5495E+02	9.091	317	311	136	71	37	13
4500	1.0382E+02	1.7977E+03	1.1004E+01	1.7977E+03	4.1762E+01	3.1133E+02	5.1837E-01	3.1133E+02	10.227	354	339	152	77	41	14
5000	7.9402E+01	1.4406E+03	2.5727E+01	1.4406E+03	3.5087E+01	2.7478E+02	1.3288E+00	2.7478E+02	11.364	390	366	167	83	45	14
5500	6.2261E+01	1.1727E+03	4.9876E+01	1.1727E+03	2.9893E+01	2.4412E+02	2.8004E+00	2.4412E+02	12.500	425	393	183	89	49	15
6000	4.9885E+01	9.6808E+02	8.4380E+01	9.6808E+02	2.5747E+01	2.1827E+02	5.1133E+00	2.1827E+02	13.636	461	419	198	95	53	16
6500	4.0665E+01	8.0917E+02	1.2893E+02	8.0917E+02	2.2371E+01	1.9635E+02	8.3816E+00	1.9635E+02	14.773	496	444	213	100	57	17
7000	3.3651E+01	6.8386E+02	1.8222E+02	6.8386E+02	1.9579E+01	1.7762E+02	1.2643E+01	1.7762E+02	15.909	531	468	228	105	61	19
7500	2.8210E+01	5.8368E+02	2.4233E+02	5.8368E+02	1.7242E+01	1.6151E+02	1.7867E+01	1.6151E+02	17.045	566	493	243	111	65	1E
8000	2.3918E+01	5.0261E+02	3.0710E+02	5.0261E+02	1.5266E+01	1.4756E+02	2.3965E+01	1.4756E+02	18.182	600	516	258	116	68	19
8500	2.0482E+01	4.3625E+02	3.7435E+02	4.3625E+02	1.3582E+01	1.3541E+02	3.0816E+01	1.3541E+02	19.318	635	540	272	121	72	20
9000	1.7694E+01	3.8138E+02	4.4211E+02	4.4211E+02	1.2137E+01	1.2475E+02	3.8274E+01	1.2475E+02	20.455	669	563	287	126	76	21
10000	1.3510E+01	2.9706E+02	5.7276E+02	5.7276E+02	9.8079E+00	1.0700E+02	5.4414E+01	1.0700E+02	22.727	737	608	316	135	83	22
10500	1.1923E+01	2.6438E+02	6.3328E+02	6.3328E+02	8.8642E+00	9.9554E+01	6.2811E+01	9.9554E+01	23.864	771	630	331	140	87	23
11000	1.0583E+01	2.3647E+02	6.8952E+02	6.8952E+02	8.0378E+00	9.2879E+01	7.1257E+01	9.2879E+01	25.000	805	651	345	145	91	23
11500	9.4439E+00	2.1247E+02	7.4102E+02	7.4102E+02	7.3110E+00	8.6865E+01	7.9645E+01	8.6865E+01	26.136	838	673	360	149	94	24
12000	8.4680E+00	1.9172E+02	7.8752E+02	7.8752E+02	6.6695E+00	8.1422E+01	8.7887E+01	8.7887E+01	27.273	872	694	374	154	98	25
12500	7.6266E+00	1.7368E+02	8.2893E+02	8.2893E+02	6.1012E+00	7.6473E+01	9.5908E+01	9.5908E+01	28.409	905	715	388	158	102	25
13000	6.8971E+00	1.5790E+02	8.6532E+02	8.6532E+02	5.5960E+00	7.1957E+01	1.0365E+02	1.0365E+02	29.545	938	736	402	163	105	26
13500	6.2609E+00	1.4404E+02	8.9682E+02	8.9682E+02	5.1454E+00	6.7820E+01	1.1107E+02	1.1107E+02	30.682	971	757	417	167	109	26

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A

```
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READING DATA...
PLOT TYPE (LIN=LINEAR, LOG=LOG-LOG)? LOG

MINIMUM DOWNWIND DISTANCE (FEET) (USE 0 FOR ALL DISTANCES)? 0

MAXIMUM DOWNWIND DISTANCE (FEET) (USE 0 FOR ALL DISTANCES)? 0

ENTER I FOR INSTANTANEOUS, A FOR AVGRAGE CONCENTRATIONS I

SELECT THE STABILITY CLASS - ENTER
U - UNSTABLE
N - NEUTRAL
S - STABLE
M - MAXIMUM OF THE THREE STABILITIES
ENTER U, N, S, OR M? M

D>
```

FIGURE 3 VAB.0001126441

EXAMPLE OF TRPUF5

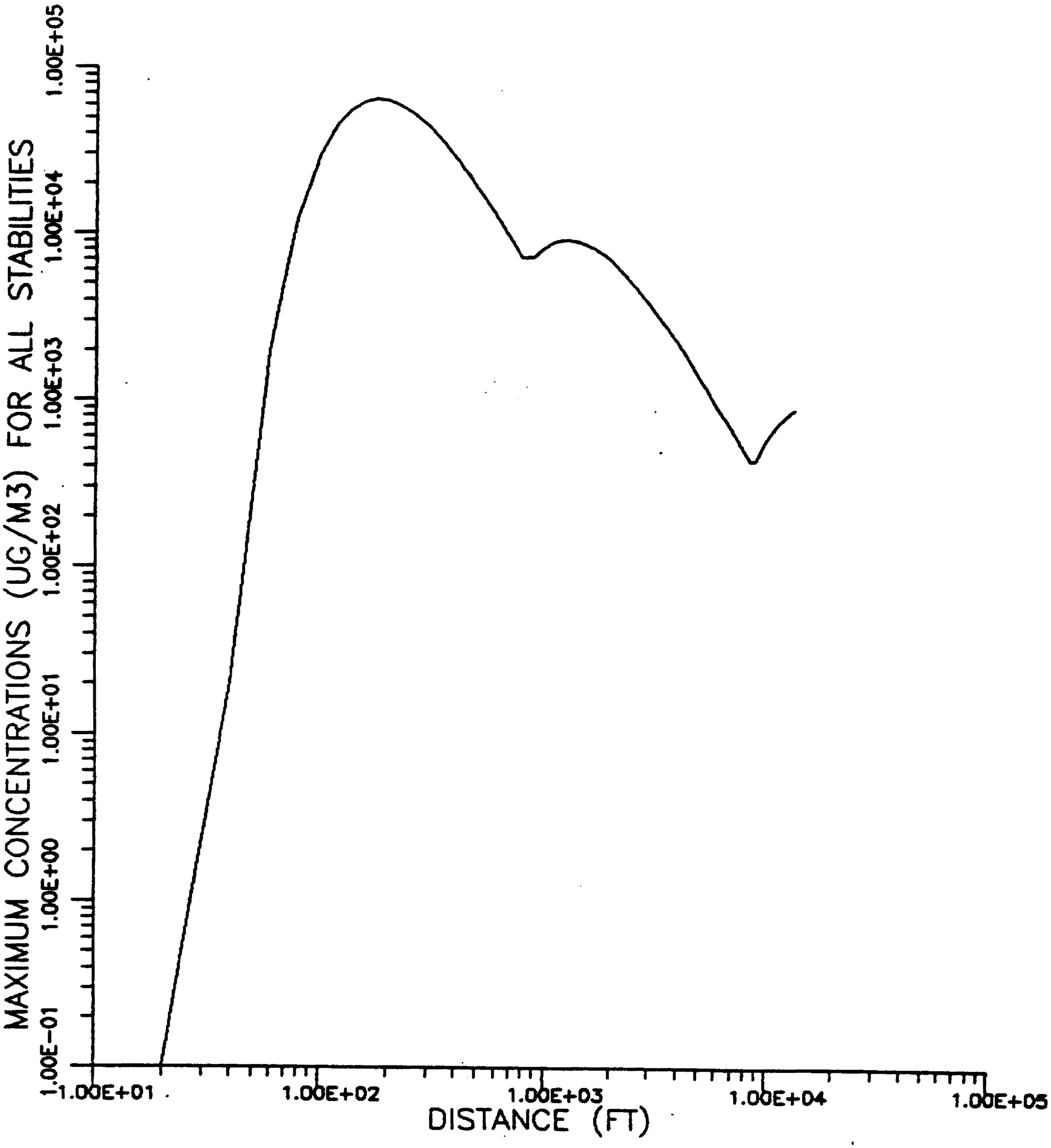

FIGURE 4 VAB.0001126442

EXAMPLE OF TRPUF5

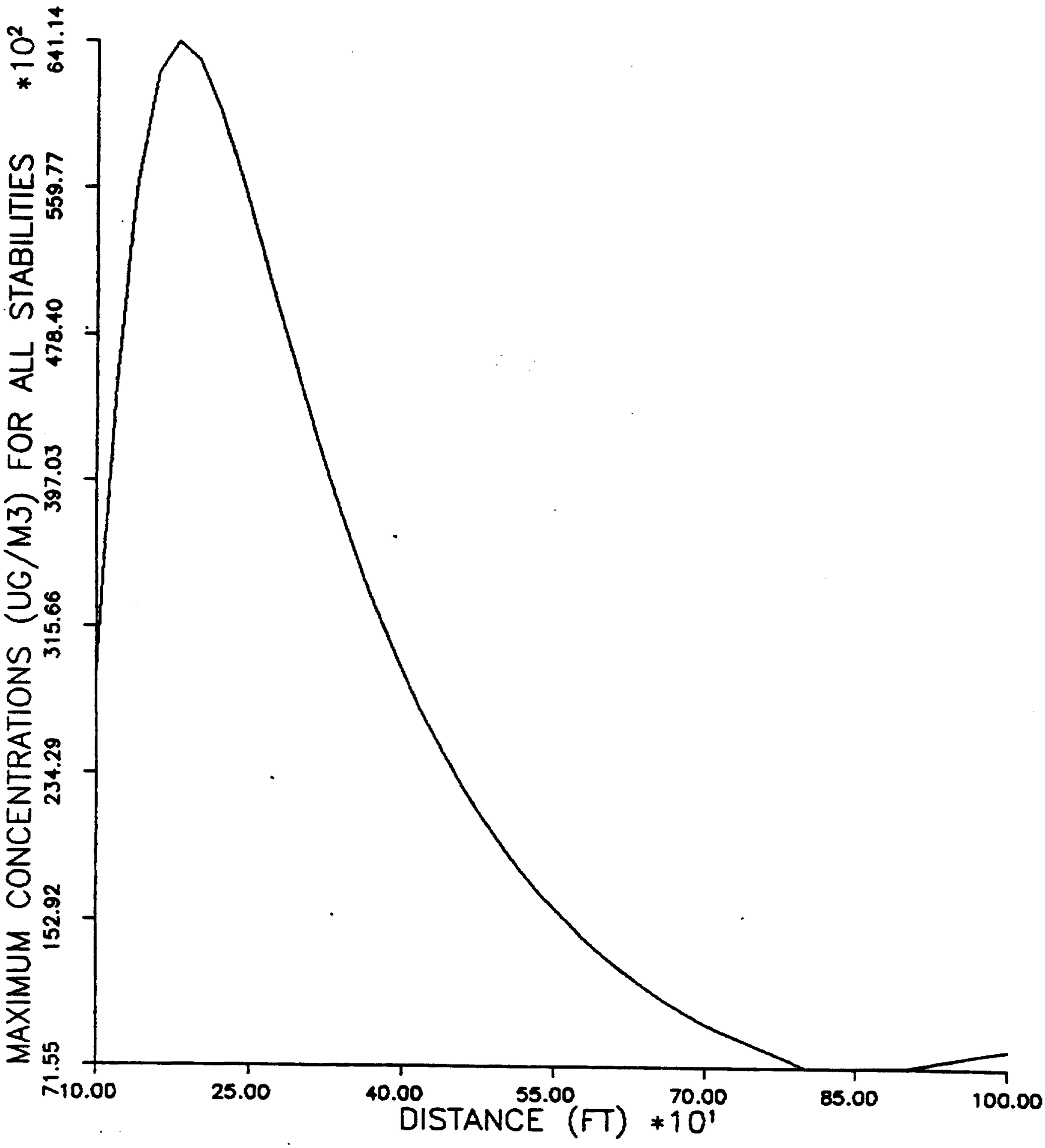

FIGURE 5 VAB.0001126443

A

EVALUATION SHEET

PRACTICAL PLANNING FOR TOXIC GAS RELEASES

July 31, 1985

Your evaluation of this course would help make future workshops more useful to others. Would you please fill out this evaluation and return it in the enclosed stamped envelope.

Information Presented

Coverage of Subject	**___Appropriate**	**___Too Little**	**___Too Much**
Technical Depth	**___Appropriate**	**___Too Simple**	**___Too Advanced**
Usefulness	**___Very Practical**	**___Average**	**___Limited**

Quality of Presentation

Organization of Material	**___Well Planned**	**___Average**	**___Poor**
Presentation	**___Good**	**___Average**	**___Poor**
Length of Course	**___Too Long**	**___Too Short**	**___About Right**

Overall Evaluation

How would you rate the course overall?

___Excellent **___Good** **___Adequate** **___Unsatisfactory**

If given again, would you recommend the course to your associates?

___Yes **___No**

PLEASE CONTINUE ON REVERSE SIDE

PRACTICAL PLANNING FOR TOXIC GAS RELEASES

Richard H. Schulze
July 31, 1985

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Suite 600
Richardson, Texas 75080
(214) 234-8567

VAB.0001126445

1. Dow - DMquinine - Speakers in homes next to Cl2 plant. Stay inside if a release.

2. 2 "Safer" systems in So. Miss. H2S from gas wells feeding sulfur removal plant.

3. British Gas.

4. Speculate on what is most likely to happen.

5. Ground level releases will be greatest under stable conditions.

6. Elevated releases will be greatest at unstable conditions.

7. Canadian DOT- Manual for Spills of Hazardous Materials.

Environment Canada

EP Service.

Tech Services Branch

EPS

Env. Can.

Ottawa Canada.

Cat. No En 40-320/1984E

PRACTICAL PLANNING FOR TOXIC GAS RELEASES

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PREFACE

This manual is designed for use with a one-day short course entitled "Practical Planning For Toxic Gas Releases". I decided that it was best to prepare a manual instead of a set of notes.

This course was offered for the first time in April, 1985. This manual is prepared as a result of comments on the first course and research I conducted since then.

I would welcome any ideas or suggestions for making this manual a more effective teaching tool.

RICHARD H. SCHULZE

Richardson, Texas

July 24, 1985

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I. INTRODUCTION

The purpose of this manual is to help the engineer, safety specialist or other technically trained person prepare for and evaluate the dispersion of a potentially toxic gas. Some compounds will enter the atmosphere as a gas while others will be the result of evaporation from a liquid pool.

Interest in this subject, at least judged by inquiries to our firm, has increased steadily since 1980. It was the tragic events in Bhopal, India, in December, 1984, that has galvanized corporations and regulatory agencies to re-examine their contingency plans.

A. Regulations affecting Toxic Gas Accidents

For the most part, toxic gas releases are not subject to environmental regulations. In contrast, oil spill planning is. In 40CFR112, detailed requirements are set forth for the preparation of Spill Prevention Control and Countermeasure Plans (SPCC Plans). The preparation of plans is required if an organization stores more than 42,000 gallons in an underground tank or 1,320 gallons in above ground containers. Surprisingly, no such plan is required for the discharge of hazardous substances in waste waters but the reporting of such a discharge is required by 40CFR116 and 117.

In general, the response to any toxic gas accident is handled by

VAB.0001126452

local public safety personnel such as the State Police, a city fire department, the Sheriff or special disaster response teams.

In nearly all cases, the scope and detail of any contingency plan is a decision made by the organization which manufactures, transports or stores hazardous materials.

In some instances local emergency response organizations are involved with the planning performed by the manufacturer, storer or transporter of hazardous materials.

Outside the United States, the British have led the world in addressing the problem of toxic and hazardous substances. S.I. 1982 No. 1357 is entitled "The Notification of Installations Handling Hazardous Substances Regulation". S.I. 1984 No. 1902 is entitled "The Control of Industrial Major Accident Hazards Regulations". The first of these regulations enabled the Health Safety Executive to identify installations and define priorities for inspection programs.

The second requires, among other things, the preparation of a hazards analysis, an emergency plan, and an off-site emergency plan. It also requires that members of the public living in the vicinity of an industrial activity be informed about the activity and associated hazards. The Appendix contains a flow chart of the regulations taken from the Health Safety Executive Guide for the 1984 regulations.

These regulations implement Directive 82/501/EEC of the European

Communities.

In February, 1985, the World Bank issued a draft guideline entitled "World Bank and IFC Guidelines for Identifying, Analyzing and Controlling Major Hazard Installations in Developing Countries". It is based on the two British regulations and is currently used to evaluate proposed facilities in developing countries that are seeking funding from the World Bank. This draft is included in the Appendix.

B. Affected Industries

There are certain industries and organizations that have risks associated with toxic gas releases. Broadly speaking, releases can occur in transportation accidents or at plant or warehouse sites.

The chemical industry manufactures materials such as chlorine and ammonia. In addition, the plant chemical industry uses a number of toxic gases as intermediates in the production of final products. These include phosgene, phosphine and the cause of the Bhopal disaster, methyl isocyanate.

Chlorine is the most ubiquitous of the hazardous gases. It is widely used throughout the country for drinking water treatment and in the sterilization of swimming pools. Ammonia is also widely used, primarily as a fertilizer.

Ethylene oxide is used in the sterilization of equipment,

supplies and disposable items used in the medical field. Although large volume sterilizers such as the manufacturers of plastic disposables have facilities equipped with scrubbers, many smaller users, such as hospitals, do not.

About 20 percent of the natural gas produced in the United States contains some hydrogen sulfide which must be removed before the gas is delivered to common-carrier pipelines. There is risk both in drilling for gas and in processing the gas. Hydrogen sulfide is also of concern in refineries where up to several tons of the compound can be contained in pipelines or process vessels. The liquid extraction of elements such as sulfur or bromine often involves processing hydrogen sulfide.

The semi-conductor industry uses some unusually toxic gases such as arsine, hydrogen selenide and phosphine in the manufacture of wafers. As the use of metal-organic vapor phase epitaxy reactors come into wider use, increased quantities of these hazardous gases will be used.

Human error is another major cause of toxic gas releases. Water in place of nitrogen was introduced to the storage tank of methyl isocyanate in Bhopal. Operators have pumped a caustic solution into a sulfuric acid tank. Maintenance personnel have used inappropriate chemicals to clean a contaminated tank. Material in an epoxy resin blending tank got too warm and started a reaction which caused a cloud of gas to drift over a nearby school.

Transportation spills are difficult to assess. The most elaborate system is operated for the Department of Defense by Lawrence Livermore Laboratory. If a nuclear weapon accident occurs anywhere in North America as a result of a plane crash, a missile silo accident or other cause, the direction and concentrations in the released material can be forecasted.

More commonly, however, a trucking or railroad accident occurs and local public safety officials do the best they can to reduce the risk to those nearby. The most difficult task, however, is to determine the quantity of gas released. When a tank car is laying in a ditch it is difficult to determine whether the tank has a small puncture or a large gash.

The major uncertainty in most situations is the value of the "source term", that is the quantity that is or was actually introduced into the atmosphere. Next, in order of uncertainty, are the meteorological parameters. Finally, there is the inherent uncertainty regarding the accuracy of the model. In summary, there is usually a great deal of uncertainty, and thus, most analyses of actual or potential accidents tends to stress the "worst case".

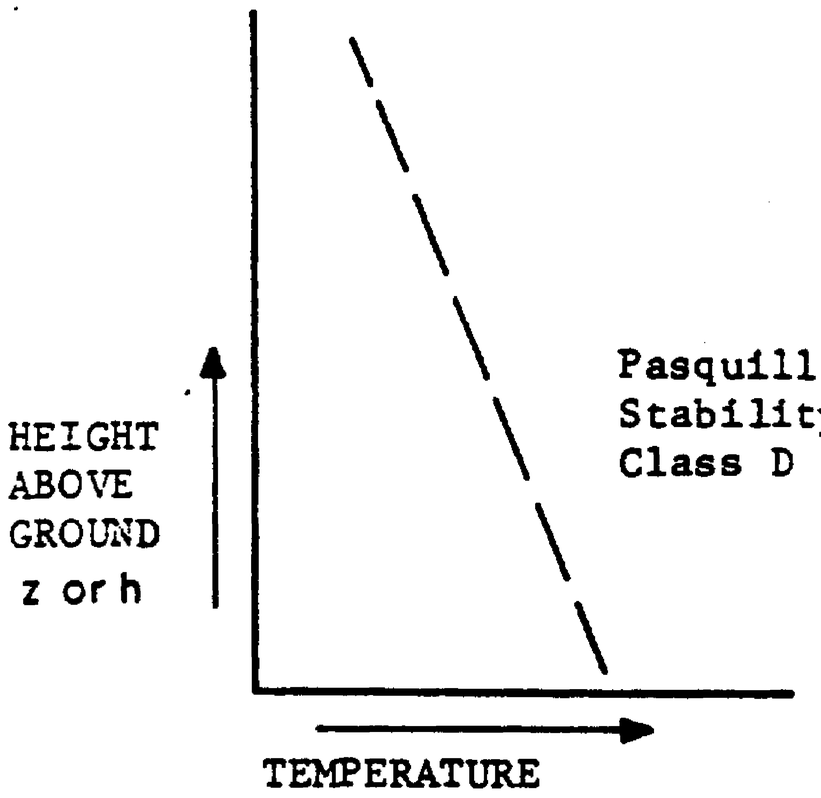
II. ATMOSPHERIC TURBULENCE

A. Description of Turbulence

Atmospheric turbulence is caused both by the wind and by surface heating and cooling (thermal) effects. The meteorological terms are mechanical and convective turbulence.[1]

WIND surface heating

An atmosphere that is well mixed because of strong winds - vigorous mechanical mixing in meteorological terms - under overcast skies is termed "neutral." Under these conditions, there are no surface heating or cooling effects and the temperature decreases with altitude at the "ADIABATIC LAPSE RATE". Lapse rate is the change in temperature with elevation. This is illustrated as follows:



ADIABATIC LAPSE RATE IS -5.4°F/1000 FT
OR ~-0.01°C/METER
DUE TO MECHANICAL TURBULENCE ONLY.

This condition is typical of overcast days and nights with strong winds.

This is an idealized illustration. The actual lapse rate shows a variable change in slope, particularly with lighter winds. In

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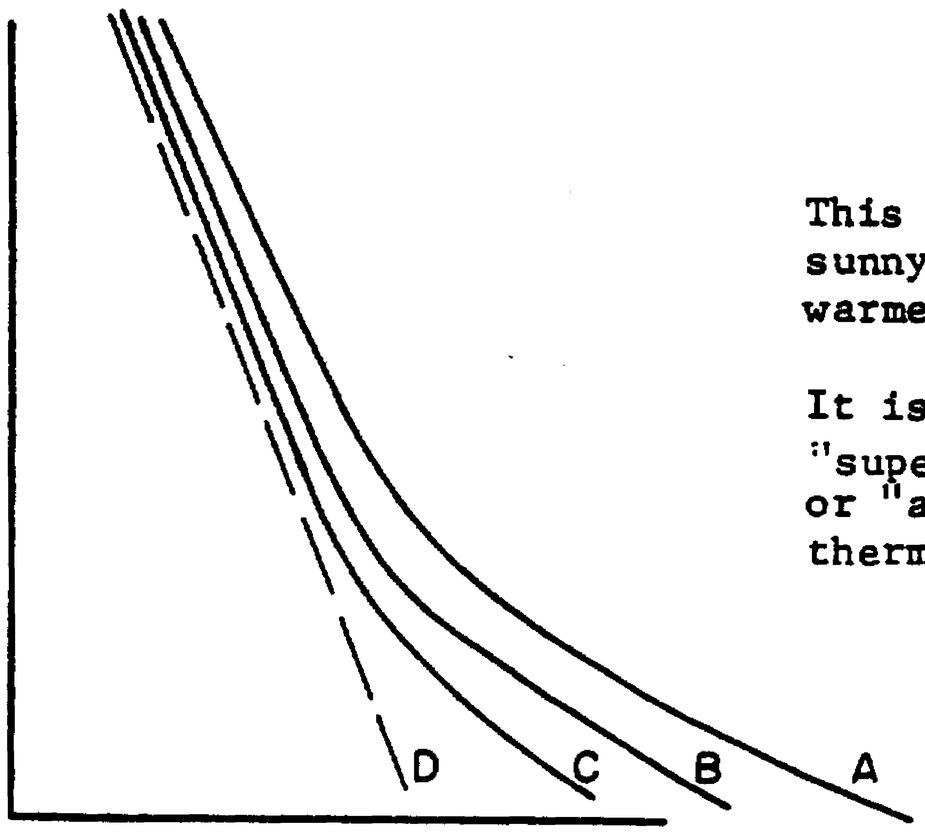
the Pasquill system of categorizing stability, this condition is called D. Sometimes meteorologists refer to the potential lapse rate. This term is equal to the actual temperature lapse rate less the adiabatic lapse rate. For example if the actual lapse rate is 0.01°C/m, the potential lapse rate is 0.02°C/m (0.01-(-.01)).

If the winds are moderately strong, in excess of 10 m/sec, the atmosphere is well mixed from the surface to the top of the boundary layer. The boundary layer is usually defined by an upper air inversion, where the slope of lapse rate becomes positive or nearly so. When the winds are lighter under overcast skies, the atmosphere can be considered to consist of a number of mixing zones. Surface friction will create a turbulent zone between 10 and 100 meters thick. Above this will be zones that exhibit relatively laminar flow. The transition between the zones is quite gradual.

The primary source of surface heat on the earth is the sun, or more exactly, solar radiation. As the sun rises in the morning or as an overcast sky becomes partly cloudy, a larger amount of solar radiation reaches the earth's surface. This causes the air near the surface to warm and "cells" of this warm air start to rise much as steam is formed on the bottom surface of a pot of boiling water. The amount of solar radiation reaching the surface is determined largely by the cloud cover and

the elevation of the sun (solar insolation). The more direct the sunlight, the more heating of the surface and the greater the thermally induced, convective, turbulence. As the cells of warm air leave the surface, they are replaced by downward moving cells of colder air.



This condition is typical of sunny days when the sun has warmed the earth.

It is called "unstable," "superadiabatic," "overturning," or "advecting" because of thermally induced turbulence.

The unstable conditions have been subdivided into three categories by Pasquill: A, B, or C.[2] Turner refined Pasquill's definitions somewhat to facilitate the use of computers to determine stability from routine surface observations.[3] Category A applies when the sun is 60° or more above the horizon and the sky is cloudless or nearly so. Category B applies when the sun has less elevation or the sky is cloudier. Category C is only slightly unstable. Under

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these conditions, the lapse rate is called "superadiabatic," "overturning," "unstable," or "advecting".

Since about 1972 a number of studies have been conducted to help in understanding convective turbulence better. Briggs enumerates these in a 1975 review. During the day, convective turbulence strongly mixes the lower atmosphere, but this mixing ends abruptly at the top of the mixing layer. Nearly all of the time there is a stable air (a lapse rate with a positive slope) layer aloft that acts as a lid on mixing. In rural areas on clear mornings the mixing zone starts as a shallow layer near the ground at sunrise and continues to increase during the day as long as the radiation input from the sun exceeds the earth's outward radiation. The lower boundary of the upper air stable layer increases in height as more of this stable air becomes involved in the convective turbulent layer.

The temperature gradient is superadiabatic only in the lowest tenth or so of the mixing depth and just slightly less than adiabatic above this. The mixing layer consists of upward thermals carrying heated air from the surface and of compensating downdrafts. The turbulence is much greater inside the thermals than in the subsiding downdrafts. Extremely unstable conditions

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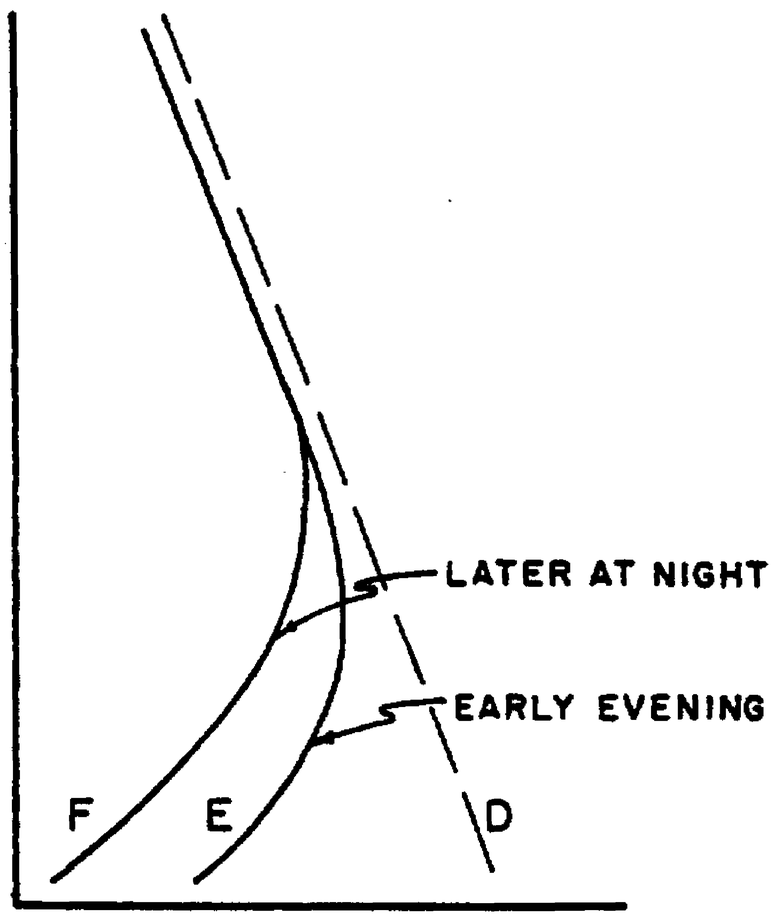
can only exist during periods of light winds. Moderately unstable conditions can exist with winds up to moderate speeds.

As night comes and solar radiation ceases, the earth cools as it radiates heat. The earth, like the sun, radiates heat in proportion to the fourth power of the absolute temperature. In the absence of wind, the cooling air near the surface shrinks in volume and tends to settle. This results in cool air tending to "drain" downhill. For example, in the fall, frost will most often first occur in the valleys rather than on the tops of the hills.



This condition is typical of relatively cloudless nights with light winds. The elevation at which the actual lapse rate reverses is the depth of the "inversion layer".

This condition is called "stable".

Pasquill divided the stable conditions into two categories.

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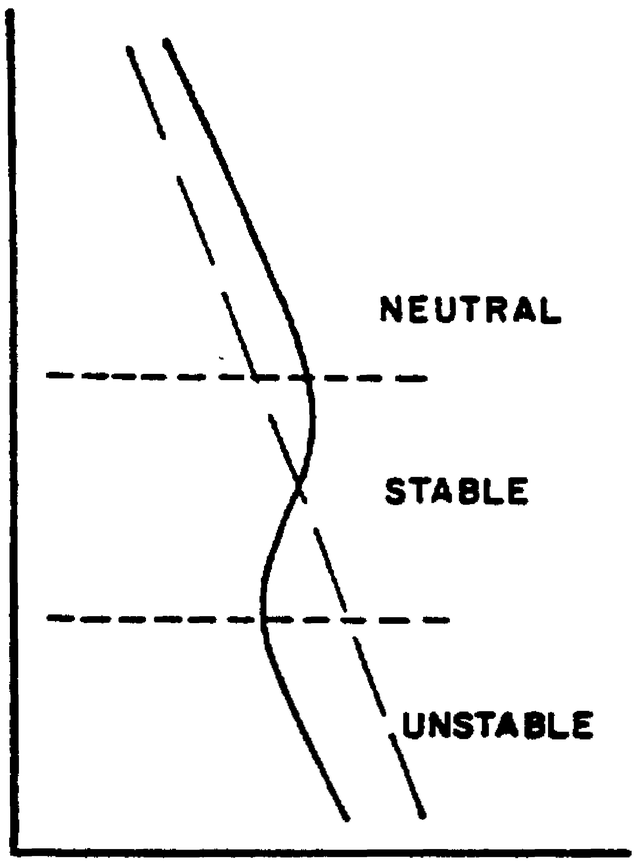
Stability E applies with clear nights and moderate winds or partly cloudy nights and light winds. Stability F applies to calm clear nights in rural areas. The United States Environmental Protection Agency uses a potential lapse rate of 0.02°C/m for E and 0.035°C/m for F stability or actual lapse rates of 0.01°C/m and 0.025°C/m respectively for E and F.

During the Arctic winter, rather severe inversions can occur. During extended periods of cloudless still days with virtually no sun, lapse rates of .036 to .055 degrees per meter are not uncommon in places such as Fairbanks, Alaska. Strong inversions can also occur at the surface as warm winds blow across cold bodies of water. This is typical of spring conditions on the Great Lakes. It can also occur as cold winds are drawn in across land such as in the Los Angeles basin. Stabilities stronger than E or F are sometimes referred to as G and H.

After sunrise on clear mornings, the sun starts to heat the surface. The layer of thermally induced turbulence starts at the surface and gradually increases in depth as it erodes the stable layer from beneath. The inversion layer generally disappears within 5 to 7 hours after sunrise.



This condition is typical of the period after sunrise when the sun starts to warm the surface and the night-time inversion starts to disappear.

Mixing takes place only within layers in the atmosphere, not between the layers. Thus in the morning situation just described, the layer closest to the ground will be very well mixed due to the vertical motions typical of superadiabatic conditions. The start of the stable layer forms a lid. If pollutants were emitted into the stable layer during the night, they would remain in this layer until the unstable layer erodes the stable layer and reaches a depth equal to the centerline of the plume. At this point, the pollutants will be mixed rapidly in the unstable layer. Meteorologists call this condition "Inversion Breakup Fumigation".

Under typical daytime conditions, after disappearance of the nocturnal inversion layer, the surface boundary layer continues to have a reasonably well-defined upper limit that is usually between 500 and 2000 meters deep. At night the surface layer is stable in nature and is not nearly as deep as the daytime layer because of the absence of ground thermals.

The diurnal changes in the atmosphere are illustrated in Figure 1. It shows average wind speeds by hour for the 27 days of June at an Alabama location at a 10-meter elevation and at a nearby 150-meter elevation. It is apparent that there is a strong inversion at night. The surface wind speed is a small fraction of the wind aloft. By about 0900 the surface has become warmed so that good vertical mixing is occurring and the winds at the surface are equal to those aloft. This condition continues past mid-day when the cumulus clouds start to increase. By evening the winds subside. At night only the aloft winds increase, suggesting a surface-based inversion.

B. Categories of Atmospheric Turbulence

Figure 2 is the description of Atmospheric Stability Categories taken from Turner's "Workbook of Atmospheric Dispersion Estimates". This table is similar to that on page 368 in F. Pasquill, "Atmo-

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FIGURE 1

AVERAGE WIND SPEED AT ANNISTON AIRPORT (SURFACE) AND PLANT (500' ELEVATION) JUNE 3-29, 1975

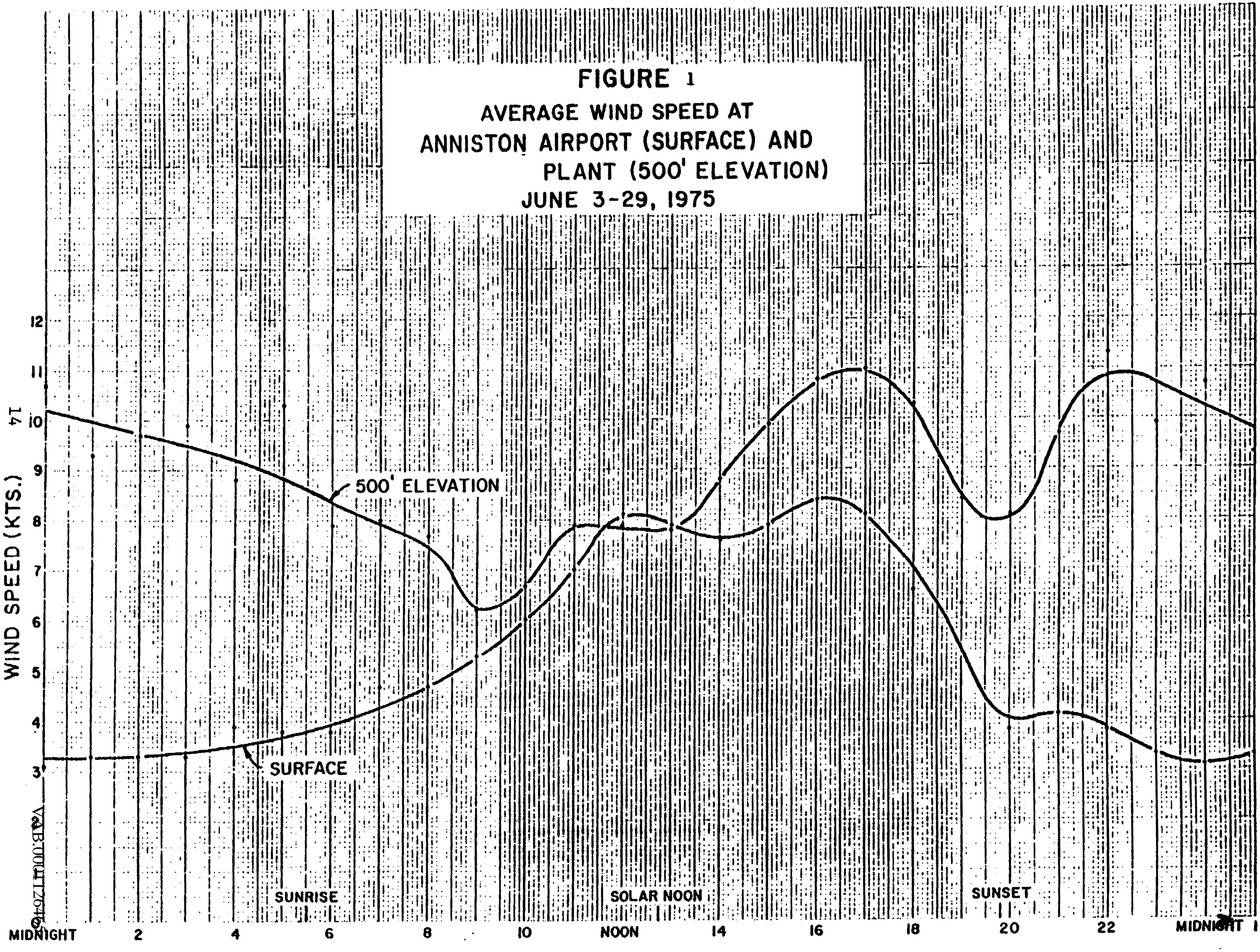

FIGURE 2

DESCRIPTION OF ATMOSPHERIC STABILITY CATEGORIES

KEY TO STABILITY CATEGORIES*

Surface Wind Speed at 10 m. Altitude 2.24 MPH = 1.95 Knots = 3.6 KPH = 1.0 m/sec			Day			Night	
			Incoming Solar Radiation			Thinly Overcast or	
			Strong	Moderate	Slight	>4/8 Low Cloud	<3/8 Cloud
MPH	Knots	m/sec					
<4.5	<3.9	<2	A	A-B	B		
4.5-6.7	3.9-5.8	2-3	A-B	B	C	E	F
6.7-11.2	5.8-9.7	3-5	B	B-C	C	D	E
11.2-13.4	9.7-11.7	5-6	C	C-D	D	D	D
>13.4	>11.7	>6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night. Night refers to a period from 1 hour before sunset to 1 hour after sunrise. For purposes of the computer program Stability Category A=1, B=2, etc.

"Strong" incoming solar radiation corresponds to a solar altitude greater than 60° with clear skies in midsummer; "slight" insolation corresponds to similar conditions in midwinter or to a solar altitude from 15° to 35° with clear skies in midsummer. Cloudiness will decrease incoming solar radiation and should be considered along with solar altitude in determining solar radiation. Incoming radiation that would be strong with clear skies can be expected to be reduced to moderate with broken (5/8 to 7/8 cloud cover) middle clouds and to slight with broken low clouds.

Caution should be used when forecasting to result in ambient concentrations with wind velocities of less than 2 meters per second (4.5 MPH or 3.9 knots). At low velocities the winds tend to meander widely. In addition, surface wind speeds at low velocities are rarely indicative of aloft velocities or of upper air stability categories.

Stability categories are reliable in open, rural areas. In urban and heavily wooded areas, the surface roughness and heat islands have an effect on the category, particularly on still nights. On calm clear nights stability E or F night occurs in rural areas where D is likely to occur over urban areas.

*D. Bruce Turner, Workbook of Atmospheric Dispersion Estimates, U.S. Department of Health, Education, and Welfare, Revised 1970.

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spheric Diffusion" (second edition). Turner defined stabilities in terms of solar insolation angles and cloud cover instead of such terms as "sunny midday in summer in England" used by Pasquill. Turner also omitted a notation Pasquill used in his table which reads "for A-B take average of values for A and B etc." The Appendix contains the description of a computer algorithm that determines stability category from routine surface meteorological observations that is used in the "STAR" program.

Figure 3 illustrates the Combinations of Wind Speed and Stability anlayzed by PTMAX, a computer program by Turner that analyzes a single stack. This matrix of stabilities and wind speed in PTMAX contains some inconsistancies with Figure 2. According to Figure 2, stability A can't exist with winds in excess of 2 or 2.5 meters per second. Low wind speeds can exist for both C- and F-stabilities. PTMAX also analyzes wind speeds of 4 and 5 meters per second for F-stability that, according to Pasquill's definition, cannot occur. It is also questionable that any sort of modeling will be very accurate with winds of 1 meter per second or less.

The National Climatic Center produces a "STAR" listing of the frequency of stability, wind speed, and wind direction based on historical meteorological data. The degree of atmospheric tur-

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FIGURE 3

COMBINATIONS OF WIND SPEED AND STABILITY
ANALYZED BY PTMAX

WIND SPEED (M/SEC.)	STABILITY (PASQUILL)					
	A=1	B=2	C=3	D=4	E=5	F=6
.5	■	■		■		
.8	■	■		■		
1.0	■	■		■		
1.5	■	■		■		
2.0	■	■	■	■	■	■
2.5	■	■	■	■	■	■
3.0	■	■	■	■	■	■
4.0		■	■	■	■	■
5.0		■	■	■	■	■
7.0			■	■		
10.0			■	■		
12.0			■	■		
15.0			■	■		
20.0				■		

Shaded area indicates 49 combinations of wind speed and stability analyzed by PTMAX Computer Program. This program was developed by D. B. Turner of the Environmental Protection Agency to analyze single stacks following the method described his "Workbook of Atmospheric Dispersion Estimates."

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bulence is inferred from the surface observations. Figure 4 illustrates the frequency distributions of wind speed and stability for New Orleans, Louisiana and Williston, North Dakota. It provides an idea of the relative frequency of the occurrence of various stability and wind speed combinations.

New Orleans generally has less cloudiness so it has a higher frequency of both A-, B-, and F-stability than North Dakota. For these two locations, unstable conditions exist between 14 and 25 percent of the time while stable conditions exist between 29 and 39 percent of the time. Neutral conditions occur between 38 and 57 percent of the time. Extremely unstable conditions, Category A, occur relatively rarely.

"Sigma" as a measure of stability

There are two other methods used by some scientists to determine stability. One relates stability to variation in wind direction. The other method physically measures the vertical lapse rate on a tower or with a balloon.

The standard deviation of wind direction in the horizontal direction is termed "horizontal sigma". It can be determined by analyzing the directional trace of anemometer either manually or by use of computer averaging techniques. Below are two schemes for

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FIGURE 4

FREQUENCY OF OCCURRENCE OF WIND SPEED AND STABILITY COMBINATIONS

Stability	Wind Speed (Kts)	Wind Speed (m/sec)	New Orleans International Airport Frequency (percent)	New Orleans International Airport Hours per Year	Williston, North Dakota Frequency (percent)	Williston, North Dakota Hours per Year
A	calm		0.09	8	0.26	23
	1 - 3	.5 - 1.5	.20	18		
	4 - 6	2.1 - 3.1	1.02	89	0.14	12
	TOTAL		1.31	115	0.40	35
B	calm		0.34	30	1.00	88
	1 - 3	0.5 - 1.5	1.24	109		
	4 - 6	2.1 - 3.1	4.09	358	1.73	152
	7 - 10	3.6 - 5.1	3.82	335	1.09	95
	TOTAL		9.50	832	3.82	335
C	calm		0.32	28	1.09	95
	1 - 3	0.5 - 1.5	0.57	50		
	4 - 6	2.1 - 3.1	3.57	313	2.80	245
	7 - 10	3.6 - 5.1	8.02	703	5.08	445
	11 - 16	5.6 - 8.2	1.43	125	1.07	94
	17 - 21	8.7 -10.8	0.05	4	0.12	11
	> 21	>10.8			0.04	4
	TOTAL		13.95	1223	10.19	893
D	calm		0.27	24	1.05	92
	1 - 3	0.5 - 1.5	0.87	76		
	4 - 6	2.1 - 3.1	5.84	512	8.15	714
	7 - 10	3.6 - 5.1	14.21	1245	17.43	1527
	11 - 16	5.6 - 8.2	13.23	1159	23.24	2036
	17 - 21	8.7 -10.8	1.47	129	5.63	493
	> 21	>10.8	0.19	17	1.34	117
	TOTAL		36.08	3162	56.84	4979
E	4 - 6	2.1 - 3.1	6.83	598	5.55	486
	7 - 10	3.6 - 5.1	5.54	485	6.87	602
	TOTAL		12.37	1083	12.43	1089
F	calm		7.58	664	5.70	499
	1 - 3	0.5 - 1.5	9.04	792		
	4 - 6	2.1 - 3.1	10.18	892	10.63	931
	TOTAL		26.80	2348	16.33	1430

Period of Record: New Orleans, January, 1960 - December, 1964
Sloulin Field, January, 1967 - December, 1971

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classifying stability, one from Meteorology and Atomic Energy, page 102, and one from the Brookhaven National Laboratory Studies as quoted "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents", published by the American Society of Mechanical Engineers (ASME).[4]

Meteorology and Atomic Energy

Stability	Standard Deviation Horizontal Direction (Degrees)
A	25
B	20
C	15
D	10
E	5
F	2.5
G	1.7

A S M E

Stability	Standard Deviation Horizontal Direction (Degrees)
Unstable	10.5
Stable	2

As indicated in the table, significant wind meander is expected in unstable air. Minimal meander is typical of stable conditions.

The Nuclear Regulatory Commission (NRC) uses a third method to determine stability. It is specified in NRC Guide 1.23.[5] Applicants for nuclear power plants are required to erect a tower and measure temperature at two different elevations. Most towers are 50 meters high and, therefore, measure the lapse rate only in the lowest portion of the atmosphere. This is satisfactory for nuclear

applications where accidental discharges have no plume rise and disperse within 100 meters of the ground. But such a technique may be misleading for discharges from tall stacks or from stacks having significant plume rises. Below is data taken by Louisiana Power and Light from a tower located within 13 miles across flat terrain from the New Orleans Airport.

Stability Classifications, NRC 1.23

Stability Category	Lapse Rates °C/m	Frequency of Occurrence (percent per year) LP&L* 1.23 Method 7/72 - 7/75	N.O. Airport Pasquill's Method (from Table 4)
A	> -.019	14.9	1.3
B	-.019 to -.017	1.7	9.5
C	-.017 to -.015	2.1	14.0
D	-.015 to -.005	24.1	36.0
E	-.005 to .015	31.9	12.4
F	.015 to .040	14.5	}26.8
G	> .040	10.8	

*Temperature measured at 9 and 40 meter elevations

One notable aspect of the NRC system is the rather narrow range of values assigned B- and C-stabilities. It appears that this was the result of an arbitrary decision by meteorologists at the NRC who incorrectly assigned lapse rates for these categories. In the opinion of many USEPA meteorologists, it is incorrect to assess stability based on measured lapse rates because it is only one of

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the turbulence producing mechanisms. In addition, lapse rates are typically measured in the first 50 meters of the atmosphere while most industrial plumes disperse at elevations ranging from 100 to 500 meters.

CHAPTER II: REFERENCES

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2. F. Pasquill, Atmospheric Diffusion, 2nd Edition, John Wiley & Sons Inc., New York, 1974.

3. D. Bruce Turner, Workbook of Atmospheric Dispersion Estimates, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1970. pp. 1-2.

4. Martin John R., Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, 3rd Edition, American Society of Mechanical Engineers, New York, 1979. pp. 7-12.

5. Nuclear Regulatory Commission Guide 1.23.

III. PLUME DISPERSION

Plume dispersion is a problem involving fluid turbulence. Up to now the fluid turbulence problem has resisted all attempts at a general solution. Therefore, the best present solution contains both hypothetical and empirical elements. In the final analysis, the results can only be judged by comparison with data.

A. Gaussian Models

Numerous experiments have been conducted to study the shape of plumes. The publication Meteorology and Atomic Energy lists over twenty experiments, many of which have been conducted by the Atomic Energy Commission (now the U. S. Department of Energy).[1] In general, most investigators have been satisfied that a Gaussian distribution is a good mathematical approximation of plume behavior for periods on the order of five minutes to one hour.

Accuracy +100 -50%

Although Gaussian models, properly applied, are peerless as a practical diffusion modeling tool in terms of simplicity, of flexibility and of correlations between predicted and measured values, they contain some definite shortcomings.

The Gaussian distribution assumes uniform conditions in the vertical direction. In reality, the lapse rate shows changes with elevation as does wind speed. In addition, the dispersing plume will deposit material on the surface.

There is, of course, much more uniformity in the horizontal direction. Strictly speaking, the Gaussian equation implies an infinite speed of propagation of pollutants which is physically unrealistic. Pasquill, however, has pointed out that the exact form of the tails of the distribution is not important as a practical matter.

5. Accuracy of Models

Despite these objections, Gaussian models provide reasonable estimates in flat or gently rolling terrain. Gently rolling is generally described as terrain elevations of less than twenty percent of effective stack height. Turner states that the estimates provided are generally accurate by a factor of 2 (plus 100, minus 50 percent).[2] This is significantly less accurate than most engineering calculations or work done with computers. An American Meteorological Society Committee evaluated the accuracy of models and quoted Pasquill in saying that under ideal conditions, the error can be as little as 10 to 20 percent, but "Factor of 2 accuracy is perhaps the best that can be expected in most applications of urban-scale dispersion models".[3]

This estimate of accuracy also underscores the need for a monitoring program should calculated values start to approach the ambient air standards. It has been the experience of Trinity Consultants that most of the computer models used by EPA tend to over-predict, rather than under-predict concentrations.

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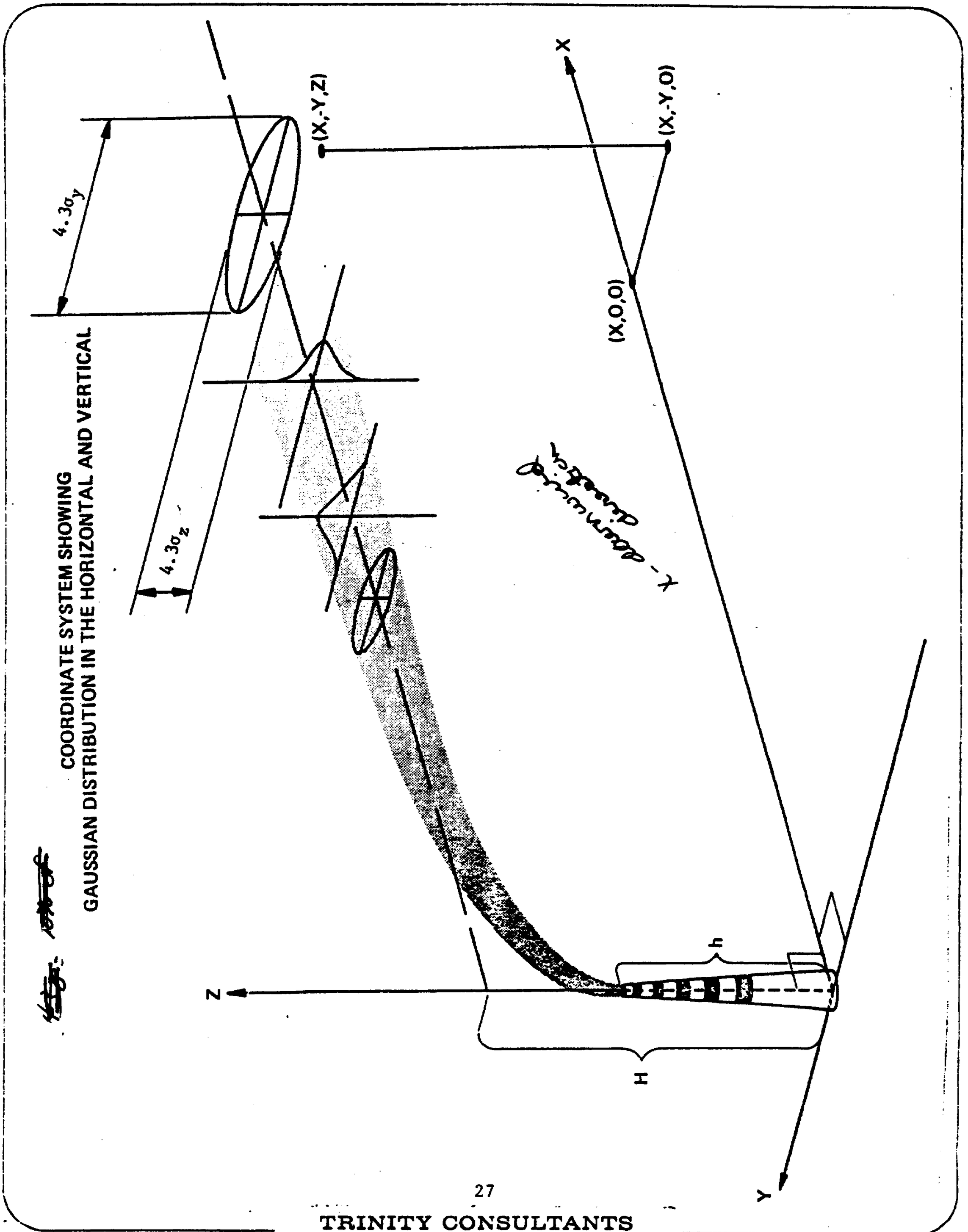
C. Pasquill-Gifford Coefficients

Figure 5 illustrates the coordinate system of a typical plume. The downwind direction is "x," the horizontal crosswind is "y," and the vertical is "z." As a result of field studies, coefficients of dispersion in the y and z direction have been developed. Figures 6 through 9 show the Pasquill-Gifford dispersion coefficients as a function of distance from the stack, both in graphical form from Turner and in formulas used in several EPA models. Although these coefficients have many shortcomings, they are those in widest current use. As discussed previously, mixing - and therefore diffusion - is more rapid in unstable air. The plot also shows that diffusion in both the y and z direction is accentuated when the air is unstable and minimized when the air is stable.

D. Continuous Release Equations

There are four equations that are useful for estimated ground-level concentrations.



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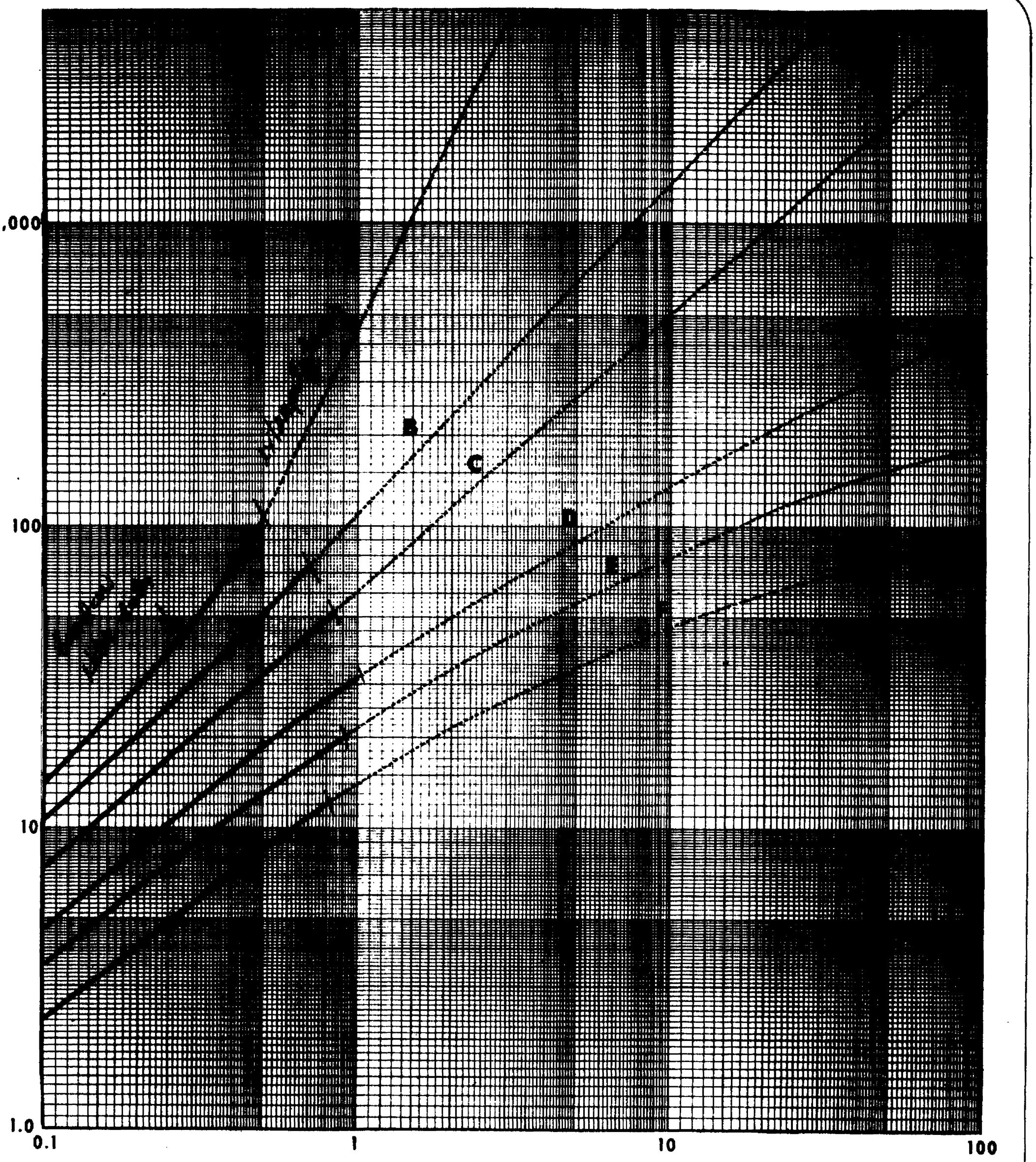
PASquill-Gifford Dispersion Coefficients

A



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

FIGURE 7

Constants Used to Calculate σ_z in EPA Developed Programs

Std. Dev. of wind direction in vert. direction → $\sigma_z = ax^b$

	DBTSIG (used in PTMTP, ISC, CRSTER, RAM)			CDM[5], TEM, TCM		
Stability (Pasquill)	Downwind Distance (x) (kilometers)	Values for σ_z (meters) a	b	Downwind Distance (x) (meters)	a	b
A	< .1	122.8	.9447			
	.1 - .15	158.08	1.0542			
	.15 - .2	170.22	1.0932			
	.2 - .25	179.52	1.1262	100 - 500	.0383	1.2812
	.25 - .3	217.41	1.2644			
	.3 - .4	258.89	1.4094			
	.4 - .5	346.75	1.7283	500 - 5000	.000254	2.0886
	.5 - 3.11	453.85	2.1166			
	> 3.11	*				
B	< .2	90.673	.93198			
	.2 - .4	98.483	.98332	100 - 500	.1393	.9467
	.4 - 35.0	109.30	1.0971	500 - 5000	.04936	1.1137
	>35.0	*				
C				100 - 500	.1120	.9100
	>123.0 -	61.141	.91465	500 - 5000	.1014	.9260
	<123.0	*		5000 -123000	.1154	.9109
D	< .3	34.459	.86974	DAY		
	.3 - 1.0	32.093	.81066	100 - 500	.0856	.8650
	1.0 - 3.0	32.093	.64403	500 - 5000	.2591	.6869
	> 3.0 - 10.0	33.504	.60486	5000 - 50000	.7368	.5642
	10.0 - 30.0	36.650	.56589	NIGHT		
	30.0 -	44.053	.51179	100 - 500	.0818	.8155
				500 - 5000	.2527	.6341
				5000 - 50000	1.2969	.4421

*The maximum calculated value for σ_z is 5000 meters.

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FIGURE 7
(Continued)

$$\sigma_z = ax^b$$

Stability (Pasquill)	DBTSIG (used in PTMTP, ISC, CRSTER, RAM) Downwind Distance (x) (kilometers)	Values for σ_z (meters) a	b	CDM[4], TEM, TCM Downwind Distance (x) (meters)	a	b
E	< .1	24.260	.83660	E & F (CDM & TCM)		
	.1 - .3	23.331	.81956	100 - 500	.0545	.8124
	.3 - 1.0	21.628	.75660	500 - 5000	.2017	.6020
	1.0 - 2.0	21.628	.63077	5000 - 50000	1.5763	.3606
	2.0 - 4.0	22.534	.57154	E (TEM)		
	4.0 - 10.0	24.703	.50527	100 - 500	.1094	.7657
	10.0 - 20.0	26.970	.46714	500 - 5000	.2452	.6358
	20.0 - 40.0	35.420	.37615	5000 - 50000	.9204	.4805
	>40.0	47.618	.29592			
F	< .2	15.209	.81558	F (TEM)		
	.2 - .7	14.457	.78407	100 - 500	.05645	.8050
	.7 - 1.0	13.953	.68465	500 - 5000	.1930	.6072
				5000 - 50000	1.505	.3662
	1.0 - 2.0	13.953	.63227			
	2.0 - 3.0	14.823	.54503			
	3.0 - 7.0	16.187	.46490			
	7.0 - 15.0	17.836	.41507			
	15.0 - 30.0	22.651	.32681			
	30.0 - 60.0	27.074	.27436			
	>60.0	34.219	.21716			

Example Calculation:

C-Stability 3000 meters

PTMTP $\sigma_z = 61.141(3.0)^{.91465} = 167.0$

CDM $\sigma_z = .1014(3000)^{.9260} = 168.2$

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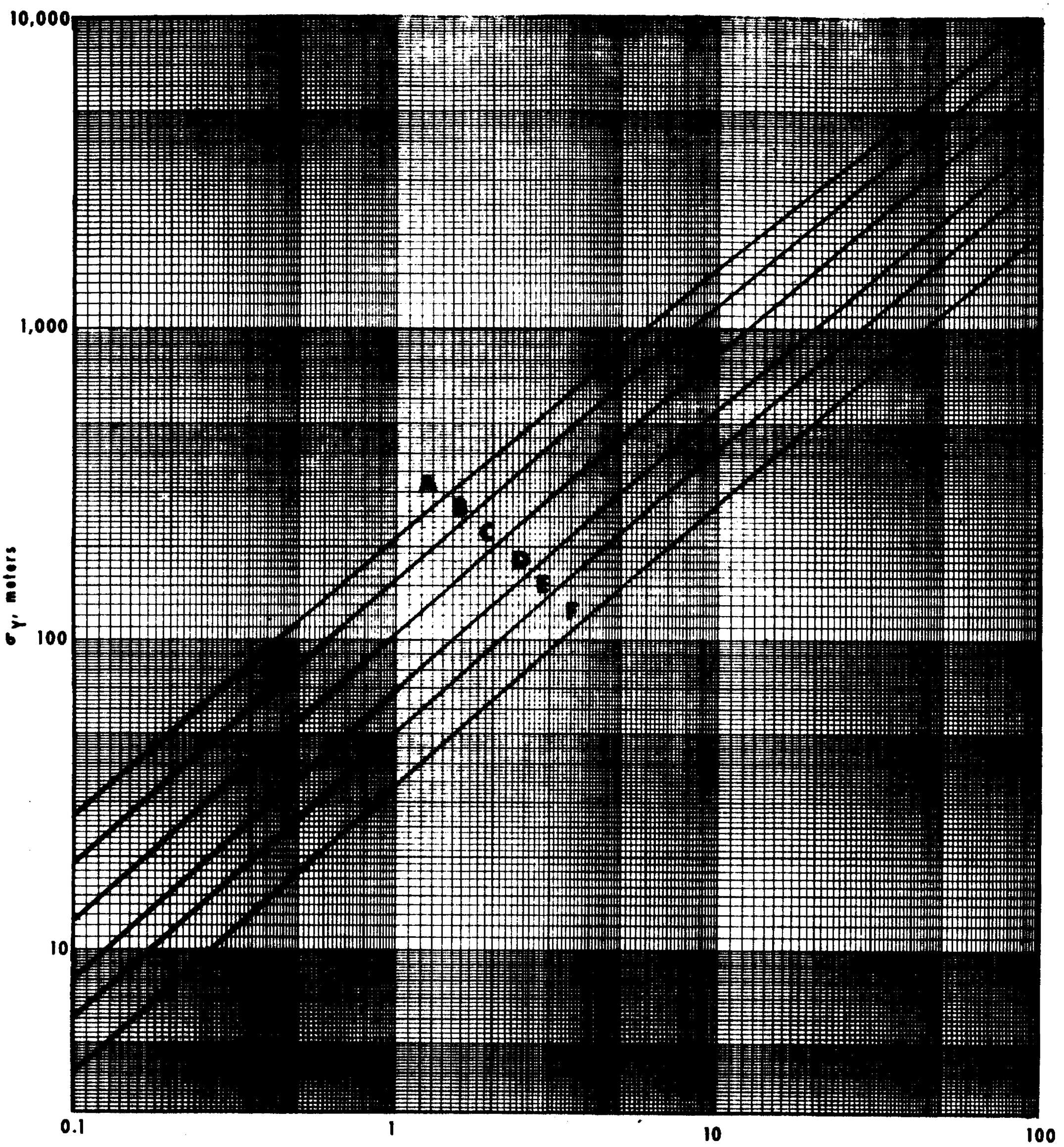

Horizontal dispersion coefficient as a function of downwind distance from the source.

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FIGURE 9

Constants Used to Calculate
in EPA Developed Subroutine DBTSIG

$$= \frac{1000\ xk\ \sin\theta}{2.15\quad \cos\theta} = 465.12\ xk\ \tan\theta$$

xk = downwind distance in Kilometers

Stability (Pasquill)	Value of θ (radians)
A	$\frac{24.167-2.5334\ \log_e\ xk}{57.2958}$
B	$\frac{18.333-1.8096\ \log_e\ xk}{57.2958}$
C	$\frac{12.5-1.0857\ \log_e\ xk}{57.2958}$
D	$\frac{8.333-.72382\ \log_e xk}{57.2958}$
E	$\frac{6.25-.54287\ \log_e\ xk}{57.2958}$
F	$\frac{4.1667-.36191\ \log_e\ xk}{57.2958}$

(Continued on next page)

FIGURE 9
(continued)

Example calculation:

C-Stability 3000 meters

$$= \frac{12.5 - 1.0857\ \ln 3.}{57.2958} = \frac{12.5 - 1.0857 \bullet 1.099}{57.2958} = \frac{11.307}{57.2958} = .19735$$

$$= (465.12)(3.)(\tan .19735) = (465.12)(3.)(.19995) = 279.0$$

Constants Used to Calculate σ_y in TEM

Stability (Pasquill)	Downwind Distance (x) (meters)	$\sigma_y = cx^d$ Values for σ_y (meters) c	d
A	<10,000	.495	.873
	>10,000	.606	.851
B	<10,000	.310	.897
	>10,000	.523	.840
C	<10,000	.197	.908
	>10,000	.285	.867
D	<10,000	.122	.916
	>10,000	.193	.865
E	<10,000	.0934	.912
	>10,000	.141	.868
F	<10,000	.0625	.911
	>10,000	.0800	.884

Example calculation: C stability 3000 meters $\sigma_y = (.197)3000^{.908} = 282.9$

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The basic dispersion equation is:

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

where the term $\exp -\frac{a}{b} = e^{-\frac{a}{b}}$

This equation is valid if the source emits at a continuous rate.

If only ground level concentrations are of interest then $z = 0$ and the equation becomes

$$(2) \qquad \chi(x,y,o;H) = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left\{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right\} \exp\left\{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right\}$$

And if only center line concentrations are of interest then the equation can be further simplified.

$$(3) \qquad \chi(x,o,o;H) = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left\{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right\}$$

If the point of release is at ground level and there is no effective plume rise ($H = 0$) then the centerline concentration is:

$$(4) \qquad \chi(x,o,o;o) = \frac{Q}{\pi\sigma_y\sigma_z u}$$

where χ = ground level concentration (grams per cubic meter)
Q = source strength (grams per second)
π = 3.1416
σ_y = horizontal dispersion coefficient (meters) (Figure 10)
σ_z = vertical dispersion coefficient (meters) (Figure 8)
u = wind speed (meters per second)
H = effective stack height (meters)

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A

PROBLEM A:

1. It is estimated that 80 grams per second of hydrogen sulfide is being emitted from an extinguished flare at a petroleum refinery at an average effective height of 60 meters. At 8 a.m. on an overcast winter morning with the surface wind of 6 meters per second, what is the ground level concentration directly downwind from the refinery at a distance of 500 meters?

∴ D stability

SOLUTION:

H = 60 m
Q = 80 gm/sec. = 80×10^6 micrograms/sec.
500 m downwind
σ_y = 36.15 m
σ_z = 18.3 m
u = 6 m/sec.

Use equation 3

$$\chi = \frac{80}{\pi(36.1)\ (18.3)6} \exp\left[-\frac{1}{2}\left(\frac{60}{18.3}\right)^2\right]$$

$$= 6.42 \times 10^{-3} \exp\left[-\frac{1}{2}(3.28)^2\right]$$

$$e^{-\frac{1}{2}(3.28)^2} = e^{-\frac{1}{2}(10.75)} = e^{-5.37} = \frac{1}{e^{5.37}} = \frac{1}{216}$$

$$\chi = \frac{6.42}{216} \times 10^{-3} = 29.7 \times 10^{-6} \text{ grams/meter}^3 = 30\mu g/m^3$$

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PROBLEM B

2. Under the conditions of problem 1 what is the concentration at the same distance downwind but at a distance 50 meters from the x-axis? That is:

$\chi(500, 50, 0: 60) =$

SOLUTION:

Use equation 2 and calculation made for Problem 1.

$$\chi = 33 \times 10^{-6} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma y}\right)^2\right]$$

$$\exp\left[-\frac{1}{2}\left(\frac{50}{36.1}\right)^2\right] = \exp\left[-\frac{1}{2}(1.385)^2\right] = \frac{1}{e^{.959}} = \frac{1}{2.61}$$

$$\chi = 29.7 \times .3835 = 11.4\ \mu g/m^3$$

E. Description of Puff Release

The dispersion of a puff can be described in Gaussian terms just as the continuous release. In a continuous model the plume disperses in the vertical (z) and horizontal cross wind (y) direction. In a puff model the dispersion takes place in the z,y and downwind (x) direction. The calculated concentration is the peak instantaneous concentration and it is independent of wind speed.

When a release occurs the gas forms a spherically-shaped cloud just above the point of release. The concentration in the cloud is highest at the center. The cloud then is transported by the wind growing in size as it entrains ambient air. The growth of the cloud and its movement can be compared to a balloon that gradually inflates as it is moved by the wind. The mass of the gas in the cloud does not change as the cloud moves downwind, but its concentration does, as more ambient air is entrained.

Sometimes the release is not instantaneous but takes place over a period of several minutes such as when gas in a cylinder leaks out or during the interval between the time a leak in a valve is discovered and it can be stopped. In cases such as these the cloud may become somewhat elongated and look like a blimp or a hot dog. By assuming an instantaneous release a puff model will overestimate peak concentrations, but it will have virtually no effect on average concentrations provided the averaging time is long enough.

F. Puff Model Dispersion Coefficients

The EPA puff model uses dispersion coefficients developed by studying instantaneous release.[6] These coefficients generally provide for less plume dilution than the familiar Pasquill-Gifford coefficients. The table shows the dispersion coefficients. Figures 1 and 2 plot the coefficients on a diagram of the Pasquill-Gifford coefficients.

Coefficient = ax^b where x is downwind distance in meters

Stability	Horizontal (x and y) a	b	Vertical (z) a	b
Unstable	.14	.92	.53	.73
Neutral	.06	.92	.15	.70
Very Stable	.02	.89	.05	.61

Since the dispersion in the x and y direction are generally considered to be equal, some authors refer to the standard deviation in the horizontal as σ_r (r for radius).

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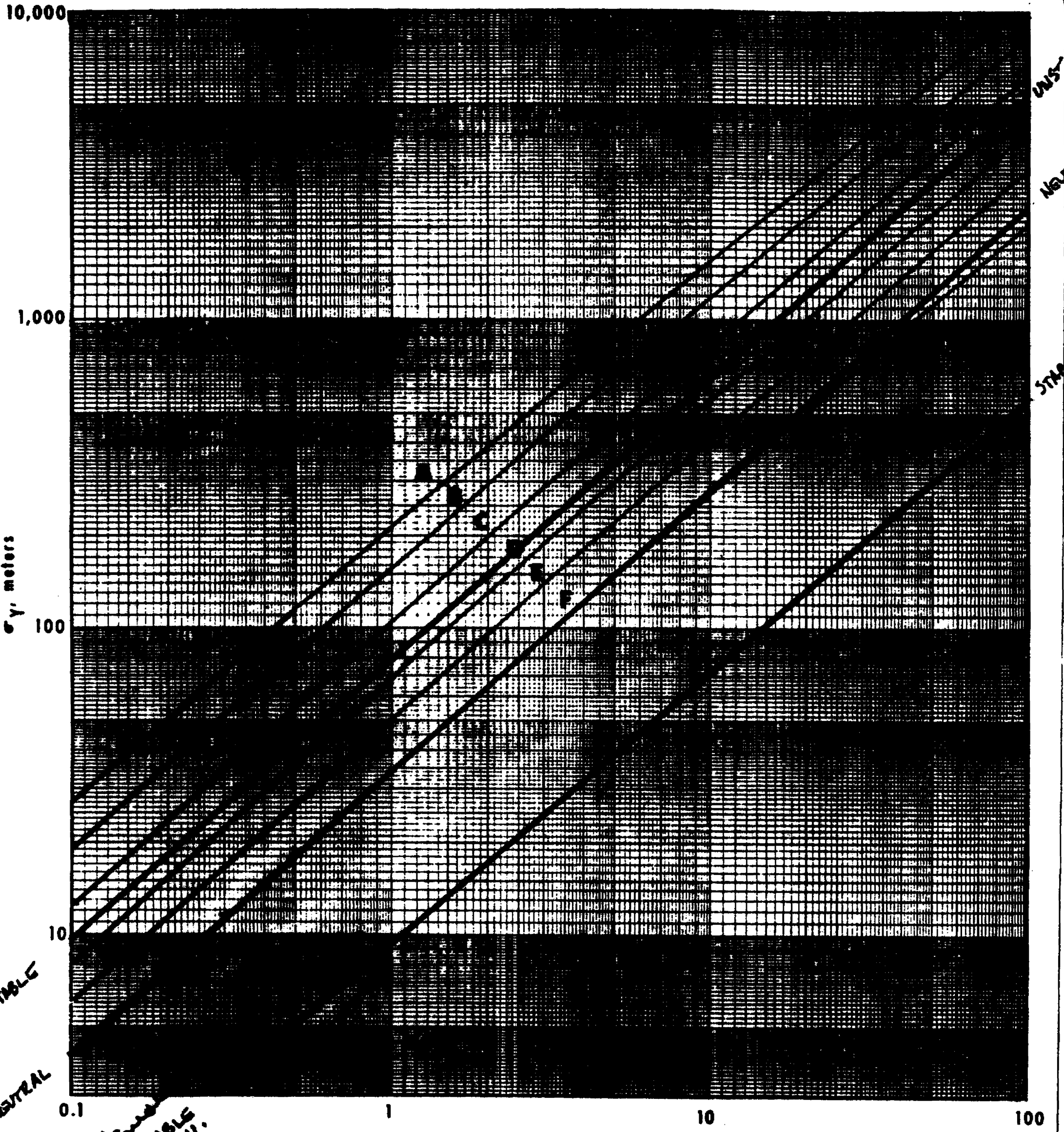
Figure 10



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

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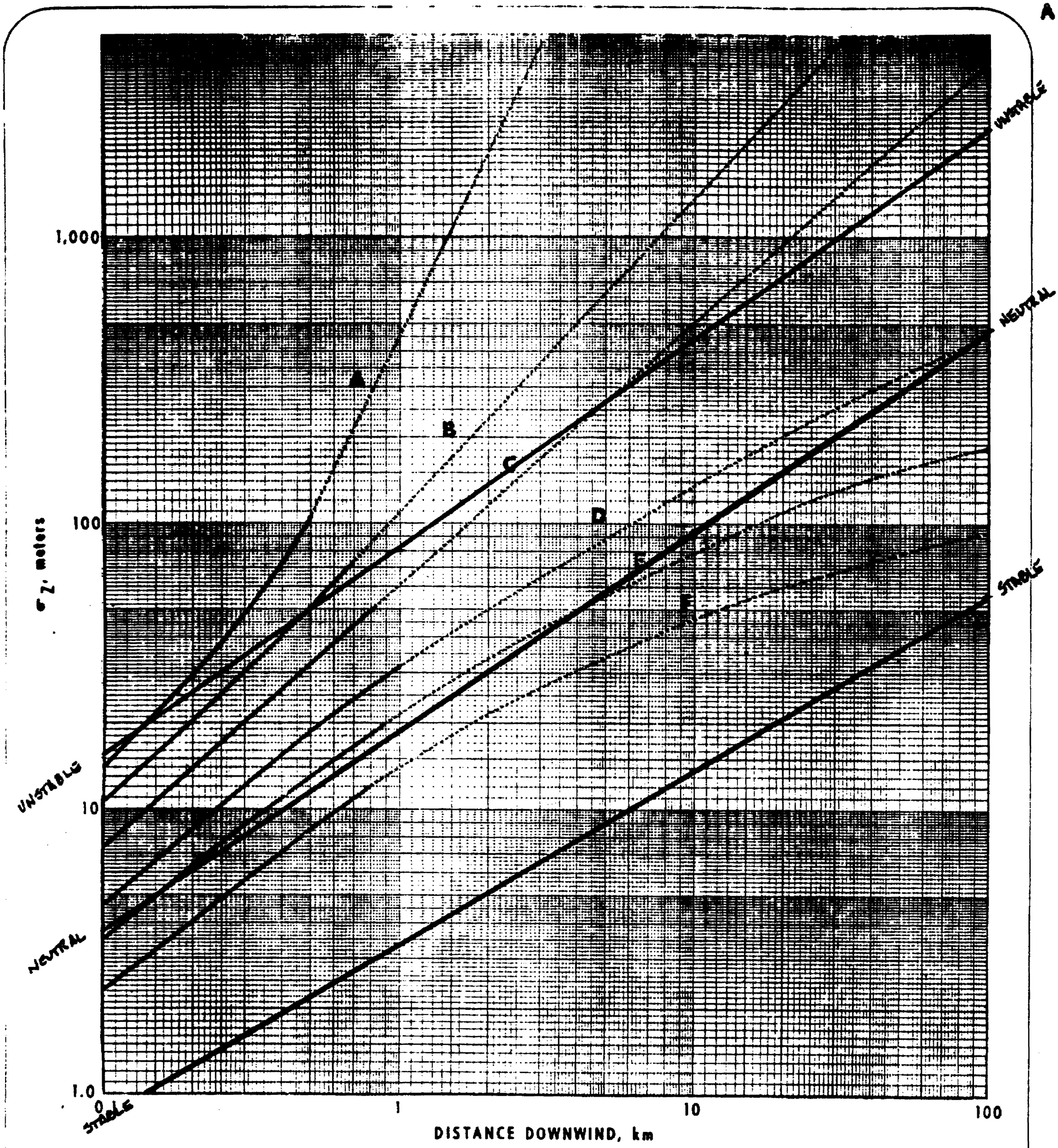
Figure 4.1



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

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G. Average Concentrations from Puff Releases

The average concentration is a function of wind speed. For example, a wind of 10 knots will transport twice as much air past a site as wind of 5 knots. The average concentration is a function of the number of standard deviations in the horizontal direction (sigma-x or sigma-r) that pass a given point for the averaging time in question. At long downwind distances and low wind speeds the average concentration will not be much less than the peak instantaneous concentration. The puff has become so dilute that possibly less than one sigma passes a point for the averaging time specified.

At the other extreme, there is a significant difference between average and peak instantaneous close to the release point. This is because the puff is small in dimension and most of the material passing a point is air except for the very concentrated puff. Figure 12 illustrates how a puff would disperse from a pipeline break.

Figure 12

A

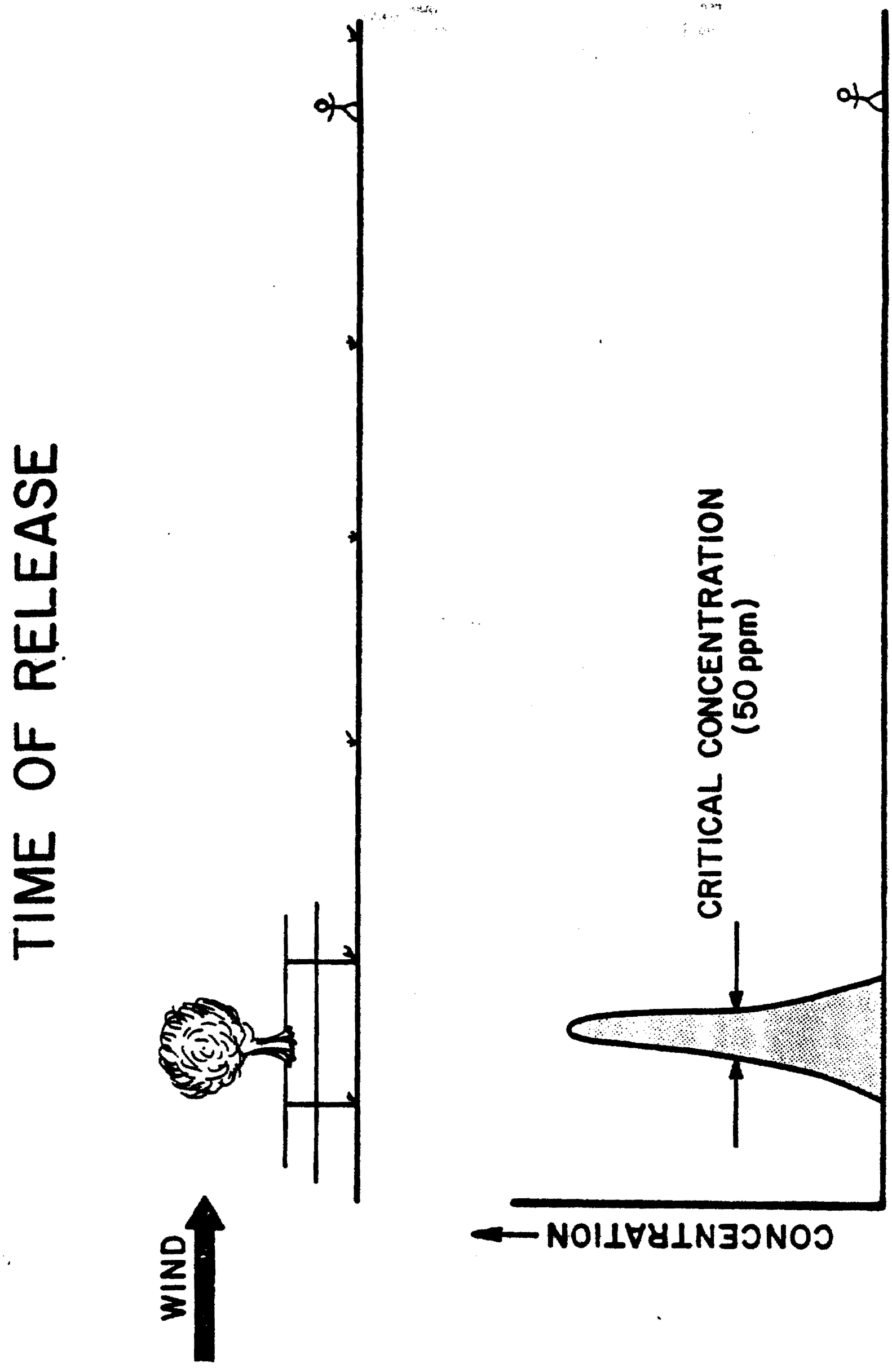

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Figure 12 (cont'd)

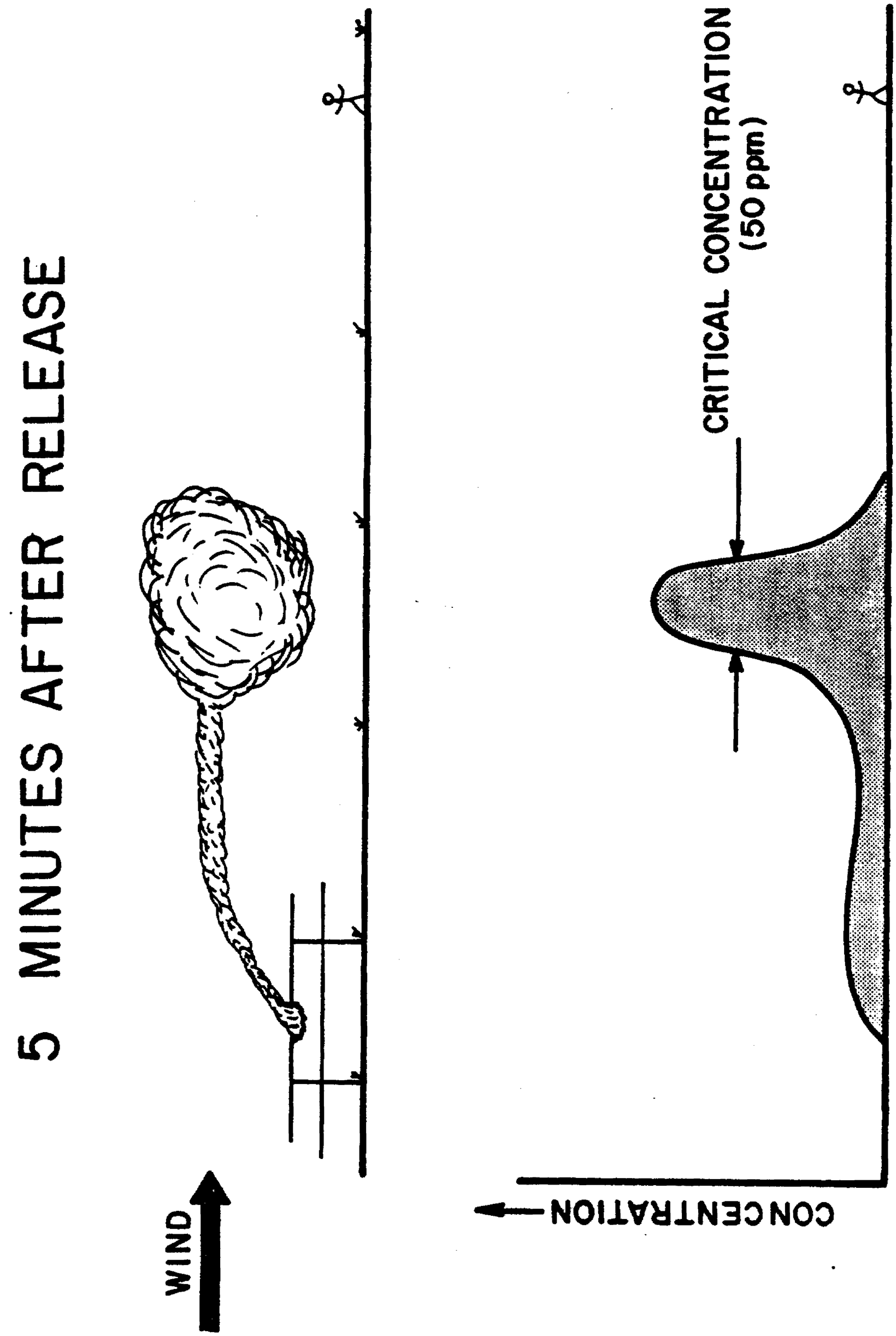

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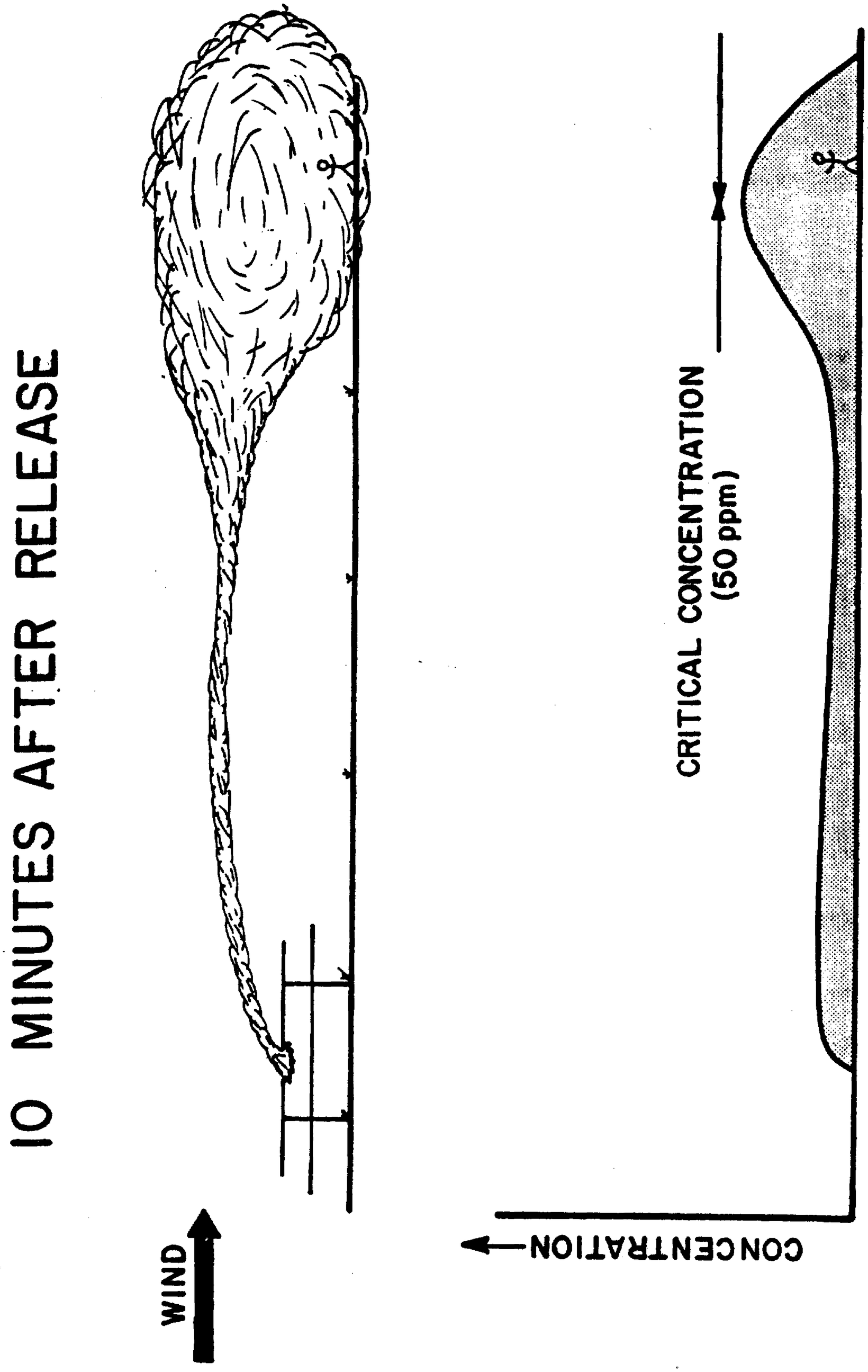
Figure 12 (cont'd)



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H. Puff Equations

The basic equation is:

at H = 0
$e^0 = 1$ $1+1 = 2$

$$\chi = \frac{Q}{(2\pi)^{1.5}\sigma_x\sigma_y\Xi z} \exp\{-\frac{1}{2}(\frac{y}{\sigma y})^2\} \{\exp\{-\frac{1}{2}(\frac{H+z}{\sigma_z})^2\} + \exp\{-\frac{1}{2}(\frac{H-z}{\sigma_z})^2\}\}$$

no wind speed because equation is not valid. This is calculated when NAX moves with wind, so wind is not a factor.

Note that Q is a release quantity in this equation, not a release rate. χ is a peak instantaneous concentration, not the average concentration.

χ = peak instantaneous concentration (grams per cubic meter)

Q = Source strength (grams)

π = 3.1416

σ_x = horizontal downwind dispersion coefficient (meters) (This value is often set equal to)

σ_y = horizontal crosswind dispersion coefficient (meters)

σ_z = vertical dispersion coefficient (meters)

H = effective stack height (meters)

at H = 0

$$\chi = \frac{2Q}{(2\pi)^{1.5}\sigma_x\sigma_y\sigma_z}$$

σ_x & σ_y are usually equal.

I. When to use Puff or Continuous Release Models

The puff model should be used when the release interval of the cloud is less than the travel time of the cloud. For example, if the release took place over a period of 10 minutes, then it would be appropriate to calculate concentrations at receptors beyond a 10-minute travel time using a puff model. For receptors within a 10-minute travel time distance it would be appropriate to use a puff model based on the release of a series of puffs at intervals of, say, one minute or use a continuous release model such as PAL or ISCST.

Answer Sheet

Problem C

It is estimated that 4800 grams of hydrogen sulfide is emitted from an extinguished flare at a petroleum refinery from at an effective stack height of 60 meters. At 8 a.m. on an overcast winter morning with a surface wind of 6 meters per second, what is the peak instantaneous concentration at a distance of 500 meters from the flare and how long does it take to reach that distance?

1. Time of travel: 500m/6m/sec = 83.3 seconds = 1 minute, 23.3 seconds

2. Peak concentration:

$$Q = 4800$$

$$\sigma_y = .06(500)^{.92} = 18.25$$

$$\sigma_z = .15(500)^{.70} = 11.62$$

$$\chi = \frac{2Q}{(2\pi)^{1.5}\sigma_y{}^2\sigma_z} \exp -\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$$

$$\chi = \frac{2 \times 4800 \times 10^6}{(15.75)(18.25)^2(11.62)} \exp -\frac{1}{2}\left\{\frac{60}{11.62}\right\}^2$$

$$\chi = (157492) \quad \text{exp-13.331}$$

$$\chi = 0.256 \quad \mu g/m^3$$

CHAPTER III: REFERENCES

1. Slade, op. cit. pp. 117-188.

2. Turner, op. cit. pp. 5-10.

3. "Accuracy of Dispersion Models," Bulletin of the American Meteorological Society, Volume 59, Number 8 (August, 1978) p. 1025.

4. U. S. Environmental Protection Agency, UNAMAP Series of Dispersion Models. Data derived by examination of coded data in program.

5. Adrian D. Busse and John R. Zimmerman, "User's Guide for the Climatological Dispersion Model," U. S. Environmental Protection Agency publication number EPA-R4-73-024, Research Triangle Park, North Carolina, 1973, p. 8.

6. Slade, op. cit. p. 120, p. 173-175.

1984 Summary Exposure Guidelines DOT

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IV. Initial Cloud Size and Building Wake Effects.

A. Accounting for Initial Cloud Size

Rarely is the source a point. Instead a cloud of finite dimensions is formed. For example, a cylinder in a gas cabinet may break. The cylinder contains 165 cubic feet of 90 percent hydrogen and 10 percent arsine. The ventilated gas cabinet has a volume of 83 feet. Thus a cloud containing the arsine will have a volume before dilution in the atmosphere of 248 cubic feet of which 16.5 cubic feet will be arsine. The initial concentration of arsine is 66,500 ppm and 248 cubic feet would occupy a sphere with a diameter of 2.38 meters at 68°F.

The cloud in already 2.38 meters in the x,y and z direction before it leaves the point of release. The standard deviation is calculated by dividing the horizontal extent of the cloud by 4.3 and the vertical extent of the cloud by 2.15. The appropriate way to adjust the dispersion coefficient for the initial cloud size is to vectorially add the standard deviation of the cloud dimensions to the standard deviation calculated from the dispersion coefficients.

$$\sigma_{ya} = \sqrt{\sigma_y^2 + \sigma_{yo}^2}$$

$$\sigma_{za} = \sqrt{\sigma_z^2 + \sigma_{zo}^2}$$

a Subscript for adjusted sigma values

o Subscript for sigma values at origin

In a Gaussian cloud the material is assumed to be distributed in

a Gaussian fashion. In dispersion modeling the concentration at the edge of the cloud is assumed to be 10 percent of the central value. Statistically speaking, the cloud is 4.3 standard deviations wide. Within this area 96.48 percent of material is contained. The average concentration across such a cloud is:

$$\frac{.9648}{(4.3)(.3989)} = 0.5625$$ of the value at the center of a two dimensional Gaussian curve

What really happens is that instead of having a sphere of uniformly mixed gas 2.38 meters in diameter, there is a cloud with a gaussian distribution of contaminants. At the center of this cloud the concentration is 66,500 ppm. The mathematics to convert the two dimension values to three dimensions are complex. The equivalent gaussian sphere with a diameter of 4.3 standard deviation is about 2.04 times the diameter of a cloud containing uniformly mixed gas. In the example the diameter of the cloud is 4.86 meters. Sigma y is 1.13 meters and sigma z is 2.26 meters.

When using computer programs that request a user-supplied dimension of the initial cloud size, it is best to estimate the initial sphere size and then adjust it in the manner described above.

The degree of accuracy in estimating the initial cloud size can make a significant difference at receptors close to the source, those within a few hundred meters. At greater distances

atmospheric turbulence dominates dispersion and rarely does the initial cloud size have much effect on concentrations at distances beyond one or two kilometers.

B. Virtual Distance Method

Instead of making detailed calculations of initial cloud size, a computer program can be written which will calculate a virtual distance. The virtual distance will be added to the actual downwind distance for the purpose of determining dispersion coefficients.

The virtual distance is the distance a puff would have to travel for atmospheric turbulence to dilute it to a concentration equal to the initial center-of-cloud concentration calculated. Usually a computer program iterates up-wind in 1 or 10 meter increments until the virtual distance is too great then reverses direction and iterates in 0.1 or 1 meter steps to find the correct distance.

The initial concentrations are most often known in terms of parts per million (ppm). If a pure gas escapes the concentration at the center of the cloud is 1,000,000 ppm. But the model is designed to calculate concentrations in grams per cubic meter. A calculation must be made involving molecular weight, temperature and pressure to relate ppm to grams per cubic meter.

In the example in Chapter II, the initial concentration was 66,500 ppm of arsine (molecular weight = 77.9). If this release were to take place at 77°F and at sea level, the concentration would be:

$$\chi = \frac{77.9 \text{ X } 1013.2 \text{ x } 66{,}500}{298.16 \text{ x } .0831} = 211.8 \text{ grams per cubic meter}$$

Under neutral conditions the virtual distance is calculated to be 29.3 meters. The sigma x and sigma y value is 1.342 meters and the sigma z value is 1.596 meters.

C. Conversion of Concentration Units

Concentrations are usually expressed in a volume ratio such as ppm or in a weight per unit volume such as micrograms per cubic meter.

The equation to convert concentrations is:

$$\chi(\text{ppm}) = \frac{\chi(\mu g/m^3) \text{ x } T(K) \text{ x } R}{M \text{ x } P(mb)}$$

where:

T	Absolute temperature (K)	298.16
R	Gas constant (mb m3/gm-mol K)	0.0831
M	Molecular weight (gm-mol)	
P	Atmospheric pressure (mb)	1013.2

Standard conditions are defined in 40 CFR50.3 and are noted to the right of the definitions.

$$\chi \text{ (ppm)} = \frac{.02445}{M} \cdot \chi \text{ (ug/m3)}$$

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Increases in altitude reduce atmospheric pressure and result in increases in concentrations expressed in ppm. The table below summarizes values for various altitudes:

Altitude (feet)	Atmospheric pressure (mb)	Molecular weight where ppm equals micrograms per cubic meter
0	1013.2	.02445
2,000	942.1	.02630
4,000	875.0	.02832
6,000	812.05	.03051
8,000	752.45	.03293
10,000	696.9	.03555

D. Obstructions

If a cloud or plume is traveling downwind and it encounters an obstruction such as a building the cloud will generally flow around the building. In flowing around the building the cloud grows in size so that it is as large as the building. Other disturbances that can cause the cloud to grow include automobile traffic on a road or a complex open structure such as structural steel supports of process units at a chemical plant.

This phenomenon suggests that as obstructions to wind-driven flow increase, the greater the probability that the cloud will become diluted.

In 1977 and 1979, Alan Huber of the U.S. Environmental Protection Agency published the results of extensive wind tunnel investigations. The conclusions of the study were that the wake could be divided into three areas:[1,2]

	Downwind Distance (x) Divided by Height of Building (Hb)
Zone I	3.
Zone II	3. to 10.
Zone III	10.

The building studied was twice as long as it was high, representing a typical type of structure.

The vertical dispersion parameter for stack heights less than the sum of H + 1.5H in Zone II was determined to be:

$$\sigma_z' = 0.7H_b + 0.067\ (x - 3H_b)$$

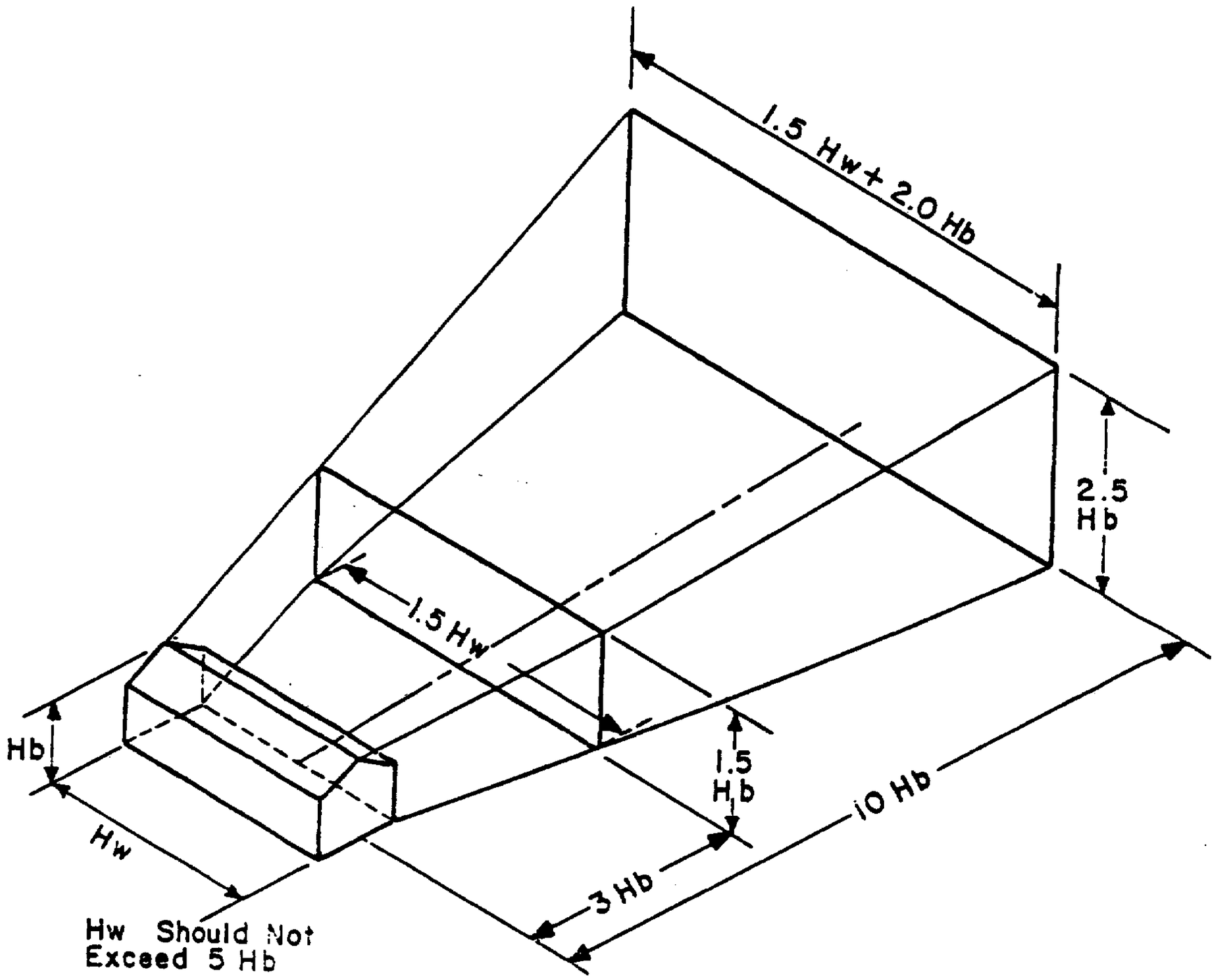
$$\sigma_y' = \frac{0.7H_w}{2} + 0.067\ (x - 3H_b)$$

where: H_w = width of building perpendicular to the wind

Figure 13 illustrates the growth of the wake. The value for σ_y' is determined by dividing the wake width by 4.3. The value for σ_z' is determined by dividing the half height by 2.15.

For Zone III calculations, an enhanced dispersion parameter can be estimated using a virtual displacement. The plume widths are estimated based on moving the source somewhat further away from its actual location.

Figure 13



GROWTH OF WAKE

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$$\sigma_y' = (x + S_y)$$

$$\sigma_z' = (x + S_z)$$

where: S_y is the virtual source distance such that

$$\sigma_y'(10H_b) = 0.7H_w/2 + 0.46H_b .$$

S_z is the virtual source distance such that

$$\sigma_z'(10H_b) = 1.167H_b .$$

If the building is taller than it is wide, substitute H_w for H_b in the calculations of both σ_y' and σ_z'.

An example will clarify the calculations:

Assume a building 15 meters in height, 50 meters in width, D stability and Pasquill-Gifford dispersion coefficients.

Downwind Distance		Wake Area		Undisturbed Flow	
Meters	Multiple of Building Height	σ_y' (m)	σ_z' (m)	σ_y (m)	σ_z (m)
45	3	17.5	10.5	3.9	2.3
75	5	19.5	12.5	6.3	3.6
150	10	24.6	17.6	11.9	6.6
300	20	34.7	21.9	22.6	12.1
328		36.5	22.8	24.6	13.0
478		46.2	26.8	34.5	17.6
1000	67	79.1	39.4	68.1	32.1

A

At 150 meters (10 characteristic dimensions) downwind σ_y' = 24.55 meters which is the same σy as undisturbed flow for a downwind distance of 328 meters. The virtual distance for the calculation is σ_y' is 178 meters (328 less 150 meters).

In the wake σ_y' for 300 meters downwind is based on the width of undisturbed flow at 478 meters. For 1000 meters it is based on 1178 meters. The σ_y should not be adjusted if the stack height is greater than 1.2Hb according to Huber.

At 150 meters σ_z' is 17.55 meters which is the same width as undisturbed flow for a downwind distance of 475 meters. The virtual distance is 325 meters. The σ_z' for 300 and 1000 meters is determined from the σ_z for 625 and 1325 meters respectively.

Huber recommends ignoring the horizontal dispersion parameter enhancement if the stack height is greater than $1.2H_b$.

This algorithm for wake effects is included in the following computer models: ISCST, ISCLT, TEM8 and TCM2.

CHAPTER IV: REFERENCES

1. Alan H. Huber, "Incorporating Building/Terrain Wake Effects on Stack Effluents", presented at Joint Conference on Applications of Air Pollution Meteorology, November 29 - December 1, 1977, Salt Lake City, Utah.

2. Alan H. Huber, "An Evaluation of Obstacle Wake Effects on Plume Dispersion", presented at American Meteorological Society, Fourth Symposium on Turbulence, Diffusion, and Air Pollution, January 15-18, 1979, Reno, Nevada.

V. Effective Stack Heights

In order to calculate ground-level concentrations, the effective height of emission must be known. The diffusion experiments described in the previous chapter all oriented the source of tracer material in the horizontal position and emitted material at ambient temperatures. This sidestepped the practical problem associated with industrial stacks of plume rise due to momentum or thermal effects.

The simplest way to calculate effective stack height is to add physical stack height to the observed or calculated plume rise:

$$H = h + \Delta h$$

Where: H is effective stack height

h is physical stack height

Δh is plume rise

Some confusion centers on the meaning of plume rise. Ideally it is the elevation above the stack top of the centerline of a plume traveling in a horizontal direction. The only difficulty, according to Briggs, is that in more than 90 percent of the recorded observations the plume had not yet become level when it was no longer visible. Measured plume rise is strongly a function of measuring technique. Plumes dispersing in stable or neutral atmospheres are relatively easy to measure. Those under unstable conditions are nearly impossible to measure accurately.

To overcome this problem Briggs suggests that plume rise be defined as the difference between stack height and the effective stack height one would need in the diffusion equation to correctly calculate the maximum ground-level concentration.[1]

Plume rise is both a function of momentum and buoyancy. Terms related to one or both factors are included in all plume rise formulas. For cold stacks, those with emissions of less than 5 to 10°C. above ambient, momentum is probably the most important. For hot stacks (those warmer than about 50°C) buoyancy, due to the light weight of hot gases, is the most important.

Caution should be used on stacks where the emissions include moisture droplets. As the water in the plume leaving the stack vaporizes, it requires heat of vaporization which quickly cools the diluting stack gases. Under conditions of low humidity this can cause the plume to fall to the ground rather than rise. This condition is often visible on cooler days.

Over the years more than 100 plume rise formulas have been proposed by over 50 groups of investigators according to Briggs. For the most part, these investigators limited their studies to specific stacks. Many also studied plume rise under a limited range of conditions.

Although there has been widespread disagreement within the environmental community regarding the accuracy and appropriateness

of dispersion modeling there has been virtually no challenge to the plume rise formulas developed by Briggs. These formulas are incorporated in all EPA models and are appropriate in modeling puff releases.

A. Briggs' Buoyancy Formula

In 1969 Gary A. Briggs, then an employee of the Atomic Energy Commission, made a very thorough study of the available plume rise equations. Figure 14 is taken from Briggs' work[3] and it compares calculated and observed values for selected formulas. Briggs went on to study plumes, most of them from coal-fired power plants, in much greater detail than previous investigators. He then proposed his own set of formulas.

Following a detailed evaluation of Briggs' original work and two subsequent modifications, the Environmental Protection Agency adopted his equations.[4,5] Briggs' equations have been recommended in place of Holland for calculating dispersion following Turner's Workbook of Atmospheric Dispersion Estimates starting with the sixth edition, published in December, 1972.

Table 5.1 (Continued)

Code	Source	Reference	Ratio of calculated to observed values of u Δh: Moses and Carson[110]	Stümke[108]	Holland[6]	Priestley[73,87] (first phase)	Lucas, Moore, and Spurr[91]	Lucas[109]	Eq. 4.32 ("2/3 law")	Eq. 4.34
B	Ball	76	1.59		0.04	1.31	1.51	0.78	0.86	0.72
HA	Harwell A	75	0.43	0.74	0.23	2.00	1.70	1.27	1.40	0.95
HB	Harwell B	75	0.48	0.83	0.25	1.60	1.59	1.19	1.17	0.93
BO	Bosanquet	73	0.92	0.75	0.44	1.19	1.38	1.12	0.98	0.98
DS	Darmstadt	80	0.78	1.04	0.25	1.49	1.69	1.36	1.13	1.09
DB	Duisburg	80	0.74	1.12	0.38	1.47	1.62	1.60	1.17	1.16
T	Tallawarra	87	0.57	1.53	0.30	0.91	1.02	0.87	0.76	0.75
L	Lakeview	88	0.28	0.41	0.31	0.78	0.62	0.68	0.66	0.64
	CEGB plants									
E	Earley	91	0.40	0.72	0.18	2.49	1.59	1.30	1.73	1.05
E	Earley	91	0.48	0.57	0.37	2.26	1.44	1.16	1.71	1.25
CD	Castle Donington	91	0.43	0.74	0.44	1.57	1.01	1.01	1.29	1.17
CD	Castle Donington	91	0.39	0.62	0.47	1.34	0.86	0.86	1.13	1.05
N	Northfleet	93	0.47	0.79	0.44	2.24	1.24	1.35	1.75	1.46
N	Northfleet	93	0.56	0.84	0.65	2.43	1.35	1.47	1.96	1.73
	TVA plants	99								
S	Shawnee		0.68	0.90	0.54	1.88	1.69	1.36	1.53	1.40
C	Colbert		0.66	0.96	0.55	0.86	0.96	0.82	0.77	0.77
J	Johnsonville		0.59	0.66	0.66	1.37	1.24	1.21	1.19	1.17
WC	Widows Creek		0.94	1.32	1.18	1.94	1.76	1.92	1.73	1.72
G	Gallatin		0.53	0.90	0.64	1.35	1.05	1.15	1.10	1.09
G	Gallatin		0.68	1.53	0.58	1.41	1.37	1.50	1.21	1.20
P	Paradise		0.39	0.65	0.51	1.19	0.80	0.96	1.03	1.00
P	Paradise		0.42	0.70	0.58	1.28	0.85	1.03	1.11	1.09
	Median for all data		0.54 ± 34%	0.79 ± 27%	0.44 ± 37%	1.44 ± 26%	1.36 ± 21%	1.18 ± 20%	1.17 ± 23%	1.09 ± 19%
	Median for selected data		0.48 ± 19%	0.72 ± 24%	0.47 ± 26%	1.41 ± 18%	1.24 ± 22%	1.16 ± 14%	1.17 ± 12%	1.09 ± 7%

FIGURE 14

Comparison of Calculated Values with Observations for Neutral Conditions

Equation 4.32: $$\Delta h = \frac{1.8F^{0.33}x^{0.67}}{u}$$

Briggs later substitutes 1.6 for 1.8, a reduction of 11 percent.

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BRIGGS' BUOYANCY PLUME RISE EQUATIONS

For neutral and unstable conditions (stability categories A, B, C and D) at distance x downwind

$$\Delta h = \frac{1.6F^{.333}(x)^{.667}}{u}$$

For final rise:

$$\Delta h = \frac{21.425F^{.75}}{u} \qquad F < 55$$

$$\Delta h = \frac{38.710F^{.6}}{u} \qquad F > 55$$

Final plume rise is achieved when the downwind distance x equals 3.5x*.
For final plume rise under stable conditions (stability categories E and F)

$$\Delta h = 2.6\left(\frac{F}{us}\right)^{.333}$$

Where $F = \frac{gV_f}{\pi}\left(1 - \frac{T}{T_s}\right)$

$x^* = 14F^{.625}$ where $F < 55$

$x^* = 34F^{.4}$ where $F > 55$

$s = \frac{g}{T}\left(\frac{\delta\theta}{\delta z}\right)$

$\delta\theta/\delta z$ = Vertical potential temperature gradient in the atmosphere

E category	.02° K/m	(stable conditions)
F category	.035°K/m	(stable conditions)

F = buoyancy flux (m^4/sec^3)

Δh = plume rise above stack top (m)

u = wind speed at stack level (m/sec)

x = horizontal downwind distance (m)

x^* = horizontal distance from the stack at which atmospheric turbulence begins to dominate entrainment

$3.5x^*$ = distance to point of final rise for unstable conditions (m)

g = gravitational acceleration = 9.8 m/sec^2

T = ambient air temperature = 293°K (usually)

T_s = stack gas temperature (°K)

V_f = stack gas volume flow (m^3/sec)

In some lectures Gary A. Briggs has commented on the shortcomings of his widely used formula for plume rise.

1. Buoyancy Flux

The Briggs' formula assumes that the stack gases have a molecular weight similar to that of air. For fuel combustion sources this assumption is accurate within five percent. The products of natural gas combustion have a molecular weight of about 27.5 which is slightly lighter than air because of the water vapor formed from the combustion of hydrogen. The products of coal burning have a molecular weight of about 30, which is slightly heavier than air because of the large amount of carbon dioxide. As a practical matter, nitrogen nearly always dominates the composition of stack gases so that molecular weights significantly different from air are rare.

On the other hand, an incinerator burning hydrogen sulfide or one emitting chlorine compounds does not have the same weight as air and some adjustment may be appropriate.

The term $(1 - T/T_s)$ reflects the buoyancy of the heated gases. It is this term in the buoyancy flux, F, that can be modified to account for differences in the molecular weight of the stack gases.

$$F = \frac{gVf}{\pi}\left(1 - \frac{w_m T}{28.9 T_s}\right)$$

where w_m= molecular weight of stack gases

When using computer models which don't allow entry of molecular weight, it is often easier to adjust the stack temperature for the molecular weight difference. Trinity Consultants recommends that this adjustment should only be attempted if the use of routine plume rise formulas produces results which are quite different than observations.

2. Wind Speed

The wind speed in the various formulas should be the centerline of the plume as it rises. Some investigators developed a computer program which adjusted wind speed for the height of the stack top. Then for each incremental plume rise, the wind speed was recalculated until the final plume rise was determined. It turned out that if one made an appropriate adjustment for the wind speed at stack top, then it wasn't necessary to make the incremental adjustments.

The CDM, RAM, TEM, TCM and CRSTER programs make adjustments for higher average wind speed at the top of the stack compared to anemometer height. The PTMAX, PTMTP and VALLEY programs do not make wind speed adjustment, but this may or

may not be a flaw depending on how these programs are used. If the programs are being used to calibrate a model, then it is likely that correction for the higher speed winds aloft than those measured at the surface is appropriate. If the program is being used to forecast worst case, then assuming a uniform vertical wind field may be better.

3. Restoring Acceleration

In the plume rise equation for stable air the "potential lapse rate" represented by the term $\delta\theta/\delta z$ is used. This is assigned a somewhat arbitrary value by EPA in their models.

Briggs suggests that when evaluating a specific site the restoring acceleration value should be the difference between the adiabatic lapse rate (-0.01°C/meter) and the actual lapse rate from the top of the stack to the plume centerline, not the lapse rate close to the ground. In other words:

$$\delta\theta/\delta z = \Delta T/\Delta h + 0.01$$

Where: ΔT is the air temperature difference between the plume centerline and the top of the stack.

Δh is the plume rise in meters.

In all EPA models z is assumed to be 0.02 and 0.035°C/m for E- and F-stabilities respectively. These values are typical

values in the lowest 50 meters of the atmosphere. At higher elevations it may be more appropriate to use lower values because the lapse rate will tend to become more adiabatic. For tall stacks on a power plant, a value of 0.01°C/meter is probably more appropriate.

4. Size of Plants

The Briggs formulas have generally been validated for plants with an approximate fuel consumption greater than 200 X 10^6 BTU per hour or roughly 34 cubic meters per second of stack gases at about 300°F (422°K) assuming fuel oil combustion and 30 percent excess air. The use of Briggs formulas for smaller stacks is often done, but there is an absence of validation on these smaller stacks. Among other things, it appears that the coefficient for the stable plume rise is less (about 2.4) for smaller stack and greater (up to 3.1) for larger stacks.

B. Plume Rise of Flares

Flares are incinerators that burn waste gases in the open atmosphere. Typically, a flare is a vertical stack through which waste gas, and sometimes fuel gas, is emitted to the atmosphere. At the top of the stack the mixture burns in the atmosphere. The flare tip is often equipped with an automatic device to keep the flare lit. It is also often equipped with a steam line. The steam acts to make the flare "smokeless."

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Most flares at industrial facilities are used for the emergency release of process gases during upsets. Thus emissions from flares are rarely included in emission inventories and are rarely modeled, except for the annual rate of emissions. An exception is the natural gas processing industry which uses a large number of continuous flares for disposing of acid gases (hydrogen sulfide and carbon dioxide) from the amine plants used to "sweeten" the gas.

Flares tend to be very efficient in converting hydrocarbons to products of combustion. A study was performed by Engineering Science, Inc. in 1983 and jointly sponsored by the Chemical Manufacturers Association and the United States Environmental Protection Agency.[7] This study reports that

> "when flares are operated under conditions which are representative of industrial practices, excluding emergency releases, the combustion efficiencies in a flare plume are greater than 98%."

The Briggs' buoyancy plume rise formulas can be easily adapted to forecast the plume rise from flares. These formulas require parameters that are commonly available such as the stack temperature and the volumetric flow rate in the stack. From these values the user calculates buoyancy flux, F, which is equal to the heat release of the stack. If manual calculations are being made, F can be calculated knowing the volume and heat content of the gases being flared. But if a computer is being used, it is often easier to first calculate F, assume a stack temperature and calculate a synthetic volumetric flow rate.

This latter method permits one to use all existing EPA computer programs to analyze flares.

1. Calculating F from Heat Release

Briggs states the following equivalencies in Equationas 4.19c and 4.20.

$$F = gvr^2(1 - \frac{\rho_s}{\rho}) = \frac{gQ_H}{\pi C_p \rho T} = 3.68 \times 10^{-5} Q_H \qquad (1)$$

where:

F = buoyancy flux parameter (m^4/sec^3)
g = gravitational constant (9.8 m/sec^2)
v = stack velocity (m/sec)
r = stack radius (m)
ρ = density of air (1205 $\mu g/m3$)
ρ_s = density of stack gases
Q_H = heat release (low heat value) (calories/sec)
C_p = specific heat of air (0.24 calories/g K)
T = ambient air temperature (usually 68°F = 20°C = 293 K)
T_s = stack gas temperature (K)
V = volume of stack gases at standard conditions (m3)
V_f = volume of stack gases at stack conditions

The equation on page 57 of this manual is:

$$F = \frac{gV_f}{\pi}(1 - \frac{T}{T_s}) \qquad (2)$$

The equality between equations (1) and (2) can be demonstrated

$\frac{\rho_s}{\rho}$ is proportional to $\frac{T}{T_s}$ and $V_f = \pi r^2 v$.

Thus, $$F = gvr^2(1 - \frac{\rho_s}{\rho}) = \frac{gV_f}{\pi}(1 - \frac{T}{T_s}) \qquad (3)$$

The heat release is the product of the volume of gases, the specific heat per unit volume and the temperature change. The specific heat of gases is given in units per weight so

one must multiply this by the density to get specific heat per unit volume. A value for V can be calculated and substituted in equation (3).

$$Q_H = VC_p\rho(T_s - T) \qquad (4)$$

substituting stack conditions: $V = V_f\frac{T}{T_s}$

$$Q_H = V_f C_p \rho \frac{T}{T_s}(T_s - T) \qquad (5)$$

rewriting to get an equations for V_f :

$$V_f = \frac{Q_H}{C_p \rho T}\left(\frac{T_s}{T_s - T}\right) \qquad (6)$$

substituting this value for V_f in equations (3)

$$F = \frac{gQ_H}{\pi C_p \rho T}\left(\frac{T_s}{T_s - T}\right)\left(\frac{T_s - T}{T_s}\right) = \frac{gQ_H}{\pi C_p \rho T}$$

The usual problem is to intermix flare stacks with conventional stacks. In the usual form of Briggs' plume rise equation, heat release is calculated from stack temperature and the volumetric flow rate of the stack. For a flare, heat release is known, but in order to intermix flares with conventional stacks, a stack temperature is assumed and an equivalent volumetric flow rate determined.

Trinity Consultants usually makes the following assumptions and then substitutes in equation (6).

$$T = 68°F = 20°C = 293°K$$

$$C_p = 0.24 \text{ cal/gram}°K$$

$$\rho = 1205 \text{ gram/m3}$$

$$T_s = 1000°K$$

$$V_f = \frac{Q_H}{0.24(1205)(293)} \left[\frac{1000}{1000 - 293}\right] = 16.7 \times 10^{-5} Q_H$$

Although the products of combustion usually have a higher specific heat than air and are heated first, these products become rapidly diluted with ambient air. Hence the specific heat of air should be used for calculating plume rise.

At higher altitudes the density of air decreases, as does the density of the plume. Although this increases the absolute plume buoyancy, the buoyancy relative to ambient air remains unchanged. Altitude has no effect on plume rise.

2. Losses Due to Radiation

Most of the heat of combustion is used to heat the products of combustion. A small portion is radiated. The visible and ultraviolet emissions rarely exceed 0.4 percent of the heat of combustion. The infrared emissions are much larger and often range from 2 to 20 percent. The energy lost

through infrared radiation is a function of the surface area and the fourth power of the absolute temperature of the hot gas envelope. If the flame is burning smoothly, and turbulence is at a minimum, then a higher radiation loss will occur. As turbulence increases, due to either the nature of the gas discharge jet or wind, the radiation loss decreases. This is a result of a higher rate of dilution and a smaller hot gas envelope.

Judgment should be used to determine the amount of radiated heat. In order not to underestimate radiation and therefore overstate plume rise, Trinity Consultants assumes a 20 percent loss. This means that 80 percent of the heat of combustion is used to heat the products of combustion.

3. Effect of Addition of Steam

Steam is often used to make a flare "smokeless." High pressure steam is throttled through nozzles into the area of combustion. If the nozzle were perfect, then the flow would be isentropic (constant entropy). Most nozzles have an efficiency of between 87 and 92 percent.

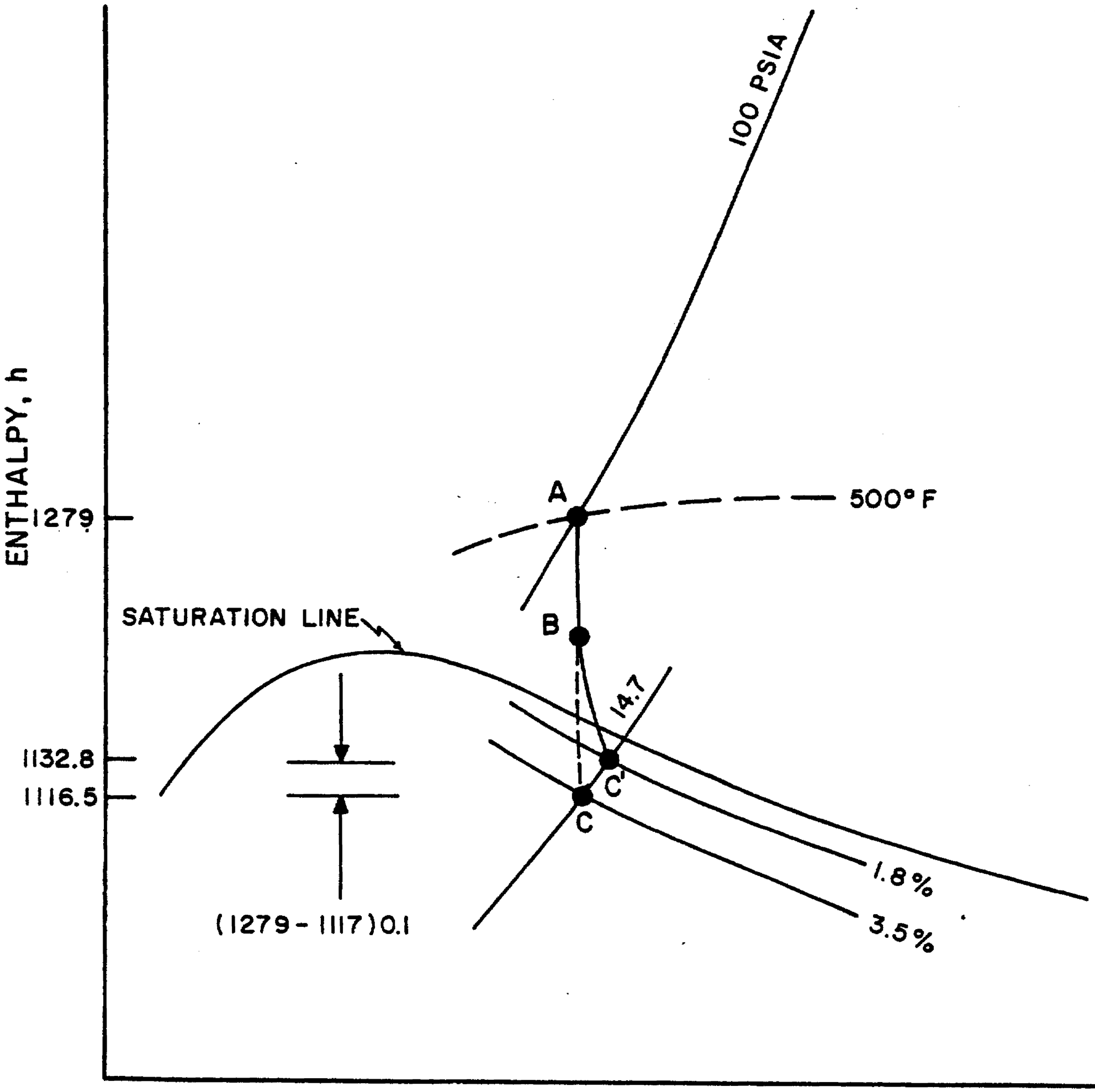
Trinity Consultants assumes that 90 percent of the enthalpy loss at isentropic (constant entropy) conditions occurs and from this calculates the enthalpy at the nozzle outlet. This is compared to the enthalpy of water vapor at standard conditions and the difference subtracted (or added) to the

heat of combustion. This can be illustrated with a schematic Mollier chart.

In the example shown in Figure 15, the steam to the flare has a pressure of 100psia and 500°F. Its initial enthalpy is 1279 BTU per pound. If the nozzle were perfect the change would take place at constant entropy and the final enthalpy would be 1117 BTU per pound. The discharge steam would contain 3.5 percent water vapor. Because of the inefficiency of the nozzle only 90 percent of the enthalpy loss takes place (to 1133), and entropy increases somewhat. The discharge stream contains 1.8 percent water. Since 970 BTU's are required to convert each pound of water to steam, 17 BTU's (970 times .018) must be supplied per pound of steam by the combustion of the flare to vaporize the water formed.

The heat content in fuels is described by two numbers, the high heat value and the low heat value. The difference between the two is that the high heat value includes the heat of vaporization. Low heat is the high heat value less the heat required to vaporize water formed during combustion. Between the point of formation of water vapor to ultimate plume rise of a flare, water is rarely condensed. Therefore, as a matter of being conservative, the use of the low heat value is recommended.

FIGURE 15



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A

PROBLEM E:

An acid gas stream of the following composition is being sent to a flare. No fuel gas is being used:

	% by volume
Methane (CH_4)	1.97
Ethane (C_2H_6)	.55
Propane (C_3H_8)	.41
Other (C_4+)	.68
Hydrogen Sulfide (H_2S)	43.40
Carbon Dioxide (CO_2)	52.84
Nitrogen (N_2)	.15
	100.00

The measured flow rate is 452,000 cubic feet per day measured at 60°F at 14.65 pounds per square inch pressure. No steam or fuel gas is being used. The first form is used to correct gas flows from measured conditions (which vary widely) to standard conditions. The second form calculates the effective heat release (Q_H) and the equivalent volumetric flow rate for an assumed stack temperature of 1000K. Calculate the equivalent volumetric flow rate assuming an equivalent stack gas temperature of 1000K.

CALCULATION OF VOLUME

WASTE GAS FLOW RATE .3139 10^3 CF/MIN. AT STD. CONDITIONS 60 °F 14.65 psia

FUEL GAS FLOW RATE _____ 10^3 CF/MIN. AT STD. CONDITIONS _____ °F _____ psia

CORRECTED FLOW RATE TO 68°F = 20°C = 293°K, 14.7 psia				
	WASTE GAS		FUEL GAS	
COMPONENT	mol%	10^3 CFM	mol%	10^3 CFM
CH_4	1.97	.006		
C_2H_6	.55	.002		
C_3H_8	.41	.001		
C_4+	.68	.002		
CO				
H_2S	43.40	.138		
CO_2	52.84	.168		
N_2	.15			
H_2O				
TOTAL	100.00	.318	100.00	

TO CORRECT FUEL GAS FLOW RATE:

RATE AT 60°F, 14.65 psia $\frac{460 + 68}{460 + 60} \times \frac{14.65}{14.70} = 1.012$

A

CALCULATION OF HEAT RELEASE

FUEL	10^3 CFM BURNED	LOW HEAT VALUE 10^3 BTU PER CF AT 68°F 14.7 PSIA	HEAT RELEASED 10^6 BTU/MIN
CH_4	.006	.896	.005
C_2H_6	.002	1.594	.003
C_3H_8	.001	2.282	.002
C_4+	.002	~3.000	.006
CO		.316	
H_2S	.138	.560	.077
TOTALS			.093

HEAT RELEASE FROM COMBUSTION .093 10^6 BTU/MIN

PORTION OF HEAT USED TO HEAT PRODUCTS OF COMBUSTION .80 (Usually .80 or greater)

NET HEAT RELEASE (Q_H) .0744 10^6 BTU/MIN x $\frac{252}{60}$ = [.312] 10^6 CAL/SEC

252 Calories = 1 BTU 60 Seconds = 1 Minute

Using an assumed stack temperature of 1000°K (1340°F)

$V_f = 16.7 \times 10^{-6} Q =$ [5.22] m^3/sec

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C. Briggs' Momentum Formulas

Since 1967 there has been considerable research done on the plumes from sources where momentum, not buoyancy, is the principal source of rise. Briggs proposed these formulas in 1971 and they are used in most of the newer models. In these models, the plume rises are calculated by adding the buoyant rise to the momentum rise. The greater of the two values is then used for further calculations. The formulas used are as follows:

Unstable: $$\Delta h = 1.89 \left(\frac{v^2 d}{u(v + 3u)} \right)^{.667} x^{.333}$$

$$\Delta h(max) = 3\frac{vd}{u}$$

Stable:

$$\Delta h(max) = .945(vd)^{.667} u^{-.333} s^{-.167}$$

Where:

x = downwind distance (m)
v = stack exit velocity (m/sec)
u = wind speed (m/sec)
d = stack diamter (m)

$$s = \frac{g}{T} \frac{\partial \theta}{\partial z}$$

g = gravitational acceleration (9.8) m/sec^2
T = ambient air temperature (293°K usually)
$\partial\theta/\partial z$ = vertical temperature gradient in the atmosphere. Both EPA and Texas assume:

E-stability category	.02°C/m
F-stability category	.035°C/m

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As a practical matter final plume rise with unstable conditions is reached rather rapidly so the use of the final plume rise formula rarely results in an error. It is questionable whether the gases from short vents on buildings enter a stable atmosphere. The atmosphere in the immediate vicinity of buildings, especially in industrial areas is more likely to be neutral than stable.

CHAPTER V: REFERENCES

1. Gary A. Briggs, "Plume Rise Predictions," Chapter 3 in Lectures on Air Pollution and Environmental Impact Statements, American Meteorological Society, Boston, 1975. pp. 59-111.

2. Turner, op. cit. p. 31.

3. Briggs, Plume Rise, op. cit. p. 45.

4. Gary A. Briggs, "Some Recent Analyses of Plume Rise Observations," Proceedings of the Second International Clean Air Congress, Academic Press, New York, 1971. pp. 1029-1032.

5. Gary A. Briggs, "Discussion on Chimney Plumes in Neutral and Stable Surrounding," Atmospheric Environment, 6 (July 1972). pp. 507-510.

6. Gary A. Briggs, a taped lecture contained in "Effective Stack Height/Plume Rise," U.S. Environmental Protection Agency, 1974. (Available as Course No. SI 406 from National Audiovisual Center, Order Dept. (GSA), Washington, D.C. 20409).

7. Chemical Manufacturers Association, "A Report on a Flare Efficiency Study" March, 1983.

VI. Toxicological Considerations

A. Chronic and Acute Toxicity

Chronic toxicity refers to long term effects on the human body. Chronic effects are usually estimated using annual average models.

Acute toxicity refers to short term effects on the human body. Time spans ranging from a few seconds to 30 minutes are generally of interest when studying acute effects.

Section 112 of the Clean Air Act requires EPA to develop regulations for hazardous air pollutants. The term hazardous air pollutant means

> "an air pollutant to which no ambient air quality standard is applicable and which in the judgment of the Administrator causes, or contributes to, air pollution which may reasonably be anticipated to result in a increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness."

Under this section EPA has generally limited its studies to the continuous releases of chronic pollutants such as asbestos, vinyl chloride, benzene, acrylonitrite and similar compounds. The EPA has not employed probability estimates for episodic releases of such pollutants. A human can be exposed to a rather large concentration of some of these but if the duration is quite brief the long terms effects will be rather small. Vinyl chloride is a good example of such an air contaminant.

On the other hand some compounds are dangerous in high concentrations for brief periods of time but relatively harmless in lower concentrations for extended periods. Hydrogen sulfide is generally fatal if concentrations exceed 1000 ppm for 5 minutes but the workplace standard allows values of 10 ppm for an 8-hour work day.

Because each chemical compound has different short and long term effects, it is suggested that a toxicologist be consulted to establish safe acute toxicity levels for human exposure. The appendix contains a sample report prepared for arsine.

B. Air Contaminant Limits in the Work Place

The most comprehensive set of suggestions is published annually by the American Conference of Governmental Industrial Hygienists (ACGIH).[1] The 1968 version of this publication forms the basis for the Occupational Safety and Health Administration (OSHA) rules affecting air contaminants 29CFR1910.93.[2] It also is used by various state agencies. One example is "Airborne Contaminants" published by the State of California, Department of Industrial Relations (CAL/OSHA).

The ACGIH publication contains four columns of data for each substance. The time weighted average (TWA) and The Short Term Exposure Limit (STEL) are shown in terms of ppm and milligrams per cubic meter.

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The TWA is defined as follows:

> "The time-weighted average concentration for a normal 8-hour work day and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect."

The STEL is defined as follows:

> "a 15-minute time-weighted average exposure which should not be exceeded at any time during the work day even if the eight-hour time weighted average is within the TLV. Exposures should not be longer than 15 minutes and should be repeated more than four times per day. There should be at least 60 minutes between successive exposures to the STEL. (It is a) concentration to which workers can be exposed continually for a short period of time without suffering from: 1) irritation, 2) chronic or irreversible tissue change or 3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency."

For the great majority of substances with a TLV, there is not enough toxicological data available to warrant a STEL. The ACGIH recommends that short term exposures should exceed 3 times the TLV-TWA for no more than 30 minutes during the work day and under no circumstance should they exceed five times the TLV provided the TLV-TWA is not exceeded. Thus this most widely used publication is directed towards the work place environment and provides limited aid in assessing safe levels for a one-time intensive exposure to a toxic gas.

The U.S. Government has two organizations involved in worker safety. Under the Department of Labor, OSHA has general responsibility for developing and enforcing regulations. Under the Department of Health and Human Services, the National Institute for Occupational Safety and Health (NIOSH) is

responsible for research to develop the technical basis for standards. These organizations jointly published a guide that defines acute levels of toxicity.[3] It is entitled, "NIOSH/OSHA Pocket Guide to Chemical Hazards". This is probably the most useful publication to establish safe one-time short-term exposure levels for assessing the hazard caused by a toxic gas cloud.

One concept that is commonly used by toxicologists is ppm/min. For example, chlorine may have a value of 1000 meaning that a person can withstand 1000 ppm for one minute, 200 ppm for five minutes, or any other combination of values in which the product of concentration and time in minutes is 1000.

It is improper to apply this technique to the TLV-TWA values without professional advice because the physiological effects of substances differ so widely.

Two other publications provide a rich source of information to help establish tolerable levels of contaminants. N. Irving Sax is the author of "Dangerous Properties of Industrial Materials".[4] "Patty's Industrial Hygiene and Toxicology"[5] is a publication consisting of five volumes.

C. Air Contaminant Limits in Ambient Air

Starting with Montreal in 1978 numerous governments in North America

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have adopted procedures for analyzing the continuous emissions of toxic compounds from industrial plants in the ambient air.

According to a recent report, 14 states and 6 local programs have toxics regulatory programs in place.[6] An even larger number have programs in preparation.

Many states and localities use some form of ambient guideline or standard for the control of toxic air pollutants. Most of these use "factored" occupational values as a basis for developing the ambient limit, at least for some pollutants. A factored occupational value is the use of a constant fractional value to apply to all of a specific set of occupational limits to convert from a workplace guideline (based on exposure to a particular contaminant over an eight-hour day, five days a week) to an ambient guideline.

The occupational limits used most commonly for this purpose are the TLV-TWA, the OSHA limits and the NIOSH recommended criteria for occupational exposures in air. NIOSH recommendations are based primarily on medical science while OSHA considers technical feasibility and economic factors in its role as regulator.

Figure 16 is a summary of the limits adopted or proposed by selected state and local air pollution control programs.[7]

D. Time Averaged Concentrations

As was discussed in Chapter III, the time average concentration

Figure 16

SAFETY FACTORS USED TO DERIVE ACCEPTABLE AMBIENT CONCENTRATIONS FROM OCCUPATIONAL LIMITS

State or Locality	Safety Factor Applied to Occupational Limit	Averaging Time
Alabama	2.5% (1/40)	1 hour
Arkansas	1% (1/100)	24 hour
Connecticut[1]	0.5% (1/200), 1% (1/100), or 2% (1/50), depending on pollutant group	8 hour
Georgia[1]	0.33% (1/300) if known human carcinogen, 1% (1/100) if not known human carcinogen	24 hour
Illinois	0.33% (1/300) for non carcinogens	24 hour
Indiana[1]	1% (1/100)	24 hour
Michigan	1% (1/100) for selected pollutants	8 hour
Minnesota	1% (1/100)	8 hour
Mississippi	3.3% (1/30), usually	NA[2]
Montana	2.4% (1/42)	1 year[3]
Nevada	10% (1/10)	8 hour
New Hampshire[1]	1% (1/100)	NA[2]
New York	0.33% (1/300), 2% (1/50) depending on toxicity category	1 year
Rhode Island[1]	1% (1/100)	24 hour
South Carolina	0.24% (1/420)	NA[2]
Texas	1% (1/100), 0.1% (1/1000)	30 minute 1 year

(Continued)

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State or Locality	Safety Factor Applied to Occupational Limit	Averaging Time
Vermont	0.24% (1/420)	24 hour or 1 year depending on pollutant
Virginia	1% (1/100) for carcinogens 1.7% (1/60) for non-carcinogens	24 hour 24 hour
Wisconsin[2]	2.4% (1/42)	NA[2]
Wyoming[3]	2.4% (1/42), 2% (1/50), 0.33% (1/300)	1 year, 24 hour, 1 hour
SCAQMD, California	100% for selected pollutants	8 hour
Philadelphia, Pennsylvania	0.24% (1/420) or 2.4% (1/42)	1 year

[1]Tentative: program in preparation.
[2]Not available at the time of this writing.
[3]As reported in Radian Corporation, "Survey of State and Local Agency Programs for Control of Toxic Air Pollutants," Draft Report, Prepared for U.S. EPA, Office of Air Quality Planning and Standards, State and Territorial Air Pollution Program Administators, and Association of Local Air Pollution Control Officials, June 8, 1983.

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is determined by counting the number of standard deviations of a cloud that pass a certain point. If an observer is located close to a brief (few-second release), then an observer may only be breathing the toxic gas for a few seconds. The rest of the air breathed over, say, five minutes will be fresh air. On the other hand if the observer is several kilometers away the peak instantaneous concentration would be nearly equal to the maximum 30-second average concentration.

The science of establishing safe acute levels for 30-second, 1-minute or even 5-minute periods is not well developed. Therefore, when analyzing possible accidents it may be best to analyze several averaging times.

Most people spend most of their time indoors. There is a significant buffering effect in air movement into a building. Under ideal conditions the occupants of a building could be warned and they would then shut off all ventilation. When the cloud had passed, ventilation should be increased to the maximum extent possible to flush out any toxic gases that might have permeated the building.

E. Method Used by EPA for Chronic Toxicity Studies.

For years EPA has studied the risk of citizens living near chemical plants. These studies are based on the use of the CDM computer model and meteorological data collected at nearby

airports.

There is some question regarding the effectiveness of this approach. First CDM is an urban model and many plants are located in rural areas. Nearby airport meteorological data may not be representative of conditions near the plant, particularly in mountainous areas. The CDM model does not consider the wake effects of individual structures, rather it adjusts the vertical dispersion coefficient if the release height is less than 50 meters.

CHAPTER VI: REFERENCES

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III. Large Spills and Heavy Gases

A review of the TLV-TWA list shows values ranging from less than 1 ppm up to 5000 ppm. Some "inert" gases such as acetylene, helium and methane act as simple asphyxiants. No TLV is recommended but the suggested minimum oxygen content is 18 percent by volume.[1] Some of these asphyxiants are explosive and care should be exercized to keep concentrations below the lower explosive limit. If oxygen is 18 percent by volume, the inert gas would be 14.3 percent by volume (143,000 ppm). OSHA sets a limit of 19.5 percent oxygen in 29CFR1910.94 (d)(9)(vi) and 16.5 percent oxygen in 29CRF1915.11 (c)(2).

A. Common Dilute Clouds

Since the concentrations of primary concern for most gases is in the range of less than 1 ppm up to 5000 ppm, this means that the cloud contains no less than 99.5 percent air. As such, the molecular weight of the contaminant, or its original temperature, have virtually no effect on dispersion and can be ignored. More complex processes may exist near or at the source, but by the time the gas has been diluted to concentrations of interest, the cloud will be nearly all ambient air. Moreover, the rate of dilution of the cloud will be primarily governed by the prevalent atmospheric turbulence.

B. Descriptions of Spills

Whenever there is an accidental spill of a liquid or gas, some or all of the material volatizes. As the cloud of volatile material and air moves gradually downwind, the natural process of atmospheric turbulence reduces the concentrations. If the spill is of a hazardous material, the concentrations at some point downwind will fall below the toxic level. Regardless of the nature of the spill, atmospheric turbulence is generally the major factor in diluting the plume as it moves downwind. The initial turbulence of the actual release generally has only a minor effect on concentrations at distances beyond 250 meters or so from the spill.

There are three types of spills: liquids, gases stored as liquids, and gases. In nearly all cases dense gas clouds are created. Buoyant clouds are created only when there is a small hole in a container of gas or when there is evaporation from a liquid pool on the ground. Buoyant plumes are also created when there is a fire. A more detailed description of the three types of spills follows:

1. Liquid spills.

The spill of a material which is normally a liquid at

atmospheric pressure and temperature causes a pool to form. Examples of such liquids include benzene, acrylonitrile, and vinyl chloride. The liquid will evaporate from the pool at a rate that can be calculated based on the vapor pressure of the liquid which governs the rate of liquid to gas transfer, the area of the pool, the heat of evaporation, the air temperature, the ground temperature and the heat transfer of convection and radiation. The viscosity of the liquid will determine the rate of growth of the pool on flat ground. If the material is spilled into a ditch, both the surface exposed to the atmosphere and the surface exposed to the warm earth will be reduced, thus cutting the evaporation rate. In fact one suggestion for minimizing the emissions from spills is to build concrete basins under the potentially leaking vessel. A small deep basin will result in minimum evaporation. By putting a sump in the basin, the spilled material can be quickly recovered.

For most liquids the initial rate of emission will be greater per unit area than the equilibrium rate. As evaporation takes place, the pool will be cooled, reducing the temperature of the adjacent air into which the liquid is evaporating. Wu and Schroy have provided a good summary of the thermodynamics and heat transfer associated with liquid spills.[2]

If the spill of a liquid occurs on water, then the release rate of the material will be much greater than if the spill occurs on land. On land there is no circulation, only conduction, a much less efficient means of heat transfer. The rate of release of toxic material decreases as the temperature of the underlying surface decreases. If the pool is floating on water, then circulation patterns in the water will help keep the pool relatively warm. The Chlorine Institute suggests that chlorine spilled on water should be assumed to vaporize.[3]

2. Liquid Gas Spills.

Many materials are stored in pressurized or refrigerated containers. These include ammonia, chlorine and liquified natural gas (LNG) and liquified petroleum gas (LPG). The nature of the failure has much to do with how the release disperses.

a. Small Hole in Vapor Space

If the spill is a puncture in the top of the container where liquids do not escape, the material will enter the atmosphere as a gas. If the release rate is slow and if

the gas has a molecular weight less than air, the release will have buoyant plume rise.[4] If the molecular weight is greater than air, the plume will rise due to momentum and then sink because of density differences.

b. Large Hole in Vapor Space.

If a large hole should suddenly exist in a tank containing liquified ammonia under pressure, the consequences are quite different than those associated with a small hole. If the hole is small, the escaping vapor can be replenished by evaporation from the liquid surface above which the pressure changes little if at all. If the hole is large, the pressure above the surface is relieved instantaneously. Pressure at and below the liquid surface (which is the sum of atmospheric pressure and static head) is less than the saturation vapor pressure. As a result, bulk boiling occurs and most of the contents of the vessel will be flung into the air. For ammonia at 20°C the heat will be sufficient to vaporize about 20 percent of the vessel contents. The remaining 80 percent becomes an airborne cloud of finely divided boiling liquid droplets at a temperature of -33°C. Experiments confirm that when rapid depressurization occurs, the entire contents of

the container becomes airborne.

c. Hole in Liquid Space.

If the puncture or release occurs below the liquid level, then liquid will enter the atmosphere. If the contents are stored at atmospheric pressure the liquid will form a pool and as it evaporates gas will enter the atmosphere. One conclusion that can be drawn from this observation is that it is safer to store liquified gases refrigerated at atmospheric pressure than in pressurized containers. If the contents are pressurized, then a portion of the liquid will immediately flash to a gas while the liquid portion is rapidly cooled.

d. Dense Gas Cloud.

Because of the turbulence induced by the flashing of gas most of the liquids do not form a pool on the ground but rather form an aerosal of liquid droplets. This cloud, composed of suspended boiling droplets, is called a "dense gas cloud".

A dense gas cloud is also formed when there is a catastrophic failure of an ammonia or chlorine tank.

When all the boiling liquid droplets in a dense gas cloud vaporize, the cloud becomes neutrally buoyant and the usual Gaussian dispersion equation apply. The location, dimensions and concentrations of gases in a dense gas cloud are analyzed using differential equations that are totally different than the familiar Gaussian equations.

A set of six partial differential equations has been proposed to analyze the characteristics of a dense gas cloud[5] including:

Equation	Variables
Width	Horizontal velocity, gravity spread velocity and entrainment velocity.
Lateral Momentum	Hydrostatic force and surface drag.
Mass Conservation	Entrainment velocities.
Mass Fraction Conservation	Boil off from surface pool is added to local flux valves.
Longitudinal Momentum	Entrainment of ambient momentum (wind speed), acceleration from hydrostatic gradients, and surface drag.
Enthalpy Conservation	Surface heat transfer, entrainment of water vapor, ground ource of boiling cryogenic liquid and longitudinal dispersion.

e. Descriptions of Releases

In the case of a sudden release, such as a tank rupture, the dispersion process can be described as four phases according to Griffiths and Kaiser.[6] First, there is the turbulence, called "flash off", caused by the rapid escape of the liquid or gas. For a 20-ton ammonia tank rupture, tests suggest that about 20 percent becomes vapor while 80 percent remains as a liquid aerosol. A similar fraction of chlorine will flash at an ambient temperature of 85 F according to the Chlorine Institute. The liquid aerosol appears to observers as a cloud in the shape of a column or vertical cylinder. The gases within this cylinder are quite cold due to the evaporation of part of the gas.

Second, this cylinder starts to slump, much in the way a column of water starts to spread out. During slumping, air is entrained fairly slowly and this stage will typically last 30 to 40 seconds for a 20-ton gas spill.

Third, the cloud of liquid droplets now enters the ground-hugging phase in which the entrainment of air takes place at a rate less than that expected for a passively diffuse plume. The area of the top surface is

much greater than the area of the sides and, therefore, most of the entrainment of air takes place through the top surface. Depending on the ambient temperature, the gases in the cloud will reach ambient air density in 3 to 5 minutes after slumping starts from a 20-ton spill.

Fourth, the natural process of atmospheric turbulence takes over and the cloud diffuses like any other gas in the atmosphere.

The boundaries between the phases are rather blurred and indistinct. The description of the four phases, however, is useful when discussing the atmospheric dispersion of dense gases.

In the case of large volume releases, the dense cloud can remain intact for some distance. For example, the cloud of vapor formed from the release of 40 tons of ammonia at Pensacola, Florida, was tracked on a radar for an hour out to a distance of nine miles before it dissipated into a neutrally buoyant phase.

On May 11, 1976, in Houston, an ammonia truck crashed from the elevated structure of the Southwest Freeway - I-610 interchange. The grass was "burned" in a circle

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with a radius of about 150 meters from the point of impact and in the downwind distance out to a distance of about 1000 meters. The "burned" grass apparently reflects the initial slumping column followed by a ground-hugging dense gas cloud of liquid droplets that eventually warmed to become a gas.

f. Shape and Characteristics of Dense Gas Clouds

Slumping of a dense gas cloud takes place rapidly and it causes the cloud to spread out radially including movement upwind until arrested by the wind. A raised front is formed with the slumped cloud assumming a doughnut-like shape and eventually decaying to pancake shape. The shape and movement of a dense gas cloud is nearly independent of atmospheric stability.

A dense gas cloud moves more slowly than a buoyant cloud because of surface drag. Tests in the Burro series reported by Meroney show that with a wind speed of 2m/sec the center of the cloud moved at about a third the wind speed. The cloud dimensions for a 10 ton spill of LNG were approximately 200 meters wide and 6 meters deep at a location 140 meters downwind, 200 seconds after the release.

Griffiths and Kaiser report that a 20 ton ammonia spill forms a cloud up to 400 meters in diameter after 50 seconds and up to 600 meters in diameter after 100 seconds.

Another characteristic of a dense gas cloud is that as the cylindrical cloud slumps, concentrations occur upwind of the center of the release. In the case of Burro, they occurred up to 35 meters upwind. In Houston they extended about 150 meters upwind.

The effects of gravity on a dense gas cloud are strong. In an effort to restrict the number and type of variables that require consideration, the significant dense gas tests have been conducted on flat, open uniform terrain. These include Porton Down, Maplin Sands, China Lake (Burro) and the recent Thorney Island experiments.

It is known qualitatively that dense gas clouds do not move uphill except with moderate strong winds and they may even roll down a hill against slight winds. Further research is necessary to qualify the effects of topography.[7]

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There has been extensive research conducted on dense gas spills mostly involving liquified petroleum gas. The studies generally are directed at determining the lower flammable limit (LFL) of a gas/air mixture. Depending on the gas, the LFL are in the range of 10,000 to 125,000 ppm, far in excess of a safe level for gases such as chlorine or ammonia.

The dissipation of the dense gas cloud into a neutrally buoyant cloud and the dilution of the buoyant cloud down to levels of 100 to 500 ppm has not been studied. Various assumptions are made by scientists and a more accurate solution to this issue may not occur for some time.

g. Modeling Dense Gas Clouds.

Although many scientists believe that adequate data exists to validate dense gas models, most are awaiting the availability of data from the China Lake and Thorney Island experiments for confirmation.

At the point of transition to a neutrally buoyant cloud, the dense gas cloud may be up to several hundred meters wide but only a few meters deep.

For highly toxic substances, for which the concentration of concern may be in the ppm range, the behavior during the gravity influenced phase of dispersion may not significantly affect the calculations. Moreover, in most if not all cases, the Gaussian dispersion calculation will tend to overestimate concentrations relative to methods which combine a dense gas dispersion and Gaussian calculations.[8]

3. Gas Spills.

The spill of a material which is normally a gas both at atmospheric conditions and at storage and/or transporation conditions results in the formation of air/gas mixture at a temperature somewhat below ambient temperature. The reduced temperature is the result of the pressure reduction between storage and/or transportation conditions and atmospheric pressure. An analysis of such a release using hydrogen sulfide as an example is provided by Echols.[9]

C. Bursts with Continuing Emissions

When a tank or vessel fails, the release of the gas starts at a high rate but it rapidly decreases as the container becomes depressurized.

Some materials could have a cumulative effect. Hg e.g.

Under these conditions it is appropriate to divide the release into a series of individual bursts. The first the largest burst should be analyzed first. This provides a worst case analysis. The following bursts or puffs will contain less contaminants. If a person can survive or avoid the first puff, the person should be able to survive the subsequent puffs.

D. Lower Flammable Limits

All combustible gases have a lower flammable limit. If the concentration is higher than this level, then any spark or flame can cause an explosion. As a result, good engineering practice is to keep storage tanks of combustibles some distance away from open flames or sources of sparks.

CHAPTER VII: REFERENCES

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VIII. Location of Spills and Data Required

In all cases the most difficult part of analyzing a spill is to determine the quantity spilled. This task is particularly difficult in transportation accidents.

A. Transportation

In most transportation accidents the person at the scene in rural areas is usually local firemen, a state policeman or a sheriff. In urban areas, many larger fire departments have a hazard material coordinator.

The U.S. Department of Transportation publishes "Emergency Response Guidebook" (1984). Copies of this guide have been made available to each police, fire, civil defense and rescue squad vehicle in the United States.

The procedure to use this guide is as follows:

1. Identify the material from:
   a) Data on Shipping papers
   b) Four digit number on an orange panel
   c) Material name that may appear on vehicle
2. Look up Material's 2-digit guide.
3. Turn to numbered guide pages.

The on-scene coordinator is encouraged to call CHEMTREC for immediate advice for those at the scene of emergencies. CHEMTREC immediately contacts the shipper of the hazardous materials for more detailed assistance and appropriate follow-up. It is strongly suggested that the on-scene coordintor keep the phone line open. The CHEMTREC facility consists of a teleconferencing bridge which allows experts from the shipper or anyone else to communicate with the on-scene coordinator.

The user of the Guide is advised to purchase U.S/ Geological Survey Maps of the area of responsibility to aid in evacuations where they are necessary. Preplanning and response team training is recommended.

Figure 17 is a reproduction of the Guide 20 which is used for chlorine, nitrogen dioxide, nitrogen tetroxide, and other gases.

The guide also contains tables (Figure 18) specifying evacuation distances during the initial phase of an accident involving hazardous liquids or gases shipped in bulk or multiple-container loads.

If a hazardous material cloud goes between several multi-story

HEALTH HAZARDS

Poisonous; may be fatal if inhaled.
Contact may cause burns to skin and eyes.
Contact with liquid may cause frostbite.
Runoff from fire control or dilution water may cause pollution.

FIRE OR EXPLOSION

May ignite other combustible materials (wood, paper, oil, etc.).
Mixture with fuels may explode.
Container may explode in heat of fire.
Vapor explosion and poison hazard indoors, outdoors or in sewers.

Keep unnecessary people away; isolate hazard area and deny entry.
Stay upwind; keep out of low areas.
Ventilate closed spaces before entering them.
Wear **positive pressure** breathing apparatus and full protective clothing.
Evacuate area endangered by gas. (See Isolation and Evacuation Table in back of guidebook; find the material by name.)
FOR EMERGENCY ASSISTANCE CALL CHEMTREC **(800) 424-9300.**
If water pollution occurs, notify appropriate authorities.

FIRE

Small Fires: Dry chemical or CO_2.
Large Fires: Water spray, fog or foam.
Move container from fire area if you can do it without risk.
Stay away from ends of tanks.
Cool containers that are exposed to flames with water from the side until well after fire is out.
For massive fire in cargo area, use unmanned hose holder or monitor nozzles; if this is impossible, withdraw from area and let fire burn.

SPILL OR LEAK

Keep combustibles (wood, paper, oil, etc.) away from spilled material.
Stop leak if you can do it without risk.
Use water spray to reduce vapor but **do not** put water on leak or spill area.
Isolate area until gas has dispersed.

FIRST AID

Move victim to fresh air; call emergency medical care.
If not breathing, give artificial respiration.
If breathing is difficult, give oxygen.
Remove and isolate contaminated clothing and shoes at the site.
In case of contact with material, immediately flush skin or eyes with running water for at least 15 minutes.
Keep victim quiet and maintain normal body temperature.
Effects may be delayed; keep victim under observation.

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Figure 18

TABLE OF ISOLATION & EVACUATION DISTANCES

NAME OF MATERIAL SPILLING OR LEAKING (ID No.)	INITIAL ISOLATION SPILL or LEAK FROM (drum, smaller container, or small leak from tank) ISOLATE in all Directions feet	INITIAL EVACUATION LARGE SPILL FROM A TANK (or from many containers, drums, etc.)		
		FIRST ISOLATE in all Directions feet	THEN EVACUATE IN A DOWNWIND DIRECTION Width miles	Length miles
Acrolein (1092)	300	620	1.5	2.4
Acrylonitrile (1093)	90	180	0.4	0.6
Ammonia, anhydrous liquified (1005) Ammonia solution, with more than 44% (2073) Anhydrous ammonia (1005)	80	160	0.4	0.6
Boron trifluoride (1008)	320	670	1.7	2.6
Bromine (1744)	170	350	0.8	1.3
Carbon bisulfide (1131) Carbon disulfide (1131)	50	100	0.2	0.3
Chloride of phosphorus (1809)	110	220	0.5	0.8
Chlorine (1017)	140	290	0.7	1.0
Dimethylamine, anhydrous (1032)	80	170	0.4	0.6
Dimethyl sulfate (1595)	80	170	1.4	2.2
Epichlorohydrin (2023)	40	80	0.2	0.3
Ethylene imine (1185)	270	570	1.4	2.2
Ethylene oxide (1040)	80	160	0.4	0.5
Fluorine, cryogenic liquid (9192)	460	980	2.5	3.9
Hydrochloric acid, anhydrous (1050) Hydrogen chloride, anhydrous (1050) Hydrogen chloride, liquid (refrigerated) (2186)	190	450	1.0	1.4
Hydrocyanic acid (1051) Hydrogen cyanide, anhydrous (1051)	90	190	0.5	0.7
Hydrofluoric acid, anhydrous (1052) Hydrogen fluoride, anhydrous (1052)	150	300	0.7	1.1

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Figure 18 (Cont'd)

TABLE OF ISOLATION & EVACUATION DISTANCES

NAME OF MATERIAL SPILLING OR LEAKING (ID No.)	INITIAL ISOLATION: SPILL or LEAK FROM (drum, smaller container, or small leak from tank) ISOLATE in all Directions feet	INITIAL EVACUATION: LARGE SPILL FROM A TANK (or from many containers, drums, etc.) FIRST ISOLATE in all Directions feet	THEN EVACUATE IN A DOWNWIND DIRECTION Width miles	Length miles
Hydrogen sulfide (1053)	120	240	0.6	0.9
Methylamine, anhydrous (1061) Monomethylamine, anhydrous (1061)	110	220	0.5	0.8
Methyl bromide (1062)	50	90	0.2	0.3
Methyl chloride (1063)	30	60	0.1	0.2
Methyl mercaptan (1064)	370	770	1.9	3.0
Methyl sulfate (1595)	80	170	1.4	2.2
Nitric acid, fuming (2032) Nitric acid, red fuming (2032)	100	210	0.5	0.7
Nitric oxide (1660) Nitric oxide and Nitrogen tetroxide mixture (1975)	90	180	0.4	0.6
Nitrogen dioxide (1067) Nitrogen peroxide (1067) Nitrogen tetroxide (1067)	110	220	0.5	0.8
Oleum (1831)	280	580	1.5	2.2
Perchloromethyl-mercaptan (1670)	220	450	1.1	1.6
Phosgene (1076)	600	1250	3.3	5.2
Phosphorus trichloride (1809)	110	220	0.5	0.8
Sulfur dioxide (1079)	120	250	0.6	0.9
Sulfuric acid, fuming (1831) Sulfuric anhydride (1829) Sulfur trioxide (1829)	280	580	1.5	2.2
Titanium tetrachloride (1838)	30	60	0.2	0.2
Trimethylamine, anhydrous (1083)	50	90	0.2	0.3

THIS INFORMATION IS FOR USE IN ADDITION TO THE GUIDE PAGE RECOMMENDATIONS FOR HANDLING THE TOXIC HAZARDS OF THESE MATERIALS IF THEY ARE NOT ON FIRE

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buildings or down a valley, the cloud could affect people much further away than the distance specified. The guide also notes that occupants on the upper floors of multi-story buildings are likely to be safer remaining where they are if the heating and air-handling equipment in the building can be shut down.

If a fire begins to burn the spilled material, the health hazard may become less important and the evacuation distance may not have to be as great as they were with no fire involvement.

In order to estimate the dispersion of the gas at a spill, the following information is needed:

Whether it is day or night
Estimated wind speed
Wind direction
Amount of cloud cover (to determine stability)
Description of topography

Some firms maintain libraries of USGS maps of the transportation corridors most commonly used in shipping dangerous materials.

B. Accidents at Plant Sites

The instrumentation at a plant often provides a good estimate of the amount of gas released. It is recommended that all plants which handle or process toxic gases record meteorological data and have that data available at several locations in the plant. This data should include the following parameters:

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a) Wind speed

b) Wind direction

c) Standard deviation of wind direction

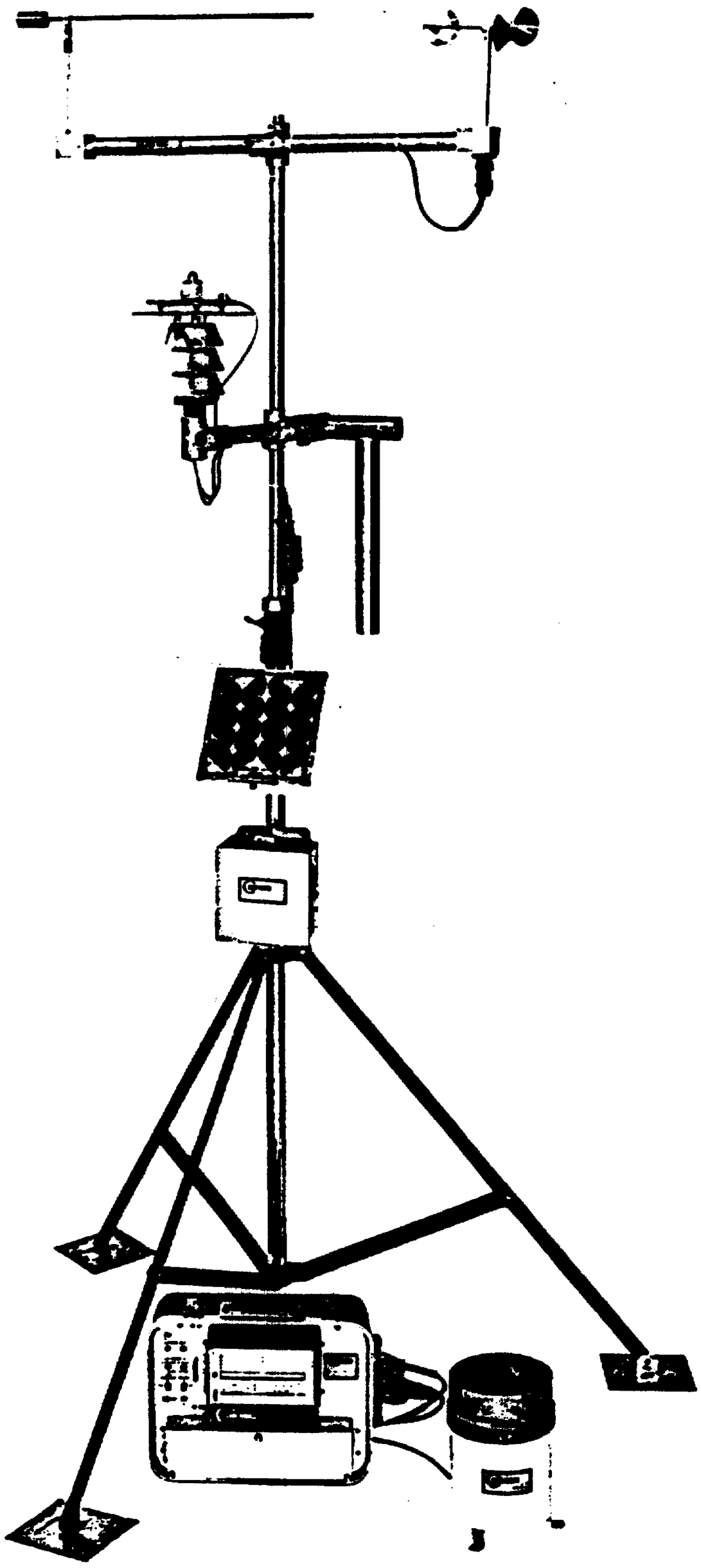
Wind direction should be recorded with a low-mass wind vane, not the type that looks like a wingless, single-engine airplane. The vane should respond quickly to variations in wind direction.

Figure 19 illustrates a typical Weather Station. It is recommended that wind speed and direction be recorded at a 10 meter elevation. The approximate costs are as follows:

Parameter(s)	Cost
Wind speed, wind direction, temperature and strip chart recorder	$ 3200
Sigma-theta card	600
Cassette recorder	2800
Tripod mast as shown	150
10 meter mast	300
Dew point sensor	675
Solar panel (Solar radiation)	450
Tipping bucket rain guage	475

The availability of real-time meteorological data will aid in forecasting the speed and direction of travel of any released material. Moreover, the recording of the data will be invaluable in determining the validity of any claims for compensation should there be an accident.

Figure 19



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Some firms that handle toxic gases place monitors along fence lines. An analysis should be made of the width and the vertical dimension of any possible release. This should be compared to the actual or proposed spacing of inlets to the sampler. It is therefore suggested that the inlets to the sampler should be no more than 3 times sigma y apart in the horizontal direction and about one sigma z above grade for releases within 5 meters of the ground.

IX. Techniques for Reducing Risk

A

There are numerous techniques for reducing the risks.

1. Limit the amount stored at the site. Design a manufacturing process that immediately consumes any toxic gases in further processing. The reduced risk of an accident must be weighed against the reliability of the manufacturing process in which, for example, the failure of a phosgene production unit results in the immediate shutdown of the toluene diisocyanate plant.

2. Construct a building around the plant or loading area. Many chemical plants are built outside with pipes and vessels suspended from a structural steel framework. If the entire process were located in a building, then a monitor could be installed on the forced draft building exhaust vent. Furthermore, the building exhaust vent could be elevated, like a stack, to greatly reduce ground level concentrations.

   In some types of facilities there is a fear of an explosion which militates against an enclosed structure. One firm enclosed the process area down to an area about six feet above grade. A large cooling tower fan was installed on the gabled roof. This arrangement overcame possible explosion problems while insuring that most gases from any release would occur at

a significant elevation.

3. Conduct hazardous operations when dispersion is best. Bright, sunny days with moderate to strong winds are indicative of a great deal of atmospheric turbulence and the conditions which will most rapidly dilute a cloud. It may also be possible to select days or times when the winds would not carry any cloud towards populated centers. If a railroad were to attempt to move a punctured tank car of hydrogen fluoride, it should be accomplished on a clear day with strong winds in a direction to affect the fewest people. A semi-conductor manufacturer should choose to move bottles of toxic gases such as arsine during the lunch hour when employees are absent or during the weekend day shift.

4. Properly train people. When a disaster occurs, the reaction of most people is unpredictable. There have been cases where employees have run towards a chlorine cloud and successfully sued their employer. Therefore, it is prudent to develop a detailed plan and to rehearse it.

Nearly everyone recalls the fire drills that took place when they went to grammar school. The fire bell would ring and students and teacher would proceed quickly and orderly outdoors. After a while the fire drill became routine and because it is, deaths from school fires are virtually

non-existent today.

A similar attitude is beneficial at a plant where drills should be conducted not just during the working day, but at all hours. Most of these drills can be announced in advance, but a few can be a surprise.

The drill can test evacuation procedures, evacuation and plant shutdown procedures, evacuation and fire procedures. The drills can be only for plant personnel and on site contractors or they can be held jointly with local public safety officials.

The ideal situation is one in which all personnel involved react out of habit as a result of regular drills.

5. Design unique fittings to avoid misconnections. One of the causes of the Bhopal disaster was the introduction of water instead of nitrogen into a storage tank. One can speculate that the threads on the fittings of the water and nitrogen lines were alike. By making these fittings unique, an error of this type can be avoided.

6. Use existing equipment to increase dispersion. For example, if a vent that could carry a toxic gas release is near a boiler stack, duct the vent to it. The plume rise on the boiler stack will greatly reduce ground level concentrations. If there is an incinerator or burner, supply at least part of the burner

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air from the forced draft ventilation of a building in which hazardous gases are used.

7. Provide communications equipment to nearby residents. In at least one location plant safety personnel can broadcast a message directly into homes that could be affected by a release. The residents can be directed to first, close all windows, second, open windows after the cloud has passed or, third, evacuate the area. Some plants are starting to rely on automatically dialed telephone messages. Although some plant managers have been reluctant to share their knowledge of the risks with nearby residents, this will be a requirement of British law effective January 1, 1986.

8. Use water sprays. Tests show that water spray curtains can mitigate the consequences of the release of heavy gases into the atmosphere.[1,2] The water spray curtain acts to entrain large quantities of air producing a rapid dilution of a dense plume. Several conclusions are drawn from the studies. Location of the barrier makes little difference but by placing it closer to a source, both water use and construction costs are lowered. As wind speeds tripled from 2 to 6 m/sec, the effectiveness of the barrier fell by 50 percent. Increasing the water pressure increased the rate of dilution.

The water spray systems were most effective under stable

conditions. In nearly all cases the resulting dilution was at least a factor of 10 and often could get as large as 50. The barriers are most effective in rapidly decreasing concentrations of flammable gases below the lower explosive limit. The use of water sprays appears to have only limited value where concentrations are less than 10,000ppm or distances are greater than 1000 meters from the source.

9. Construct retention areas. Construct dikes around storage tanks and build basins underneath large process vessels and rail or truck loading facilities. Design the basin to maximize the depth of the liquid and reduce the surface area. Make provision for pumping accumulated liquids to safe storage tank.

10. Ignite flammable gases. The standard procedure in natural gas drilling operations is to ignite a well blow-out if there is significant hydrogen sulfide in the gas. Not only does this convert the hydrogen sulfide to sulfur dioxide (a less hazardous gas) but it adds significantly to plume elevation because of plume buoyancy.

11. Store gases as refrigerated liquids. The catastrophic failure or even a large hole of a pressurized container results in an immediate release of the contents. If the same material were stored in a refrigerated container at atmospheric pressure, the

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leak from or failure of the container would result in a boiling pool on the ground. This would extend the period of release reducing the peak concentrations and allowing those in the path of the cloud more time to escape. If a method of containing the leak exists, then it may be possible to recover the product reducing the magnitude of the release.

12. Use pressure relief valves. Many containers have "blow-out" plugs that melt or are forced out under excessive internal pressure. The use of pressure relief valves will reduce the quantity of the material released and distribute the release of the entire contents of a vessel over an extended period.

13. Sample for contaminants. One reason many accidents occur is because of contaminated raw materials. It is wise to sample all incoming raw materials as well as manufactured raw materials to reduce the risk that contamination could cause an unplanned release.

14. Rely on a plan. Real-time systems for forecasting the path of a toxic cloud can be helpful. On the other hand, the use of these systems may reduce managements' interest in frequent, serious drills and thereby impart a false sense of security. Moreover, power to a computer may be lost if the accident is a result of a power failure or the catastrophic release itself causes a power failure. Management may wish to use the

periodic, unplanned power failures at its plants as a means to evaluate shut-down procedures and emergency procedures using computer-based aids.

15. Keep people indoors. The indoor concentrations of pollutants are generally less than those outdoors. The ratio of the two concentrations is:[3]

$$\frac{\chi_i}{\chi_o} = 1-e^{-ct}$$

χ_i = Indoor concentration

χ_o = Outdoor concentration

c = Air changes per unit time

t = Time interval

Typically a sealed building will experience between 0.1 and 1.5 air change per hour depending on the make-up air to the ventilation system. A building with open windows on a breezy day will experience 5 to 10 changes per hour. In a typical office building with 1.5 changes per hour the indoor five minute concentration will be only $(1-e^{-1.5/12})$ or 12 percent of the outdoor concentration.

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CHAPTER IX: . REFERENCES

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A

X. Computer Models

The first eleven models employ puff algorithms and may also use continuous release algorithms. The next group of models starting with K. PTPLU are continuous release models that are part of the UNAMAP series of programs.

A. SPILLS

This model was developed by Shell Development Company, Houston, Texas, and given to the U.S. Government for public distribution.[1]

Three options depending on the nature of the spill have been incorporated in the model: 1) continuous spills, such as leaks from tank cars, tanks or pipelines, 2) instantaneously-formed pools of liquids or liquefied gases and 3) stacks, where the emission rate is assumed to be known. This model does not analyze concentrations from dense gas clouds. For options 1 and 2, thermophysical properties (available as a subroutine in the computer program) of 36 potentially hazardous chemicals are used to calculate, through heat and mass transfer mechanisms, the evaporation rate, which becomes the emission rate for the atmospheric dispersion calculations.

The first option is for a small continuous leak of a liquid. Two key variables are unknown, the area of the pool and the emission rate into the atmosphere. Since the area of the pool is difficult to determine, the model makes the simplifying assumption that the emission rate from the leak is equal to the emission rate to the atmosphere. The model calculates the spill area based on convective mass transfer (evaporation). The model also assumes that the liquid spilled is at ambient temperature and pressure so that there is no heat transfer between the pool and the earth.

The second option considers instantaneously formed pools. The mechanism by which the evaporation will take place depends on the nature of the chemical spilled. Chemicals with a normal boiling point below ambient temperature will first flash off due to the pressure drop between the storage pressure (the storage temperature has to be specified by the user) and atmospheric pressure. The evaporation rate due to this adiabatic flash calculation is assumed to occur during the first minute after the spill. The chemical will then form a pool of liquefied gas at its normal boiling point. In reality the remaining liquid after rapid depressurization is often an aerosol rather than a boiling pool. The difference between the temperature of the boiling pool and the ambient temperature will cause heat to be transferred from the ground (the soil is assumed to be at

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ambient temperature) to the pool by conduction, and from the atmosphere to the pool by convection. Mass transfer, due to the wind blowing over the pool, takes over when the heat transfer evaporation rate becomes equal to the mass transfer evaporation rate. Note that this occurs because the heat transfer rate decreases as time increases whereas, the mass transfer rate is independent of time. The emission rate is set to zero when all the chemical is evaporated. With this option the user must specify, both the amount spilled and the area of the pool.

The third option provides for dispersion of gases from stacks, vents, leaks or other point sources. The user supplies up to 100 emission rates for each time interval from the initiation of the phenomenon. If only one rate is supplied, the program considers the case to be steady state. This option incorporates the Briggs plume rise formulas.

This Pasquill-Gifford dispersion coefficients are used in this model. Total calculated concentrations at a receptor are determined by integrating the contributions from puff centers within four standard deviations from the receptor. For area sources the initial plume width is set equal to the area width divided by 4.3.

The output of the program contains a printer-plot of the

isopleths of concentrations from a release. Typically, the TLV-TWA and the STEL are displayed for the 36 chemicals analyzed by the program.

This program is designed for use on an IBM mainframe computer. Although it is user-friendly, the user must have some type of communications link to the host computer.

B. SAFER

This system is the most widely used real-time toxic gas response system today. It is a sophisticated product that has been marketed very effectively. There are over 30 installations including some overseas. The manufacturer is SAFER Emergency Systems, Inc., 756 Lakefield Road, Westlake Village, CA 91361.

The system is designed around a 32-bit microprocessor employing a Motorola 68000 CPU. It includes a high-resolution 19-inch color graphics screen, a monochrome CRT and a printer. Meteorological information is recorded on site and directly entered into the system. Monitored information on chemicals can also be entered directly.

In its usual operating mode the programs are activated by a light pen. The color graphics terminal typically displays

diagrams of the plant so the operator can pinpoint a leak and maps of the area around the plant on which the projected path of a gas cloud is displayed.

The monochrome screen provides instructions to the operator such as persons to be notified and their telephone numbers. The printer is useful to print out the meteorological record for the previous day as well as a list of landmarks, phone numbers, time of arrival of cloud, direction it is coming from, distance from the plant and the proper message to give the authorities. Also reported is the type of chemical, release time, spill size, maximum downwind distance the cloud will travel and a table of critical concentrations at various downwind distances.

The system can also place telephone calls automatically, send messages over the telephone lines, and keep track of which calls were made and which calls were completed.

The system answers critical questions often asked by plant officials during a release of a hazardous chemical. These include: 1) which direction the vapor cloud is moving, 2) will the concentrations downwind of the plant site exceed critical toxicity levels or explosive limits, 3) how soon will the cloud arrive at population center, 4) when will the cloud disperse to a safe level.

In the case of a leak, sensors tied directly into the system automatically detect the ambient concentrations of the escaping vapors and sound an alarm at the central station, thus alerting the plant operator to the release. The plant operator then enters information into the system regarding type of chemical released and size of leakage ("default" amounts are pre-stored for each plant equipment). Wind direction, speed, temperature and stability data, measured from a tower and sensors located on the plant site, are continuously fed into the system and automatically updated.

The system then quickly calculates the projected path of the vapor cloud and atmospheric dispersion rate of a specific chemical. This calculation of the cloud is displayed in different colors and superimposed over base maps of the plant and surrounding community. Should the wind direction change, the system will automatically shift the projection of the cloud to the new direction. Properties of the plant's chemicals are already pre-programmed into the system so that density, dilution and evaporation effects are taken into account in the on-going calculations.

Print-outs of the emergency actions to be taken are tailored to the severity of the situation, thus eliminating the problem of

over-reacting and causing an unnecessary evacuation.

However, should the release be a severe one, the print-out provides pre-planned instructions on whom to call and what to say. This includes telephone number, areas affected, evacuation routes, emergency procedures and health effects from exposure to the vapors.

The dispersion model is a multiple Lagrangian Wall and can consider both puffs and continuous sources. Complex terrain and wind channeling can be incorporated. No information was provided on the dispersion coefficients or on the mechanics for determining liquid evaporation or buoyancy effects.

The basic price of this system is in the $70,000 range. The most common use of SAFER is in postulating scenarios and in conducting drills.

C. CHARM

This model was developed by Radian Corporation, 8501 Mo-Pac Boulevard, Austin, TX 78766. CHARM is an acronym for Complex Hazardous Air Release Model and it has been implemented on an IBM-PC with a color graphics screen. Data on 57 compounds are stored. Algorithms for continuous liquid release, continuous

gas release, instantaneous liquid or gas releases and fires are included.

The dispersion model has been validated against actual tracer studies of gas release experiments and can simulate the transport and dispersion of buoyant, neutral or heavier-than-air releases.

use for planning; to model real-time met data input.

Meteorological data can be input automatically or by the user. All event data and inputs are archived for documentation and data analysis. The software is priced at about $10,000 and there are about 40 purchases. Not all purchasers have been able to implement CHARM.

Developer of software has left Radian. Radian has released him as a consultant. Members of Houston Regional Monitoring Network have copies.

D. CARE

This system was developed by Environmental Systems Corporation, 200 Tech Center Drive, Knoxville, TN 37912. CARE is an acronym for Computerized Airborne Release Evaluation System. The software can be implemented on an IBM-PC or HP200 personal computer.

The system consists of 5 modules. The source module contains an inventory of chemicals and their properties. It includes a gravitational slumping model for use with dense gas clouds. The meteorological module relies on observed data or it modifies

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observed data via a three dimensional wind-field model for use in complex terrain.

The dispersion module is based on a puff-advection model that has a variable trajectory. The display shows the location and concentration of the hazardous chemical. An effects module provides information on the hazard posed to health and welfare by the materials in the plume. It includes dose calculations for nuclear releases as well as data on the TLV and IDLH for chemicals. The fifth module provides the user with recommended response actions.

E. HASTE

This system was developed by Environmental Research and Technology, Inc., 696 Virginia Road, Concord, MA 01742. HASTE is an acronym for Hazard Assessment System for Toxic Emissions. The system can be implemented on an IBM-PC or on an NEC APC. There is one known installation. The system sell for about $40,000.

+ sale State of La.

The system features include a menu driven decision assistance program supported by color graphics, computerized inventories of hazardous chemicals and their properties, pre-programmed release scenarios, dispersion models for dense gas and neutrally buoyant

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plumes, real-time or user-input meteorological data, archiving capability for input data and results and automated emerging protocols.

F. EPCHEMS II

This system was developed by Enviroplan, 59 Main Street, West Orange, NJ 07052. EPCHEMS II consists of Enviroplan's Chemical Emergency Mitigation System and a Continuous Emissions Monitoring Data Acquisition System.

The system bases its source term on the continuous monitoring or pressure, flow and level for any number of storage tanks and pipes to determine whether parameters are in accepted safe ranges. It alerts control room personnel and aids personnel to respond to the emergency. It calculates and displays concentrations from the release on maps of the area. The system is implemented on a small Data General minicomputer.

G. MESOCHEM, JR.

This system was developed by Impell Corporation (a subsiding of Combustion Engineering, Inc.) 350 Lennon Lane, Walmut Creek, CA 94598.

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This system was originally developed on a main frame computer for clients in the nuclear industry. It uses color graphics and has many if not all the features common to SAFER, HASTE, CARE and EPCHEMS II.

H. Other Systems

Both NUS (Gaithersburg, MD) and Dames & Moore (Chicago, IL) have been prominent in developing systems for emergency response in the nuclear industry on large main frame computers. Both firms offer similar systems to chemical firms for toxic gas releases.

Two other systems under development include CEES, Energy Impact Associates, Pittsburgh, PA and MARRS, Ensco, Indian Harbor, FL.

I. EPA Puff

In 1982, EPA published "Estimating Concentrations Downwind from an Instantaneous Puff Release".[2] A copy of this publication is included in the Appendix. This model is based on a summary of experiments on the dispersion of clouds from quasi-instantaneous releases contained in Meteorology and Atomic Energy.[3] Turner refers to this work in the Workbook of Atmospheric Dispersion Estimates.[4] Although it is difficult to make direct comparisons between the puff model and continuous models, the concentrations calculated using the quasi-instantaneous dispersion coefficients

are several times those using Pasquill-Gifford coefficients.

The EPA program calculates peak instantaneous values and time-averaged values for times selected by the user. It assumes steady state wind conditions. The user supplies the initial height of the release, and the standard deviations of the initial cloud size. The three stability categories analyzed are unstable, neutral and stable.

Concentrations are calculated for 12 downwind distances ranging from 10 meters to 30 kilometers. This model is not particularly user-friendly in terms of both the calculations required by the user before creating an input and in the input format. The model does represent EPA's thinking regarding the analysis of quasi-instantaneous spills.

J. TRPUF

This model is based on the EPA puff model and was developed by Trinity Consultants, Inc. Its input is much more user-friendly and the output is significantly more useful than EPA puff. The model is executable on an IBM-PC and includes a graphics capability in which plots are produced on the PC printer. Figure 20 summarizes the differences between TRPUF and the EPA puff model. Figure 21 is a copy of the output of TRPUF and Figure 22 is a plot of the output produced on an IBM-PC printer. This model is used primarily to help management analyze various

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Figure 20

Major Differences Between TRPUF and EPA Puff Models

	TRPUF	EPA Model
Concentration at release point and farther downwind	Calculates a virtual distance so that the calculated concentration at release point is equal to the concentration used as input. The user can also specify the distance downwind for which cloud dimensions are known.	Vectorially adds initial sigma values to sigma values for downwind distances.
Average Concentrations	Calculates peak instantaneous as well as average concentrations for all receptors.	Calculates peak instantaneous at all receptors and average concentrations only at discrete receptors.
Receptors	Receptor grid consists of 70 downwind distances selected easily by the user.	Receptor grid consists of 12 downwind distances from 10 meters to 30 kilometers downwind.
Plume Rise	Uses Briggs' unstable/ neutral momentum plume rise for all stability classes.	User inputs a fixed value independent of wind speed.
Concentration Units	User selects ppm, mg/m^3 or $\mu g/m^3$	$grams/m^3$
Other Information	Displays travel time and sigma values	—

Figure 21

TRPUF - MOD5
COPYRIGHT 1985 TRINITY CONSULTANTS, INC.
A PUFF MODEL DEVELOPED BY TRINITY CONSULTANTS, RICHARDSON, TEXAS 214/234-8567

EXAMPLE OF TRPUF5

RELEASE AMOUNT (POUNDS) = 2.20500 RECEPTOR HEIGHT ABOVE GRADE (FEET) = 5. INITIAL CONCENTRATION (PPM) = 5.00E+05
MOLECULAR WEIGHT = 64.00 EXIT VELOCITY (FEET PER SECOND) = 5.000 INITIAL HORIZONTAL SIGMA (FEET) = .00
AMBIENT TEMPERATURE (DEG F) = 88.00 STACK DIAMETER (FEET) = 1.50 INITIAL VERTICAL SIGMA (FT) = .00
AMBIENT PRESSURE (MB) =1013.00 WIND SPEED (MPH) = 5.0 DOWNWIND DISTANCE (FT) = 0.
STACK HEIGHT (FEET) = 60.00

COMPUTED VIRTUAL DISTANCES (FT) HORIZONTAL VERTICAL

UNSTABLE	3.3	3.3
NEUTRAL	16.4	16.4
STABLE	85.3	85.3

DOWNWIND DISTANCE (FEET)	PEAK INSTANTANEOUS CONCENTRATIONS (UG/M3)				AVERAGE CONCENTRATIONS FOR 300. SECONDS (UG/M3)				TRAVEL (MINUTES)	--- SIGMAS (FEET) ---					
	UNSTABLE	NEUTRAL	STABLE	MAXIMUM	UNSTABLE	NEUTRAL	STABLE	MAXIMUM		UNSTABLE HOR	UNSTABLE VER	NEUTRAL HOR	NEUTRAL VER	STABLE HOR	STABLE VER
20	5.5409E-07	2.2128E-09	6.7703E-09	5.5409E-07	1.7591E-09	4.5425E-12	1.1093E-11	1.7591E-09	.045	3	7	2	3	1	1
40	2.0281E+01	7.2767E-10	4.4680E-09	2.0281E+01	1.1391E-01	2.2348E-12	8.5457E-12	1.1391E-01	.091	5	11	3	4	2	2
60	1.9562E+03	3.3662E-10	3.1362E-09	1.9562E+03	1.5583E+01	1.3668E-12	6.8435E-12	1.5583E+01	.136	7	15	4	4	2	2
80	1.2150E+04	1.8649E-10	2.3043E-09	1.2150E+04	1.2461E+02	9.3783E-13	5.6399E-12	1.2461E+02	.182	9	18	4	5	2	2
100	2.8975E+04	1.1553E-10	1.7539E-09	2.8975E+04	3.6224E+02	6.9102E-13	4.7519E-12	3.6224E+02	.227	11	22	5	6	2	2
120	4.5077E+04	4.2469E-10	1.3728E-09	4.5077E+04	6.6321E+02	2.9391E-12	4.0747E-12	6.6321E+02	.273	13	25	6	7	3	2
140	5.6339E+04	1.9488E-07	1.0993E-09	5.6339E+04	9.5187E+02	1.5296E-09	3.5444E-12	9.5187E+02	.318	15	27	7	7	3	2
160	6.2312E+04	1.7899E-05	8.9711E-10	6.2312E+04	1.1873E+03	1.5694E-07	3.1199E-12	1.1873E+03	.364	17	30	8	8	3	2
180	6.4114E+04	5.3571E-04	7.4386E-10	6.4114E+04	1.3586E+03	5.1847E-06	2.7738E-12	1.3586E+03	.409	19	33	8	9	3	3
200	6.3107E+04	7.4087E-03	6.2525E-10	6.3107E+04	1.4710E+03	7.8394E-05	2.4873E-12	1.4710E+03	.455	20	35	9	9	3	3
220	6.0408E+04	5.9064E-02	5.3177E-10	6.0408E+04	1.5350E+03	6.7793E-04	2.2469E-12	1.5350E+03	.500	22	38	10	10	4	3
240	5.6808E+04	3.1416E-01	4.5695E-10	5.6808E+04	1.5621E+03	3.8856E-03	2.0429E-12	1.5621E+03	.545	24	40	11	10	4	3
260	5.2823E+04	1.2322E+00	3.9622E-10	5.2823E+04	1.5620E+03	1.6331E-02	1.8680E-12	1.5620E+03	.591	26	43	12	11	4	3
280	4.8773E+04	3.8245E+00	3.4633E-10	4.8773E+04	1.5427E+03	5.4052E-02	1.7168E-12	1.5427E+03	.636	28	45	12	12	4	4
300	4.4843E+04	9.8854E+00	3.0491E-10	4.4843E+04	1.5103E+03	1.4836E-01	1.5848E-12	1.5103E+03	.682	30	47	13	12	5	4
320	4.1134E+04	2.2095E+01	2.7017E-10	4.1134E+04	1.4692E+03	3.5084E-01	1.4690E-12	1.4692E+03	.727	31	50	14	13	5	4
340	3.7693E+04	4.3934E+01	2.4079E-10	3.7693E+04	1.4228E+03	7.3547E-01	1.3666E-12	1.4228E+03	.773	33	52	15	13	5	5
360	3.4536E+04	7.9416E+01	2.1575E-10	3.4536E+04	1.3733E+03	1.3983E+00	1.2756E-12	1.3733E+03	.818	35	54	15	14	5	5
380	3.1659E+04	1.3271E+02	1.9424E-10	3.1659E+04	1.3225E+03	2.4508E+00	1.1942E-12	1.3225E+03	.864	37	56	16	14	5	5
400	2.9050E+04	2.0776E+02	1.7566E-10	2.9050E+04	1.2717E+03	4.0143E+00	1.1212E-12	1.2717E+03	.909	38	58	17	15	6	6
420	2.6688E+04	3.0788E+02	1.5949E-10	2.6688E+04	1.2215E+03	6.2112E+00	1.0553E-12	1.2215E+03	.955	40	60	18	15	6	6
440	2.4554E+04	4.3556E+02	1.4536E-10	2.4554E+04	1.1726E+03	9.1568E+00	9.9557E-13	1.1726E+03	1.000	42	62	18	16	6	6
460	2.2625E+04	5.9227E+02	1.3294E-10	2.2625E+04	1.1252E+03	1.2952E+01	9.4130E-13	1.1252E+03	1.045	44	65	19	16	6	6
480	2.0882E+04	7.7844E+02	1.2198E-10	2.0882E+04	1.0797E+03	1.7680E+01	8.9179E-13	1.0797E+03	1.091	45	67	20	17	6	6
500	1.9305E+04	9.9350E+02	1.1225E-10	1.9305E+04	1.0361E+03	2.3400E+01	8.4648E-13	1.0361E+03	1.136	47	69	21	17	7	6
520	1.7877E+04	1.2360E+03	1.0359E-10	1.7877E+04	9.9452E+02	3.0148E+01	8.0487E-13	9.9452E+02	1.182	49	71	21	17	7	6
540	1.6583E+04	1.5038E+03	9.5846E-11	1.6583E+04	9.5490E+02	3.7935E+01	7.6657E-13	9.5490E+02	1.227	51	72	22	18	7	7
560	1.5408E+04	1.7940E+03	8.8899E-11	1.5408E+04	9.1724E+02	4.6751E+01	7.3121E-13	9.1724E+02	1.273	52	74	23	18	7	7
580	1.4339E+04	2.1035E+03	8.2645E-11	1.4339E+04	8.8147E+02	5.6565E+01	6.9849E-13	8.8147E+02	1.318	54	76	24	19	7	7
600	1.3366E+04	2.4290E+03	7.6997E-11	1.3366E+04	8.4753E+02	6.7328E+01	6.6813E-13	8.4753E+02	1.364	56	78	24	19	8	7
620	1.2478E+04	2.7668E+03	7.1881E-11	1.2478E+04	8.1534E+02	7.8978E+01	6.3992E-13	8.1534E+02	1.409	57	80	25	20	8	7
640	1.1667E+04	3.1135E+03	6.7234E-11	1.1667E+04	7.8480E+02	9.1440E+01	6.1363E-13	7.8480E+02	1.455	59	82	26	20	8	7
660	1.0924E+04	3.4656E+03	6.3002E-11	1.0924E+04	7.5585E+02	1.0463E+02	5.8910E-13	7.5585E+02	1.500	61	84	26	21	8	7
680	1.0244E+04	3.8200E+03	5.9138E-11	1.0244E+04	7.2839E+02	1.1847E+02	5.5616E-13	7.2839E+02	1.545	62	86	27	21	8	8
700	9.6184E+03	4.1736E+03	5.5602E-11	9.6184E+03	7.0232E+02	1.3285E+02	5.4467E-13	7.0232E+02	1.591	64	87	28	21	9	8

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Figure 21 (Cont'd)

A

TRPUF - MOD5
COPYRIGHT 1985 TRINITY CONSULTANTS, INC.
A PUFF MODEL DEVELOPED BY TRINITY CONSULTANTS, RICHARDSON, TEXAS 214/234-9567

EXAMPLE OF TRPUF5

RELEASE AMOUNT (POUNDS) = 2.20500
MOLECULAR WEIGHT = 64.00
AMBIENT TEMPERATURE (DEG F) = 88.00
AMBIENT PRESSURE (MB) =1013.00

RECEPTOR HEIGHT ABOVE GRADE (FEET) = 5.
EXIT VELOCITY (FEET PER SECOND) = 5.000
STACK DIAMETER (FEET) = 1.50
WIND SPEED (MPH) = 5.0
STACK HEIGHT (FEET) = 60.00

INITIAL CONCENTRATION (PPM) = 5.00E+05
INITIAL HORIZONTAL SIGMA (FEET) = .00
INITIAL VERTICAL SIGMA (FT) = .00
DOWNWIND DISTANCE (FT) = 0.

COMPUTED VIRTUAL DISTANCES (FT) HORIZONTAL VERTICAL

UNSTABLE	3.3	3.3
NEUTRAL	16.4	16.4
STABLE	85.3	85.3

DOWNWIND DISTANCE (FEET)	PEAK INSTANTANEOUS CONCENTRATIONS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	AVERAGE CONCENTRATIONS FOR 300. SECONDS (UG/M3) UNSTABLE	NEUTRAL	STABLE	MAXIMUM	TRAVEL (MINUTES)	--- SIGMAS (FEET) --- UNSTABLE HOR	VER	NEUTRAL HOR	VER	STABLE HOR	VER
800	7.1553E+03	5.8462E+03	4.1752E-11	7.1553E+03	5.9044E+02	2.0986E+02	4.5504E-13	5.9044E+02	1.818	72	96	32	23	10	5
900	5.4742E+03	7.2158E+03	3.2330E-11	7.2158E+03	5.0321E+02	2.8807E+02	3.8735E-13	5.0321E+02	2.045	81	105	35	25	11	5
1000	4.2882E+03	8.2037E+03	2.5660E-11	8.2037E+03	4.3417E+02	3.6025E+02	3.3524E-13	4.3417E+02	2.273	89	113	39	27	11	6
1100	3.4273E+03	8.8252E+03	2.0786E-11	8.8252E+03	3.7870E+02	4.2249E+02	2.9373E-13	4.2249E+02	2.500	97	122	42	29	12	6
1200	2.7867E+03	9.1378E+03	1.7128E-11	9.1378E+03	3.3350E+02	4.7338E+02	2.6012E-13	4.7338E+02	2.727	105	129	45	31	13	6
1300	2.2997E+03	9.2101E+03	2.2435E-11	9.2101E+03	2.9620E+02	5.1310E+02	3.6422E-13	5.1310E+02	2.955	113	137	49	33	14	7
1400	1.9225E+03	9.1056E+03	3.2298E-10	9.1056E+03	2.6504E+02	5.4262E+02	5.5789E-12	5.4262E+02	3.182	121	145	52	34	15	7
1500	1.6255E+03	8.8774E+03	4.2657E-09	8.8774E+03	2.3874E+02	5.6329E+02	7.8081E-11	5.6329E+02	3.409	129	152	56	36	16	7
1600	1.3882E+03	8.5673E+03	4.0331E-08	8.5673E+03	2.1634E+02	5.7651E+02	7.7955E-10	5.7651E+02	3.636	137	160	59	38	17	7
1700	1.1962E+03	8.2069E+03	2.8638E-07	8.2069E+03	1.9709E+02	5.8361E+02	5.8267E-09	5.8361E+02	3.864	145	167	62	39	18	8
1800	1.0390E+03	7.8191E+03	1.6029E-06	7.8191E+03	1.8041E+02	5.8578E+02	3.4233E-08	5.8578E+02	4.091	152	174	66	41	19	8
1900	9.0896E+02	7.4205E+03	7.3509E-06	7.4205E+03	1.6587E+02	5.8401E+02	1.6438E-07	5.8401E+02	4.318	160	181	69	43	20	8
2000	8.0039E+02	7.0225E+03	2.8491E-05	7.0225E+03	1.5310E+02	5.7917E+02	6.6581E-07	5.7917E+02	4.545	168	188	72	44	21	8
2500	4.5860E+02	5.2344E+03	4.1562E-03	5.2344E+03	1.0768E+02	5.2927E+02	1.1757E-04	5.2927E+02	5.682	206	221	89	51	25	10
3000	2.8996E+02	3.9020E+03	9.5734E-02	3.9020E+03	8.0500E+01	4.6614E+02	3.1695E-03	4.6614E+02	6.818	244	252	105	58	29	11
3500	1.9643E+02	2.9558E+03	7.9806E-01	2.9558E+03	6.2829E+01	4.0661E+02	3.0201E-02	4.0661E+02	7.955	281	283	121	65	33	12
4000	1.4003E+02	2.2832E+03	3.6077E+00	2.2832E+03	5.0615E+01	3.5495E+02	1.5335E-01	3.5495E+02	9.091	317	311	136	71	37	13
4500	1.0392E+02	1.7977E+03	1.1004E+01	1.7977E+03	4.1762E+01	3.1137E+02	5.1677E-01	3.1137E+02	10.227	354	339	152	77	41	14
5000	7.9402E+01	1.4406E+03	2.5727E+01	1.4406E+03	3.5087E+01	2.7478E+02	1.3238E+00	2.7478E+02	11.364	390	366	167	83	45	14
5500	6.2281E+01	1.1727E+03	4.9876E+01	1.1727E+03	2.9893E+01	2.4412E+02	2.8014E+00	2.4412E+02	12.500	425	393	183	89	49	15
6000	4.9885E+01	9.6808E+02	8.4380E+01	9.6808E+02	2.5747E+01	2.1827E+02	5.1133E+00	2.1827E+02	13.636	461	419	198	95	53	16
6500	4.0665E+01	8.0917E+02	1.2893E+02	8.0917E+02	2.2371E+01	1.9635E+02	8.3816E+00	1.9635E+02	14.773	496	444	213	100	57	17
7000	3.3651E+01	6.8386E+02	1.8222E+02	6.8386E+02	1.9575E+01	1.7762E+02	1.2643E+01	1.7762E+02	15.909	531	469	228	105	61	18
7500	2.8210E+01	5.8368E+02	2.4233E+02	5.8368E+02	1.7242E+01	1.6151E+02	1.7667E+01	1.6151E+02	17.045	566	493	243	111	65	18
8000	2.3918E+01	5.0261E+02	3.0710E+02	5.0261E+02	1.5266E+01	1.4756E+02	2.3965E+01	1.4756E+02	18.182	600	516	258	116	68	19
8500	2.0482E+01	4.3625E+02	3.7435E+02	4.3625E+02	1.3582E+01	1.3541E+02	3.0816E+01	1.3541E+02	19.318	635	540	272	121	72	20
9000	1.7694E+01	3.8138E+02	4.4211E+02	4.4211E+02	1.2137E+01	1.2475E+02	3.8274E+01	1.2475E+02	20.455	669	563	287	126	76	21
10000	1.3510E+01	2.9706E+02	5.7276E+02	5.7276E+02	9.8079E+00	1.0700E+02	5.4414E+01	1.0700E+02	22.727	737	608	316	135	83	22
10500	1.1923E+01	2.6438E+02	6.3328E+02	6.3328E+02	8.8642E+00	9.9554E+01	6.2811E+01	9.9554E+01	23.864	771	630	331	140	87	23
11000	1.0583E+01	2.3647E+02	6.8952E+02	6.8952E+02	8.0379E+00	9.2879E+01	7.1257E+01	9.2879E+01	25.000	805	651	345	145	91	23
11500	9.4439E+00	2.1247E+02	7.4102E+02	7.4102E+02	7.3110E+00	8.6865E+01	7.9645E+01	8.6865E+01	26.136	838	673	360	149	94	24
12000	8.4680E+00	1.9172E+02	7.8752E+02	7.8752E+02	6.6695E+00	8.1422E+01	8.7837E+01	8.7887E+01	27.273	872	694	374	154	98	25
12500	7.6266E+00	1.7368E+02	8.2893E+02	8.2893E+02	6.1012E+00	7.6473E+01	9.5908E+01	9.5908E+01	28.409	905	715	388	158	102	25
13000	6.8971E+00	1.5790E+02	8.6532E+02	8.6532E+02	5.5960E+00	7.1957E+01	1.0365E+02	1.0365E+02	29.545	938	736	402	163	105	26
13500	6.2609E+00	1.4404E+02	8.9682E+02	8.9682E+02	5.1454E+00	6.7820E+01	1.1107E+02	1.1107E+02	30.682	971	757	417	167	109	26

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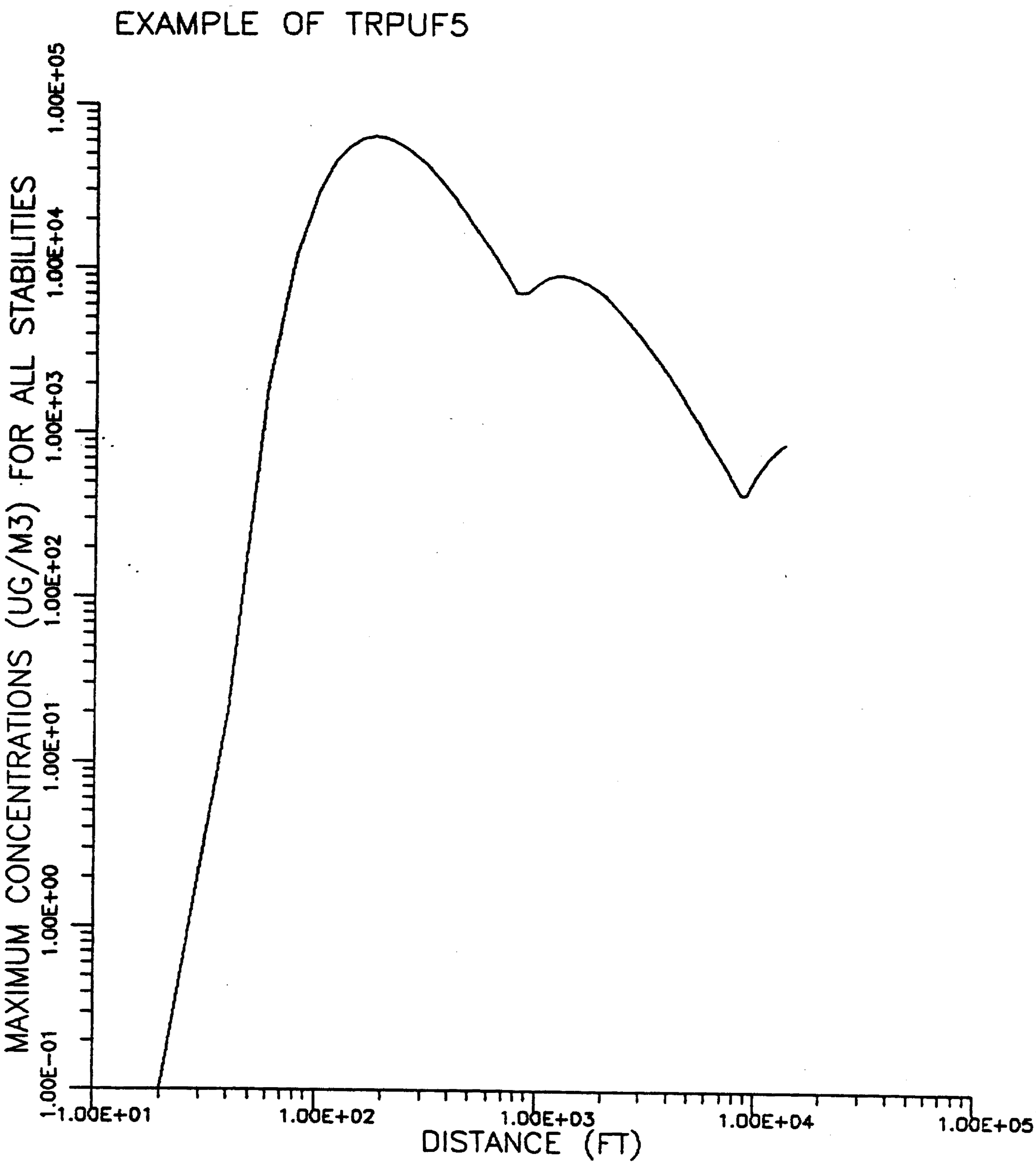
Figure 22



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This model is used primarily to help management analyze various leak scenarios and determine the likely risks.

K. PTPLU

PTPLU is an adapted and improved version of PTMAX for quickly analyzing the approximate location of maximum concentrations and the meteorological conditions under which it occurs for a single point source. Most air quality studies will start by analyzing a representative sample of stacks with this program to guide the receptor placement in more extensive modeling.

PTPLU determines maximum concentrations through a process of iteration. In this process, concentrations are calculated for gradually increasing downwind distances until the peak is passed, then the program decreases the downwind distance until a peak is passed again. After several reversals, the maximum is found. Stack tip downwash and partial plume rise can be considered in the calculations.

L. PAL

PAL requires the user to specify the meteorology. In addition to analyzing point sources, it accepts area sources, two types of line sources and two types of curved path sources. Up to 99

sources of each type can be analyzed. Concentration estimates can be made at 99 user-specified receptor locations. One unique feature is a superior area source algorithm. This makes models particularly useful in analyzing, fugitive dust sources, emissions from waste treatment ponds and land fills, transportation sources, and situations involving sources other than stacks.

M. ISCST

This model is the most versatile of the EPA model for analyzing short term concentrations because of its numerous features that aid the user. If used unwisely, it can be very expensive in terms of computer time.

Sources may be grouped so that average concentrations or deposition from combined sources can be calculated. The ISCST model can analyze point, area and volume sources. Source emission rates may be varied. Receptors may be located in Cartesian or polar coordinates. The effects of stack-tip downwash, building wakes and gravitational settling may also be modeled.

ISCST has one rural and two urban modes. The Rural Mode uses rural mixing heights and Pasquill-Gifford dispersion

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coefficients. Urban Mode 1 uses urban mixing heights, Pasquill-Gifford coefficients, and redefines the E and F stability classes as D (neutral) stability. Urban Mode 2 also uses urban mixing heights and Pasquill-Gifford coefficients. Additionally, Urban Mode 2 combines the E and F stability classes, and uses the Pasquill-Gifford dispersion coefficients for the stability class one step more unstable than the indicated category. For example, if the meteorological data indicate C stability, Urban Mode 2 will use the coefficients for B stability.

Urban Mode 2 is recommended for area sources but should not be used for stack sources in modeling studies for regulatory purposes.

If the pollutant is depleted by an exponential time-dependent decay mechanism, the user can specify a decay coefficient. Particulate matter with an appreciable gravitational settling velocity can be modeled by using the gravitational settling option. The user divides particulate emissions into a maximum of 20 settling categories according to particle size. The settling velocity, mass fraction of total particulate emissions, and surface reflection coefficients must be specified for each category.

Emission rates may be varies, 1) by hour of the day, 2) by season or month, 3) by hour of the day and season or 4) by wind speed and stability class.

For point sources the following parameters must be specified: release height, exit velocity, inside diameter and exit temperature. The effect of nearby building wakes on concentrations can be modeled using the Huber-Snyder method by entering the building height, width and length. Entering these dimensions automatically causes the wake effects option to be used.

For area sources, the user enters the location of the southwest corner of each area source square, the length of a side and the effective emission height. For volume sources, the user enters the location and the height of the center of the volume source and the initial horizontal and vertical plume dimensions. The building wake effects option cannot be used with volume or area sources.

The user may select either a Cartesian or polar coordinate system to locate receptors. UTM coordinates can be entered if a Cartesian system is specified. For the polar system a radial distance from a user designated origin and the angle measured clockwise from north are specified. For a single source or a

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group of sources in close proximity, the polar system is easiest to use. For widely separated sources, the Cartesian system is usually more convenient. The user may elect to enter a receptor grid and/or discrete receptors. A Cartesian or polar grid can be generated by the program.

Discrete receptors may be located in either Cartesian or polar coordinates. The coordinate system used to specify discrete receptors does not have to be the same as the grid system. The user may find it convenient, for example, to use Cartesian coordinates to locate discrete receptors along a plant fence line and polar coordinates for locating a receptor grid beyond the fence line in the same run.

If the source or sources being modeled are located in gently rolling terrain, the user may input terrain elevations for the base of each source and for each receptor. Receptor heights cannot exceed the lowest stack height or effective emission height.

There are six categories of program output. Any or all of these categories may be output at the user's option. The first category reproduces the input data for the problem run. This category contains all control parameters, meteorological and other constants, receptor data and source data. Additionally,

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all hourly meteorological data processed by the program may be output as part of this category. The second category produces an output containing the concentrations at each receptor for each day of meteorological data processed in the problem run. For each day, tables showing concentrations for time periods and groups of sources specified by the user are printed. The third category produces an output containing the concentrations at each receptor for groups of sources specified by the user averaged over the number of days of meteorological data processed in the run. This option allows average concentrations for time periods up to a year to be calculated with ISCST. The fourth category contains tables of the highest and second highest concentrations calculated at each receptor, for sources or groups of sources time periods specified by the user. The fifth category contains a table of the maximum 50 concentrations calculated for the problem run for each time period and source group combination. The sixth category outputs the concentrations to magnetic tape. If deposition is being calculated, deposition values can be output using the above options.

N. VALLEY

This model has two modes of use. It can be used to estimate 24-hour and annual concentrations at receptors located above

stack height. Only VALLEY, COMPLEX I and COMPLEX II can do this. Alternatively, VALLEY can be used to calculate annual averages in flat terrain for rural areas.

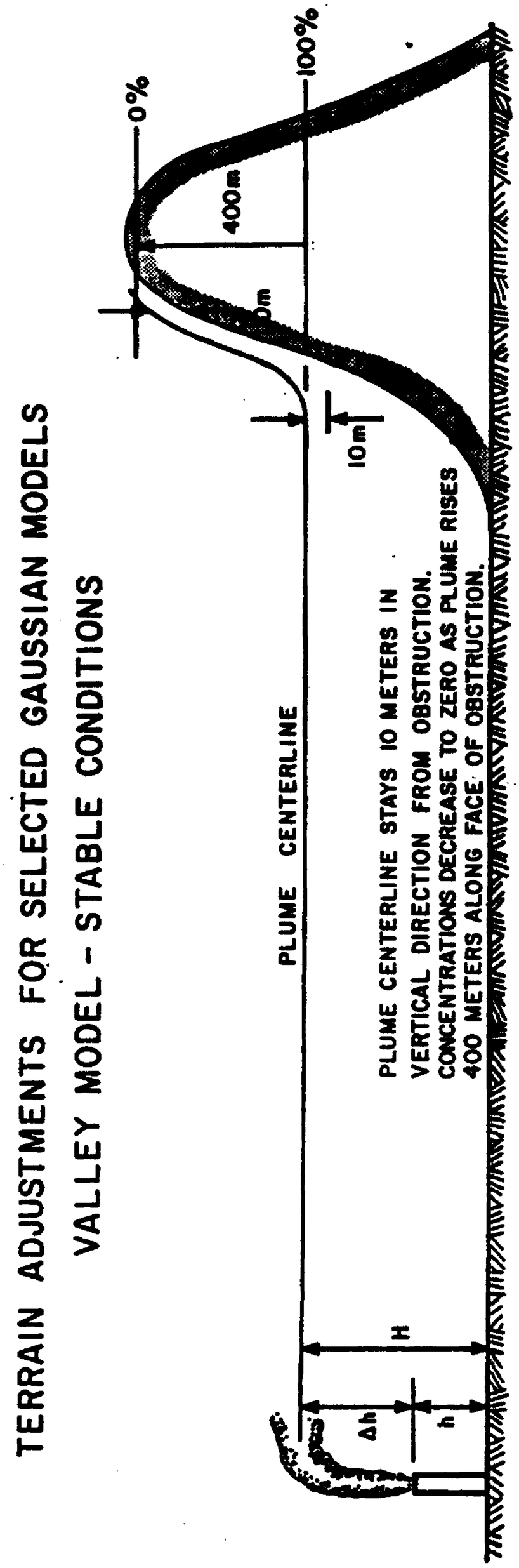
The model analyzes 112 receptors located at seven distances on sixteen radial lines. The user can also specify worst-case short-term meteorology for use in complex terrain. Ground-level elevations are subtracted from the effective stack height. In no case, however, is the effective stack height allowed to be less than ten meters. This is illustrated in Figure 23. Short-term calculated concentrations from area and/or point sources are calculated using Briggs' plume rise and Pasquill-Gifford vertical dispersion coefficients. In the horizontal, the plume is assumed to be 22.5 degrees wide. The model assumes that a given type of meteorology will persist for 6 hours out of 24. Thus the short-term calculated values are divided by 4 to produce a 24-hour estimate. The output consists of a print-plot of calculated concentrations along with detailed data. The user can specify a print-plot of each source, the total from all sources and an elevation map. A convenient option permits one to scale the map so that it can be placed directly over standard U.S. Geological Survey maps.

This model has been criticized widely, but EPA continues to use it until a better model is proven. One of the frequent

Figure 23

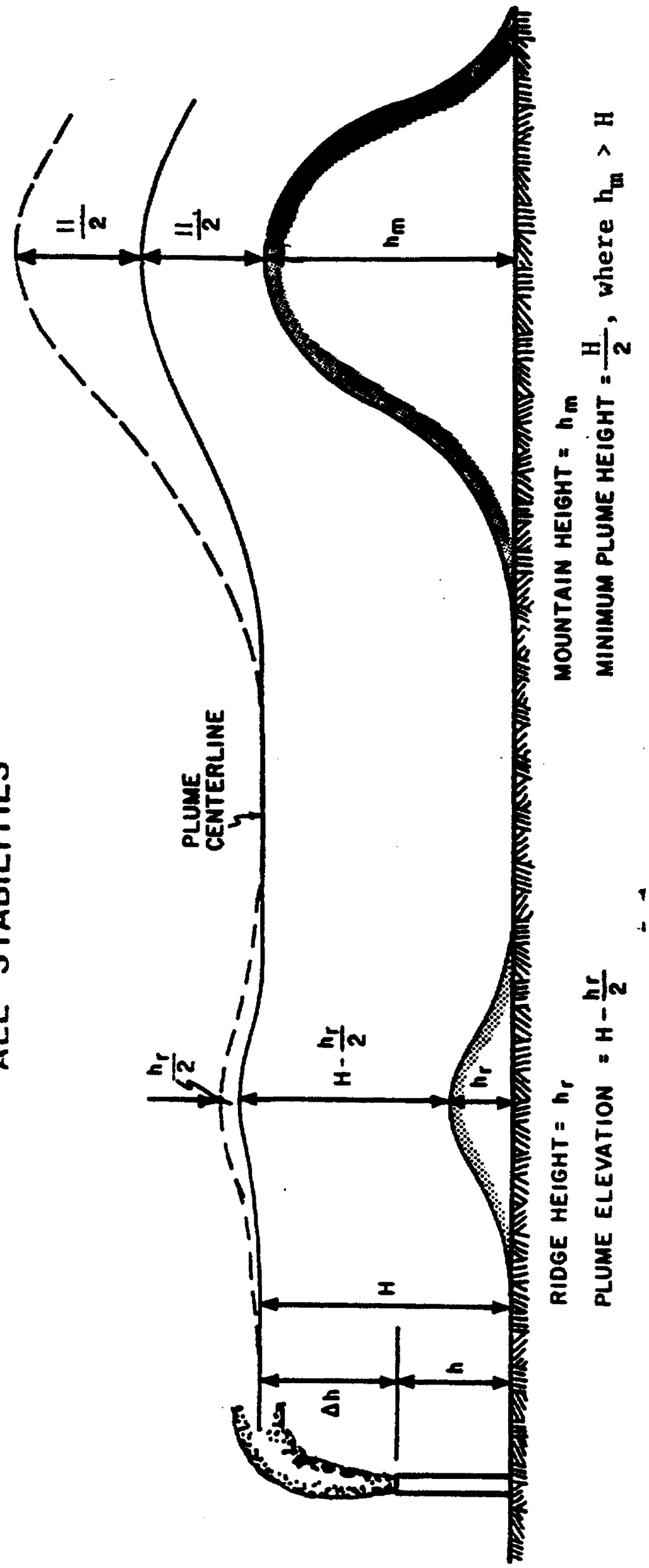
TERRAIN ADJUSTMENTS FOR SELECTED GAUSSIAN MODELS

VALLEY MODEL - STABLE CONDITIONS



HALF HEIGHT PLUME MODEL

ALL STABILITIES



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questions concerns the 10-meter assumption, but it is relatively unimportant at distances of 2 kilometers or more from a stack. More important is the shape of the terrain. If a plume is carried towards a vertical cliff then plume inpingement may occur. On the other hand, if the terrain were rather gently sloping, the air would tend to follow the slope. One study indicated that the overestimate in this case was a factor of 20.

O. TEM8

The TEM (Texas Episodic Model) was developed by the Texas Air Control Board to predict air pollution concentrations for periods up to 24 hours. Since then, it has been revised and modified to increase its flexibility and utility. The current version is TEM-8 (Version 8). The TEM was developed as an alternative to the EPA models, PTMPT and PAL. In developing the TEM, the Texas Air Control Board incorporated a number of enhancements that provided flexibility and speed in the program operation.

PTMPT and PAL were originally developed to provide a method to compare calculated and observed pollutant concentrations. For this comparison, the user input receptor points and meteorological data that would correspond to actual conditions. In contrast, the TEM calculates concentrations for a program generated grid using meteorological data supplied by the user.

By varying the input of meteorological data, the TEM is used primarily to identify worst case conditions over the area covered by the grid. Both PTMPT and PAL could also be used to simulate worst case conditions, but these conditions could only be analyzed for user-specified receptor points.

An additional enhancement made to TEM reduces the program run time. This enhancement creates a data table of precalculated constants. This data table allows the program to go through the concentration calculations only once and interpolate the other values. This enhancement provides accurate concentration predictions with a substantial saving of computer time.

In 1983, TEM was modified to allow the user to input building dimensions so that wake effects can be analyzed as they are in ISCST.

Finally, the TEM uses a time-averaging technique to spread the plume in the crosswind direction. The program takes the calculated sigma-y values for a 10-minute period and adjusts it to a 30-minute, 1-hour or 3-hour value. In this method the mass of the plume cross section is conserved for all averaging times. The 24-hour concentration may be obtained by summing the three-hour values for eight scenarios or 24 1-hour values.

ADJUSTED SIGMA-Y RELATED TO SAMPLING TIME

Stability (P-G)	10 Minutes	30 Minutes	1 Hour	3 Hour
A	1.0	2.10	3.35	7.04
B	1.0	1.83	2.68	4.90
C	1.0	1.60	2.14	3.42
D	1.0	1.40	1.71	2.38
E & F	1.0	1.21	1.37	1.66

Sampling time options 1 through 4 correspond to 10-, 30-, 60- and 180-minute averaging times. Sampling time options 5 and 6 are for 24-hour evaluations using either eight 3-hour scenarios or twenty-four 1-hour scenarios. The last two options are for a variable evaluation time depending on the number of scenarios entered. Option 7 assumes the scenarios are for 10 minutes while option 8 assumes one hour. For example, using option 7 with six 10-minute scenarios will produce a 1-hour average.

TEM calculates concentrations at up to 2500 locations in a rectangular grid from up to 300 point sources (stacks) and 50 area sources.

The user has several options for presenting the calculated data: a list of receptors with concentrations, a print plot with concentrations in their correct relative location, a punched card output of concentrations for subsequent use in plotting, a list of the amount of pollutant contributed by the five most important sources to each receptor and a list of maximum concentrations for each scenario.

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CHAPTER X: REFERENCES

1. Fleischer, M.T. "SPILLS An Evaporation/Air Dispersion Model for Chemical Spills on Land", December 1980. User's Guide available from National Technical Information Service (NTIS), publication number PB83-109470 ($403).

2. Petersen, William B. "Estimating Concentrations Downwind from an Instantaneous Puff Release", August 1982. Available from U.S. Environmental Protection Agency as EPA 600/3-82-078 or from NTIS as PB82-261959.

3. Slade, David H. "Meteorology and Atomic Energy", 1968. U.S. Atomic Energy Commission, pp 120, 173-175.

4. Turner, p. 41.

XI. Evaluation of Risks

"Safe" does not mean risk-free. There is no activity or product that does not carry some potential for accidental injury. Often this is related to the misuse of a product or equipment. What "safe" means is that society considers the risk acceptable.

This chapter is concerned with how to identify possible hazardous situations, some typical causes of hazards, how to conduct a hazard and operability survey and briefly how to relate the hazard to risk.

A. Development of Accident Scenarios

Before applying the techniques for analyzing dispersion in the atmosphere, an analysis should be performed to define the possible disaster scenarios. From such an analysis the plant manager can distinguish the accidents which have trivial consequences from those that are significant. Furthermore, the significant possible accidents can be dissected to determine whether improved process design, modification of equipment, improved operator training or other safety measures could be employed to reduce the risk.

This analysis of significant disaster scenarios will aid in the preparation of contingency plans for the plant. Although the computer provides plant managers with the ability to respond in real-time, it would be unwise to not rehearse responses for the

most likely disaster scenarios.

The loss of life from releases or ignition of flammable materials in this century is about equal to the loss of life from hazardous gas releases. Most studies of hazards generally include both ignitable releases as well as toxic gas releases. The property damage from explosions and fires is often much greater than from a toxic gas release alone. The table below summarizes accident statistics.

Substance	Reference	Accidents Total	Accidents Fatal	Deaths in Fatal Accidents
Chlorine	1	18	10	112*
Chlorine	2	28	15	120*
Ammonia	1	11	5	41
Flammable gases	1	24	19	306+
Ammonium Nitrate	1	3	3	1132
Ethylene Oxide	1	2	2	5

* Excludes deaths of about 5000 allied troups at Ypres, Belgium in April, 1915.

\+ Excludes the LPG incident in Mexico City, 1984 in which 300 lives were lost.

Reference 1 is dated 1979 while Reference 2 is dated 1974.

There have been other releases of toxic gases and compounds:

Year	Location	Substance	Deaths
1928	Hamburg, Germany	Phosgene	10
Late 70's	Lake Charles, LA	Phosgene	1
1976	Seveso, Italy	2,3,7,8 TCDD	none
Early 80's	Palo Alto, CA	Arsine	1
1984	Bhopal, India	Methyl diisocyante	1600

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B. Causes of Failures

On June 1, 1974 a release of 40 tons of cyclohexane was ignited in a large fire ball which largely destroyed a chemical plant at Flixborough, England, killing 28 workers. Several public inquiries were held and one result was a decision to conduct an extensive study of the chemical refinery complex at Canvey near the mouth of the Thames. This study was the first major risk assessment study made for a large refinery/chemical complex.

The British Health and Safety Executive Commissioned a $600,000 study which was conducted by the Safety and Reliability Directorate of the Atomic Energy Authority. The selection of the contractor was a recognition of the fact that the nuclear industry has pioneered the development of risk analysis procedures.[3,4]

The principal factors involved in failures include:[5]

a. Operator errors
b. Metallurgical fatigue or aging of materials
c. Internal or external corrosion
d. Loss of process control, e.q. pressure temperature, flow, etc.

e. Overfilling
f. Introduction of Impurities
g. Fire and/or explosion
h. Missiles
i. Flooding

Risk is usually stated in terms of the probability of an event

in a year. Thus, an event that can occur once in 100 years has

a probability of 10E-2 this year. One event in a million years is 10E-6.

A surprising number of accidents are the result of operator error in which water is introduced to a tank inadvertently, an improper chemical is used to clean a tank or an operator incorrectly pumps caustic soda into a tank of sulfuric acid. It is not enough to examine the obvious sources of a toxic gas release, it is also important to speculate on the reactions of chemicals manufactured, stored or consumed at a site.

C. Hazard and Operability (HAZOP) Studies

One of the first steps to assess potential hazards is a carefully structured hazard and operability (HAZOP) study. It is suggested that a team of three to five members be assembled along with flow sheets of a proposed or an existing process.[6]

The team should meet for no more than three hours at a time and a seasoned study leader should act as chairman. As a general rule, each individual part studied, such as each main pipeline into a vessel, will take about 15 minutes. Another way to estimate time is to allow 2.5 hours per vessel.

The author of the Guide indicates that after several sessions the initial tedium vanishes and the members start to derive satisfaction from such a thorough analysis of a design.

The purpose of the study is to define the hazards. In some cases solutions for the hazards can readily be identified but in other cases special studies may be necessary to develop solutions.

D. Risk Analysis

It is generally desirable to distinguish between individual risk and societal risk. "Individual Risk" is defined as the risk to an individual of an event. "Societal Risk" is the risk to society of an event in terms of number of fatalities. Thus, individual risk varies from place to place depending on where the person happens to be at the time of a major accident. The societal risk is a measure of a combination of the likelihood and severity of a single event.

Risk is a quantified by three factors:

a. Accident frequency or probability
b. Accident severity
c. Exposure - the measure of the opportunity to be involved with an accident.

1. Analyzing Risk

Once hazards are identified it becomes relatively simple to assess probabilities. Consider, for example, a plant with 200 meters of piping. The risk of failure of pipe is 3*10E-7 per meter per year.[7] Thus, the likelihood of failure for the network is

200 * 3 * 10E-7 = 6 * 10E-5 per year

Assume that valves exist to limit the quantity released but there is 1 in 100 chance that they will fail to work. The total risk of a large failure is:

6 * 10E-5 * 10E-2 = 6 * 10E-7

There is also a risk of release of smaller quantities of gas between the values of

0.99 * 6 * 10E-5 = 6 * 10E-5

If the gas is flammable, the risk of release can be multiplied by the probability that ignition will occur before the released gases are diluted below the lower favorable limit. Finally, meteorological and population location data is used to assess the probability of a gas release affecting nearby residents.

Statistical data is available to assess the probability of many other events. Some of the probabilities used in the second Canvey report include:

Rupture of refinery process vessels from all modes	4.4 * 10E-5 per year
Railroad tank car derailment and puncture	10E-8 per km
Probability of fire after LPG car puncture	0.73 per event
Aircraft crash into process area of a refinery	5 * 10E-6 per year

The Canvey report provides an extensive risk analysis of

ship loading and unloading accidents.

The final result of this work was a series of tables that by the second report had assessed the average individual risk at 35 * 10E-6 per year for residents living near the Canvey complex. There was also a one in a thousand risk that ten or more lives would be lost in an incident each year.

By way of reference the individual risk of death from motor vehicle accidents in Great Britain is 130 * 10E-6 and all other accidents about 190 * 10E-6.

4000-5000 x10^{-6} Cigarette smoking premature death.

2. Computer Model

Needless to say, it is expensive and time consuming to prepare a detailed plan for a plant or for a large complex. A London-based consultant, Technica, Ltd., completed a traditional study in 1981 for selected areas near Rotterdam for the Rijnmond Authority. They then developed a user-friendly computer program for risk analysis of process plants called "SAFETI".[8] The code sells for about $70,000, but it is available from timesharing vendors.

The user will typically be trained for about a week and spend an added one or two days collecting data for each process unit such as a group of storage vessels, chlorine plant cell room, or cracking furnace section.

A plant data file is created by an interactive program which prompts the analyst in a logical sequence. Other data needed includes the distribution of population by location, the distribution of ignition sources and meteorological data.

The output consists of individual risk contour plots which are overlaid on a map of the area and so called F-N plots. The frequency of an event (F) is plotted against the number of fatalities (N) for societal risk in a log-log presentation.

3. Value of Risk Analysis

There are many uncertainties involved in any HAZOP and risk analysis survey. First, it is difficult to speculate on all the possible operator errors that could occur. Even if a reasonable method of assessing risk is completed, there is still a great deal of uncertainty as to the consequences given the rather inaccurate nature of dispersion modeling, the number of people that will be affected, the response of individuals to acutely toxic doses and whether the people affected will be outdoors or in buildings with varying ventilation rates.

Perhaps the best that can be accomplished is to use risk assessment to evaluate relative risks. The iteration of

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models with different hazard scenarios can tell management how much safer one type of control system is compared to another.

Chapter XI: References

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Publications Dept
Chem. Ind. Association LTD
Alembic House
93 Albert Embankment
London, SE1 7TU

£ 7.50

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Kletz article in
Hazop.

APPENDIX

A. Implementation Schedule for S.I. 1984/1902, "The Control of Industrial Major Accident Hazards Regulations".

B. Tabulation of Pasquill-Gifford dispersion coefficients for various downwind distance.

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D. Wei, E. T., "Report for Trinity Consultants (on Arsine)", July 21, 1984, Personal Communication.

E. "World Bank and IFC Guidelines for Indentifying, Analyzing and Controlling Major Hazard Installations in Developing Counties" (Draft-February 1985) World Bank, Washington, DC.

Table 1 Timetable for compliance - manufacturers

Requirement	*Category of industrial activity*	*Date in force*	*Relevant Regulation*
Demonstration of safe operation (Reg 4)	New and existing industrial activities	1.4.85	Reg 1(b)
Reporting major accidents (Reg 5)	New and existing industrial activities	1.4.85	Reg 1(b)
Safety case (Regs 7 to 9)	Existing activity*	Required by 8.7.89 but a limited notification by 1.4.85	Reg 7(3)
	New activity† commenced not more than 6 months after implementation	No later than 8.4.85	Reg 7(2)
	New activity†	At least 3 months before commencement of activity	Reg 7(1)
On-site emergency plan (Reg 10)	Existing activity	1.4.85	Reg 10(3)(b)
	New activity† commenced not more than 3 months after implementation	No later than 8.4.85	Reg 10(3)(a)
	New activity†	Before commencement of activity	Reg 10(3)(a)
Off-site emergency plan (Reg 11) Manufacturer to provide information to local authority (county or equivalent level)	Existing activity and new activity† commenced before 1.10.85	1.10.85 or within 6 months of the local authority being notified by HSE, whichever is the later	Reg 11(3)
	New activity†	Before commencement of activity or within 6 months of the local authority being notified by HSE, whichever is the later	Reg 11(3)
Informing the public (Reg 12)	Existing activity	1.1.86	Reg 12(3)
	New activity† commenced before 1.1.86	1.1.86	Reg 12(3)
	New activity†	Before commencement of activity	Reg 12(3)

* For existing activities, HSE has the power to exempt manufacturers from the submission of the safety case (Regulation 7(4)). However the safety case must be prepared.

† Regulation 6(2) defines a new industrial activity for the purposes of Regulations 7 to 12 and guidance is given in paragraph 104.

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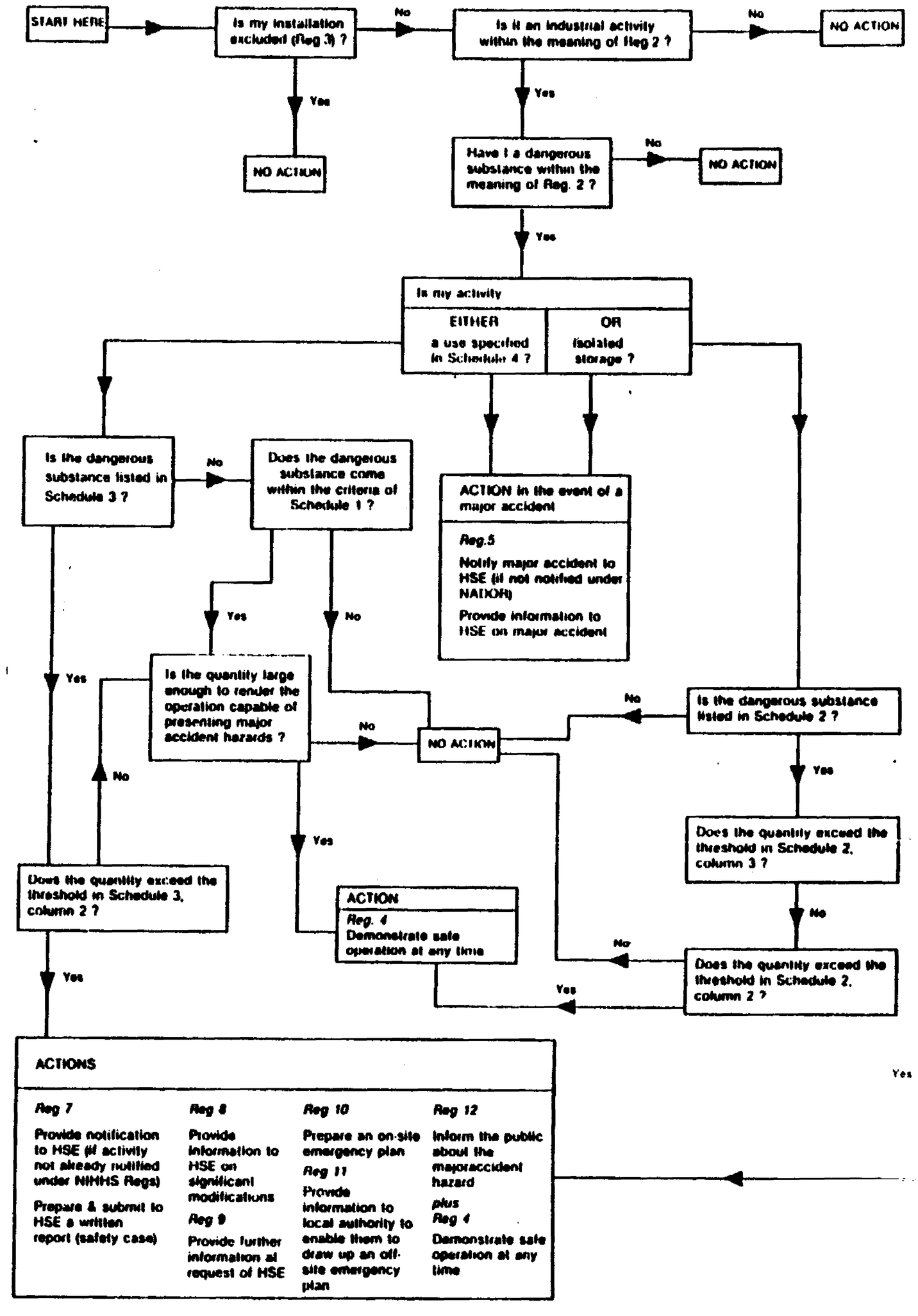

FIGURE A MANUFACTURER'S GUIDE TO THE CIMAH REGULATIONS

A

RURAL VERTICAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND DIST (KM)	STABILITY A	B	C	D	E	F
0.010	1.58	1.24	0.91	0.63	0.51	0.36
0.020	3.05	2.37	1.71	1.15	0.92	0.63
0.030	4.47	3.45	2.47	1.63	1.29	0.87
0.040	5.87	4.51	3.22	2.10	1.64	1.10
0.050	7.25	5.56	3.95	2.55	1.98	1.32
0.060	8.61	6.59	4.66	2.98	2.31	1.53
0.070	9.96	7.61	5.37	3.41	2.62	1.74
0.080	11.30	8.61	6.07	3.83	2.93	1.94
0.090	12.63	9.61	6.76	4.24	3.24	2.13
0.100	13.95	10.60	7.44	4.65	3.53	2.33
0.110	15.43	11.59	8.12	5.05	3.82	2.51
0.120	16.91	12.57	8.79	5.45	4.10	2.70
0.130	18.40	13.54	9.46	5.84	4.38	2.88
0.140	19.89	14.51	10.12	6.23	4.66	3.06
0.150	21.40	15.47	10.78	6.62	4.93	3.24
0.160	22.96	16.43	11.44	7.00	5.20	3.41
0.170	24.53	17.39	12.09	7.38	5.46	3.58
0.180	26.11	18.34	12.74	7.76	5.72	3.76
0.190	27.70	19.29	13.39	8.13	5.98	3.93
0.200	29.30	20.23	14.03	8.50	6.24	4.09
0.210	30.96	21.23	14.67	8.87	6.49	4.25
0.220	32.62	22.22	15.31	9.23	6.75	4.41
0.230	34.30	23.21	15.94	9.60	7.00	4.57
0.240	35.98	24.21	16.57	9.96	7.24	4.72
0.250	37.67	25.20	17.21	10.32	7.49	4.88
0.260	39.59	26.19	17.83	10.68	7.74	5.03
0.270	41.52	27.18	18.46	11.03	7.98	5.18
0.280	43.48	28.17	19.08	11.39	8.22	5.33
0.290	45.45	29.16	19.71	11.74	8.46	5.48
0.300	47.44	30.14	20.33	12.09	8.70	5.62
0.310	49.69.	31.13	20.95	12.42	8.92	5.77
0.320	51.96	32.12	21.56	12.74	9.13	5.92
0.330	54.26	33.11	22.18	13.06	9.35	6.06
0.340	56.60	34.09	22.79	13.38	9.56	6.20
0.350	58.96	35.08	23.41	13.70	9.77	6.35
0.360	61.34	36.06	24.02	14.02	9.98	6.49
0.370	63.76	37.05	24.63	14.33	10.19	6.63
0.380	66.20	38.03	25.23	14.65	10.40	6.77
0.390	68.67	39.02	25.84	14.96	10.61	6.91
0.400	71.16	40.00	26.45	15.27	10.81	7.05
0.410	74.27	41.10	27.05	15.58	11.02	7.19
0.420	77.42	42.20	27.65	15.89	11.22	7.32
0.430	80.64	43.30	28.25	16.19	11.42	7.46
0.440	83.91	44.41	28.85	16.50	11.62	7.59
0.450	87.23	45.52	29.45	16.80	11.82	7.73
0.460	90.61	46.63	30.05	17.10	12.02	7.86
0.470	94.04	47.74	30.65	17.40	12.22	8.00
0.480	97.52	48.86	31.24	17.70	12.41	8.13
0.490	101.06	49.97	31.84	18.00	12.61	8.26
0.500	104.65	51.09	32.43	18.30	12.80	8.40

RURAL VERTICAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND DIST (KM)	STABILITY A	B	C	D	E	F
0.510	109.13	52.22	33.03	18.59	12.99	8.53
0.520	113.71	53.34	33.62	18.89	13.19	8.66
0.530	118.39	54.47	34.21	19.18	13.38	8.79
0.540	123.17	55.59	34.80	19.47	13.57	8.92
0.550	128.05	56.72	35.39	19.77	13.76	9.05
0.560	133.02	57.86	35.98	20.06	13.95	9.18
0.570	138.10	58.99	36.56	20.35	14.14	9.30
0.580	143.28	60.13	37.15	20.64	14.32	9.43
0.590	148.56	61.27	37.73	20.92	14.51	9.56
0.600	153.94	62.41	38.32	21.21	14.69	9.69
0.610	159.42	63.55	38.90	21.50	14.88	9.81
0.620	165.00	64.69	39.49	21.78	15.06	9.94
0.630	170.69	65.84	40.07	22.07	15.25	10.06
0.640	176.47	66.99	40.65	22.35	15.43	10.19
0.650	182.36	68.13	41.23	22.63	15.61	10.31
0.660	188.35	69.29	41.81	22.92	15.79	10.44
0.670	194.44	70.44	42.39	23.20	15.97	10.56
0.680	200.63	71.59	42.97	23.48	16.15	10.68
0.690	206.93	72.75	43.54	23.76	16.33	10.81
0.700	213.33	73.91	44.12	24.03	16.51	10.93
0.710	219.83	75.06	44.70	24.31	16.69	11.04
0.720	226.43	76.23	45.27	24.59	16.87	11.14
0.730	233.14	77.39	45.85	24.87	17.05	11.25
0.740	239.95	78.55	46.42	25.14	17.22	11.35
0.750	246.87	79.72	47.00	25.42	17.40	11.46
0.760	253.89	80.88	47.57	25.69	17.57	11.56
0.770	261.01	82.05	48.14	25.97	17.75	11.67
0.780	268.24	83.22	48.71	26.24	17.92	11.77
0.790	275.57	84.39	49.28	26.51	18.10	11.87
0.800	283.00	85.57	49.85	26.78	18.27	11.98
0.810	290.54	86.74	50.42	27.05	18.44	12.08
0.820	298.19	87.92	50.99	27.32	18.61	12.18
0.830	305.94	89.09	51.56	27.59	18.78	12.28
0.840	313.79	90.27	52.13	27.86	18.96	12.38
0.850	321.75	91.45	52.70	28.13	19.13	12.48
0.860	329.82	92.63	53.26	28.40	19.30	12.58
0.870	337.99	93.81	53.83	28.67	19.47	12.68
0.880	346.26	95.00	54.39	28.93	19.63	12.78
0.890	354.64	96.18	54.96	29.20	19.80	12.88
0.900	363.13	97.37	55.52	29.47	19.97	12.98
0.910	371.72	98.56	56.09	29.73	20.14	13.08
0.920	380.42	99.75	56.65	30.00	20.31	13.18
0.930	389.23	100.94	57.21	30.26	20.47	13.28
0.940	398.14	102.13	57.78	30.52	20.64	13.37
0.950	407.16	103.32	58.34	30.79	20.80	13.47
0.960	416.28	104.51	58.90	31.05	20.97	13.57
0.970	425.51	105.71	59.46	31.31	21.14	13.67
0.980	434.85	106.90	60.02	31.57	21.30	13.76
0.990	444.30	108.10	60.58	31.83	21.46	13.86
1.000	453.85	109.30	61.14	32.09	21.63	13.95

RURAL VERTICAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND DIST (KM)	STABILITY A	B	C	D	E	F
1.050	503.22	115.31	63.93	33.12	22.30	14.39
1.100	555.30	121.35	66.71	34.12	22.97	14.82
1.150	610.08	127.41	69.48	35.12	23.62	15.24
1.200	667.59	133.50	72.24	36.09	24.26	15.66
1.250	727.83	139.62	74.98	37.05	24.90	16.07
1.300	790.83	145.76	77.72	38.00	25.52	16.47
1.350	856.60	151.92	80.45	38.94	26.14	16.87
1.400	925.14	158.10	83.17	39.86	26.74	17.26
1.450	996.47	164.31	85.89	40.77	27.34	17.65
1.500	1070.60	170.53	88.59	41.67	27.93	18.03
1.550	1147.54	176.78	91.29	42.56	28.51	18.41
1.600	1227.31	183.05	93.98	43.44	29.09	18.78
1.650	1309.90	189.33	96.66	44.31	29.66	19.15
1.700	1395.34	195.63	99.34	45.17	30.23	19.52
1.750	1483.63	201.96	102.01	46.02	30.78	19.88
1.800	1574.79	208.30	104.67	46.86	31.34	20.23
1.850	1668.82	214.65	107.33	47.70	31.88	20.59
1.900	1765.72	221.02	109.98	48.52	32.42	20.94
1.950	1865.52	227.41	112.62	49.34	32.96	21.28
2.000	1968.22	233.82	115.26	50.15	33.49	21.63
2.050	2073.82	240.24	117.89	50.96	33.96	21.92
2.100	2182.34	246.68	120.52	51.75	34.43	22.21
2.150	2293.78	253.13	123.14	52.54	34.90	22.50
2.200	2408.15	259.59	125.76	53.33	35.36	22.78
2.250	2525.47	266.07	128.37	54.10	35.82	23.06
2.300	2645.73	272.57	130.97	54.87	36.27	23.34
2.350	2768.95	279.07	133.58	55.64	36.72	23.61
2.400	2895.13	285.59	136.17	56.40	37.17	23.89
2.450	3024.28	292.13	138.77	57.15	37.61	24.16
2.500	3156.40	298.68	141.35	57.90	38.04	24.42
2.550	3291.51	305.24	143.94	58.65	38.48	24.69
2.600	3429.61	311.81	146.52	59.38	38.91	24.95
2.650	3570.71	318.39	149.09	60.12	39.33	25.21
2.700	3714.81	324.99	151.66	60.84	39.75	25.47
2.750	3861.93	331.60	154.23	61.57	40.17	25.73
2.800	4012.06	338.22	156.79	62.29	40.59	25.98
2.850	4165.21	344.85	159.35	63.00	41.00	26.23
2.900	4321.39	351.49	161.91	63.71	41.41	26.48
2.950	4480.62	358.15	164.46	64.42	41.82	26.73
3.000	4642.88	364.81	167.01	65.12	42.22	26.98
3.050	4808.19	371.49	169.55	65.77	42.62	27.18
3.100	4976.55	378.18	172.09	66.42	43.02	27.39
3.150	5000.00	384.87	174.63	67.07	43.42	27.60
3.200	5000.00	391.58	177.16	67.71	43.81	27.80
3.250	5000.00	398.30	179.69	68.35	44.20	28.00
3.300	5000.00	405.03	182.22	68.98	44.59	28.20
3.350	5000.00	411.76	184.74	69.61	44.97	28.40
3.400	5000.00	418.51	187.26	70.24	45.35	28.59
3.450	5000.00	425.27	189.78	70.86	45.73	28.79
3.500	5000.00	432.03	192.29	71.48	46.11	28.98

RURAL VERTICAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
3.550	5000.00	438.81	194.80	72.10	46.49	29.17
3.600	5000.00	445.59	197.31	72.71	46.86	29.36
3.650	5000.00	452.39	199.82	73.32	47.23	29.55
3.700	5000.00	459.19	202.32	73.92	47.60	29.74
3.750	5000.00	466.00	204.82	74.53	47.96	29.92
3.800	5000.00	472.83	207.32	75.13	48.33	30.11
3.850	5000.00	479.66	209.81	75.72	48.69	30.29
3.900	5000.00	486.49	212.30	76.31	49.05	30.48
3.950	5000.00	493.34	214.79	76.90	49.41	30.66
4.000	5000.00	500.20	217.27	77.49	49.77	30.84
4.050	5000.00	507.06	219.76	78.08	50.08	31.02
4.100	5000.00	513.93	222.24	78.66	50.39	31.19
4.150	5000.00	520.81	224.71	79.24	50.70	31.37
4.200	5000.00	527.70	227.19	79.81	51.01	31.54
4.250	5000.00	534.60	229.66	80.39	51.32	31.72
4.300	5000.00	541.50	232.13	80.96	51.62	31.89
4.350	5000.00	548.41	234.60	81.53	51.92	32.06
4.400	5000.00	555.33	237.06	82.09	52.22	32.23
4.450	5000.00	562.26	239.53	82.65	52.52	32.40
4.500	5000.00	569.19	241.99	83.21	52.82	32.57
4.550	5000.00	576.14	244.45	83.77	53.12	32.74
4.600	5000.00	583.09	246.90	84.33	53.41	32.91
4.650	5000.00	590.04	249.36	84.88	53.70	33.07
4.700	5000.00	597.01	251.81	85.43	53.99	33.24
4.750	5000.00	603.98	254.26	85.98	54.28	33.40
4.800	5000.00	610.96	256.70	86.53	54.57	33.56
4.850	5000.00	617.94	259.15	87.07	54.86	33.73
4.900	5000.00	624.93	261.59	87.61	55.14	33.89
4.950	5000.00	631.93	264.03	88.15	55.43	34.05
5.000	5000.00	638.94	266.47	88.69	55.71	34.21
5.500	5000.00	709.37	290.74	93.95	58.46	35.76
6.000	5000.00	780.42	314.82	99.03	61.08	37.23
6.500	5000.00	852.05	338.74	103.94	63.60	38.64
7.000	5000.00	924.22	362.49	108.71	66.03	40.00
7.500	5000.00	996.90	386.11	113.34	68.37	41.16
8.000	5000.00	1070.04	409.58	117.85	70.64	42.28
8.500	5000.00	1143.63	432.94	122.25	72.84	43.36
9.000	5000.00	1217.64	456.17	126.56	74.97	44.40
9.500	5000.00	1292.05	479.30	130.76	77.05	45.41
10.000	5000.00	1366.85	502.32	134.89	79.07	46.38
10.500	5000.00	1442.01	525.25	138.66	80.89	47.33
11.000	5000.00	1517.51	548.08	142.36	82.67	48.26
11.500	5000.00	1593.35	570.82	145.99	84.40	49.15
12.000	5000.00	1669.51	593.48	149.54	86.10	50.03
12.500	5000.00	1745.98	616.06	153.04	87.76	50.89
13.000	5000.00	1822.75	638.56	156.47	89.38	51.72
13.500	5000.00	1899.81	660.99	159.85	90.97	52.54
14.000	5000.00	1977.14	683.34	163.18	92.53	53.34
14.500	5000.00	2054.74	705.63	166.45	94.06	54.12
15.000	5000.00	2132.60	727.85	169.67	95.56	54.88

RURAL VERTICAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
15.500	5000.00	2210.72	750.01	172.85	97.03	55.48
16.000	5000.00	2289.08	772.11	175.98	98.48	56.05
16.500	5000.00	2367.68	794.15	179.08	99.91	56.62
17.000	5000.00	2446.50	816.14	182.13	101.31	57.18
17.500	5000.00	2525.56	838.06	185.14	102.69	57.72
18.000	5000.00	2604.84	859.94	188.11	104.05	58.25
18.500	5000.00	2684.32	881.76	191.05	105.39	58.78
19.000	5000.00	2764.02	903.53	193.96	106.71	59.29
19.500	5000.00	2843.92	925.26	196.83	108.02	59.80
20.000	5000.00	2924.02	946.93	199.67	109.30	60.29
21.000	5000.00	3084.80	990.15	205.26	111.33	61.26
22.000	5000.00	3246.33	1033.19	210.74	113.29	62.20
23.000	5000.00	3408.57	1076.06	216.10	115.20	63.11
24.000	5000.00	3571.50	1118.78	221.37	117.06	64.00
25.000	5000.00	3735.09	1161.34	226.54	118.87	64.86
26.000	5000.00	3899.31	1203.76	231.63	120.64	65.69
27.000	5000.00	4064.15	1246.03	236.63	122.36	66.51
28.000	5000.00	4229.59	1288.18	241.55	124.05	67.30
29.000	5000.00	4395.59	1330.19	246.39	125.70	68.08
30.000	5000.00	4562.16	1372.09	251.16	127.31	68.84
31.000	5000.00	4729.26	1413.86	255.41	128.89	69.46
32.000	5000.00	4896.89	1455.52	259.59	130.44	70.07
33.000	5000.00	5000.00	1497.07	263.72	131.96	70.66
34.000	5000.00	5000.00	1538.51	267.78	133.45	71.24
35.000	5000.00	5000.00	1579.85	271.78	134.91	71.81
36.000	5000.00	5000.00	1621.08	275.72	136.35	72.37
37.000	5000.00	5000.00	1662.22	279.62	137.76	72.91
38.000	5000.00	5000.00	1703.26	283.46	139.15	73.45
39.000	5000.00	5000.00	1744.21	287.25	140.52	73.97
40.000	5000.00	5000.00	1785.08	291.00	141.86	74.49
41.000	5000.00	5000.00	1825.85	294.70	142.90	75.00
42.000	5000.00	5000.00	1866.54	298.36	143.92	75.49
43.000	5000.00	5000.00	1907.15	301.97	144.93	75.98
44.000	5000.00	5000.00	1947.68	305.55	145.92	76.46
45.000	5000.00	5000.00	1988.12	309.08	146.89	76.94
46.000	5000.00	5000.00	2028.50	312.58	147.85	77.40
47.000	5000.00	5000.00	2068.79	316.04	148.79	77.86
48.000	5000.00	5000.00	2109.02	319.46	149.72	78.31
49.000	5000.00	5000.00	2149.17	322.85	150.64	78.75
50.000	5000.00	5000.00	2189.25	326.21	151.54	79.19

RURAL HORIZONTAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
0.010	3.36	2.34	1.47	0.96	0.72	0.48
0.020	6.29	4.42	2.80	1.84	1.37	0.91
0.030	9.08	6.41	4.08	2.68	2.00	1.33
0.040	11.77	8.34	5.33	3.50	2.61	1.74
0.050	14.39	10.23	6.56	4.31	3.22	2.14
0.060	16.96	12.09	7.77	5.11	3.81	2.53
0.070	19.49	13.92	8.96	5.89	4.40	2.92
0.080	21.98	15.72	10.14	6.67	4.98	3.31
0.090	24.43	17.50	11.31	7.44	5.55	3.69
0.100	26.85	19.27	12.46	8.20	6.12	4.07
0.110	29.25	21.01	13.61	8.96	6.69	4.45
0.120	31.63	22.74	14.75	9.71	7.25	4.82
0.130	33.98	24.46	15.88	10.46	7.81	5.19
0.140	36.31	26.16	17.00	11.20	8.36	5.56
0.150	38.63	27.86	18.12	11.93	8.91	5.92
0.160	40.93	29.54	19.23	12.67	9.46	6.29
0.170	43.21	31.21	20.34	13.40	10.01	6.65
0.180	45.48	32.87	21.44	14.12	10.55	7.01
0.190	47.73	34.52	22.53	14.84	11.09	7.37
0.200	49.97	36.17	23.62	15.56	11.63	7.73
0.210	52.20	37.80	24.71	16.28	12.16	8.08
0.220	54.41	39.43	25.79	16.99	12.69	8.44
0.230	56.62	41.05	26.86	17.70	13.23	8.79
0.240	58.81	42.66	27.93	18.41	13.76	9.14
0.250	60.99	44.27	29.00	19.12	14.28	9.50
0.260	63.17	45.87	30.07	19.82	14.81	9.84
0.270	65.33	47.46	31.13	20.52	15.33	10.19
0.280	67.48	49.05	32.19	21.22	15.85	10.54
0.290	69.63	50.63	33.24	21.92	16.38	10.89
0.300	71.76	52.20	34.29	22.61	16.89	11.23
0.310	73.89	53.77	35.34	23.30	17.41	11.58
0.320	76.01	55.34	36.38	23.99	17.93	11.92
0.330	78.12	56.90	37.43	24.68	18.44	12.26
0.340	80.23	58.45	38.47	25.37	18.96	12.60
0.350	82.33	60.00	39.50	26.05	19.47	12.95
0.360	84.42	61.55	40.54	26.74	19.98	13.29
0.370	86.50	63.09	41.57	27.42	20.49	13.62
0.380	88.58	64.62	42.60	28.10	21.00	13.96
0.390	90.65	66.15	43.62	28.78	21.51	14.30
0.400	92.71	67.68	44.65	29.46	22.01	14.64
0.410	94.77	69.21	45.67	30.13	22.52	14.97
0.420	96.82	70.73	46.69	30.80	23.02	15.31
0.430	98.87	72.24	47.71	31.48	23.52	15.64
0.440	100.91	73.75	48.72	32.15	24.03	15.98
0.450	102.94	75.26	49.74	32.82	24.53	16.31
0.460	104.97	76.77	50.75	33.49	25.03	16.64
0.470	107.00	78.27	51.76	34.15	25.52	16.97
0.480	109.02	79.77	52.76	34.82	26.02	17.31
0.490	111.03	81.26	53.77	35.48	26.52	17.64
0.500	113.04	82.75	54.77	36.15	27.02	17.97

A

RURAL HORIZONTAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND DIST (KM)	STABILITY A	B	C	D	E	F
0.510	115.04	84.24	55.77	36.81	27.51	18.30
0.520	117.04	85.72	56.77	37.47	28.01	18.62
0.530	119.04	87.21	57.77	38.13	28.50	18.95
0.540	121.03	88.69	58.77	38.79	28.99	19.28
0.550	123.01	90.16	59.76	39.45	29.48	19.61
0.560	124.99	91.63	60.75	40.10	29.97	19.93
0.570	126.97	93.10	61.74	40.76	30.46	20.26
0.580	128.94	94.57	62.73	41.41	30.95	20.59
0.590	130.91	96.03	63.72	42.07	31.44	20.91
0.600	132.88	97.50	64.71	42.72	31.93	21.24
0.610	134.84	98.95	65.69	43.37	32.42	21.56
0.620	136.79	100.41	66.68	44.02	32.90	21.88
0.630	138.75	101.86	67.66	44.67	33.39	22.21
0.640	140.69	103.32	68.64	45.32	33.88	22.53
0.650	142.64	104.76	69.62	45.97	34.36	22.85
0.660	144.58	106.21	70.60	46.61	34.84	23.17
0.670	146.52	107.65	71.57	47.26	35.33	23.50
0.680	148.45	109.09	72.55	47.90	35.81	23.82
0.690	150.38	110.53	73.52	48.55	36.29	24.14
0.700	152.31	111.97	74.49	49.19	36.77	24.46
0.710	154.23	113.40	75.46	49.83	37.25	24.78
0.720	156.15	114.84	76.43	50.47	37.73	25.10
0.730	158.07	116.27	77.40	51.11	38.21	25.41
0.740	159.98	117.69	78.37	51.75	38.69	25.73
0.750	161.89	119.12	79.33	52.39	39.17	26.05
0.760	163.80	120.54	80.30	53.03	39.64	26.37
0.770	165.70	121.96	81.26	53.67	40.12	26.69
0.780	167.61	123.38	82.22	54.30	40.60	27.00
0.790	169.50	124.80	83.18	54.94	41.07	27.32
0.800	171.40	126.21	84.14	55.58	41.55	27.63
0.810	173.29	127.63	85.10	56.21	42.02	27.95
0.820	175.18	129.04	86.06	56.84	42.50	28.27
0.830	177.06	130.45	87.02	57.48	42.97	28.58
0.840	178.95	131.85	87.97	58.11	43.44	28.90
0.850	180.83	133.26	88.92	58.74	43.91	29.21
0.860	182.70	134.66	89.88	59.37	44.39	29.52
0.870	184.58	136.06	90.83	60.00	44.86	29.84
0.880	186.45	137.46	91.78	60.63	45.33	30.15
0.890	188.32	138.86	92.73	61.26	45.80	30.46
0.900	190.19	140.26	93.68	61.89	46.27	30.78
0.910	192.05	141.65	94.63	62.51	46.74	31.09
0.920	193.91	143.04	95.57	63.14	47.21	31.40
0.930	195.77	144.43	96.52	63.77	47.67	31.71
0.940	197.63	145.82	97.46	64.39	48.14	32.02
0.950	199.48	147.21	98.41	65.02	48.61	32.33
0.960	201.33	148.59	99.35	65.64	49.08	32.64
0.970	203.18	149.98	100.29	66.26	49.54	32.95
0.980	205.02	151.36	101.23	66.89	50.01	33.26
0.990	206.87	152.74	102.17	67.51	50.47	33.57
1.000	208.71	154.12	103.11	68.13	50.94	33.88

RURAL HORIZONTAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
1.050	217.88	160.99	107.80	71.23	53.26	35.43
1.100	227.00	167.82	112.46	74.31	55.56	36.96
1.150	236.06	174.62	117.10	77.38	57.86	38.49
1.200	245.07	181.38	121.71	80.44	60.15	40.01
1.250	254.03	188.11	126.32	83.49	62.43	41.53
1.300	262.94	194.81	130.90	86.52	64.70	43.04
1.350	271.81	201.48	135.46	89.54	66.96	44.55
1.400	280.63	208.11	140.01	92.56	69.21	46.05
1.450	289.41	214.72	144.54	95.56	71.46	47.54
1.500	298.16	221.31	149.06	98.55	73.70	49.03
1.550	306.86	227.86	153.56	101.53	75.93	50.51
1.600	315.52	234.39	158.04	104.50	78.15	51.99
1.650	324.15	240.90	162.51	107.46	80.37	53.47
1.700	332.75	247.38	166.97	110.41	82.57	54.94
1.750	341.31	253.83	171.41	113.35	84.78	56.41
1.800	349.83	260.27	175.85	116.29	86.97	57.87
1.850	358.33	266.68	180.26	119.22	89.16	59.33
1.900	366.79	273.08	184.67	122.13	91.35	60.78
1.950	375.22	279.45	189.06	125.05	93.53	62.23
2.000	383.62	285.80	193.45	127.95	95.70	63.68
2.050	392.00	292.13	197.82	130.84	97.87	65.12
2.100	400.34	298.44	202.18	133.73	100.03	66.56
2.150	408.66	304.73	206.52	136.61	102.18	67.99
2.200	416.95	311.01	210.86	139.49	104.33	69.42
2.250	425.21	317.27	215.19	142.36	106.48	70.85
2.300	433.45	323.51	219.51	145.22	108.62	72.28
2.350	441.66	329.73	223.82	148.07	110.76	73.70
2.400	449.85	335.93	228.11	150.92	112.89	75.12
2.450	458.02	342.12	232.40	153.76	115.02	76.53
2.500	466.16	348.30	236.68	156.60	117.14	77.95
2.550	474.28	354.46	240.95	159.43	119.26	79.36
2.600	482.37	360.60	245.21	162.25	121.37	80.76
2.650	490.45	366.73	249.47	165.07	123.48	82.17
2.700	498.50	372.84	253.71	167.88	125.59	83.57
2.750	506.53	378.94	257.94	170.69	127.69	84.97
2.800	514.54	385.02	262.17	173.49	129.78	86.36
2.850	522.53	391.09	266.39	176.29	131.88	87.76
2.900	530.50	397.15	270.60	179.08	133.97	89.15
2.950	538.45	403.19	274.81	181.86	136.05	90.54
3.000	546.38	409.22	279.00	184.65	138.13	91.92
3.050	554.29	415.23	283.19	187.42	140.21	93.31
3.100	562.18	421.24	287.37	190.19	142.29	94.69
3.150	570.05	427.23	291.54	192.96	144.36	96.07
3.200	577.91	433.20	295.71	195.72	146.42	97.44
3.250	585.74	439.17	299.87	198.48	148.49	98.82
3.300	593.56	445.12	304.02	201.23	150.55	100.19
3.350	601.37	451.07	308.16	203.98	152.60	101.56
3.400	609.15	457.00	312.30	206.72	154.66	102.92
3.450	616.92	462.92	316.43	209.46	156.71	104.29
3.500	624.67	468.82	320.56	212.19	158.75	105.65

A

RURAL HORIZONTAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
3.550	632.41	474.72	324.68	214.92	160.80	107.01
3.600	640.13	480.61	328.79	217.65	162.84	108.37
3.650	647.83	486.48	332.90	220.37	164.88	109.73
3.700	655.52	492.34	336.99	223.09	166.91	111.08
3.750	663.20	498.20	341.09	225.81	168.94	112.43
3.800	670.85	504.04	345.18	228.52	170.97	113.79
3.850	678.50	509.87	349.26	231.22	173.00	115.13
3.900	686.13	515.70	353.33	233.92	175.02	116.48
3.950	693.74	521.51	357.40	236.62	177.04	117.83
4.000	701.34	527.31	361.47	239.32	179.06	119.17
4.050	708.93	533.11	365.52	242.01	181.07	120.51
4.100	716.50	538.89	369.58	244.69	183.08	121.85
4.150	724.05	544.66	373.62	247.38	185.09	123.19
4.200	731.60	550.43	377.66	250.06	187.10	124.52
4.250	739.13	556.18	381.70	252.74	189.10	125.86
4.300	746.65	561.93	385.73	255.41	191.10	127.19
4.350	754.15	567.67	389.76	258.08	193.10	128.52
4.400	761.64	573.39	393.78	260.74	195.10	129.85
4.450	769.12	579.11	397.79	263.41	197.09	131.18
4.500	776.58	584.82	401.80	266.07	199.08	132.50
4.550	784.03	590.53	405.81	268.72	201.07	133.83
4.600	791.48	596.22	409.81	271.38	203.06	135.15
4.650	798.90	601.90	413.80	274.02	205.04	136.47
4.700	806.32	607.58	417.79	276.67	207.02	137.79
4.750	813.72	613.25	421.78	279.31	209.00	139.11
4.800	821.11	618.91	425.76	281.95	210.98	140.42
4.850	828.49	624.56	429.74	284.59	212.95	141.74
4.900	835.86	630.20	433.71	287.23	214.92	143.05
4.950	843.22	635.84	437.67	289.86	216.89	144.36
5.000	850.56	641.47	441.64	292.48	218.86	145.67
5.500	923.42	697.34	481.01	318.60	238.42	158.69
6.000	995.25	752.50	519.98	344.45	257.77	171.58
6.500	1066.14	807.01	558.57	370.05	276.94	184.34
7.000	1136.17	860.93	596.81	395.43	295.94	196.99
7.500	1205.40	914.30	634.72	420.59	314.78	209.54
8.000	1273.88	967.15	672.34	445.55	333.47	221.98
8.500	1341.67	1019.52	709.67	470.32	352.02	234.34
9.000	1408.80	1071.44	746.74	494.92	370.44	246.61
9.500	1475.32	1122.92	783,55	519.36	388.74	258.79
10.000	1541.25	1174.01	820.13	543.64	406.92	270.90
10.500	1606.63	1224.71	856.48	567.77	424.99	282.94
11.000	1671.48	1275.04	892.62	591.76	442.96	294.90
11.500	1735.83	1325.02	928.55	615.61	460.82	306.80
12.000	1799.70	1374.67	964.29	639.34	478.59	318.63
12.500	1863.11	1424.00	999.84	662.94	496.27	330.41
13.000	1926.08	1473.02	1035.20	686.43	513.86	342.12
13.500	1988.62	1521.75	1070.40	709.79	531.36	353.78
14.000	2050.76	1570.20	1105.42	733.05	548.78	365.38
14.500	2112.50	1618.37	1140.29	756.21	566.12	376.93
15.000	2173.87	1666.28	1175.00	779.26	583.39	388.43

RURAL HORIZONTAL DISPERSION COEFFICIENTS (METERS)

DOWNWIND	STABILITY					
DIST (KM)	A	B	C	D	E	F
15.500	2234.87	1713.93	1209.56	802.21	600.58	399.88
16.000	2295.52	1761.33	1243.98	825.06	617.70	411.28
16.500	2355.82	1808.50	1278.25	847.83	634.75	422.64
17.000	2415.80	1855.44	1312.39	870.50	651.73	433.95
17.500	2475.45	1902.15	1346.40	893.09	668.65	445.22
18.000	2534.78	1948.64	1380.27	915.59	685.50	456.44
18.500	2593.82	1994.92	1414.03	938.01	702.29	467.63
19.000	2652.56	2041.00	1447.66	960.35	719.03	478.77
19.500	2711.01	2086.87	1481.17	982.61	735.70	489.88
20.000	2769.18	2132.55	1514.57	1004.79	752.32	500.95
21.000	2884.72	2223.34	1581.03	1048.94	785.39	522.98
22.000	2999.22	2313.41	1647.06	1092.81	818.25	544.86
23.000	3112.73	2402.78	1712.68	1136.41	850.91	566.62
24.000	3225.29	2491.49	1777.91	1179.75	883.38	588.25
25.000	3336.95	2579.57	1842.77	1222.84	915.66	609.75
26.000	3447.74	2667.04	1907.27	1265.70	947.77	631.14
27.000	3557.70	2753.93	1971.43	1308.33	979.70	652.41
28.000	3666.85	2840.25	2035.24	1350.73	1011.47	673.57
29.000	3775.23	2926.03	2098.75	1392.93	1043.08	694.63
30.000	3882.87	3011.29	2161.94	1434.92	1074.54	715.59
31.000	3989.78	3096.04	2224.83	1476.72	1105.85	736.45
32.000	4096.00	3180.30	2287.43	1518.32	1137.02	757.21
33.000	4201.54	3264.09	2349.75	1559.74	1168.05	777.88
34.000	4306.43	3347.42	2411.80	1600.98	1198.95	798.46
35.000	4410.68	3430.31	2473.59	1642.05	1229.72	818.96
36.000	4514.32	3512.76	2535.12	1682.94	1260.36	839.37
37.000	4617.36	3594.79	2596.40	1723.67	1290.87	859.70
38.000	4719.82	3676.41	2657.44	1764.25	1321.27	879.95
39.000	4821.72	3757.64	2718.24	1804.66	1351.55	900.12
40.000	4923.06	3838.48	2778.81	1844.93	1381.72	920.22
41.000	5023.86	3918.94	2839.16	1885.04	1411.78	940.25
42.000	5124.14	3999.03	2899.29	1925.01	1441.73	960.20
43.000	5223.91	4078.76	2959.21	1964.84	1471.57	980.08
44.000	5323.18	4158.14	3018.92	2004.54	1501.31	999.89
45.000	5421.97	4237.17	3078.43	2044.10	1530.95	1019.64
46.000	5520.27	4315.87	3137.73	2083.52	1560.49	1039.32
47.000	5618.11	4394.25	3196.84	2122.82	1589.94	1058.94
48.000	5715.49	4472.30	3255.77	2162.00	1619.29	1078.49
49.000	5812.43	4550.04	3314.50	2201.05	1648.55	1097.99
50.000	5908.94	4627.46	3373.05	2239.97	1677.72	1117.42

Estimating Concentrations Downwind from an Instantaneous Puff Release

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Research Triangle Park, NC

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ESTIMATING CONCENTRATIONS DOWNWIND FROM AN INSTANTANEOUS PUFF RELEASE

by

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This document provides an approach to estimating concentrations downwind of an instantaneous puff release. Dispersion of the puff is described by the Gaussian puff equation, using the dispersion parameters presented in Meteorology and Atomic Energy. The primary purpose of this work is to provide estimates of the instantaneous peak concentration or average concentration through the use of simple equations and nomograms. Example problems are provided to demonstrate the use of the equations and nomograms. A computerized Gaussian puff model is also presented.

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SECTION 1
INTRODUCTION

This document is provided in response to the need for making dispersion estimates of accidental releases of hazardous chemicals. Every year there are news stories of industrial or transportation related spills requiring the evacuation of nearby residents. The main objective of this work is to provide the air pollution specialist a methodology for estimating peak concentrations downwind of an instantaneous release.

The model estimates are appropriate for travel times where the atmosphere can be assumed to be steady state. A number of factors affect the length of time the atmosphere will remain approximately steady: season of the year, latitude, synoptic conditions and local meteorology such as sea breeze and terrain flows. During periods of transition (such as sunrise or sunset) stability, mixing height, wind profile, wind speed and wind direction are likely to change and therefore particular care should be exercised in characterizing the atmosphere during these time periods. Persistence of atmospheric stability is discussed by Budney (1977). For situations where the travel time of the puff is greater than an hour, the factors which affect the dispersion and trajectory of the puff should be incorporated in the concentration estimates.

The Gaussian instantaneous puff model is applicable for neutrally buoyant non-reactive releases. The dispersion of a small negatively buoyant release can be modeled using the puff equation provided the material mixes rapidly with the ambient air and disperses like a neutrally buoyant source.

The equations, nomograms and methodology described in this document were not designed for the fireman at the site of an accidental spill. He will not have the time nor the technical background to properly use the equations

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and nomcgrams. The factors affecting his decision to order an evacuation will primarily be based on the size of the spill, the nature and toxicity of the substance. However, material provided in this document would be valuable to the air pollution specialist who is providing assistance to the fire department for the establishment of procedures to determine toxic corridors. The dispersion algorithms described would provide the basis for a model catered to the specific needs of the user. The computer algorithm described in Section 4 could also be adapted for on site use at a chemical plant using real time meteorology to predict downwind concentrations.

The document is composed of three major sections. The first few pages of Section 2 describe a technique for estimating peak concentrations of instantaneous puff releases as a function of atmospheric stability and downwind distance. This discussion was designed so that estimates of peak concentration could be provided to the agencies which are directly concerned with the immediate health and welfare of the public within a matter of minutes after an accidental spill. These initial estimates could be provided without the aid of a computer. The remainder of Section 2 is concerned with estimating average concentrations and exposure. Section 3 provides a discussion of a generalized Gaussian puff equation with the same assumptions and limitations of the approach described in Section 2. The equations in Section 3 are the basis for a computer model described in Section 4.

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SECTION 2

CONCENTRATION ESTIMATES

INSTANTANEOUS PEAK CONCENTRATIONS

The peak ground level concentration from an instantaneous surface release is given by Equation 1.

$$x_p = \frac{2Q}{(2\pi)^{3/2}\ \sigma_x \sigma_y \sigma_z} \qquad (1)$$

Where: Q is the total emission (g),
σ_x is the downwind dispersion parameter (m),
σ_y is the crosswind dispersion parameter (m),
σ_z is the vertical dispersion parameter (m).

Typically it is assumed that $\sigma_x = \sigma_y$ for puff-type dispersion estimates. Nickola (1971) showed that, for ground level releases, σ_x is greater than σ_y in the first few hundred meters of travel, but the puffs become more symmetrical as travel distances approach 800 meters. For the purposes of this work σ_x and σ_y are assumed to be equal, and the dispersion in the xy plane will be indicated by σ_r. Equation 1 can then be expressed as:

$$x_p = \frac{2Q}{(2\pi)^{3/2}\ \sigma_r^2\ \sigma_z} \qquad (2)$$

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Figure 1 shows peak ground level concentrations normalized by emission strength, x_p/Q, versus downwind distance for three stability regimes unstable, neutral, and very stable. The stability regimes can be determined from cloud cover, ceiling height and wind speed, using Turner's stability classification scheme (1970). In the absence of meteorological data at the site of release or from a nearby weather station, the stability regimes can be approximated as follows. On a clear, sunny day with light winds, use the unstable curves. During windy or cloudy conditions, use the neutral curves. On a clear night with calm or light winds, use the very stable curves. The dispersion coefficients for the three stability classes are those recommended by Slade (1968). Figure 1 was derived using Equation 2 with the dispersion coefficients mentioned above. Equation 2 is applicable only for surface releases. Solid lines on the curve represent distances of observed data. Dashed lines are extrapolations.

Example Problem 2-1

A 1000 kg instantaneous release of chlorine occurs during neutral stability conditions with a mean wind speed of 3 m/sec. What is the peak concentration 5 km downwind?

Step 1. Use Figure 1 to determine x_p/Q at 5 km downwind on the neutral stability curve.

$x_p/Q = 9.5 \times 10^{-8}$ Note: x_p/Q is independent of u.

Step 2. Compute $x_p = x_p/Q \times Q$

$x_p = (9.5 \times 10^{-8}) \times (1.0 \times 10^{6}) = 9.5 \times 10^{-2}$ g/m^3

If the atmosphere was actually very stable rather than neutral, to what downwind distance would the peak concentration be greater than that computed in Step 2?

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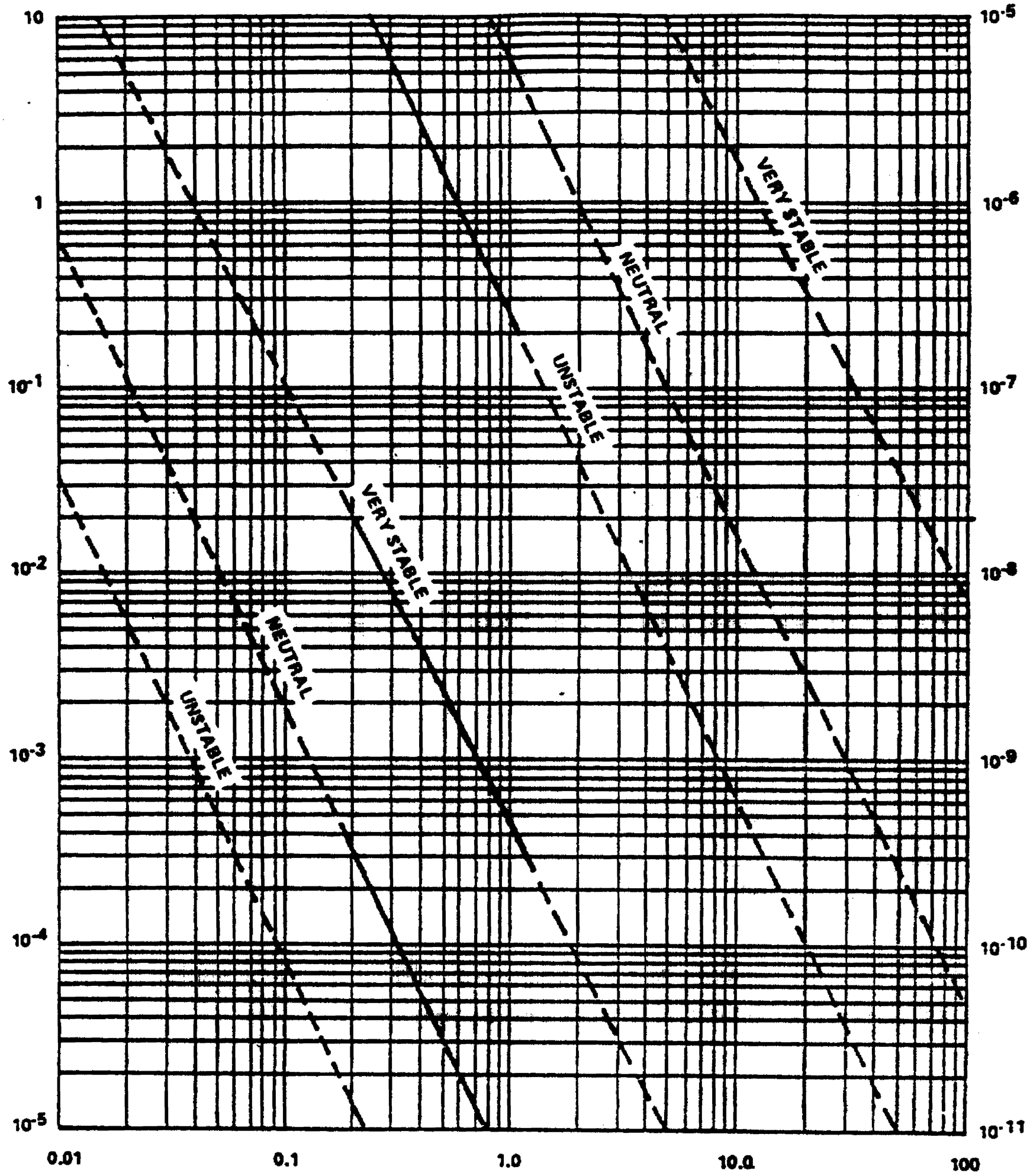

FIGURE 1. χ_p/Q VERSUS DOWNWIND DISTANCE. THE LEFT HAND SCALE IS FOR χ_p/Q VALUES OF 10^{-5} TO 10. THE RIGHT HAND SCALE IS FOR χ_p/Q VALUES OF 10^{-11} TO 10^{-5}.

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Step 1. Find χ/Q (9.5×10^{-8}) on Figure 1, on the very stable curve.

Step 2. Read down to the distance scale.

x = 32 km.

CONVERSION OF CONCENTRATION UNITS

The equation of state can be used for conversion of concentrations from $\mu g/m^3$ to ppm.

$$x(ppm) = \frac{x(\mu g/m^3) \times T(K) \times R}{M \times P(mb)}$$

where: T is the absolute temperature (K),

M is the gram molecular weight (gm-mole),

P is the atmospheric pressure (mb),

R is the universal gas constant 8.31×10^{-2} $\frac{mb\ m^3}{gm\text{-}mole\ K}$.

The equation to convert ppm to ug/m^3 is given below.

$$x(\mu g/m^3) = \frac{x(ppm) \times M \times P(mb)}{T(K) \times 8.31 \times 10^{-2}}$$

In the example above the ambient temperature was 80°F and the atmospheric pressure was 980 mb. Find the concentration in ppm.

$$T(^oC) = 5/9(T(^oF)-32)$$

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The absolute temperature is 299.7 (K). The molecular weight of chlorine (CL_2) is 70.91.

$$\chi_{(ppm)} = \frac{95000(\mu g/m^3) \times 299.7(K) \times 8.31\times10^{-2}}{70.91 \times 980(mb)} = 34 \text{ (ppm)}$$

The peak concentration 5 km downwind is 0.095 g/m^3 or 34 ppm.

AVERAGE CONCENTRATIONS

In the paragraphs that follow a methodology is described for computing ground level concentrations from an instantaneous surface release for a given stability class and sampling time. The average concentration over sampling time τ can be expressed as some fraction of the peak concentration.

$$\bar{\chi}_\tau = \chi_p \times F, \qquad (3)$$

where: χ_τ is the average concentration for a given sampling time τ,
τ is the sampling time, i.e. 5 min., 1-hour etc.,(expressed in seconds)
χ_p is the instantaneous peak concentration,
F is the correction factor for sampling time, which always has a value less than or equal to one.

The correction factor F can be computed as follows:

$$F = \frac{(A-0.5)}{(N)\ 0.3989}, \qquad (4)$$

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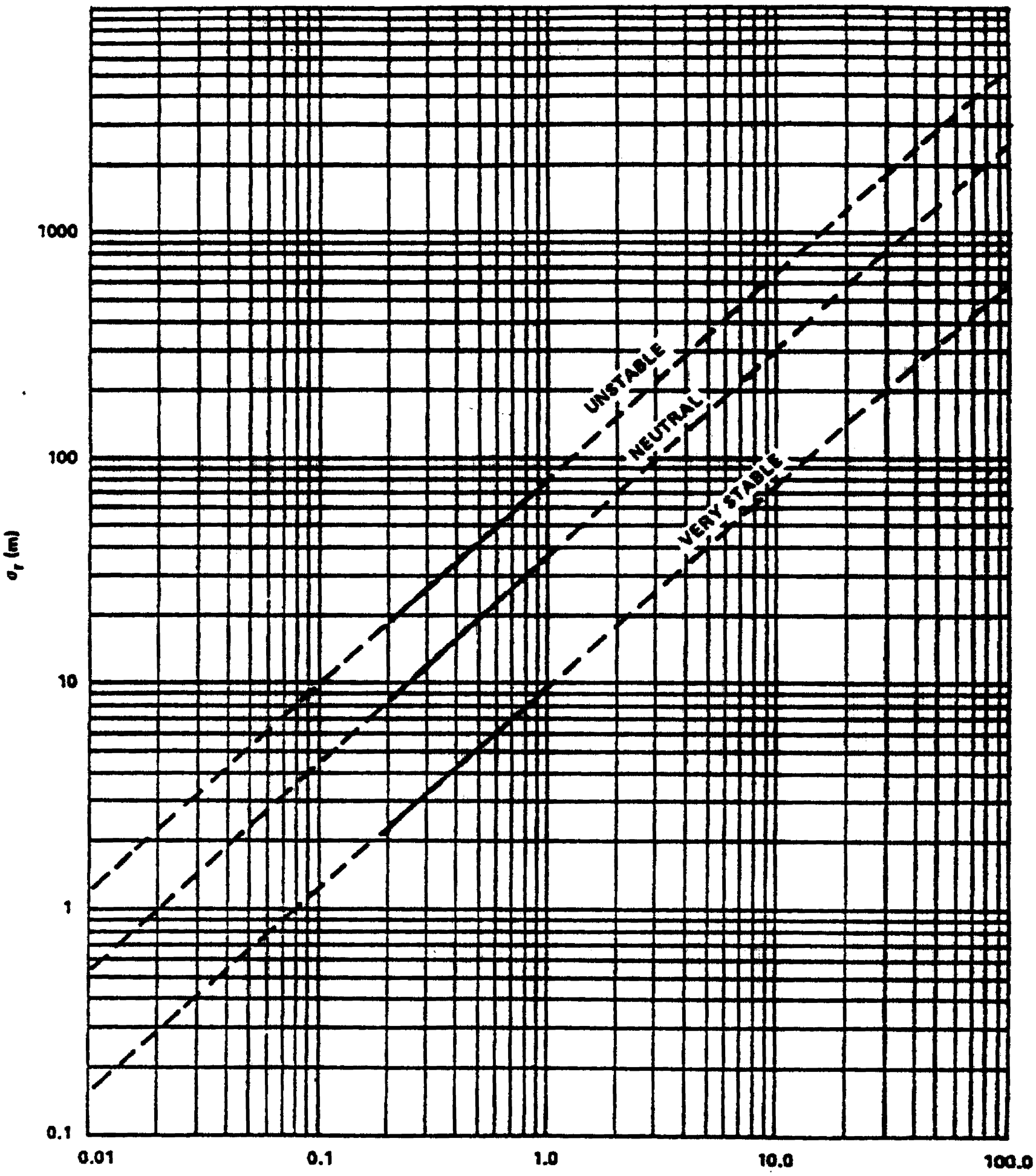

FIGURE 2. σ_r VERSUS DOWNWIND DISTANCE

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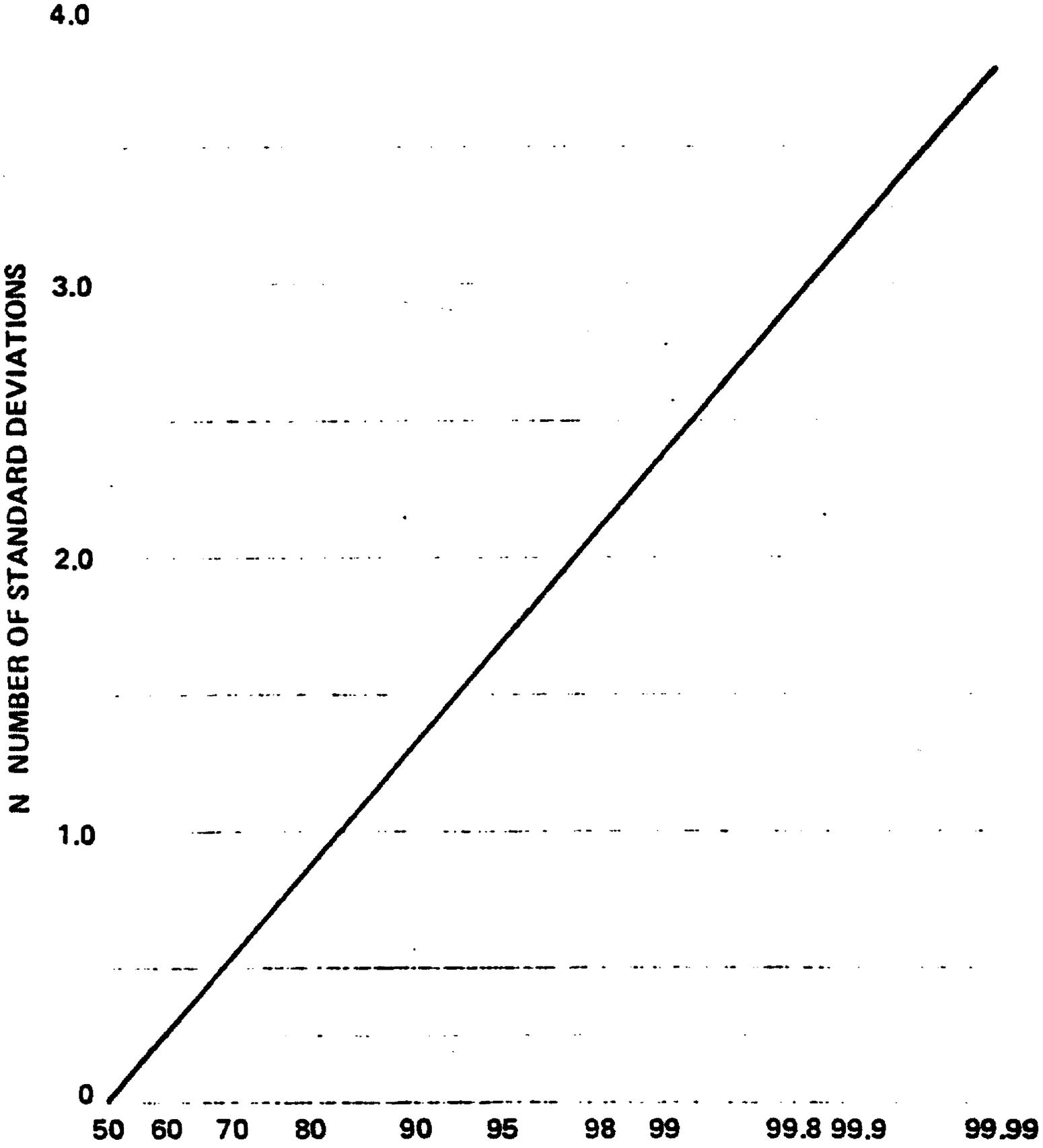

Figure 3. Percent area under normal curve for a given number of standard deviations.

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where: A is the cumulative area under the normal curve (Figure 3),

N is the number of standard deviations out from the peak of the Gaussian distribution.

$$N = \frac{\tau u}{2\sigma_r},$$

u is the mean wind speed,

σ_r is the horizontal dispersion coefficient (Figure 2).

The concentration at a given receptor location ranges from zero to a peak value as the puff moves towards the receptor. The peak instantaneoous concentration is always assumed to occur at time t when the center of the puff is at the receptor location. If the growth of the puff is small as the puff passes over the receptor, then the peak average concentration for sampling time τ at a particular location occurs during the time period $t - \tau/2$ to $t + \tau/2$.

Example Problem 2-2

For the conditions given in Example problem 2-1, find the peak 5 minute average concentration and the peak 1-hour average concentration at 5 km downwind.

Step 1. Compute the instantaneous peak concentration χ_p.

From problem 2-1, $\chi_p = 9.5 \times 10^{-2}$ g/m^3.

Step 2. Compute A.

(a) Determine the number of standard deviations.

$$N = \frac{\tau u}{2\sigma_r} = \frac{300(3)}{(2)(150)} = 3.0$$

σ_r is approximately 150 meters, determined from Figure 2 at 5 km downwind.

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(b) Given a value of N = 3.0 determine A from Figure 3.

A = 0.998

Step 3. Compute χ_τ.

Substitute A into Equation 4.

$$F = \frac{(0.998-0.5)}{(3.0)\ 0.3989} = 0.42$$

Substitute F into Equation 3 to determine peak 5 minute average concentration.

$$\bar{\chi}_\tau = 0.42 \times 9.5\times10^{-2} = 4.0\times10^{-2}\ g/m^3.$$

In a manner analogous to the above, the peak 1-hour average concentration can be computed.

$$N = \frac{3600\ (3)}{2\ \sigma_r} = 36.$$

From Figure 3, A = 1.

$$F = \frac{(1.-0.5)}{(36)\ \ 0.3989} = 0.035$$

Substitute F into Equation 3 to find the peak 1-hour average concentration.

$$\bar{\chi}_\tau = 0.035 \times 9.5\times10^{-2} = 3.3\times10^{-3}\ g/m^3.$$

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The total dosage, D, at a given downwind distance, stability class, and wind speed can be approximated using the following equation.

$$D \cong \chi_p \times \frac{2.5\ \sigma_r}{u} \text{ (matter-time/volume)} \qquad (5)$$

σ_r is determined for the given stability class and downwind distance.

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SECTION 3

INSTANTANEOUS PUFF MODEL

The preceding section presented an approach to estimating peak ground level concentrations from instantaneous releases for a given sampling time. No mention was made of the basic assumptions inherent in the approach. Neither was there any discussion of the approach to computing concentrations out from the puff center for ground level releases or elevated releases. These topics were intentionally omitted from Section 2 for the sake of clarity and brevity. Also, it is likely that the peak concentration estimates for ground level releases are the most critical estimates in an emergency situation.

This section will present a more generalized Gaussian puff model, allowing for factors such as mixing height, cross wind concentration estimates, and elevated releases. A computerized puff model is presented in Section 4 and an example output of the model presented in Appendix A. An example problem is also presented to demonstrate the use of the model.

PUFF EQUATIONS

The generalized puff equation is given as:

$$\chi(x, y, z, h) = \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-1/2\left(\frac{x-ut}{\sigma_x}\right)^2\right] \exp\left[-1/2\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-1/2\left(\frac{z+h}{\sigma_z}\right)^2\right] + \exp\left[-1/2\left(\frac{z-h}{\sigma_z}\right)^2\right]\right\}$$

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Following the puff, and assuming $\sigma_x = \sigma_y$, the puff equation can be written as follows:

$$\chi_{(r,z,h)} = \frac{Q}{(2\pi)^{3/2}\,\sigma_r^2\,\sigma_z}\ \exp\left[-1/2\left(\frac{r}{\sigma_r}\right)^2\right]\left\{\exp\left[-1/2\left(\frac{z+h}{\sigma_z}\right)^2\right] + \exp\left[-1/2\left(\frac{z-h}{\sigma_z}\right)^2\right]\right\} \quad (6)$$

Equation 2 is a simplification of Equation 6 for estimating peak ground level concentrations from surface releases. The peak concentration at distances beyond the point where σ_z is greater than 0.8L (mixing height) can be expressed as:

$$\chi(x,0,0,0) = \frac{Q}{2\pi\sigma_r^2\,L} \qquad \text{for } \sigma_z > 0.8L \quad (7)$$

The concentration at the ground from an elevated release at a radial distance r from the puff center is given by Equation 8.

$$\chi_{(x,r,o,h)} = \frac{Q}{2\pi\,\sigma_r^2\,L}\ \exp\left[-1/2\left(\frac{r}{\sigma_r}\right)^2\right] \qquad \text{for } \sigma_z > 0.8L \quad (8)$$

Equations 7 and 8 account for reflection from the top of the mixed depth layer and are appropriate for surface level releases during netural and unstable conditons. However, if the effective release height is small compared to the mixing height, Equations 7 and 8 are still good approximations.

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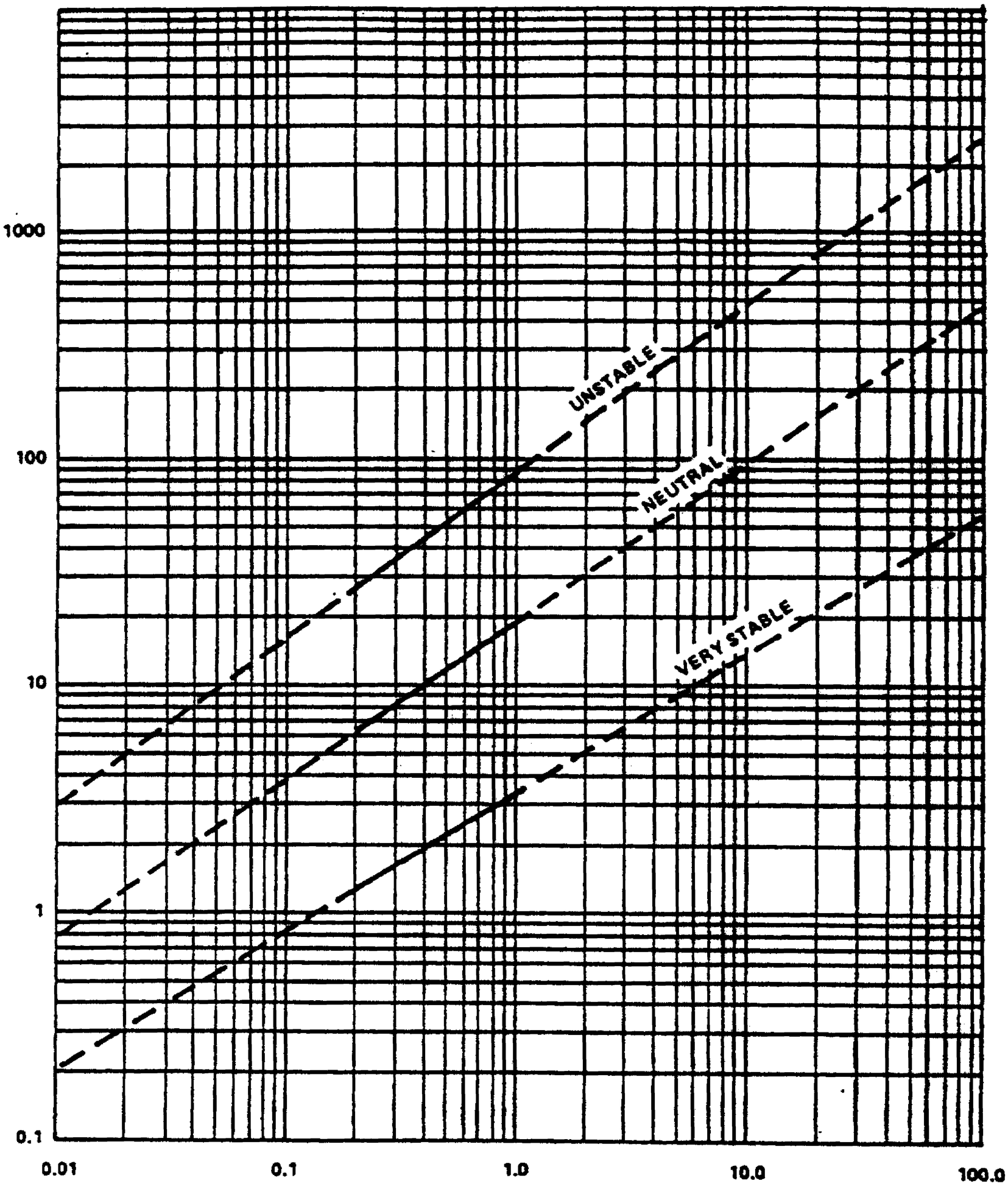

FIGURE 4. σ_z VERSUS DOWNWIND DISTANCE

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Frequently, instantaneous releases are large enough in the horizontal and vertical dimensions that the initial size cannot be ignored in the concentration estimates. One approach to assessing the impact of the initial size on downwind concentrations is to introduce an initial horizontal dispersion parameter, σ_{r_o}, and an initial vertical dispersion parameter, σ_{z_o}. σ_{r_o} can be approximated by dividing the total initial width (W) of the puff by 4.3, $\sigma_{r_o} = W/4.3$. σ_{z_o} can be approximated by dividing the initial vertical extent of the puff (h) by 2.15, $\sigma_{z_o} = h/2.15$. The total horizontal and vertical dispersion parameters are then given by:

$$\sigma_{r_t} = (\sigma_r^2 + \sigma_{r_o}^2)^{1/2}, \qquad (9)$$

$$\sigma_{z_t} = (\sigma_z^2 + \sigma^2_{z_o})^{1/2}. \qquad (10)$$

σ_r and σ_z are obtained from Figures 2 and 4 for the specified stability and downwind distance.

Example Problem 3-1

A nuclear power reactor has a sudden radioactive release of 1.5×10^4 curies at 2 in the afternoon. The reactor building is hemispherically shaped with a radius of 20 meters. The existing meteorological conditions are unstable with a 1500 m mixing height and a 3 m/sec wind. From the weather forecast, it is anticipated that the puff will pass over or near a receptor 10 km downwind.

(A) What is the peak concentration 10 km downwind?

If the puff release is about the same size as the reactor building then $\sigma_{z_o} = 20/2.15 = 9.3$ m, and $\sigma_{y_o} = 40/4.3 = 9.3$ m. From Figures 2 and 4, σ_r and σ_z are 670 m and 440 m, respectively. Using Equations 9 and 10, $\sigma_{r_t} = 670.1$ and $\sigma_{z_t} = 440.1$. Since 440.1 is less than 0.8 times the mixing height, χ_p can be determined from Equation 2, or Figure 1.

$$\chi_p = 9.6 \times 10^{-6} \text{ curies/m}^3.$$

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(B) At 10 km downwind, what is the radial dimension of the puff where the concentration drops to 0.1 χ_p? What area does the puff cover?

For a surface concentration estimate, Equation 6 reduces to

$$\chi = \frac{Q}{(2\pi)^{3/2}\,\sigma_r^2\,\sigma_z}\ \exp\left[-1/2\left(\frac{r}{\sigma_r}\right)^2\right] \quad \text{or} \quad \chi = \chi_p\ \exp\left[-1/2\left(\frac{r}{\sigma_r}\right)^2\right]$$

$$\text{If } \chi/\chi_p = 0.1 \text{ then } 0.1 = \exp\left[-1/2\left(\frac{r}{\sigma_r}\right)^2\right]$$

The expression above can now be solved for r. σ_r at 10 km dowwind is 670 m.

$$r = \sigma_r \times 2.15 = 1440.5 \text{ m.}$$

The radial dimension of the puff 10 km downwind is ~ 1440 m.

The area covered by the puff at this distance is = πr^2 = 6.5 km^2.

(C) What is the total dosage 10 km downwind, where the puff center passes?

Using the unstable curve 10 km downwind on Figure 2, $\sigma_r \cong 670$ m. Equation 5 can be used to compute the total dosage.

$$D = 9.6\times10^{-6} \times 2.5 \times \underline{670} \cong 5.4\times10^{-3} \text{ curie-sec/m}^3.$$

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(D) If the puff center passes 1 km from a receptor, what is the estimated dosage at the receptor?

For off-center computations of dosages, a more generalized form of the dosage equation can be used.

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$$D = \frac{Q}{\pi \sigma_r \sigma_z u} \exp\left[-\left(\frac{r^2}{2\sigma_r^2} + \frac{h^2}{2\sigma_z^2}\right)\right]$$

$$D = \frac{1.5 \times 10^4}{3.1415\ (670)\ (440)\ 3} \exp\left[-\frac{1}{2}\left(\frac{1000}{670}\right)^2\right]$$

$$D = 1.8 \times 10^{-3} \text{ curie-sec/m}^3.$$

STABILITY PARAMETERS

As mentioned before, the stability parameters used in the instantaneous puff model are those recommended in Meteorology and Atomic Energy (1968). Slade classified the data according to the broad categories of unstable, neutral, and very stable. A review of the data reveals two pertinent points: (1) There was very little data upon which to base the σ_z's during unstable conditions. (2) Much of the dispersion data during stable conditions lie closer to the Pasquill-Gifford F curve than to the curve recommended by Slade.

A plot of σ_z versus downwind distance is shown in Figure 4. The figure was not presented in Section 2 because it was not directly needed for the analysis presented. The vertical dispersion parameters are embodied in the χ/Q values in Figure 1. Figure 1 could, of course, be developed for any set of dispersion parameters appropriate for a given release. Appendix C lists the changes that would be required to change the dispersion parameters in the code of the puff model.

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MODEL APPLICABILITY

Estimating concentrations at point locations are very difficult because of the deficiencies in determining the trajectory of the puff. Puff trajectory is most important if concentration estimates are to be made at specific points. However, the modeling effort is significantly simplified if the magnitudes of the concentrations are needed without regard to exactly where the concentrations will occur. Releases are seldom point sources, but are more typically small area sources. Small area source releases can be modeled to some extent by using initial dispersion parameters. The initial horizontal dispersion is typically calculated by dividing the initial horizontal dimension of the area source by 4.3. This method will give reasonable concentration estimates at downwind distances greater than about 5 times the horizontal dimension of the source. As with the lateral dispersion, the initial vertical dispersion parameter is typically evaluated by dividing the initial vertical extent of the surface release by 2.15.

No model description would be complete without some guidance concerning areas of applicability. Many sources are not truly instantaneous. However, if the travel time is long compared to the release time then the puff model can be used to estimate concentrations. If the travel time to a receptor is on the same order or smaller than the release time, the Gaussian plume model can be used (see Turner, (1970). For the case where the release time is finite but smaller than the travel time, the instantaneous puff model will provide a worst-case estimate of peak concentrations for the same total release. It is difficult to evaluate the effect on average concentrations over a given sampling time for a finite release using simple models, since the puff is distorted in the downwind direction. Finally, I would like to reiterate that the modeling procedures outlined in the document are simple approaches to very complex problems. In general these techniques will yield worst case concentration estimates. The proper modeling of any sudden release requires the skills of an air quality specialist and a thorough understanding of the physical and chemical properties of the release.

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SECTION 4
COMPUTER ALGORITHM

The FORTRAN computer program consists of a main program and three subroutines. Figure 5 depicts the general flow of the model. The main program reads all input data and produces all output. The dispersion equations given in Sections 2 and 3 are solved in the main routine as well. Subroutine DBTMX computes the distance to maximum concentration for an elevated release. Subroutine PUFSIG is called by the main program for sigma y and z values. Subroutine AVCOR computes the area under the normal curve used in the computation of average concentration estimates.

INPUT DATA

The main routine reads control information to determine output modes and a control to read new data or modify previous data. A source data card is then required giving information on source characteristics. A meteorology card is then required followed by cards specifying locations where concentration estimates are to be made. A description of each input card type is provided in Table 1. The last card of the data set (card type 6) is used only if IOUT3 on card type 2 is equal to 1. This sequence of input data cards is shown in Figure 6. All input data are in free format which is easy to use but care should be exercised to make sure each variable is given a value in the correct order. Each variable must be separated by a comma. A brief description of each input parameter is given in Table 1 with appropriate units. The metric system of units is used throughout the puff model.

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TABLE 1. DESCRIPTION OF INPUT DATA

Card type 1	KTL	
KTL	Input data control KTL=1 New problem, read all input data KTL=2 Change options only, use previous data KTL=3 Change options and source data KTL=4 Change options and meteorological data KTL=5 Change options and locations of concentration estimates KTL=6 Change options and meteorological data, and locations of concentration estimates KTL>100 STOP	
Card type 2	IOUT1,IOUT2,IOUT3	
IOUT1	If IOUT1=1 a table of peak concentrations for different stability classes, sampling times and downwind distances is printed out	
IOUT2	If IOUT2=1 concentration estimates are printed for the given input data only	
IOUT3	If IOUT3=1 A critical concentration must be input. The program will compute distance to critical concentration	
Card type 3	Q,H,SYOP,SZOP	
Q	Source strength	(g)
H	Effective source height	(m)
SYOP	Initial σ_r	(m)
SZOP	Initial σ_z	(m)
Card type 4	u,HL,AVT,KST	
u	Wind speed	(m/sec)
HL	mixing height	(m)
AVT	Sampling time for concentration estimates	(sec)
KST	Stability class 1-3	
Card type 5	NREC,XR,RR,ZR	

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TABLE 1 (Continued)

NREC	Number of locations for which concentration estimates are to be made	
XR	Distance downwind from release point	(km)
RR	Radial distance from puff center	(m)
ZR	Height above ground	(m)
Card type 6	XCHI	
XCHI	If IOUT3=1 read XCHI, critical concentration	(g/m^3)

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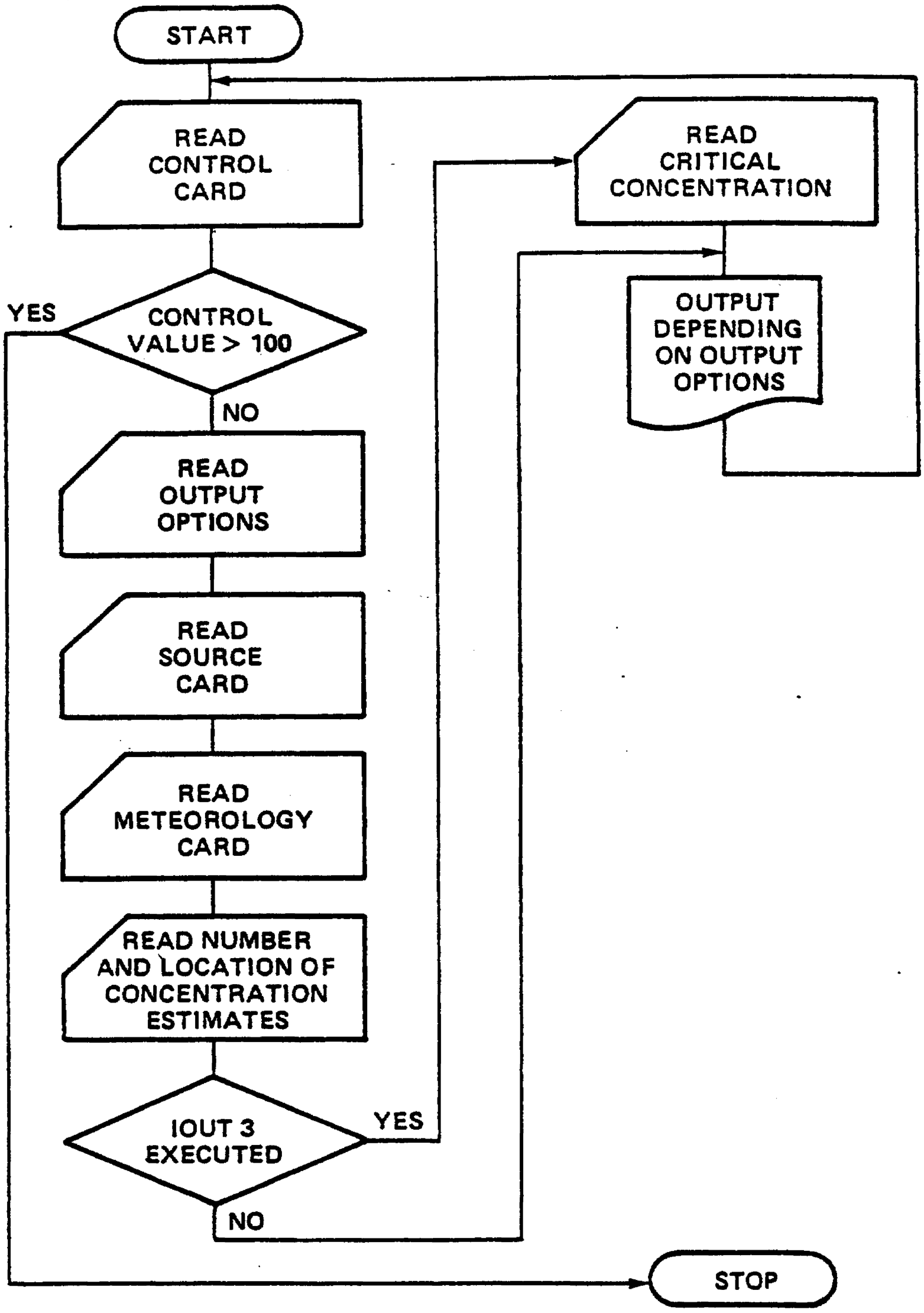

Figure 5. General flow diagram for instantaneous puff model.

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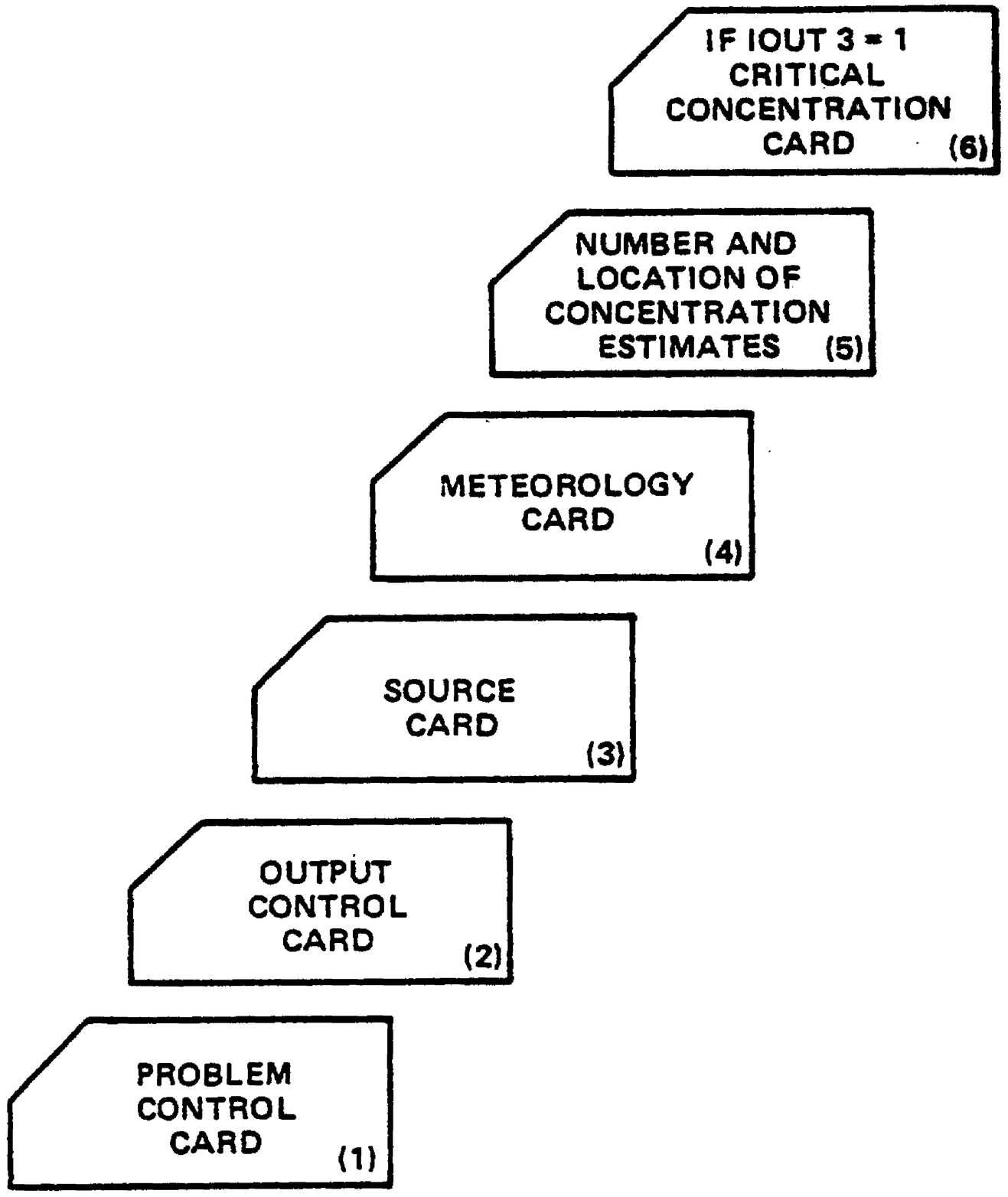

Figure 6. Input data deck for instantaneous puff model.
Card type numbers are in parenthesis.

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APPENDIX A
EXECUTION OF INSTANTANEOUS PUFF MODEL

An example problem is provided to demonstrate the use of the instantaneous puff model. Example problems 2-1 and 2-2 are used as input into the model. Also, a puff is modeled whose effective height of release is 50 m. Table A-1 shows the input data cards for these examples. The numbers in the left hand column of the table are the card type numbers. For a description of each card type see Table 1.

Table A-2 presents the output of the model for these examples. The first ten pages of Table A-2 are a result of exercising option 1 on card type 2. This part of the output lists peak concentrations for a variety of mixing heights, stabilities, wind speeds, sampling times, and downwind distances. While these listings are helpful in assessing the impact of a puff release, they are optional and can be deleted from the output by assigning a value other than 1 to IOUT1 on card type 2. The first part of the output for all of the options is a listing of the input data.

Most of the input data and the output of the instantaneous puff model is straightforward. However, a brief discussion on a few points about the model should be profitable. The variable AVT (sampling time) on card type 4 must be assigned a value greater than zero. For peak concentration estimates, a value of 1-second for AVT is a sufficiently short time to give a good estimate of the peak. If option 3 (IOUT3) on card type 2 is utilized, the model will predict the distance to the critical concentration specified on card type 6. When using option 3 for an elevated release, the model will also give the maximum concentration and the distance to the maximum concentration. You have probably already asked yourself the question for an elevated release, which distance does the distance to critical concentration refer to, since the

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critical concentration can occur at two distinct downwind distances? The distance to critical concentration is always greater than or equal to the distance to maximum concentration, thus assuring that the critical concentration will not be predicted beyond the estimated distance to critical concentration.

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TABLE A-1. INPUT DATA FOR EXAMPLE PROBLEMS

CARD TYPE	
1	1
2	1,1,0
3	1000000.,0.,0.,0.
4	3.,1500.,1.,2
5	1,5.,0.,0.
1	4
2	0,1,0
4	3.,1500.,300.,2
1	4
2	0,1,0
4	3.,1500.,3600.,2
1	1
2	0,1,1
3	1000000.,50.,0.,0.
4	3.,1500.,300.,2
5	3,1.,0.,0.,3.,0.,0.,5.,0.,0.
6	0.0001
1	999

↑

Add comma per p21 f22

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TABLE A-2 COMPUTER MODEL OUTPUT

OPTION 1 YES
OPTION 2 YES
OPTION 3 NO

SOURCE INFORMATION

SOURCE STRENGTH (Q)	1000000.0
SOURCE HEIGHT (M)	.0
INITIAL SIGMA R (M)	.0
INITIAL SIGMA Z (M)	.0

METEOROLOGICAL DATA

WIND SPEED (M/SEC)	3.0
MIXING HEIGHT (M)	1500.0
SAMPLING TIME (SEC)	1.0
STABILITY CLASS	2

RECEPTOR DATA

LOCATION NUMBER	DOWNWIND DISTANCE (KM)	RADIAL DISTANCE (M)	HEIGHT ABOVE GROUND (M)
1	5.000	.00	.00

MIXING HEIGHT (M) 500.

STAB. CLAS	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
1	3.290+04	1.954+03	5.259+02	2.215+02	8.856+01	1.415+00	2.384-01	1.416-02	3.810-03	1.604-03	7.089-04	9.391-05
2	6.782+05	4.164+04	1.138+04	4.840+03	1.956+03	3.281+01	5.641+00	3.463-01	9.462-02	4.025-02	1.627-02	9.988-04
3	2.587+07	1.872+06	5.523+05	2.471+05	1.054+05	2.250+03	4.293+02	3.107+01	9.166+00	4.102+00	1.749+00	1.266-01

MIXING HEIGHT (M) 1000.

STAB. CLAS	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0

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TABLE A-2 (Continued)

1	3.290+04	1.954+03	5.259+02	2.215+02	8.856+01	1.415+00	2.384-01	1.416-02	3.810-03	1.604-03	6.415-04	4.695-05
2	6.782+05	4.164+04	1.138+04	4.840+03	1.956+03	3.281+01	5.641+00	3.463-01	9.462-02	4.025-02	1.627-02	9.988-04
3	2.587+07	1.872+06	5.523+05	2.471+05	1.054+05	2.250+03	4.293+02	3.187+01	9.166+00	4.102+00	1.749+00	1.266-01

MIXING HEIGHT (M) 2000.

STAB. CLAS	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
1	3.290+04	1.954+03	5.259+02	2.215+02	8.856+01	1.415+00	2.384-01	1.416-02	3.810-03	1.604-03	6.415-04	3.811-05
2	6.782+05	4.164+04	1.138+04	4.840+03	1.956+03	3.281+01	5.641+00	3.463-01	9.462-02	4.025-02	1.627-02	9.988-04
3	2.587+07	1.872+06	5.523+05	2.471+05	1.054+05	2.250+03	4.293+02	3.187+01	9.166+00	4.102+00	1.749+00	1.266-01

MIXING HEIGHT (M) 4000.

STAB. CLAS	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
1	3.290+04	1.954+03	5.259+02	2.215+02	8.856+01	1.415+00	2.384-01	1.416-02	3.810-03	1.604-03	6.415-04	3.811-05
2	6.782+05	4.164+04	1.138+04	4.840+03	1.956+03	3.281+01	5.641+00	3.463-01	9.462-02	4.025-02	1.627-02	9.988-04
3	2.587+07	1.872+06	5.523+05	2.471+05	1.054+05	2.250+03	4.293+02	3.187+01	9.166+00	4.102+00	1.749+00	1.266-01

MIXING HEIGHT (M) 500.
STABILITY CLASS 1
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.601+03	2.612+02	1.125+02	6.455+01	3.576+01	1.307+00	2.330-01	1.412-02	3.805-03	1.603-03	7.007-04	9.390-05
300.	3.201+02	5.225+01	2.249+01	1.291+01	7.167+00	5.033-01	1.504-01	1.315-02	3.699-03	1.579-03	7.030-04	9.380-05
900.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	6.590-04	9.296-05
3600.	2.668+01	4.354+00	1.874+00	1.076+00	5.972-01	4.196-02	1.337-02	2.102-03	9.394-04	5.391-04	3.284-04	8.087-05
10800.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	1.103-04	3.999-05

MIXING HEIGHT (M) 500.
STABILITY CLASS 1

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TABLE A-2 (Continued)

WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.335+02	8.708+01	3.749+01	2.152+01	1.194+01	8.102-01	1.968-01	1.378-02	3.769-03	1.595-03	7.068-04	9.387-05
300.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	6.590-04	9.298-05
900.	3.557+01	5.805+00	2.499+00	1.434+00	7.963-01	5.595-02	1.783-02	2.910-03	1.252-03	7.152-04	4.216-04	8.613-05
3600.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	1.103-04	3.999-05
10800.	2.964+00	4.838-01	2.083-01	1.195-01	6.636-02	4.662-03	1.486-03	2.425-04	1.044-04	5.991-05	3.675-05	1.338-05

MIXING HEIGHT (M) 500.
STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	4.713+03	7.951+02	3.475+02	2.015+02	1.131+02	8.337+00	2.687+00	3.007-01	8.936-02	3.902-02	1.601-02	9.966-04
300.	9.427+02	1.590+02	6.951+01	4.030+01	2.261+01	1.667+00	5.425-01	9.150-02	3.988-02	2.250-02	1.149-02	9.472-04
900.	3.142+02	5.300+01	2.317+01	1.343+01	7.538+00	5.558-01	1.808-01	3.050-02	1.333-02	7.730-03	4.338-03	6.679-04
3600.	7.856+01	1.325+01	5.792+00	3.358+00	1.884+00	1.389-01	4.520-02	7.625-03	3.333-03	1.933-03	1.084-03	1.829-04
10800.	2.619+01	4.417+00	1.931+00	1.119+00	6.282-01	4.632-02	1.507-02	2.542-03	1.111-03	6.442-04	3.615-04	6.097-05

MIXING HEIGHT (M) 500.
STABILITY CLASS 2
WIND SPEED (M/SEC) 10.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.414+03	2.385+02	1.043+02	6.045+01	3.392+01	2.501+00	8.137-01	1.370-01	5.711-02	2.967-02	1.374-02	9.752-04
300.	2.828+02	4.770+01	2.085+01	1.209+01	6.784+00	5.002-01	1.627-01	2.745-02	1.200-02	6.957-03	3.904-03	6.208-04
900.	9.427+01	1.590+01	6.951+00	4.030+00	2.261+00	1.667-01	5.425-02	9.150-03	4.000-03	2.319-03	1.301-03	2.195-04
3600.	2.357+01	3.975+00	1.738+00	1.008+00	5.653-01	4.168-02	1.356-02	2.288-03	9.999-04	5.798-04	3.253-04	5.487-05
10800.	7.856+00	1.325+00	5.792-01	3.358-01	1.884-01	1.389-02	4.520-03	7.625-04	3.333-04	1.933-04	1.084-04	1.829-05

MIXING HEIGHT (M) 500.
STABILITY CLASS 3
WIND SPEED (M/SEC) 1.0

SMP.	DOWNWIND DISTANCE (KM)

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TABLE A-2 (Continued)

TIME (SEC)	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.678+05	3.229+04	1.501+04	9.058+03	5.305+03	4.745+02	1.675+02	2.493+01	8.344+00	3.892+00	1.700+00	1.261-01
300.	3.355+04	6.457+03	3.001+03	1.812+03	1.061+03	9.490+01	3.355+01	6.457+00	3.001+00	1.803+00	1.020+00	1.149-01
900.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
3600.	2.796+03	5.381+02	2.501+02	1.510+02	8.842+01	7.908+00	2.796+00	5.381-01	2.501-01	1.510-01	8.842-02	1.702-02
10800.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03

MIXING HEIGHT (M) 500.
STABILITY CLASS 3
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.592+04	1.076+04	5.802+03	3.019+03	1.768+03	1.582+02	5.592+01	1.076+01	4.894+00	2.752+00	1.388+00	1.222-01
300.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
900.	3.728+03	7.175+02	3.335+02	2.013+02	1.179+02	1.054+01	3.728+00	7.175-01	3.335-01	2.013-01	1.179-01	2.269-02
3600.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03
10800.	3.107+02	5.979+01	2.779+01	1.677+01	9.824+00	8.787-01	3.107-01	5.979-02	2.779-02	1.677-02	9.824-03	1.891-03

MIXING HEIGHT (M) 1000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.601+03	2.612+02	1.125+02	6.455+01	3.576+01	1.307+00	2.330-01	1.412-02	3.805-03	1.603-03	6.413-04	4.695-05
300.	3.201+02	5.225+01	2.249+01	1.291+01	7.167+00	5.033-01	1.504-01	1.315-02	3.699-03	1.579-03	6.362-04	4.690-05
900.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	4.649-05
3600.	2.668+01	4.354+00	1.874+00	1.076+00	5.972-01	4.196-02	1.337-02	2.182-03	9.394-04	5.391-04	2.972-04	4.043-05
10800.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	2.000-05

MIXING HEIGHT (M) 1000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0

VAB.0001126666

TABLE A-2 (Continued)

60.	5.335+02	8.708+01	3.749+01	2.152+01	1.194+01	8.102-01	1.968-01	1.378-02	3.769-03	1.595-03	6.396-04	4.693-05
300.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	4.649-05
900.	3.557+01	5.805+00	2.499+00	1.434+00	7.963-01	5.595-02	1.783-02	2.910-03	1.252-03	7.152-04	3.816-04	4.306-05
3600.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	2.000-05
10800.	2.964+00	4.838-01	2.083-01	1.195-01	6.636-02	4.662-03	1.486-03	2.425-04	1.044-04	5.991-05	3.326-05	6.668-06

MIXING HEIGHT (M) 1000.
STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	4.713+03	7.951+02	3.475+02	2.015+02	1.131+02	8.337+00	2.687+00	3.007-01	8.936-02	3.902-02	1.601-02	9.966-04
300.	9.427+02	1.590+02	6.951+01	4.030+01	2.261+01	1.667+00	5.425-01	9.150-02	3.988-02	2.250-02	1.149-02	9.472-04
900.	3.142+02	5.300+01	2.317+01	1.343+01	7.538+00	5.556-01	1.808-01	3.050-02	1.333-02	7.730-03	4.338-03	6.679-04
3600.	7.856+01	1.325+01	5.792+00	3.358+00	1.884+00	1.389-01	4.520-02	7.625-03	3.333-03	1.933-03	1.084-03	1.829-04
10800.	2.619+01	4.417+00	1.931+00	1.119+00	6.282-01	4.632-02	1.507-02	2.542-03	1.111-03	6.442-04	3.615-04	6.097-05

MIXING HEIGHT (M) 1000.
STABILITY CLASS 2
WIND SPEED (M/SEC) 10.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.414+03	2.385+02	1.043+02	6.045+01	3.392+01	2.501+00	8.137-01	1.370-01	5.711-02	2.967-02	1.374-02	9.752-04
300.	2.828+02	4.770+01	2.085+01	1.209+01	6.784+00	5.002-01	1.627-01	2.745-02	1.200-02	6.957-03	3.904-03	6.208-04
900.	9.427+01	1.590+01	6.951+00	4.030+00	2.261+00	1.667-01	5.425-02	9.150-03	4.000-03	2.319-03	1.301-03	2.195-04
3600.	2.357+01	3.975+00	1.738+00	1.008+00	5.653-01	4.168-02	1.356-02	2.288-03	9.999-04	5.798-04	3.253-04	5.487-05
10800.	7.856+00	1.325+00	5.792-01	3.358-01	1.884-01	1.389-02	4.520-03	7.625-04	3.333-04	1.933-04	1.084-04	1.829-05

MIXING HEIGHT (M) 1000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.678+05	3.229+04	1.501+04	9.058+03	5.305+03	4.745+02	1.675+02	2.493+01	8.344+00	3.892+00	1.708+00	1.261-01
300.	3.355+04	6.457+03	3.001+03	1.812+03	1.061+03	9.490+01	3.355+01	4.987+00	1.801+00	1.083+00	1.028+00	1.149-01

VAB.0001126667

TABLE A-2 (Continued)

900.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
3600.	2.796+03	5.381+02	2.501+02	1.510+02	8.842+01	7.908+00	2.796+00	5.381-01	2.501-01	1.510-01	8.842-02	1.702-02
10800.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03

MIXING HEIGHT (M) 1000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.592+04	1.076+04	5.002+03	3.019+03	1.768+03	1.582+02	5.592+01	1.076+01	4.894+00	2.752+00	1.388+00	1.222-01
300.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
900.	3.728+03	7.175+02	3.335+02	2.013+02	1.179+02	1.054+01	3.728+00	7.175-01	3.335-01	2.013-01	1.179-01	2.269-02
3600.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03
10800.	3.107+02	5.979+01	2.779+01	1.677+01	9.824+00	8.787-01	3.107-01	5.979-02	2.779-02	1.677-02	9.824-03	1.891-03

MIXING HEIGHT (M) 2000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.601+03	2.612+02	1.125+02	6.455+01	3.576+01	1.307+00	2.330-01	1.412-02	3.805-03	1.603-03	6.413-04	3.811-05
300.	3.201+02	5.225+01	2.249+01	1.291+01	7.167+00	5.033-01	1.504-01	1.315-02	3.699-03	1.579-03	6.362-04	3.807-05
900.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	3.773-05
3600.	2.668+01	4.354+00	1.874+00	1.076+00	5.972-01	4.196-02	1.337-02	2.182-03	9.394-04	5.391-04	2.972-04	3.282-05
10800.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	1.623-05

MIXING HEIGHT (M) 2000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.335+02	8.708+01	3.749+01	2.152+01	1.194+01	8.102-01	1.968-01	1.378-02	3.769-03	1.595-03	6.396-04	3.809-05
300.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	3.773-05
900.	3.557+01	5.805+00	2.499+00	1.434+00	7.963-01	5.595-02	1.783-02	2.910-03	1.252-03	7.152-04	3.816-04	3.495-05
3600.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	1.623-05
10800.	2.964+00	4.838-01	2.083-01	1.195-01	6.636-02	4.662-03	1.486-03	2.425-04	1.044-04	5.991-05	3.326-05	5.428-06

VAB.0001126668

TABLE A-2 (Continued)

MIXING HEIGHT (M) 2000.
STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	4.713+03	7.951+02	3.475+02	2.015+02	1.131+02	8.337+00	2.687+00	3.007-01	8.936-02	3.902-02	1.601-02	9.966-04
300.	9.427+02	1.590+02	6.951+01	4.030+01	2.261+01	1.667+00	5.425-01	9.150-02	3.988-02	2.250-02	1.149-02	9.472-04
900.	3.142+02	5.300+01	2.317+01	1.343+01	7.538+00	5.558-01	1.808-01	3.050-02	1.333-02	7.730-03	4.338-03	6.679-04
3600.	7.856+01	1.325+01	5.792+00	3.358+00	1.884+00	1.389-01	4.520-02	7.625-03	3.333-03	1.933-03	1.084-03	1.829-04
10800.	2.619+01	4.417+00	1.931+00	1.119+00	6.282-01	4.632-02	1.507-02	2.542-03	1.111-03	6.442-04	3.615-04	6.097-05

MIXING HEIGHT (M) 2000.
STABILITY CLASS 2
WIND SPEED (M/SEC) 10.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.414+03	2.385+02	1.043+02	6.045+01	3.392+01	2.501+00	8.137-01	1.370-01	5.711-02	2.967-02	1.374-02	9.752-04
300.	2.828+02	4.770+01	2.085+01	1.209+01	6.784+00	5.002-01	1.627-01	2.745-02	1.200-02	6.957-03	3.904-03	6.208-04
900.	9.427+01	1.590+01	6.951+00	4.030+00	2.261+00	1.667-01	5.425-02	9.150-03	4.000-03	2.319-03	1.301-03	2.195-04
3600.	2.357+01	3.975+00	1.738+00	1.008+00	5.653-01	4.168-02	1.356-02	2.288-03	9.999-04	5.798-04	3.253-04	5.487-05
10800.	7.856+00	1.325+00	5.792-01	3.358-01	1.884-01	1.389-02	4.520-03	7.625-04	3.333-04	1.933-04	1.084-04	1.829-05

MIXING HEIGHT (M) 2000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.678+05	3.289+04	1.501+04	9.058+03	5.305+03	4.748+02	1.675+02	3.493+01	8.344+00	3.892+00	1.700+00	1.261-01
300.	3.355+04	6.457+03	3.001+03	1.812+03	1.061+03	9.490+01	3.355+01	6.987+00	3.001+00	1.803+00	1.020+00	1.149-01
900.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
3600.	2.796+03	5.381+02	2.501+02	1.510+02	8.842+01	7.908+00	2.796+00	5.381-01	2.501-01	1.510-01	8.842-02	1.702-02
10800.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03

VAB.0001126669

TABLE A-2 (Continued)

MIXING HEIGHT (M) 2000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.592+04	1.076+04	5.002+03	3.019+03	1.768+03	1.582+02	5.592+01	1.076+01	4.894+00	2.752+00	1.388+00	1.222-01
300.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
900.	3.728+03	7.175+02	3.335+02	2.013+02	1.179+02	1.054+01	3.728+00	7.175-01	3.335-01	2.013-01	1.179-01	2.269-02
3600.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03
10800.	3.107+02	5.979+01	2.779+01	1.677+01	9.824+00	8.787-01	3.107-01	5.979-02	2.779-02	1.677-02	9.824-03	1.891-03

MIXING HEIGHT (M) 4000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.601+03	2.612+02	1.125+02	6.455+01	3.576+01	1.307+00	2.330-01	1.418-02	3.805-03	1.603-03	6.413-04	3.811-05
300.	3.201+02	5.225+01	2.249+01	1.291+01	7.167+00	5.033-01	1.504-01	1.315-02	3.699-03	1.579-03	6.362-04	3.807-05
900.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	3.773-05
3600.	2.668+01	4.354+00	1.874+00	1.076+00	5.972-01	4.196-02	1.337-02	2.182-03	9.394-04	5.391-04	2.972-04	3.282-05
10800.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	1.623-05

MIXING HEIGHT (M) 4000.
STABILITY CLASS 1
WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.335+02	8.708+01	3.749+01	2.152+01	1.194+01	8.102-01	1.968-01	1.878-02	3.769-03	1.595-03	6.396-04	3.809-05
300.	1.067+02	1.742+01	7.497+00	4.303+00	2.389+00	1.678-01	5.348-02	8.362-03	2.992-03	1.399-03	5.964-04	3.773-05
900.	3.557+01	5.805+00	2.499+00	1.434+00	7.963-01	5.595-02	1.783-02	2.910-03	1.252-03	7.152-04	3.816-04	3.495-05
3600.	8.892+00	1.451+00	6.248-01	3.586-01	1.991-01	1.399-02	4.457-03	7.274-04	3.131-04	1.797-04	9.978-05	1.623-05
10800.	2.964+00	4.838-01	2.083-01	1.195-01	6.636-02	4.662-03	1.486-03	2.425-04	1.044-04	5.991-05	3.326-05	5.428-06

MIXING HEIGHT (M) 4000.
STABILITY CLASS 2

VAB.00911266 70

TABLE A-2 (Continued)

WIND SPEED (M/SEC) 3.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	4.713+03	7.951+02	3.475+02	2.015+02	1.131+02	8.337+00	2.687+00	3.007-01	8.936-02	3.902-02	1.601-02	9.966-04
300.	9.427+02	1.590+02	6.951+01	4.030+01	2.261+01	1.667+00	5.425-01	9.150-02	3.988-02	2.250-02	1.149-02	9.472-04
900.	3.142+02	5.300+01	2.317+01	1.343+01	7.538+00	5.558-01	1.808-01	3.050-02	1.333-02	7.730-03	4.338-03	6.679-04
3600.	7.856+01	1.325+01	5.792+00	3.358+00	1.884+00	1.389-01	4.520-02	7.625-03	3.333-03	1.933-03	1.084-03	1.829-04
10800.	2.619+01	4.417+00	1.931+00	1.119+00	6.282-01	4.632-02	1.507-02	2.542-03	1.111-03	6.442-04	3.615-04	6.097-05

MIXING HEIGHT (M) 4000.
STABILITY CLASS 2
WIND SPEED (M/SEC) 10.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.414+03	2.385+02	1.043+02	6.045+01	3.392+01	2.501+00	8.137-01	1.370-01	5.711-02	2.967-02	1.374-02	9.752-04
300.	2.828+02	4.770+01	2.085+01	1.209+01	6.784+00	5.002-01	1.627-01	2.745-02	1.200-02	6.957-03	3.904-03	6.208-04
900.	9.427+01	1.590+01	6.951+00	4.030+00	2.261+00	1.667-01	5.425-02	9.150-03	4.000-03	2.319-03	1.301-03	2.195-04
3600.	2.357+01	3.975+00	1.738+00	1.008+00	5.653-01	4.168-02	1.356-02	2.288-03	9.999-04	5.798-04	3.253-04	5.487-05
10800.	7.856+00	1.325+00	5.792-01	3.358-01	1.884-01	1.389-02	4.520-03	7.625-04	3.333-04	1.933-04	1.084-04	1.829-05

MIXING HEIGHT (M) 4000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 1.0

SMP. TIME (SEC)	DOWNWIND DISTANCE (KM)											
	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	1.678+05	3.229+04	1.501+04	9.058+03	5.305+03	4.745+02	1.675+02	2.493+01	8.344+00	3.892+00	1.700+00	1.261-01
300.	3.355+04	6.457+03	3.001+03	1.812+03	1.061+03	9.490+01	3.355+01	6.457+00	3.001+00	1.803+00	1.020+00	1.149-01
900.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
3600.	2.796+03	5.381+02	2.501+02	1.510+02	8.842+01	7.908+00	2.796+00	5.381-01	2.501-01	1.510-01	8.842-02	1.702-02
10800.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03

MIXING HEIGHT (M) 4000.
STABILITY CLASS 3
WIND SPEED (M/SEC) 3.0

SMP.	DOWNWIND DISTANCE (KM)

VAB.000126671

TABLE A-2 (Continued)

TIME (SEC)	0.01	0.03	0.05	0.07	0.1	0.5	1.0	3.0	5.0	7.0	10.0	30.0
60.	5.592+04	1.076+04	5.002+03	3.019+03	1.768+03	1.582+02	5.592+01	1.076+01	4.894+00	2.752+00	1.388+00	1.222-01
300.	1.118+04	2.152+03	1.000+03	6.039+02	3.537+02	3.163+01	1.118+01	2.152+00	1.000+00	6.039-01	3.537-01	6.672-02
900.	3.728+03	7.175+02	3.335+02	2.013+02	1.179+02	1.054+01	3.728+00	7.175-01	3.335-01	2.013-01	1.179-01	2.269-02
3600.	9.320+02	1.794+02	8.336+01	5.032+01	2.947+01	2.636+00	9.320-01	1.794-01	8.336-02	5.032-02	2.947-02	5.672-03
10800.	3.107+02	5.979+01	2.779+01	1.677+01	9.824+00	8.787-01	3.107-01	5.979-02	2.779-02	1.677-02	9.824-03	1.891-03

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TABLE A-2 (Continued)

STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0
MIXING HEIGHT (M) 1500.
SAMPLING TIME (SEC) 1.0

DOWNWIND DISTANCE (KM)	DISTANCE FROM PUFF CENTER (M)	RECEPTOR HEIGHT (M)	CONCENTRATION (G/M**3)
5.000	.000	.000	9.461-02

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TABLE A-2 (Continued)

```
OPTION 1      NO
OPTION 2      YES
OPTION 3      NO


          SOURCE INFORMATION

SOURCE STRENGTH (G)        1000000.0
SOURCE HEIGHT (M)                .0
INITIAL SIGMA R (M)              .0
INITIAL SIGMA Z (M)              .0


          METEOROLOGICAL DATA

WIND SPEED (M/SEC)             3.0
MIXING HEIGHT (M)           1500.0
SAMPLING TIME (SEC)          300.0
STABILITY CLASS                  2


          RECEPTOR DATA
LOCATION      DOWNWIND       RADIAL        HEIGHT ABOVE
NUMBER        DISTANCE       DISTANCE        GROUND
                (KM)           (M)            (M)

   1            5.000          .00             .00
```


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TABLE A-2 (Continued)

STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0
MIXING HEIGHT (M) 1500.
SAMPLING TIME (SEC) 300.0

DOWNWIND DISTANCE (KM)	DISTANCE FROM PUFF CENTER (M)	RECEPTOR HEIGHT (M)	CONCENTRATION (G/M**3)
5.000	.000	.000	3.988-02

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TABLE A-2 (Continued)

```
OPTION 1      NO
OPTION 2      YES
OPTION 3      NO


          SOURCE INFORMATION

 SOURCE STRENGTH (G)        1000000.0
 SOURCE HEIGHT (M)                .0
 INITIAL SIGMA R (M)              .0
 INITIAL SIGMA Z (M)              .0


          METEOROLOGICAL DATA

 WIND SPEED (M/SEC)             3.0
 MIXING HEIGHT (M)           1500.0
 SAMPLING TIME (SEC)         3600.0
 STABILITY CLASS                 2


          RECEPTOR DATA

LOCATION      DOWNWIND      RADIAL      HEIGHT ABOVE
NUMBER        DISTANCE      DISTANCE    GROUND
              (KM)          (M)         (M)

    1           5.000         .00          .06
```


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TABLE A-2 (Continued)

STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0
MIXING HEIGHT (M) 1500.
SAMPLING TIME (SEC) 3600.0

DOWNWIND DISTANCE (KM)	DISTANCE FROM PUFF CENTER (M)	RECEPTOR HEIGHT (M)	CONCENTRATION (G/M**3)
5.000	.000	.000	3.333-03

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TABLE A-2 (Continued)

OPTION 1 NO
OPTION 2 YES
OPTION 3 YES

SOURCE INFORMATION

SOURCE STRENGTH (G)	1000000.0
SOURCE HEIGHT (M)	50.0
INITIAL SIGMA R (M)	.0
INITIAL SIGMA Z (M)	.0

METEOROLOGICAL DATA

WIND SPEED (M/SEC)	3.0
MIXING HEIGHT (M)	1500.0
SAMPLING TIME (SEC)	300.0
STABILITY CLASS	2

RECEPTOR DATA

LOCATION NUMBER	DOWNWIND DISTANCE (KM)	RADIAL DISTANCE (M)	HEIGHT ABOVE GROUND (M)
1	1.000	.00	.00
2	3.000	.00	.00
3	5.000	.00	.00

VAB.0001126678

TABLE A-2 (Continued)

STABILITY CLASS 2
WIND SPEED (M/SEC) 3.0
MIXING HEIGHT (M) 1500.
SAMPLING TIME (SEC) 300.0

DOWNWIND DISTANCE (KM)	DISTANCE FROM PUFF CENTER (M)	RECEPTOR HEIGHT (M)	CONCENTRATION (G/M**3)
1.000	.000	.000	1.629-02
3.000	.000	.000	4.310-02
5.000	.000	.000	2.759-02

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TABLE A-2 (Continued)

```
EMISSION STRENGTH (G)          1000000.0
EMISSION HEIGHT (M)              50.0
INITIAL SIGMA R (M)               .0
INITIAL SIGMA Z (M)               .0
WIND SPEED (M/SEC)               3.0
MIXING HEIGHT (M)             1500.0
STABILITY CLASS                  2
SAMPLING TIME (SEC)            300.0
CRITICAL CONCENTRATION (G/M**3)          1.000-04

CRITICAL DOWNWIND DISTANCE (KM)            73.687
CONCENTRATION AT CONVERGENCE (G/M**3)    1.000-04



ELEVATED RELEASE
DISTANCE OUT TO PEAK CONCENTRATION (KM)      2.287
PEAK CONCENTRATION (G/M**3)  4.730-02
```


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APPENDIX B

SOURCE CODE LISTING

```
      DIMENSION HLID(4), SPD(6), XDIS(12), XR(100), RR(100), ZR(100), CH    00010
     1IM(12), AVGT(5), YAN(2)                                               00020
      DATA YAN /'YES',' NO'/                                                00030
      DATA AVGT /60.,300.,900.,3600.,10800./                                00040
      DATA XDIS /.01,.03,.05,.07,.1,.5,1.,3.,5.,7.,10.,30./                 00050
      DATA HLID /500.,1000.,2000.,4000./                                    00060
      DATA SPD /1.,3.,3.,10.,1.,3./                                         00070
10    READ (5,330) KTL                                                      00080
      IF (KTL.GE.100) GO TO 320                                             00090
C                                                                           00100
C         KTL=1  NEW PROBLEM READ ALL INPUT DATA.                           00110
C         KTL=2  CHANGE THE OPTIONS ONLY.                                   00120
C         KTL=3  CHANGE OPTIONS AND SOURCE DATA.                            00130
C         KTL=4  CHANGE OPTIONS AND METEOROLOGY.                            00140
C         KTL=5  CHANGE OPTIONS AND LOCATIONS OF CONCENTRATION              00150
C                ESTIMATES.                                                 00160
C         KTL=6  CHANGE OPTIONS, METEOROLOGY, AND LOCATIONS OF              00170
C                CONCENTRATION ESTIMATES.                                   00180
C                                                                           00190
      READ (5,330) IOUT1,IOUT2,IOUT3                                        00200
C                                                                           00210
C         IOUT1,IOUT2, AND IOUT3 ARE OUTPUT OPTIONS. A VALUE OF 1           00220
C         INDICATES THE OPTION WILL BE EXECUTED.                            00230
C                                                                           00240
C         IOUT1=1  TABLE OF CONCENTRATIONS FOR DIFFERENT STABILITY          00250
C                   CLASSES, SAMPLING TIMES, AND DOWNWIND DISTANCES.        00260
C         IOUT2=1  CONCENTRATION ESTIMATES FOR THE GIVEN INPUT DATA ONLY    00270
C         IOUT3=1  A CRITICAL CONCENTRATION MUST BE INPUT. THE PROGRAM      00280
C                   WILL COMPUTE DISTANCE TO CRITICAL CONCENTRATION.         00290
C                                                                           00300
      GO TO (20,50,20,30,40,30), KTL                                        00310
C       READ SOURCE CARD                                                    00320
20    READ (5,330) Q,H,SYOP,SZOP                                            00330
C                                                                           00340
C     Q          SOURCE STRENGTH                          (G)               00350
C     H          EFFECTIVE SOURCE HEIGHT                  (M)               00360
C     SYOP       INITIAL SIGMA R                          (M)               00370
C     SZOP       INITIAL SIGMA Z                          (M)               00380
C                                                                           00390
      GO TO (30,50,50,30,40,30), KTL                                        00400
C       READ METEOROLOGY CARD                                               00410
30    READ (5,330) U,HL,AVT,KST                                             00420
C                                                                           00430
C     U          WIND SPEED                               (M/SEC)           00440
C     HL         MIXING HEIGHT                            (M)               00450
C     AVT        SAMPLING TIME FOR CONCENTRATION                            00460
C                ESTIMATES                                (SEC)             00470
C     KST        STABILITY CLASS     1-3                                    00480
C                                                                           00490
      GO TO (40,50,50,50,40,40), KTL                                        00500
```


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```
C       READ DOWNWIND DISTANCE, RADIAL DISTANCE FROM PUFF CENTER          00510
C       AND HEIGHT                                                        00520
40    READ (5,330) NREC,((XR(I),RR(I),ZR(I)),I=1,NREC)                   00530
C                                                                         00540
C     NREC        NUMBER OF LOCATIONS FOR WHICH CONCENTRATION            00550
C                 ESTIMATES ARE MADE                                    00560
C     XR          DISTANCE DOWNWIND FROM RELEASE POINT     (KM)         00570
C     RR          RADIAL DISTANCE FROM PUFF CENTER         (M)          00580
C     ZR          HEIGHT ABOVE GROUND                      (M)          00590
C                                                                         00600
50    IF (IOUT3.EQ.1) READ (5,330) XCHI                                   00610
C                                                                         00620
C     XCHI        CRITICAL CONCENTRATION                   (C/M**3)     00630
C                                                                         00640
      IF (IOUT1.NE.1) IOUT1=2                                             00650
      IF (IOUT2.NE.1) IOUT2=2                                             00660
      IF (IOUT3.NE.1) IOUT3=2                                             00670
      WRITE (6,340) YAN(IOUT1),YAN(IOUT2),YAN(IOUT3)                      00680
      WRITE (6,350) Q,H,SYOP,SZOP                                         00690
      WRITE (6,360) U,HL,AVT,KST                                          00700
      WRITE (6,370)                                                       00710
      DO 60 I=1,NREC                                                      00720
      WRITE (6,380) I,XR(I),RR(I),ZR(I)                                   00730
60    CONTINUE                                                            00740
      CON1=2./(2.*3.14159)**1.5                                           00750
      CON2=1./(2.*3.14159)                                                00760
      CON3=1./(2.*3.14159)**1.5                                           00770
      IF (IOUT1.NE.1) GO TO 180                                           00780
      DO 100 ILID=1,4                                                     00790
      HLL=HLID(ILID)                                                      00800
      HLE=0.8*HLL                                                         00810
      WRITE (6,390) HLL                                                   00820
      DO 90 ISTA=1,3                                                      00830
      DO 80 IDIS=1,12                                                     00840
      XX=XDIS(IDIS)                                                       00850
      CALL PUFSIG (XX,ISTA,SR,SZ)                                         00860
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                            00870
      SR=SQRT(SR*SR+SYOP*SYOP)                                            00880
      E=EXP(-0.5*(H/SZ)**2)                                               00890
      CHIM(IDIS)=Q*E*CON1/(SR*SR*SZ)                                      00900
      IF (ISTA.EQ.3) GO TO 70                                             00910
      IF (SZ.GE.HLE) CHIM(IDIS)=Q*CON2/(SR*SR*HLL)                        00920
70    CONTINUE                                                            00930
80    CONTINUE                                                            00940
      WRITE (6,400) (ISTA,(CHIM(I),I=1,12))                               00950
90    CONTINUE                                                            00960
100   CONTINUE                                                            00970
      DO 170 ILID=1,4                                                     00980
      HLL=HLID(ILID)                                                      00990
      HLE=0.8*HLL                                                         01000
```


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```
      DO 160 ISTA=1,3                                                   01010
      DO 150 IS=1,2                                                     01020
      ISN=(ISTA-1)*2+IS                                                 01030
      US=SPD(ISN)                                                       01040
      WRITE (6,410) HLL,ISTA,US                                         01050
      DO 140 IAVT=1,5                                                   01060
      AVG=AVGT(IAVT)                                                    01070
      DO 130 IDIS=1,12                                                  01080
      XX=XDIS(IDIS)                                                     01090
      CALL PUFSIG (XX,ISTA,SR,SZ)                                       01100
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                          01110
      SR=SQRT(SR*SR+SYOP*SYOP)                                          01120
      E=EXP(-0.5*(H/SZ)**2)                                             01130
      CHIMAX=Q*E*CON1/(SR*SR*SZ)                                        01140
      IF (ISTA.EQ.3) GO TO 110                                          01150
      IF (SZ.GE.HLE) CHIMAX=Q*CON2/(SR*SR*HLL)                          01160
  110 CONTINUE                                                          01170
      AVGC=1.                                                           01180
      IF (AVG.LT.1.) GO TO 120                                          01190
      SGWT=AVG*US/(SR*2.)                                               01200
      CALL AVCOR (SGWT,AVGC)                                            01210
  120 CHIM(IDIS)=CHIMAX*AVGC                                            01220
  130 CONTINUE                                                          01230
      WRITE (6,420) (AVG,(CHIM(I),I=1,12))                              01240
  140 CONTINUE                                                          01250
  150 CONTINUE                                                          01260
  160 CONTINUE                                                          01270
  170 CONTINUE                                                          01280
  180 CONTINUE                                                          01290
      IF (IOUT2.NE.1) GO TO 230                                         01300
      WRITE (6,430) KST,U,HL,AVT                                        01310
      HLE=0.8*HL                                                        01320
      DO 220 IR=1,NREC                                                  01330
      XX=XR(IR)                                                         01340
      CALL PUFSIG (XX,KST,SR,SZ)                                        01350
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                          01360
      SR=SQRT(SR*SR+SYOP*SYOP)                                          01370
      IF (SZ.GE.HLE.AND.KST.LE.2) GO TO 190                             01380
      E1=-0.5*(RR(IR)/SR)**2                                            01390
      E2=-0.5*(((ZR(IR)+H)/SZ)**2)                                      01400
      E3=-0.5*(((ZR(IR)-H)/SZ)**2)                                      01410
      CHI=(Q*CON3/(SZ*SR*SR))*(EXP(E1)*(EXP(E2)+EXP(E3)))               01420
      GO TO 200                                                         01430
  190 CONTINUE                                                          01440
      E1=EXP(-0.5*(RR(IR)/SR)**2)                                       01450
      CHI=(Q*CON2/(SR**2*HL))*E1                                        01460
  200 CONTINUE                                                          01470
      IF (AVT.LT.1.) GO TO 210                                          01480
      SGWT=AVT*U/(SR*2.)                                                01490
      CALL AVCOR (SGWT,AVGC)                                            01500
```


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```
      CHI=CHI*AVGC                                                          01510
210   WRITE (6,440) XR(IR) RR(IR),ZR(IR),CHI                                01520
220   CONTINUE                                                              01530
230   CONTINUE                                                              01540
      IF (IOUT3.NE.1) GO TO 310                                             01550
      CL=0.                                                                 01560
      XPK=0.                                                                01570
      IF (H.GT.1.) CALL DBTMX (Q,KST,H,U,AVT,SYOP,SZOP,XPK,CL)              01580
      IF (H.GT.1..AND.XCHI.GT.CL) GO TO 300                                 01590
      X=0.                                                                  01600
      HLE=0.8*HL                                                            01610
      KD=9                                                                  01620
      DO 280 K=1,KD                                                         01630
      DX=10.**(KD-K)                                                        01640
      DO 260 J=1,10                                                         01650
      X=X+DX                                                                01660
      XI=X/10000.                                                           01670
      IF (XI.LT.XPK) XI=XPK                                                 01680
      XX=XI                                                                 01690
      CALL PUFSIG (XX,KST,SR,SZ)                                            01700
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                              01710
      SR=SQRT(SR*SR+SYOP*SYOP)                                              01720
      E=EXP(-0.5*(H/SZ)**2)                                                 01730
      CHI=(Q*CON1/(SR**2*SZ))*E                                             01740
      IF (KST.EQ.3) GO TO 240                                               01750
      IF (SZ.GE.HLE) CHI=Q*CON2/(SR**2*HL)                                  01760
240   CONTINUE                                                              01770
      IF (AVT.LT.1.) GO TO 250                                              01780
      SGWT=AVT*U/(SR*2.)                                                    01790
      CALL AVCOR (SGWT,AVGC)                                                01800
      CHI=CHI*AVGC                                                          01810
250   DIFF=XCHI-CHI                                                         01820
      IF (DIFF) 260,290,270                                                 01830
260   CONTINUE                                                              01840
270   X=X-DX                                                                01850
280   CONTINUE                                                              01860
290   CONTINUE                                                              01870
      WRITE (6,450) Q,H,SYOP,SZOP,U,HL,KST,AVT,XCHI                         01880
      WRITE (6,460) XI,CHI                                                  01890
      IF (H.GT.1.) WRITE (6,470) XPK,CL                                     01900
      GO TO 310                                                             01910
300   CONTINUE                                                              01920
      WRITE (6,480) XPK,XCHI,CL                                             01930
310   CONTINUE                                                              01940
      GO TO 10                                                              01950
320   STOP                                                                  01960
C                                                                           01970
330   FORMAT ()                                                             01980
340   FORMAT ('1',8X,'OPTION 1',5X,A3,/,9X,'OPTION 2',5X,A3,/,9X,'OPTION    01990
     1 3',5X,A3,///)                                                        02000
```


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```
350   FORMAT (15X,'SOURCE INFORMATION',//,5X,'SOURCE STRENGTH (G)',T30,F   02010
     110.1,/,5X,'SOURCE HEIGHT (M)',T30,F6.1,/,5X,'INITIAL SIGMA R (M)',   02020
     2T30,F6.1,/,5X,'INITIAL SIGMA Z (M)',T30,F6.1,///)                    02030
360   FORMAT (15X,'METEOROLOGICAL DATA',//,5X,'WIND SPEED (M/SEC)',T30,F   02040
     14.1,/,5X,'MIXING HEIGHT (M)',T30,F6.1,/,5X,'SAMPLING TIME (SEC)',T   02050
     228,F7.1,/,5X,'STABILITY CLASS',T33,I1,///)                           02060
370   FORMAT (T16,'RECEPTOR DATA',/,T5,'LOCATION',T20,'DOWNWIND',T35,'RA    02070
     1DIAL',T50,'HEIGHT ABOVE',/,T6,'NUMBER',T20,'DISTANCE',T35,'DISTANC   02080
     2E',T54,'GROUND',/,T23,'(KM)',T37,'(M)',T56,'(M)',/)                  02090
380   FORMAT (T7,I3,T20,F8.3,T33,F8.2,T52,F8.2)                             02100
390   FORMAT (//////,5X,'MIXING HEIGHT (M)',2X,F6.0,/,1X'STAB.',T40,'DOW    02110
     1NWIND DISTANCE  (KM)',/,1X,'CLAS',/,T8,'0.01',T18,'0.03',T28,'0.05   02120
     2',T38,'0.07',T49,'0.1',T59,'0.5',T69,'1.0',T79,'3.0',T89,'5.0',T99   02130
     3,'7.0',T108,'10.0',T118,'30.0',//)                                   02140
400   FORMAT (2X,I1,3X,1P12(E9.3,1X))                                       02150
410   FORMAT (////,1X,'MIXING HEIGHT (M)',2X,F5.0,/,1X,'STABILITY CLASS'    02160
     1,2X,I1,/,1X,'WIND SPEED (M/SEC)',2X,F5.1,//,4X,'SMP.',T40,'DOWNWIN   02170
     2D DISTANCE (KM)',/,4X,'TIME (SEC)',/,T13,'0.01',T23,'0.03',T33,'0.   02180
     305',T43,'0.07',T54,'0.1',T64,'0.5',T74,'1.0',T84,'3.0',T94,'5.0',T   02190
     4104,'7.0',T113,'10.0',T123,'30.0',//)                                02200
420   FORMAT (2X,F7.0,2X,1P12(E9.3,1X))                                     02210
430   FORMAT ('1',4X,'STABILITY CLASS',2X,I1,/,5X,'WIND SPEED (M/SEC)',2    02220
     1X,F5.1,/,5X,'MIXING HEIGHT (M)',2X,F5.0,/,5X,'SAMPLING TIME (SEC)'   02230
     2,2X,F7.1,//,1X,'DOWNWIND',T14,'DISTANCE FROM',T31,'RECEPTOR',T47,'   02240
     3CONCENTRATION',/,1X,'DISTANCE',T15,'PUFF CENTER',T32,'HEIGHT',T50,   02250
     4'(G/M**3)',/,3X,'(KM)',T18,'(M)',T33,'(M)',/)                        02260
440   FORMAT (1X,F8.3,T14,F8.3,T31,F8.3,T48,1PE9.3)                         02270
450   FORMAT ('1',4X,'EMISSION STRENGTH (G)',T35,F10.1,/,5X,'EMISSION HE    02280
     1IGHT (M)',T35,F6.1,/,5X,'INITIAL SIGMA R (M)',T35,F5.1,/,5X,'INITI   02290
     2AL SIGMA Z (M)',T35,F5.1,/,5X,'WIND SPEED (M/SEC)',T35,F5.1,/,5X,'   02300
     3MIXING HEIGHT (M)',T35,F6.1,/,5X,'STABILITY CLASS  ',T35,I1,/,5X,'   02310
     4SAMPLING TIME (SEC) ',T35,F7.1,/,5X,'CRITICAL CONCENTRATION',' (G/   02320
     5M**3)',T45,1PE9.3,/)                                                 02330
460   FORMAT (5X,'CRITICAL DOWNWIND DISTANCE (KM) ',T45,F9.3,/,5X,'CONCE    02340
     1NTRATION AT CONVERGENCE (G/M**3) ',T45,1PE9.3,////////)               02350
470   FORMAT (///,5X,'ELEVATED RELEASE',/,5X,'DISTANCE OUT TO PEAK CONCE    02360
     1NTRATION (KM) ',F8.3,/,5X,'PEAK CONCENTRATION (G/M**3) ',1PE9.3)     02370
480   FORMAT ('1',5X,'CRITICAL CONCENTRATION IS GREATER ','THAN PEAK CON    02380
     1CENTRATION',/,5X,'DISTANCE OUT TO PEAK CONCENTRATION (KM) ',F8.3,/   02390
     2,5X,'CRITICAL CONCENTRATION (G/M**3) ',1PE9.3,/,5X,'PEAK CONCENTRA   02400
     3TION (G/M**3) ',1PE9.3)                                              02410
C                                                                          02420
      END                                                                  02430


      SUBROUTINE PUFSIG (X,KST,SR,SZ)                                      00010
      DIMENSION AY(3), AZ(3), BY(3), BZ(3)                                 00020
      DATA AY /0.14,0.06,0.02/                                             00030
      DATA AZ /0.53,0.15,0.05/                                             00040
```


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```
      DATA BY /0.92,0.92,0.89/                                          00050
      DATA BZ /0.73,0.70,0.61/                                          00060
C                                                                       00070
C       PUFSIG COMPUTES SIGMA R AND SIGMA Z, USING THE CURVES           00080
C       RECOMMENDED IN METEOROLOGY AND ATOMIC ENERGY (1968) P. 175      00090
C                                                                       00100
C         X        DOWNWIND DISTANCE                        (KM)       00110
C         KST      STABILITY CLASS                                     00120
C         SR       SIGMA R                                  (M)        00130
C         SZ       SIGMA Z                                  (M)        00140
C                                                                       00150
      XK=1000.*X                                                        00160
      GO TO (10,20,30), KST                                             00170
10    SR=AY(1)*XK**BY(1)                                                00180
      SZ=AZ(1)*XK**BZ(1)                                                00190
      RETURN                                                            00200
20    SR=AY(2)*XK**BY(2)                                                00210
      SZ=AZ(2)*XK**BZ(2)                                                00220
      RETURN                                                            00230
30    SR=AY(3)*XK**BY(3)                                                00240
      SZ=AZ(3)*XK**BZ(3)                                                00250
      RETURN                                                            00260
C                                                                       00270
      END                                                               00280
```

```
      SUBROUTINE AVCOR(SGWT,AVGC)                                       00010
C                                                                       00020
C       AVCOR COMPUTES AREA UNDER NORMAL CURVE.                         00030
C                                                                       00040
C       SGWT       NUMBER OF STANDARD DEVIATIONS                        00050
C       AVGC       AREA UNDER NORMAL CURVE                              00060
C                                                                       00070
      R=0.2316419                                                       00080
      B1=0.319381530                                                    00090
      B2=-0.356563782                                                   00100
      B3=1.781477937                                                    00110
      B4=-1.821255978                                                   00120
      B5=1.330274429                                                    00130
      C=1./SQRT(2.*3.14159)                                             00140
      X=SGWT                                                            00150
C       X IS THE NUMBER OF STANDARD DEVIATIONS ABOUT THE MEAN           00160
      E=EXP(-(X**2/2.))                                                 00170
      T=1./(1.+R*X)                                                     00180
      RR=C*E*(B1*T+B2*T**2+B3*T**3+B4*T**4+B5*T**5)                     00190
      A=1.-RR                                                           00200
      AVGC=2.*(A-0.5)/(2.*X*0.398942)                                   00210
      RETURN                                                            00220
      END                                                               00230
```


VAB.0001126686

```
      SUBROUTINE DBTMX (Q,KST,H,U,AVT,SYOP,SZOP,XL,CL)                  00010
C                                                                       00020
C       DBTMX COMPUTES DISTANCE TO MAXIMUM CONCENTRATION.               00030
C                                                                       00040
C     Q         SOURCE STRENGTH                          (G)            00050
C     KST       STABILITY CLASS                                         00060
C     H         EFFECTIVE PUFF HEIGHT                    (M)            00070
C     U         WIND SPEED                               (M/SEC)        00080
C     AVT       SAMPLING TIME                            (SEC)          00090
C     SYOP      INITIAL HORIZONTAL DISPERSION            (M)            00100
C     SZOP      INITIAL VERTICAL DISPERSION              (M)            00110
C     XL        DISTANCE TO MAXIMUM CONCENTRATION        (KM)           00120
C     CL        MAXIMUM CONCENTRATION                    (G/M**3)       00130
C                                                                       00140
      CON1=2./(2.*3.14159)**1.5                                         00150
      IA=1                                                              00160
      XL=0.0                                                            00170
      RC=0.0                                                            00180
      X=0.01                                                            00190
      DX=0.01                                                           00200
10    CL=RC                                                             00210
      XX=X                                                              00220
      CALL PUFSIG (XX,KST,SR,SZ)                                        00230
      SR=SQRT(SR*SR+SYOP*SYOP)                                          00240
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                          00250
      E=EXP(-0.5*(H/SZ)**2)                                             00260
      RC=(Q*CON1/(SR**2*SZ))*E                                          00270
      IF (AVT.LT.1.) GO TO 20                                           00280
      SGWT=AVT*U/(SR*2.)                                                00290
      CALL AVCOR (SGWT,AVGC)                                            00300
      RC=RC*AVGC                                                        00310
20    IF (RC-CL) 110,30,30                                              00320
30    XL=X                                                              00330
      X=X+DX                                                            00340
      GO TO (40,60,80,100), IA                                          00350
40    IF (X-0.192) 10,10,50                                             00360
50    IA=2                                                              00370
      X=0.2                                                             00380
      DX=0.1                                                            00390
      GO TO 10                                                          00400
60    IF (X-3.92) 10,10,70                                              00410
70    IA=3                                                              00420
      X=4.0                                                             00430
      DX=1.0                                                            00440
      GO TO 10                                                          00450
80    IF (X-19.2) 10,10,90                                              00460
90    IA=4                                                              00470
```


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```
      U=20.0                                                          00480
      DX=10.0                                                         00490
      GO TO 10                                                        00500
100   IF (X-305.0) 10,10,200                                          00510
110   IF (DX-0.001) 120,120,130                                       00520
120   RETURN                                                          00530
130   DX=0.1*DX                                                       00540
140   XL=X                                                            00550
      X=X-DX                                                          00560
      CL=RC                                                           00570
      XX=X                                                            00580
      CALL PUFSIG (XX,KST,SR,SZ)                                      00590
      SR=SQRT(SR*SR+SYOP*SYOP)                                        00600
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                        00610
      E=EXP(-0.5*(H/SZ)**2)                                           00620
      RC=(Q*CON1/(SR**2*SZ))*E                                        00630
      IF (AVT.LT.1.) GO TO 150                                        00640
      SGWT=AVT*U/(SR*2.)                                              00650
      CALL AVCOR (SGWT,AVGC)                                          00660
      RC=RC*AVGC                                                      00670
150   IF (RC-CL) 160,140,140                                          00680
160   IF (DX-0.001) 120,120,170                                       00690
170   DX=0.1*DX                                                       00700
180   XL=X                                                            00710
      X=X+DX                                                          00720
      CL=RC                                                           00730
      XX=X                                                            00740
      CALL PUFSIG (XX,KST,SR,SZ)                                      00750
      SR=SQRT(SR*SR+SYOP*SYOP)                                        00760
      SZ=SQRT(SZ*SZ+SZOP*SZOP)                                        00770
      E=EXP(-0.5*(H/SZ)**2)                                           00780
      RC=(Q*CON1/(SR**2*SZ))*E                                        00790
      SGWT=AVT*U/(SR*2.)                                              00800
      CALL AVCOR (SGWT,AVGC)                                          00810
      RC=RC*AVGC                                                      00820
      IF (RC-CL) 190,180,180                                          00830
190   IF (DX-0.001) 120,120,130                                       00840
200   XL=999.0                                                        00850
      CL=99.0                                                         00860
      RETURN                                                          00870
C                                                                     00880
      END                                                             00890
```


VAB.0001126688

APPENDIX C
CHANGES TO THE DISPERSION PARAMETERS

The horizontal and vertical dispersion parameters in the instantaneous puff model are of the form ax^b. The constants a and b are in data statements in Subroutine PUFSIG and can be easily changed. If more than three stability classes are desired, additional modifications to the code are required besides those given here. The constants a and b for the horizontal dispersion parameters are contained in arrays AY and BY respectively. Likewise the constants for the vertical dispersion parameters are in arrays AZ and BZ. Listed below are the DATA statements that contain the values of the constants a and b.

	UNSTABLE	NEUTRAL	VERY STABLE
DATA AY	0.14	0.06	0.02
DATA AZ	0.53	0.15	0.05
DATA BY	0.92	0.92	0.89
DATA BZ	0.73	0.70	0.61

To change the dispersion for the three stability classes change the values in the DATA statements in PUFSIG.

VAB.0001126689

APPENDIX D
PUFF MODEL ON PROGRAMMABLE CALCULATOR

The instantaneous puff model has been programmed on the HP-67 programmable calculator. In programming the puff model, two magnetic recording cards will be required. The dispersion algorithm is stored on the first card, and the code necessary to compute average concentrations over some sampling time is stored on the second card. The dispersion model can be executed without utilizing the second magnetic card, so that estimates of the peak concentration can be made using only the first magnetic card.

Table D-1 provides the program steps necessary to generate the two programs. Table D-2 shows the storage locations for the input parameters. To execute the dispersion model after the program has been stored in program memory and the input parameters have been stored in their appropriate registers enter the downwind distance in (km) and press "A". The calculator will show the concentration in (gm^{-3}). To perform another calculation for another downwind distance, simply enter the distance and press "A". This process can be repeated for as many downwind distances as you require.

If average concentrations are needed, the second card must be read in after the completion of the dispersion algorithm. This routine uses information generated by the dispersion routine. In addition, the wind speed must be stored in register 2 and the sampling time stored in register 3. After this information has been stored, press "A" to execute the program.

VAB.0001126690

A

To calculate concentrations for different sampling times, store the sampling time in register 3 and press "A". This can be done for as many sampling times as needed. This process could be repeated for different wind speeds as well.

To demonstrate the use of the model run the dispersion program for example problem 3-1 (A).

Steps

1. Read magnetic card with dispersion model.
2. Store stability (1) in sti.
3. Store source height (0) in register 6.
4. Store σ_{y_o} and σ_{z_o}(9.3) in register 7 and 8, respectively.
5. Store Q (1.5×10^4) in register 9.
6. Store mixing height (1500) in register E.
7. Enter 10.
8. Press A.

$$\chi_p = 9.619 \times 10^{-6} \text{ g/m}^3$$

What is the 1-hour average concentration at this downwind distance.

Steps

1. Store wind speed (3) in register 2.
2. Store averaging time (3600) in register 3.
3. Read magnetic card with sampling time routine.
4. Press "A".

$$\chi = 1.496 \times 10^{-6} \text{ g/m}^3$$

VAB.0001126691

TABLE D-1 HP-67 PROGRAM STEPS FOR PUFF MODEL

CARD ONE

001	*LBLA	21 11	
002	STO1	35 01	
003	RCL9	36 09	
004	2	02	
005	x	-35	
006	STO0	35 00	
007	2	02	
008	Pi	16-24	
009	x	-35	
010	1	01	
011	.	-62	
012	5	05	
013	Yˣ	31	
014	1/X	52	
015	RCL9	36 09	
016	x	-35	
017	STO0	35 00	
018	GSBC	23 13	
019	RCL4	36 04	
020	X²	53	
021	RCL7	36 07	
022	X²	53	
023	+	-55	
024	STOA	35 11	
025	RCL5	36 05	
026	X²	53	
027	RCL8	36 08	
028	X²	53	
029	+	-55	
030	√X	54	
031	STO8	35 12	
032	RCL4	36 11	
033	x	-35	
034	1/X	52	
035	RCL0	36 00	
036	x	-35	
037	STO0	35 00	
038	RCL5	36 05	
039	RCL8	36 12	
040	÷	-24	
041	X²	53	
042	.	-62	
043	5	05	
044	CHS	-22	
045	x	-35	
046	eˣ	33	
047	RCL0	36 00	
048	x	-35	
049	DSF3	-63 03	1
050	SCI	-12	
051	STO0	35 00	
052	RCLE	36 15	
053	.	-62	
054	8	08	
055	x	-35	
056	RCL5	36 12	
057	X>Y?	16-34	
058	GTOD	22 14	
059	RCL0	36 00	
060	RTN	24	
061	*LBLD	21 14	
062	RCLA	36 11	
063	RCLE	36 15	
064	x	-35	
065	Pi	16-24	
066	x	-35	
067	2	02	
068	x	-35	
069	1/X	52	
070	RCL9	36 09	
071	x	-35	
072	STO0	35 00	
073	RTN	24	
074	*LBLC	21 13	
075	RCL1	36 01	
076	1	01	
077	0	00	
078	0	00	
079	0	00	
080	STx1	35-35 01	
081	GTOi	22 45	
082	*LBL1	21 01	
083	.	-62	
084	9	09	
085	2	02	
086	STOA	35 11	
087	.	-62	
088	1	01	
089	4	04	
090	STOB	35 12	
091	.	-62	
092	7	07	
093	3	03	
094	STOC	35 13	
095	.	-62	
096	5	05	
097	3	03	
098	STOD	35 14	
099	RCL1	36 01	
100	RCLA	36 11	
101	Yˣ	31	
102	RCLB	36 12	
103	x	-35	
104	STO4	35 04	
105	RCL1	36 01	

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TABLE D-1 (Continued)

CARD ONE

106	RCLC	36 13
107	Y^x	31
108	RCLD	36 14
109	x	-35
110	STO5	35 05
111	RTN	24
112	*LBL2	21 02
113	.	-62
114	9	09
115	2	02
116	STOA	35 11
117	.	-62
118	0	00
119	6	06
120	STOB	35 12
121	.	-62
122	7	07
123	STOC	35 13
124	.	-62
125	1	01
126	5	05
127	STOD	35 14
128	RCL1	36 01
129	RCLA	36 11
130	Y^x	31
131	RCLB	36 12
132	x	-35
133	STO4	35 04
134	RCL1	36 01
135	RCLC	36 13
136	Y^x	31
137	RCLD	36 14
138	x	-35
139	STO5	35 05
140	RTN	24
141	*LBL3	21 03
142	.	-62
143	8	08
144	9	09
145	STOA	35 11
146	.	-62
147	0	00
148	2	02
149	STOB	35 12
150	.	-62
151	6	06
152	1	01
153	STOC	35 13
154	.	-62
155	0	00
156	5	05
157	STOD	35 14
158	RCL1	36 01
159	RCLA	36 11
160	Y^x	31
161	RCLB	36 12
162	x	-35
163	STO4	35 04
164	RCL1	36 01
165	RCLC	36 13
166	Y^x	31
167	RCLD	36 14
168	x	-35
169	STO5	35 05
170	RTN	24
171	R/S	51

VAB.0001126693

TABLE D-1 (Continued)

CARD TWO

001	*LBL A	21 11		053	4	04		
002	RCL4	36 04		054	Y^x	31		
003	2	02		055	1	01		
004	×	-35		056	.	-62		
005	1/X	52		057	8	08		
006	RCL2	36 02		058	2	02		
007	×	-35		059	1	01		
008	RCL3	36 03		060	2	02		
009	×	-35		061	5	05		
010	STO4	35 11		062	9	09		
011	2	02		063	7	07		
012	PI	16-24		064	8	08		
013	×	-35		065	CHS	-22		
014	$\sqrt{X}$	54		066	×	-35		
015	1/X	52		067	+	-55		
016	STOC	35 13		068	RCL1	36 01		
017	RCLA	36 11		069	3	03		
018	X^2	53		070	Y^x	31		
019	2	02		071	1	01		
020	÷	-24		072	.	-62		
021	CHS	-22		073	7	07		
022	e^x	33		074	8	08		
023	STOD	35 14		075	1	01		
024	RCLA	36 11		076	4	04		
025	.	-62		077	7	07		
026	0	00		078	7	07		
027	3	03		079	9	09		
028	1	01		080	3	03		
029	6	06		081	7	07		
030	4	04		082	×	-35		
031	1	01		083	+	-55		
032	9	09		084	RCL1	36 01		
033	×	-35		085	X^2	53		
034	1	01		086	.	-62		
035	+	-55		087	3	03		
036	1/X	52		088	5	05		
037	STO1	35 01		089	6	06		
038	5	05		090	5	05		
039	Y^x	31		091	6	06		
040	1	01		092	3	03		
041	.	-62		093	7	07		
042	3	03		094	8	08		
043	3	03		095	2	02		
044	0	00		096	CHS	-22		
045	2	02		097	×	-35		
046	7	07		098	+	-55		
047	4	04		099	RCL1	36 01		
048	4	04		100	.	-62		
049	2	02		101	3	03		
050	9	-09		102	1	01		
051	×	-35		103	9	09		
052	RCL1	36 01		104	3	03		

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TABLE D-1 (Continued)

	CARD TWO	
105	6	06
106	1	01
107	5	05
108	3	03
109	×	-35
110	-	-55
111	RCLD	36 14
112	×	-35
113	RCLC	36 13
114	×	-35
115	CHS	-22
116	1	01
117	+	-55
118	.	-62
119	5	05
120	-	-45
121	2	02
122	×	-35
123	STO1	35 01
124	RCLA	36 11
125	.	-62
126	3	03
127	9	09
128	8	08
129	9	09
130	4	04
131	2	02
132	×	-35
133	2	02
134	×	-35
135	1/X	52
136	RCL1	36 01
137	×	-35
138	RCL0	36 00
139	×	-35
140	STO1	35 01
141	DSP3	-63 03
142	SCI	-12
143	RCL0	36 00
144	RCL1	36 01
145	X>Y?	16-34
146	GTOD	22 14
147	RTN	24
148	*LBLD	21 14
149	RCL0	36 00
150	RTN	24
151	R/S	51

VAB.0001126695

TABLE D-2 STORAGE LOCATIONS FOR INPUT PARAMETERS

INPUT	REGISTER
Stability Class	sti
Source Height	6
Initial Sigma Y	7
Initial Sigma Z	8
Source Strength	9
Mixing Height	E
FOR CARD TWO	
Wind Speed	2
Sampling Time	3

VAB.0001126696

Trinity Consultants Addendum to EPA 600/3-82-078
Prepared by Richard H. Schulze July 24, 1984

"Estimating Concentrations Downwind from an Instantaneous Puff Release"

1. p.30 Correct 3rd last line by inserting a comma after 5. The first integer 3 suggests three sets of three real numbers, and the comma specified was omitted in error.

2. p.21 Care should be exercised in selecting option IOPT3. This option does not use the variable for height above ground (ZR). Thus, if one is analyzing receptors above ground level using IOPT2, one can show lower values for IOPT3 because the maximum is only determined for ground level.

3. p.50 The computer calculates a sigma value by taking the square root of the sum of the squares of the Slade coefficients determined by PUFSIG and the initial sigma values input by the user (line 870 is one example).

   Another way used by Trinity Consultants in its work is to determine the distance a point source would have to travel to reach the designated puff size. This distance is called the virtual distance, and it is added to the actual distance for the purposes of determining the sigma values. The call to PUFSIG under such a method would read

   CALL PUFSIG ((XX+VX(ISTA),ISTA,SR,SZ).

   This scheme generally produces lower concentrations at greater distances than the EPA puff model. In one case with a virtual distance of 5 meters, plume height of 30 meters with unstable conditions, the Trinity method gave concentrations about 3 percent lower than the EPA method.

VAB.0001126697

A

REPORT FOR TRINITY CONSULTANTS

Introduction

Arsine is a colorless gas which produces toxic effects on red blood cells (hemolysis) at low doses (1,2). The recommended threshold limit value (TLV) of arsine for an eight hour exposure in the workplace is 0.05 ppm (3). Exposure to 1 to 10 ppm of arsine for an hour is considered to be dangerous (4). The purpose of this analysis is to define and approximate what would be a "safe" or tolerable level of arsine exposure for a short period of time.

Exposure Duration and Dose

The dose of arsine received from inhaling contaminated air is a product of the airborne concentration x the breathing volume per minute x duration of exposure. One part per million (1ppm) of arsine in air is equivalent to 3.2 mg/m3 (4). An individual exposed to 0.05 ppm (TLV) for 8 hours would normally inhale 0.05 ppm x 3.2 mg/m3 x 8 m3 = 1.28 mg of arsine. This value is based on a breathing volume of 20-25 m3/ 24- hour day; a number frequently used in environmental estimations.

For shorter periods of exposure, the physical activity of the individual is an important determinant of dose. The breathing volumes for an adult male resting, doing light work or doing heavy work are 7.4, 29 and 60 liters of air per minute, respectively (5). For an exposure of 1 ppm for one hour, the individual could theoretically inhale 3.2 mg/m3 x (0.0074, 0.029 or 0.060) m3 x 60 min = 1.42, 5.57 or 11.52 mg of arsine.

If we select acceptable short term doses of 0.12, 0.25, 0.5 or 1.0 mg of arsine and conditions of "light work" (0.029 m3/min), the corresponding permissible levels in air for 0.5, 1.0 or 5.0 min exposure periods are:

estimated dose	exposure duration		
mg of arsine	0.5 min	1.0 min	5.0 min
0.12	2.7 ppm	1.3 ppm	0.3 ppm
0.25	5.4 ppm	2.7 ppm	0.6 ppm
0.50	10.8 ppm	5.4 ppm	1.2 ppm
1.00	21.6 ppm	10.8 ppm	2.4 ppm

The toxic properties of arsine are such that one should be mainly concerned with acute toxicity (1,2). Low levels of exposure are unlikely to lead to cumulative toxicity. This conclusion is reached because arsine readily reacts with body constituents such as the sulfhydryl groups of glutathione and the arsine molecule is then converted to inorganic arsenic and hydrogen. Thus, any cumulative toxicity would be the contribution of arsine intake to the body levels of inorganic arsenic. The principal source of human intake of arsenic is from the diet (6,7). Seafood, in particular, is rich in arsenic. An average total dietary intake of soluble (bioavailable) arsenic of 0.19 mg/day has been estimated (6,7).

Conclusions

The basic procedures for calculating dosages have been described. To define a tolerable dose, a finite period of measurement, for example, 0.5 to 5 min, should be established. One must also set an acceptable or tolerable dose of arsine intake, for example, 0.1 mg/day or 0.25 mg/day, then assume a breathing volume commensurate with exposure conditions. The period of exposure should be chosen such that sampling and analytical methods can measure arsine levels in air.

From the toxicologist's point of view, single acute doses of less than 0.25 mg/day are unlikley to cause harm.

References

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A

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July 21, 1984

415/642-0804

Casarett and Doull's TOXICOLOGY

The Basic Science of Poisons

All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy.

PARACELSUS
(1493–1541)

VAB.0001126701

possible effect has been confirmed in animals (Wills, 1966). Epidemiologic studies have suggested that arsenic in drinking water may be related to increased incidence of skin cancer (U.S. Public Health Service, 1962). Extraordinarily high arsenic levels in soil and water have tentatively been linked with a severe form of peripheral arteriosclerosis (blackfoot disease) observed in Taiwan. However, members of the same family, some with blackfoot disease and some without, have similarly high serum arsenic levels (Heydorn, 1970).

Arsine, the hydride of arsenic, is one of the more toxic arsenic compounds. Arsine may be generated when acids are combined with arsenic-containing metals. Poisoning by arsine is the principal source of industrial arsenic poisoning today and has been reported in connection with the refining or processing of tin, lead, and zinc. Poisonings from this source have dire consequences because of the severe hemolytic effect and the inadequacy of available therapy (Foreman, 1962). Arsine, a gas with a slight garlic-like smell detected only above safe levels, produces massive hemolysis and renal failure. Nausea, emesis, diarrhea, disturbance of the vascular bed, pulmonary edema, cyanosis, electrocardiogram abnormalities, hemoglobinuria, and liver dysfunction may occur. There is generally some delay in the onset of symptoms. Exposures as low as 10 ppm have produced delirium, coma, and death. If the exposure is not fatal, the signs of chronic arsenic poisoning may appear. Urine may continue to contain arsenic for some time after poisoning (Parry, 1963; AIHA, 1965).

BARIUM

Occurrence and Use. Barite ($BaSO_4$) and witherite ($BaCO_3$) are the more common mineral forms of barium. Barium is used in various alloys, in paints, soap, paper, and rubber, and in the manufacture of ceramics and glass. Barium fluorosilicate and carbonate have been used as insecticides. Barium sulfate, an insoluble compound, is used as a radiopaque aid to x-ray diagnosis. Barium is relatively abundant in nature and is found in plants and animal tissue. Plants accumulate barium from the soil. Brazil nuts have very high concentrations (3,000 to 4,000 ppm). Some water contains barium from natural deposits.

Absorption, Excretion, Toxicity. The soluble compounds of barium are absorbed and small amounts are retained in the body. Reports indicate the lung has an average concentration of 1 ppm (dry weight). The kidney, spleen, muscle, heart, brain, and liver concentrations are 0.10, 0.08, 0.05, 0.04, 0.03, and 0.03, respectively. Some barium is also found in the skeleton. Studies suggest that barium may be an essential element inasmuch as rats and guinea pigs maintained on barium-free diets fail to grow normally (Underwood, 1971). The soluble compounds once absorbed are transported by the plasma. The biologic half-life is short (less than 24 hours). Feces appear to be the major excretion route of absorbed barium although some is lost through the kidney. The renal tubules reabsorb barium in the filtrate.

The insoluble forms of barium, particularly barium sulfate, are not toxic by the oral route because of minimal absorption. However, the soluble barium compounds are highly toxic, in contrast to calcium and strontium, the other members of this group in the periodic table.

Accidental poisoning from ingestion of soluble barium salts has resulted in gastroenteritis, muscular paralysis, decreased pulse rate, and ventricular fibrillation and extrasystoles. Potassium deficiency occurs in acute poisoning and the heroic measure, treatment with intravenous potassium, appears beneficial. The digitalis-like toxicity, muscle stimulation, and central nervous system effects have been confirmed by experimental investigation. Baritosis, a benign pneumoconiosis, is an occupational disease arising from the inhalation of barium sulfate (barite) dust and barium carbonate. It is not incapacitating, but does produce radiologic changes in the lungs. The radiologic changes are reversible with cessation of exposure (AIHA, 1962; Browning, 1969).

BERYLLIUM

Occurrence and Use. Beryl ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$) is the chief ore of beryllium. Its industrial uses include the hardening of copper, the manufacture of nonsparking alloys for tools, and the manufacture of lightweight alloys and nuclear reactors. It is also used in the manufacture of ceramics and in the electronics industry (transistors, heat sinks, and x-ray and cathode tubes). Gas lantern mantles, when first ignited, volatilize most of the beryllium they contain. Formerly, beryllium was widely used in the manufacture of fluorescent lights and neon signs. The aerospace industry uses beryllium compounds as propellants, providing a possible source of environmental exposure; however, coal combustion is probably the largest source of environmental beryllium contamination.

Absorption, Excretion, Toxicity. Beryllium is not well absorbed when given by any route. Experimental animals may only absorb 1 percent as a maximum. After inhalation exposure beryllium is retained in the lungs and mobilized slowly. In the bloodstream a colloidal beryllium phosphate is formed. In addition, small amounts

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Patty's Industrial Hygiene and Toxicology

THIRD REVISED EDITION

Volume 2A
TOXICOLOGY

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and to copper acetoarsenite (149, 150) or to mixtures of them. Copper acetoarsenite (along with sodium arsenite and Pb and Ca arsenates) figured prominently in the insecticide discussed in Reference 148, with exposures in excess of 5 mg As/m³ until the late 1940s.

Finally, in implicating As as a carcinogen for man, a number of items emerge from the metabolic and epidemiologic studies just summarized that bring into sharper focus what appears to be the actual role of As in cancers from industrial exposures. First, As compounds vary greatly in their capacity to initiate human cancer. As a prominent example, there is no evidence that As_2O_3 per se can induce respiratory cancer in either humans or animals; promoters in the form of smoking or as irritant acid gases, and/or associated metals, Cu, Fe, and Pb, have been identified with excesses of respiratory cancer (145–147); when such promoters are absent, mortality from respiratory cancer shows no excesses over statewide rates. Further substantiation of this assertion is the lack of demonstrated As_2O_3 cancers in animals not exposed to these promoters (138, 139) and the observation of higher dietary intake of Se by animals than by humans without cancer production (136). A second factor, overlooked in past, highly uncritical reviews (151), is the pinpointing of certain arsenicals that can apparently elicit respiratory cancer without promoters; copper acetoarsenite (Paris green) (123, 149) and lead arsenate (148, 150) are two such compounds. Third, those arsenicals, whether requiring promoters or not, must be classed as human carcinogens of low potency; five independent investigators (123, 145, 146, 149, 152) estimated the latent period of exposure to be between 35 and 41 years at exposure levels well above the then-permissible TLV of 0.15 mg As/m³.

3.6 Hygienic Standards

The Threshold Limits Committee of the American Conference of Governmental Industrial Hygienists, recognizing the distinctly different health hazards associated with As_2O_3 production and its handling and use, recommended in 1975 a TLV for As_2O_3 production of 0.05 mg As/m³ with the carcinogenic classification of A1a, and with the proviso that Sb_2O_3 and SO_2 be kept below a ceiling of 0.05 mg Sb/m³ and 5 ppm SO_2. The A1a designation refers to a carcinogenic classification for those substances proven carcinogenic for workers and for which a TLV has been assigned. For As_2O_3, handling and use, a TLV of 0.25 mg As/m³ was recommended.

A NIOSH criteria document, issued in 1973, recommended especially the same limit as that for As_2O_3 production of 0.05 mg As/m³ for "arsenic." In 1975, a revised and updated NIOSH document recommended an air standard of 0.002 mg As/m³, again making no distinction between health hazards associated with different types of exposure.

3.7 Arsine, AsH_3

Arsine is a colorless, flammable gas with a garlic-like odor, now believed to be attributable to its tellurium content. AsH_3 deposits As on exposure to light and moisture.

3.7.1 Sources and Ir

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3.7.2 Physical and C

See Table 29.3.2.

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3.7.1 Sources and Industrial Exposures

The formation and liberation of AsH_3 occurs commonly in the metallurgical industry, because of As contamination of many ores, Zn, Pb, Cu, Sb, Au, Ag, and Sn, when acid contacts these As-bearing ores or metals. AsH_3 may also be liberated when H^+ ion is formed by hydrolysis of As intermetallics, as in the reaction of moisture with calcium arsenide (153); in the process of wetting Al and phosphate dross (154); in Pb refining (155); in the purification of Sn (156); during cyanide extraction of gold (157); in the leaching of Zn from its ores (158); in the cleaning of tanks and furnaces; and from ferrosilicon prepared electrolytically (159, 160).

3.7.2 Physical and Chemical Properties

See Table 29.3.2.

3.7.3 Determination in the Atmosphere

Modification of the method of atomic absorption spectrometry discussed under As (Section 3.4) is applicable to the determination of AsH_3.

3.7.4 Physiological Responses

AsH_3 is a powerful hemolytic agent in both acute and chronic exposure, and in the acute form, mortality rate is high.

Acute Effects in Man. The prominent, first signs of acute poisoning are malaise, abdominal cramps, nausea and vomiting, and a red staining of the conjunctiva (156). The time of onset varies from a few minutes to 24 hr depending on the severity of exposure. Jaundice usually appears on the second or third day. The urine may be colored red or green and in some cases anuria occurs. There may be pigmentation of the skin, pyrexia, and severe anemia; edema of the lungs is common, and in fatal cases, delerium followed by coma. Death usually occurs from myocardial failure a few days after onset of anuria. The anemia is due to hemolysis of mature red cells and not to interference with hematopoiesis. Leukocytosis may also be observed (161). The nonprotein nitrogen level of the blood shows a marked rise when hemoglobinuria is present, indicating kidney damage from hemolysis products. In all cases, fatal or nonfatal, severe or mild, elevation of the T-wave of serial EKGs was found. Survivors followed for as long as 18 months gave evidence that AsH_3 was the causal agent of myocardial degeneration and cardiac failure (162).

Chronic Effects in Man. Very few literature references to chronic AsH_3 exposure are to be found (157, 163). The main differences from acute poisoning are a delay in onset, development of peripheral neuritis, and rapid recovery under treatment, which has included blood transfusions and dithiol administration.

3.7.5 Hygienic Standard and Warning Properties

The recommended TLV of 0.05 ppm as As was adopted in 1961 by the ACGIH on the basis that urinary As values could have resulted from exposure concentrations below 0.25 ppm (164). The odor threshold of 0.5 ppm (165) cannot be considered to serve as a suitable warning property.

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4 BARIUM,

4.1 Source

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4 BARIUM, Ba

4.1 Sources and Production (1)

Barite, natural barium sulfate ($BaSO_4$), occurs in the United States in Alaska, Arkansas, California, Georgia, Missouri, Nevada, and Tennessee, and in Canada and

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DOCUMENTATION OF THE THRESHOLD LIMIT VALUES

FOURTH EDITION

1980

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGENISTS INC.

CINCINNATI, OHIO

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ARSINE

AsH_3

TLV, 0.05 ppm (≈ 0.2 mg/m³)

Arsine is a colorless gas with a disagreeable garlic odor. It has a molecular weight of 77.93, specific gravity of 2.695, melting point of −113.5° C, boiling point of −55° C, a vapor pressure of ≥ 1 atmosphere and decomposes at 230° C. It is soluble in water, slightly soluble in alcohol and alkalies.

It is used in organic synthesis; as a military poison gas; doping agent for solid state electronic compounds.

Most cases of arsine poisoning do not result from the manufacture or use of the gas itself; rather they come from formation of arsine as a byproduct of a chemical reaction involving, in most instances, a base metal, an arsenic impurity, and an acid, or, rarely, a strong alkali.

The extreme acute toxicity of arsine is well known; 250 ppm for 30 minutes is fatal, and 3 to 10 ppm can cause poisoning symptoms in a few hours.[1] Nau[2] found that animals exposed three hours a day to concentrations between 0.5 and 2 ppm developed blood changes in a few weeks.

Published reports of occupational and other poisoning from arsine describe some 310 cases, 74 of them fatal, through 1959.[3] Several reports since 1960 record 28 cases, with two deaths, in this country[4-7] and abroad.[8-10] Typical cases resulted in hemoglobinuria, jaundice and hemolytic anemia.

While data on the actual concentrations causing acute intoxication are lacking, post event concentrations of 70 to 300 ppm (Morse and Setterlind, fatal cases,[11] 5 ppm Kipling and Fothergill[8] and 0.5 ppm Elkins[3] were reported. When urine samples were analyzed at early stages concentrations of arsenic ranging from 0.5 to 2 mg/L were the rule, but occasionally much higher values were found.

Bulmer *et al*[12] reported a number of cases of chronic poisoning, with severe anemia. Urinary arsenic levels averaged 2.3 mg/L, dropping to 0.66 mg/L three days later. Greig *et al*[13] recorded three relatively mild chronic cases with arsenic in urine levels of 0.5 mg/L.

In an extensive clinical study of 14 simultaneous cases of arsine poisoning,[14] tissue arsenic levels, determined by neutron activation analysis, indicated a total body content of arsenic one-third to one-half the lethal dose (300 mg), if one "assumes" that the poisoning action of the hydride follows to some extent that of the trioxide, none of the cases were fatal, but ranged from mild to very severe. Hemolysis and renal damage typified the toxic responses. The most severely poisoned had oliguria for 40 days and required hemodialysis 10 times, but hemolysis disappeared in a few days in all others. In four cases, renal function was impaired for a long time, but was finally restored.

Since arsenic appears to be excreted rather freely in the urine,[15] the levels found in the urine of intoxicated workers could have resulted from inhalations of concentrations below 1 mg/m³ or 0.25 ppm. The recommended TLV of 0.05 ppm (0.2 mg/m³) is the same as that of other inorganic arsenic compounds, which are considered substantially less toxic.

Other recommendations: Cook (1945) 1 ppm; Smyth (1956) and Elkins (1959) 0.05 ppm; USSR (1966) 0.1 ppm; Czechoslovakia (1969) 0.06 ppm.

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ASBESTOS

TLV, Appendix A1a— Recognized Carcinogen

0.5 fiber > 5 μm/cc — Amosite
2.0 fibers > 5 μm/cc — Chrysotile
0.2 fiber > 5 μm/cc — Crocidolite
2.0 fibers > 5 μm/cc — Other forms

According to recent authoritative mineralogical definitions,[1] asbestos is "1) A collective mineralogical term encompassing the asbestiform varieties of various minerals; 2) An industrial product obtained by mining and processing primarily asbestiform minerals."

For the purpose of considering a recommendation for a threshold value of asbestos dust in the workplace, only the second definition above is applicable. Although there are four types of natural mineral fibers that have been in industrial use, only three have been used in the United States: chrysotile, amosite, and crocidolite. The fourth, anthophyllite, is mined and used in Finland. Of the three types of asbestos that have been used in North America, Canadian chrysotile has formed 95% of all natural mineral fibers used, with amosite and crocidolite (both imported from South Africa) constituting the other 5%. It should be noted that chrysotile is classified as a serpentine mineral, whereas the other three types of asbestos are amphiboles.

It is now generally recognized that excessive inhalation of asbestos dust causes chronic inflammations of lung tis-

HYDROGEN SELENIDE

H_2Se

TLV, 0.05 ppm (≈ 0.2 mg/m³), as Se

Hydrogen selenide is a colorless gas with a molecular weight of 80.98 and a specific gravity of 2.12. It has a boiling point of –41.5° C and liquifies at 0° C under a pressure of 6.6 atm. It has a disagreeable odor resembling decaying horseradish, however, it can cause olfactory fatigue and the odor is therefore not reliable as a warning of dangerous levels. Hydrogen selenide is irritating to the eyes and mucous membranes. It is soluble in carbon disulfide, carbonyl chloride and 377 mL H_2Se/100 mL water at 4° C.

Hydrogen selenide is readily produced by the action of acids on inorganic selenides. It can also be formed by the reaction of selenium with organic matter and by the direct combination of the elements.[1]

Cooper and Glover[1] classify hydrogen selenide as one of the most toxic and irritating selenium compounds.

Dudley and Miller[2] reported that single eight-hour exposures of guinea pigs to 1.0 mg/m³ (0.3 ppm) of hydrogen selenide resulted in the death of 50% of the animals. In humans a concentration of 5.0 mg/m³ (1.5 ppm) was found to be intolerable due to eye and nasal irritation while 1.0 mg/m³ (0.3 ppm) caused no irritation with exposure of a few minutes duration. They recommended that any concentration of hydrogen selenide which could be detected by odor should be avoided as being "potentially dangerous". This would reportedly be a level well below 1.0 mg/m³.

Buchan[3] reported five cases of industrial selenosis in laboratory workers due to less than 0.2 ppm of hydrogen selenide. Predominating symptoms were nausea, vomi[illegible] metallic taste in the mouth, alliaceous breath odor, [illegible] extreme lassitude and fatigue. Glover[4] adds running nose and eyes, cough, sneeze, slight tightness of the chest, and ultimately, pulmonary edema to the symptoms caused by hydrogen selenide.

In a treatise on the toxicology of selenium, Glover[4] states that *"hydrogen selenide has never caused a death or an illness lasting more than ten days in a human being"*. The two reasons given for this are, first, that hydrogen selenide is never used in quantity and, second, that hydrogen selenide is rendered to the less toxic red selenium by oxidation on the mucous membranes of the respiratory system.

A TLV of 0.05 ppm is recommended to prevent irritation and maintain the current record of preventing the onset of chronic hydrogen selenide related disease.

Swedish limit (1978) 0.01 ppm.

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HYDROGEN SULFIDE

H_2S

TLV, 10 ppm (≈ 14 mg/m³)

STEL, 15 ppm (≈ 21 mg/m³)

Hydrogen sulfide is a colorless gas with an offensive odor suggesting rotten eggs. It has a molecular weight of 34.08 and a density of 1.19 (air = 1.00). It boils at –60.2° C and freezes at –83.8° C. Hydrogen sulfide is flammable with explosive limits by volume in air of 4.3 and 46%. At 0° C, 437 cc of H_2S will dissolve in 100 mL of water; at 40° C, 180 cc.

Hydrogen sulfide has been widely employed as a reagent in analytical chemistry, and is used in the manufactur of heavy water. It is a source of elemental sulfur. The majority of occupational exposures to H_2S, however, have resulted from its occurrence in petroleum, natural gas, soil, sewer gas, and as a byproduct of chemical reactions, such as may take place in the viscose rayon and certain leather tanning processes.

In high concentrations (500-1000 ppm) hydrogen sulfide acts primarily as a systemic poison, causing unconsciousness and death through respiratory paralysis.[1] A case of polyneuritis and encephalopathy from one day's exposure to a concentration insufficient to cause loss of consciousness has been reported.[2] In lower concentrations (50-500 ppm) hydrogen sulfide acts primarily as a respiratory irritant. It is reported that pulmonary edeme and bronchial pneumonia may follow prolonged exposure at concentrations of the order of 250-600 ppm.[3] At low concentrations the effects on the eye predominate, with conjunctivitis the most common effect, while keratitis frequently occurs.[4,5] Poda,[6] however, in summarizing the effects of 174 exposures to H_2S in a heavy water plant, stated that eye irritation was relatively uncommon. More common findings were nervousness, cough, nausea, headache and insomnia. The reported LC_{50}, one hour inhalation exposure, for rats was 713 ppm and 673 ppm for mice.[7]

The concentrations at which eye effects occur have been variously reported as 100 ppm,[8] 30 ppm,[9,10] 20 ppm,[11] 15 ppm,[12] above 10 ppm,[13] 10 ppm, or even 5 ppm[14] 4–15 ppm.[15]

In view of the fact that five different sources reported eye effects at 20 ppm or below, a TLV less than this level would seem to be indicated. In addition, the experience of three members of the TLV Committee (*) tends to confirm the reports that conjunctivitis may result from exposures at 20 ppm. The limit of 10 ppm corresponds to the working level of 10 ppm used in a heavy water plant, according to Poda.[7]

In its criteria document[16] NIOSH quoted two additional references[17,18] in which eye effects from H_2S at concentrations of 20 ppm or less were reported. It also comm[illegible]ed that exposure at low concentrations for a few hours has been associated with headache, sleep disturbances, nausea, weight loss and other signs and symptoms suggestive

ratory diseases (as estimated by having a measured normal alphatrypsin inhibitory factor in blood).[16]

Some industrial operations using phosgene follow a "work practice" procedure wherein an attempt is made, using engineering techniques to preclude exposure to phosgene. Under this practice, detection of any level of phosgene is considered as evidence that a condition for potential exposure has occurred. Anyone suspected of being exposed under these circumstances to any level is medically evaluated and treated if required. Personnel are trained to recognize the odor of phosgene (odor detection limit is considered to be 0.5 ppm) and report any effluvium.[17]

The National Academy of Sciences lists a 90 day atmospheric limit for use in submarines of 0.05 ppm and a Douglas aircraft continuous atmospheric limit of 0.04 ppm.[18]

Because of its irritating effect on the respiratory tract at levels slightly above 0.1 ppm, but from which tolerance developes, a TLV of 0.1 ppm is recommended.

Other recommendations: Belgium, Holland, Romania, Sweden and Switzerland, 0.05 ppm. Most other countries, including the USSR, as well as the Council of Europe, have adopted the 0.1 ppm or its mg/m³ equivalent.

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PHOSPHINE

PH_3

TLV, 0.3 ppm (≈ 0.4 mg/m³)

STEL, 1 ppm (≈ 1 mg/m³)

Phosphine is a colorless gas with a disagreeable, garlic-like odor. It has a molecular weight of 34 and a density of 1.529. The boiling point is –85° C and the melting point is –133.5° C. It is slightly soluble in water, soluble in alcohol and ether. With an autoignition temperature of 100° F (38° C), it ignites readily at room temperature when other hydrides of phosphorus are present as impurities. Phosphine is formed by the action of moisture on metallic phosphides, or of caustic on elemental phosphorus, and may be present where these substances are handled or stored.

The chief use of phosphine is as a fumigant; it is also a doping agent for electronic components, and used in chemical synthesis.

Muller[1] found that phosphine concentrations of 5 ppm could be tolerated by laboratory animals for two months of 4-hour daily exposures, but fatalities resulted after seven similar exposures at 10 ppm.

Waritz and Brown[2] found the four-hour LC_{50} for rats to be 11 ppm. Repeated 4-hour exposures at 4 ppm slightly reduced weight gain, which returned to normal after 12 days (9 four-hour exposures). The effects of lethal concentrations were typical of respiratory irritation.

According to Harger and Spolyar,[3] 59 cases of phosphine poisoning, including 26 deaths, were recorded between 1900 and 1958. They reported the death of an acetylene generator operator from pulmonary edema. The probable cause was phosphine, which was found after the event in concentrations of the order of 8 ppm, although exposure was only one or two hours per day.

Jones et al[4,5] noted symptoms such as diarrhea, nausea and vomiting, tightness of chest and cough, headache and dizziness in a number of workers exposed intermittently at concentrations up to 35 ppm, but averaging below 10 ppm in most cases. There were no cumulative effects. These authors considered the TLV of 0.05 ppm unnecessarily low, and largely on the basis of this work the limit was changed to 0.3 ppm.

This value does not take into consideration the possibility of chronic phosphorus poisoning from phosphine, which has been stated by several authorities[6-10] to result from prolonged exposure, although no such cases have been documented in the modern literature.

It is recommended that the TLV for phosphine be 0.3 ppm and the STEL be 1 ppm.

Other recommendations: Cook (1945) 1 ppm; Smyth (1956) 0.05 ppm; Elkins (1959) 0.1 ppm; USSR (1967),

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Czechoslovakia (1969) 0.07 ppm; Sweden (1978) 0.3 ppm; West Germany (1978) 0.1 ppm.

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PHOSPHORIC ACID

H_3PO_4

TLV, 1 mg/m³

STEL, 3 mg/m³

Phosphoric acid is a colorless, odorless, non-combustible solid with a molecular weight of 98 and a specific gravity of 1.834 at 18° C. It melts at 42.35° C and has a vapor pressure of 0.03 mm Hg at 20° C. It is very soluble in water. When heated to 213° C, it is converted to pyrophosphoric acid ($H_4P_2O_7$).

Phosphoric acid is of tremendous industrial importance, being used in fertilizers, detergents, foods and beverages, water treatment, pickling and rustproofing metals and for many other purposes.

The recommended threshold limit is based by analogy from comparable experience and data for sulfuric acid. Fumes of phosphorus pentoxide at concentrations ranging from 0.8 to 5.4 mg/m³ were noticeable, but not uncomfortable, and concentrations between 3.6 and 11.3 mg/m³ caused coughing among the inexperienced, but could be tolerated. Concentrations of 100 mg/m³ were unendurable, except to hardened workers.[1] The TLV of 1 mg/m³ is accordingly below the concentration that causes throat irritation among unacclimated workers and well below that which is well tolerated by acclimated workers.

According to the AIHA Hygiene Guide,[2] phosphoric acid is less hazardous than nitric or sulfuric acid.

A maximum concentration of 1 mg/m³ as a TLV, with 3 mg/m³ STEL are recommended.

Other recommendations: Sweden (1978) 1 mg/m³; USSR (1976, P_2O_5) 1 mg/m³.

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PHOSPHORUS (YELLOW)

White phosphorus

P_4

TLV, 0.1 mg/m³

STEL, 0.3 mg/m³

Phosphorus is a white to yellow, soft, waxy, crystalline solid which darkens on exposure to light. The molecular weight is 123.83, specific gravity is 1.83 with a vapor pressure of 0.026 mm Hg at 20° C. It has a melting point of 44° C and a boiling point of 280° C. In moist air it ignites spontaneously at 30° C. One gram is soluble in 400 mL absolute alcohol, 35 mL benzene and 0.0003% soluble in 100 g water at 20° C.

It is used in gas analysis and in the manufacture of rat poisoning, fireworks and fertilizers.

Yellow or white phosphorus is one of the most highly toxic inorganic substances, death reportedly resulting from a single dose of 1 mg/kg.[1] Severe toxic symptoms in man have been reported following a single dose of 15 mg.[2] Inhalation of more than 20 ppm phosphorus vapors by rats (7 hrs/d, 5 d/wk) resulted in severe respiratory irritation and in high mortality rate due primarily to edema of lungs and bronchopneumonia with hyaline membrane formation suggesting the action of inhaled acid.[3]

Growth curves of animals exposed to 13-16 ppm/phosphorus (7 hrs/d, 5 d/wk for 4 months) were the same as controls.[5] Prolonged exposure of the animals produced bone changes uncomplicated by severe kidney or liver damage.[4] Fleming *et al*[6] found that rats injected with 0.05 mg/kg of yellow phosphorus per day eventually developed bone changes. This was the lowest dose tested therefore a zero effect dose was not attained. An increased death rate resulted from a doseage of 0.8 mg/kg/d. Buchanan *et al*[7] found that subcutaneous injection of 0.2-0.4 mg/kg/d to dogs resulted in death within a few days. Chronic poisoning, with liver damage, resulted from repeated doses of 0.1 mg/kg/d.

Inhalation of P^{32} by animals[8] showed a distribution pattern of lungs ≥ bone ≥ liver ≥ kidney. The level in soft tissue dropped rapidly when exposure was stopped, but clearance from bone was slow. Skin and hair also absorbed a considerable amount of P^{32}; results were compatible when P^{32} administered by inhalation or ingestion.

The TLV of 0.1 mg/m³ is probably sufficiently low to prevent acute poisoning, but may not provide a wide margin of safety from undesirable effects. Phosphorus necrosis of the jaw have been reported among workers in the chemical and fireworks industries.[9-11] Dental and medical

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HYGIENIC GUIDE SERIES

AMERICAN Industrial HYGIENE ASSOCIATION

Arsine

(Hydrogen Arsenide, Arseniuretted Hydrogen)

AsH_3
(Revised 1965)

Significant Physical Properties

Arsine is a colorless gas with a slight garlic-like odor.

Molecular weight:	77.93
Boiling point:	−55°C
Specific gravity of gas:	2.7 (air = 1)
Solubility:	20 volumes/100 volumes of water (20°C)
Fire hazard:	Practically nonflammable
At 25°C and 760 mm Hg:	1 ppm = 0.0032 mg/liter 1 mg/liter = 313 ppm

I. Hygienic Standards

A. RECOMMENDED MAXIMAL ATMOSPHERIC CONCENTRATIONS (8 hours): 0.05 parts of vapor per million parts of air by volume (ppm).[1] This is based on both human experience and animal data.[2,3]

B. SHORT EXPOSURE TOLERANCE: One to ten parts per million for an hour is probably dangerous.[3,4]

C. ATMOSPHERIC CONCENTRATION IMMEDI-

The Committee wishes to acknowledge the preparation of the medical information section of this Guide by the Industrial Hygiene and Clinical Toxicology Committee of I.M.A.

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ATELY HAZARDOUS TO LIFE: Uncertain, but probably greater than 70 ppm.[3]

II. Toxic Properties

A. INHALATION: Both chronic and acute exposures to arsine are dangerous. Chronic exposure to low concentrations (less than 0.5 ppm) may cause jaundice and hemolytic anemia. With acute exposures, the symptoms are delayed. The first indication of arsine intoxication is the passage of dark red urine usually four to six hours after the exposure followed by abdominal or back pain and anuria. Although the primary effect is the destruction of red blood cells, pulmonary edema is encountered from severe exposures.[3,5,6,7,8,9] The mechanism of arsine poisoning has been studied and reported by Pernis and Magistretti.[10] Based on their experiments performed with erythrocytes, a close correlation was shown to exist between the fall of glutathione-SH (GSH) and hemolytic action of AsH_3. It is important to note that a certain amount of GSH is necessary to maintain the erythrocyte structure intact. They concluded that the hemolytic activity of arsine is due to its ability to reduce the erythrocyte GSH.

B. EYE CONTACT: Few observations have been made of the local effects of arsine on the eyes probably because systemic injury occurs long before eyes would be injured. Even in fatal cases of arsine poisoning, no irritation of the eyes or respiratory tract was reported.[11]

III. Industrial Hygiene Practice

A. INDUSTRIAL USES: None.

B. OCCURRENCES: Arsine may occur in metal pickling operations when the metal contains arsenic, as a result of certain metal drossing operations, as an impurity in acetylene and as a result of exposing any inorganic arsenic compound or solution to nascent hydrogen.

C. EVALUATION OF EXPOSURES:

1. *Air sampling and analysis:*
   (a) Direct field methods: Detector tubes[12] are available commercially for making rapid, on-the-spot surveys. However, these devices should be used only after a full knowledge of their sensitivity and limitations is established.
   (b) Laboratory methods: Semi-quantitative determination of arsine in air may be made using mercuric bromide test papers:[3] by the Gutzeit Method,[13] after collecting the gas in water in an all-glass device; by the method of Jacobs and Nagler[14] or by the ACGIH Method.[15] Unless routine analyses for trace amounts of arsenic are made, the Gutzeit Method is not recommended. Many variables affect the results and necessitate the preparation of a separate standard curve for each group of samples.[16]

2. *Sampling and analysis of biological materials:* Urinary levels above 0.5 mg of arsenic per liter in individuals exposed to arsine may be indicative of harmful exposure. In the case of single exposures even lower levels might be significant, but dietary factors must be ruled out before significance is attached to any increase in the arsenic content of urine.

   Biological samples can be digested with a mixture of nitric-sulfuric-perchloric acids without the need of reflux and determined by the silver diethyldithiocarbamate or by the iodine microtitration.[17] A molybdenum blue method has been used in the past.[18,19]

D. HAZARDS AND THEIR RECOMMENDED

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RECOMMENDED

CONTROL: The atmospheric concentration of arsine in the workroom must be maintained below 0.05 ppm through the use of process enclosures and or adequate ventilation. Metal dross containing arsenic must be kept dry.

Respiratory protective equipment should not be employed as a routine control measure but rather to supplement control procedures during emergency situations. A self-contained breathing apparatus approved by the U. S. Bureau of Mines is recommended for emergency use. The universal gas mask will provide respiratory protection against low concentrations of arsine.

IV. Medical Information

A. EMERGENCY TREATMENT: Persons suffering from overexposure should be removed immediately from contaminated atmosphere, placed in bed and provided with medical care promptly. Those known to have been exposed to high concentrations of arsine should be hospitalized immediately. Both symptomatic and supportive therapy should be used as in other types of acute hemolytic anemia.

B. SPECIAL PROCEDURES: The hemoglobinuria is a reversible phenomenon once exposure has ceased. Kidney damage is delayed by several hours to a few days depending on the dose received. Red cell destruction gives rise to increased potassium levels in the extracellular spaces.

Therefore, treatment is directed at the potassium intoxication by using exchange resins and peritoneal dialysis. Fluid intake should be restricted to equal fluid output. Alkali may be needed to combat acidosis. If serum potassium is not elevated, dialysis should be reserved for use when the blood urea nitrogen (BUN) is over 100 mg %.

BAL (dimercaprol 2,3-dimercaptopropanol) is not effective in arsine poisoning. However, 2,3-dimercaptopropyl ethyl ether and certain dithiols are reported to be capable of preventing the hemolytic action of arsine and affording significant protection in experimental animals if administered shortly after exposure.[20] Dimercaptopropyl ethyl ether is not readily available. Early exchange transfusion has been recommended although there have been no reports of its utilization in human intoxication.[21]

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HANDBOOK
of
BIOLOGICAL DATA

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THE NATIONAL ACADEMY OF SCIENCES
THE NATIONAL RESEARCH COUNCIL

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248. LUNG VENTILATION: VERTEBRATES

Values, unless otherwise noted, are averages of means for the resting state. Ranges in parentheses are estimate "d" of the 95% range (cf Introduction).

	Species	Respiration Frequency breath/min	Tidal Volume[1] ml	Minute Volume[2] l
	Man (Homo sapiens)			
1	Premature	33	12.4(8.4-17.3)	0.41(0.28-0.58)
2	Newborn, asleep	43(24-116)	16.7(10.0-27)	0.72(0.43-1.41)
3	Adult ♂	11.7(10.1-13.1)[3]	750(757-895)[4]	7.4(5.8-10.3)[5]
4	♀	11.7(10.4-13.0)[6]	330(285-393)[7]	4.5(4.0-7.0)[8]
5	Cat (Felis catus)	26	12.4	0.32
6	Cow (Bos taurus)	31(27-40)	2850(2200-3800)	86(59-104)
7	Dog	18(11-38)	320(251-432)	5.2(3.3-7.4)
8	Goat	19.0	310	5.7
9	Guinea pig (Cavia cobaya)	90(69-104)	1.8(1.0-3.9)	0.16(0.09-0.38)
10	Hamster (Mesocricetus auratus)	74(33-127)	0.83(0.42-1.2)	0.054(0.025-0.084)
11	Horse (Equus caballus)[9]	11.9(10.6-13.6)	9000(8520-9680)	107
12	Manatee, Florida (Trichechus latirostris)	7.0(6.0-8.0)	(5000-9000)	45(35-60)
13	Marmot (Marmota marmota)	8.0[10]	22.0[11]	0.17[12]
14	Monkey (Macaca mulatta)	40(31-52)	21(9.8-21)	0.86(0.31-1.41)
15	Mouse (Mus musculus)	163(84-230)	0.15(0.09-0.23)	0.023(0.011-0.036)
16	Porpoise (Tursiops truncatus)	1.1(0.9-1.3)	9,000(8,000-10,000)	9.7(9.0-10.4)
17	Rabbit (Lepus cuniculus)	51(38-60)	21(19.3-24.6)	1.07(0.80-1.14)
18	Rat (Rattus norvegicus)		1.5(1.4-1.6)	0.100(0.075-0.130)
19	Rat, cotton (Sigmodon hispidus)	94(75-115)	0.35(0.24-0.70)	0.04(0.023-0.071)
20	Sloth (Choloepus hoffmanni)	13.0		0.84(0.80-1.8)
21	Sloth (Bradypus griseus)	(4.5-8.0)		0.49(0.33-0.73)
22	Turtle (Malaclemys centrata)	3.7	14.0	0.05

/1/ Air inspired per breath. /2/ Respiration frequency x tidal volume. /3/ Resting. Light work, 17.1(15.7-18.2); heavy work, 21.2(18.6-23.3). /4/ Resting. Light work, 1670(1510-1770); heavy work, 2030(1900-2110). /5/ Resting. Light work, 29(27-31); heavy work, 60(50-40). /6/ Resting. Light work, 19; heavy work, 30(25-33). /7/ Resting. Light work, 860(836-885); heavy work, 880(490-1270). /8/ Resting. Light work, 16.3(15.9-16.8); heavy work, 24.5(17.3-32.0). /9/ Percheron, gelding. /10/ Hibernating, 0.68. /11/ Hibernating, 13(11.3-15.0). /12/ Hibernating, 0.009.

249. PULMONARY VALUES, EQUATIONS, DEFINITIONS: MAN

Part I: LUNG AIR VOLUME, RECUMBENT

Values are from smoothed curves plotted from mean values, and are for the following conditions: 37°C, ambient pressure, saturated with water vapor. Ranges in parentheses are from smoothed curves of ranges, and are estimate "d" of the 95% range (cf Introduction).

	Age yr	Total Lung Capacity[1] L	Vital Capacity[2] L
1	Six ♂	1.6(1.3-2.1)	1.2(0.9-1.7)
2	♀	1.6(1.3-2.1)[3]	1.2(0.9-1.7)[3]
3	Ten ♂	2.5(2.2-3.1)	1.9(1.6-2.4)
4	♀	2.5(2.2-3.1)[3]	1.9(1.6-2.4)[3]
5	Fourteen ♂	4.6(3.5-6.1)	3.7(3.0-4.7)
6	♀	3.6(2.8-4.3)[3]	2.7(2.2-3.5)[3]
7	Eighteen ♂	5.9(4.3-8.0)	4.6(4.0-5.8)
8	♀	4.1(3.1-5.3)[3]	3.0(2.4-4.2)[3]
9	Twenty ♂	6.3(4.3-8.5)	4.9(4.0-6.0)
10	♀	4.2(3.1-5.3)[3]	3.0(2.4-4.4)[3]
11	Twenty-five ♂	6.4(4.3-9.0)	4.9(3.3-6.0)
12		4.2(3.1-5.4)	3.0(2.2-4.2)[3]
13	Thirty-five ♂	6.1(4.3-8.5)	4.5(2.3-6.0)
14	♀	4.3(3.0-5.6)	3.0(2.0-3.8)
15	Forty-five ♂	5.9(4.3-8.0)	4.3(2.8-5.1)
16	♀	4.3(2.9-5.7)	2.9(1.8-3.7)
17	Fifty-five ♂	5.8(4.3-8.0)	4.1(2.6-5.5)
18	♀	4.2(2.8-5.7)	2.7(1.6-3.5)
19	Sixty-five ♂	5.6(4.3-7.0)	3.7(2.5-5.0)
20	♀	3.9(2.8-5.5)[3]	2.3(1.4-3.4)[3]
21	Seventy-five ♂	5.2(4.3-7.0)	3.3(2.5-4.5)
22	♀	3.9(2.8-5.0)[3]	2.2(1.4-3.3)[3]

/1/ Total volume of air contained in lungs after deepest possible inspiration. Total lung capacity minus vital capacity equals residual capacity or residual air. /2/ Volume of air expired in deepest possible expiration following deepest possible inspiration. /3/ Values are estimates; a sex difference may exist.

Part II: INTRAPULMONIC (INTRA-ORAL) PRESSURE

Values are for males only. Mean lung volumes are given as per cent of vital capacity. Ranges in parentheses are estimate "b" of the 95% range (cf Introduction).

	Volume %	mm Hg
	Maximum Expiratory Pressure	
1	9.7	42(14.7-68)
2	25.0	52(10.9-94)
3	44	70(38-109)
4	60	90(47-133)
5	75	93(58-128)
6	83	107(74-144)
7	100	120(86-145)
	Maximum Inspiratory Pressure	
8	3.9	86(47-125)[1]
9	21.7	75(46-103)[1]
10	35	63(26-101)[1]
11	56	57(26-88)[1]
12	76	45(16.8-73)[1]
13	91	24(2.2-49)[1]
	Relaxation Pressure	
14	0	-19.2(-32 to -6.6)
15	13.9	-8.5(-15.5 to -1.5)
16	31	-1.3(-9.9 to 7.3)
17	51	4.1(-1.9 to 10.1)
18	72	10.5(1.9 to 19.1)
19	87	14.9(0.3 to 29.5)
20	100	20.6(10.2 to 31)

/1/ Negative pressure.

Part III: INTRAPLEURAL PRESSURE

Values are cm H_2O relative to atmospheric pressure.

	Condition	Inspiration	Expiration
1	Adults, at rest	-5 to -10	-3 to -5
2	Deep breathing	-30	
3	Müller's[1]	-50 to -60	
4	Valsalva's[2]		60
5	Normal[3]	-0.7(-0.5 to -1.0)	0.4(0-1.0)
6	Labored[3]	-1.1(-0.5 to -1.5)	2.4(1.0 to 3.0)
7	Normal[4]	-1.3(-1.0 to -1.5)	2.6(1.0 to 3.5)
8	Infants, end of inspiration	-5	
9	End of expiration		0

/1/ Inspiration with glottis closed. /2/ Expiration with glottis closed. /3/ Air pressure at posterior pharynx. /4/ Air pressure at tracheal bifurcation.

Part IV: PREDICTION EQUATIONS

Equations are applicable for the following conditions: 37°C, ambient pressure, saturated with water vapor. MBC=maximum breathing capacity, L/min; SA=body surface area, sq m; V=pulmonary ventilation, L/min; W=weight, kg; VC=vital capacity, L; H=height, cm; A=age, yr.

	Subject	Equation
1	Infants, <1 week, resting	$V = 0.139 + 0.00367\ W^1$
2	Males, 10-17 yr	$VC = 0.0562\ H + 0.0097\ AW - 6.27$
3	140-160 cm	$VC = 0.0492\ H - 4.82$
4	160-190 cm	$VC = 0.0799\ H - 9.75$
5	Males, standing	$VC = 0.025\ H^2$
6	Females, standing	$VC = 0.020\ H^2$
7	Males	$MBC = [86.5 - (0.522 \times A)] \times SA^3$
8	Females	$MBC = [71.3 - (0.474 \times A)] \times SA^3$
9	Both sexes	$MBC = H \times (1.24 - 0.0089\ A)^3$

/1/ Weight in ounces. /2/ Age correction for vital capacity: 46-55 yr = -4%; 56-65 yr = -8%; 66-75 yr = -16%; over 75 yr = -30%. /3/ Values vary widely with equipment and laboratory methods.

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Based on Brazil Hazardous Waste Rules.

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"WORLD BANK AND IFC GUIDELINES FOR IDENTIFYING, ANALYZING AND CONTROLLING MAJOR HAZARD INSTALLATIONS IN DEVELOPING COUNTRIES"

February 1985

Office of Environmental and Scientific Affairs
Projects Policy Department

WORLD BANK
Washington, D.C.

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December 1984 A

DRAFT

WORLD BANK and IFC GUIDELINES FOR IDENTIFYING, ANALYZING, AND CONTROLLING MAJOR HAZARD INSTALLATIONS IN DEVELOPING COUNTRIES

Preamble

The European Economic Community have taken a lead in developing guidelines controlling major accident hazards of certain industrial activities. The Environmental Council of the Economic Community met on June 24, 1982 and adopted such a directive which member states were required to comply with by January 8, 1984.

Impetus was given to the European Community to consider the need to control major hazards by, in particular, four serious industrial accidents; the Flixborough explosion in 1974 killed 28 workers, injured 89 people and caused widespread damage to housing in the vicinity of the plant; the disaster at Beek in Holland in 1975, an explosion and fire killed 14 people on site following the release of propylene at the refinery. The two other cases were at Seveso and Manfredonia in Italy in 1976, where highly toxic substances were released contaminating the surrounding districts, and raising implications regarding the health of people exposed to the toxic releases.

Recently the explosion of natural gas in Mexico City killing some 450 people and the toxic gas release at Bhopal in India killing more than 2,500 people has highlighted the urgent need for the World Bank to adopt similar guidelines to those developed by the EEC. These latter two incidents illustrate the even greater risks that must be controlled in installations producing hazardous substances in developing countries.

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1.0 Introduction

1. These guidelines are based substantially on the EEC directive on the major accident hazards of certain industrial activities and regulations promulgated under the United Kingdom Health and Safety at Work Act.

2. Industrial activities involving certain dangerous substances have the potential to give rise to serious injury or damage beyond the immediate vicinity of the work place. These activities have commonly come to be known as "Major Hazards". These guidelines are concerned with the protection of the health and safety of persons in the workplace and persons outside the plant boundary, as well as the protection of the environment. Furthermore, they apply generally to industrial processes, storage and transport of hazardous material, but do not apply to nuclear or to extraction or mining operations or to licensed hazardous waste disposal sites. According to the guidelines, persons in control of activities involving certain dangerous, explosive, flammable and toxic substances must demonstrate that major accident hazards have been recognized, and that measures have been taken to prevent accidents and to control and minimize the consequences of those that do occur.

3. It is the object of these guidelines to provide a framework in which a developer can supply evidence and justification for the safe operation of the proposed industrial activity. It is not the objective of these guidelines to provide details or specific methods of analysis, safe operating procedures, etc. which are the contents of a Major Hazard and Risk Assessment Manual currently in preparation by the World Bank.

4. In summary, those guidelines identify two distinct levels of analysis and control of a hazardous industrial activity. The first lower level of control classifies an installation handling certain varying quantities of dangerous materials a "Notifiable Installation" At the highest level of control an installation is classified as a "Full Safety Case" In between these two cases will be installations requiring a progressively increasing level of analysis and control.

2.0 Potential Industrial Hazards

5. Although 'major hazard (or major accident)' is defined in the guidelines and includes the phrase 'a major emission, fire or explosion', the definition uses a number of phrases which need to be interpreted. An occurrence will be a major accident if it meets the following conditions.

(a) that it leads to a serious danger to people or the environment;

(b) that it results from uncontrolled developments in the course of an 'industrial activity'; and

(c) that it involves one or more 'dangerous substances'.

6. 'Serious danger to persons' should be taken to mean death or serious injury including to health, or the threat of death or serious injury, whether caused immediately by the accident (e.g., collapse of a populated building caused by an explosion) or as a delayed effect (e.g., pulmonary oedema following some hours after exposure to a toxic gas), and affecting or potentially affecting people inside and outside the installation. It is emphasized that the accidents, actual or potential, should be major ones distinguished from other serious accidents not only by the severity of the casualties but by the numbers of them, or by the physical extent of the damage.

7. The reference to delayed effects is not intended to include the cumulative effects of frequent exposure to small amounts of the dangerous substance and, therefore, brief excursions slightly above the routine control limits for toxic substances should not be considered as major accidents.

8. 'Serious danger to the environment' should be taken to mean a significant, relatively long-lasting (but not necessarily irreversible) effect on plants or animals on land, in the air or in the water which has the potential to lead to a serious danger to man. For example, serious pollution by a toxic substance of a water course used for drinking water could pose a threat to man.

9. 'Uncontrolled developments' should be taken to mean that the occurrences of concern are likely to develop quickly; to be outside the normally expected range of operating problems; to present only limited opportunity for preventive action; and to require any such action to be in the nature of an emergency response. It also serves to indicate that the guidelines are concerned with acute rather than chronic events, i.e., uncovenanted or unusual rather than covenanted or regular releases of the dangerous substance. Similarly, 'a major emission' refers to a relatively large, sudden and unconvenanted release of the dangerous substance from its normal containment.

10. It is clearly possible to identify, using a pragmatic approach, the installations and activities that pose the main threat of a major accident. It is also relatively easy to decide whether an event was a major accident after it has occurred. It is much less easy to define 'major accident' for the purpose of making predictions, as the developer is required to do in his safety analysis as an essential step in demonstrating the adequacy of the measures taken to prevent such accidents. The following examples outline events which may be taken, prima facie, as major accidents:

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(a) any major fire giving rise to thermal radiation at the site or plant boundary exceeding 5 kw/m^2 for several seconds;

(b) any release actual or potential, of a hazardous substance where the total quantity released is a significant proportion of the quantity which invokes the guidelines, e.g., releases of kilogram quantities of Group A toxic substances; ton quantities of other toxic substances; ton quantities of pressurized or refrigerated flammable gases; or tens of tons of flammable liquid;

(c) any vapour or gas explosion which could give rise to blast overpressures at the site or plant boundary exceeding 0.5 bar; and/or

(d) any explosion of a reactive or explosive substance which could cause damage to buildings or plant outside the immediate vicinity sufficient to render them or it inoperative for weeks.

11. These estimates should include all the quantities of each substance present whether it is in pure form or part of a mixture. However, the substances should be in a form capable of giving rise to major accident hazards, e.g., no account should be taken of ammonia unless it is anhydrous or is in water solution containing more than 50% by weight, nor should account be taken of stored chlorinated potable water.

3.0 Identification System for Major Hazards

3.1 Introduction

12. The proposed system for identifying major hazards is based on the quantity (or inventory) of hazardous substance stored or processed at an industrial site or in transit. In this context the term "installation' is used to describe the general activity which may result in a major accident hazard. The term "installation" is defined further in Appendix I.

13. A two level system is used to identify potential major hazard installations. The first is defined as the threshold quantity of hazardous substance above which it is necessary for the developer to notify the World Bank of a potential major hazard (see Section 3.2). The second level is defined as the quantity of hazardous substance above which it is necessary for the developer to undertake a full safety case assessment (see Section 3.3).

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14. The quantities specified in Sections 3.2 and 3.3 relate to the total quantity of substance held on site. A developer may be involved in an activity in which the quantity of a hazardous substance varies over a period, due either to seasonal demand, or because the site is complex and includes a number of processes each of which has an inventory which varies from day to day or even hour to hour. In such cases the manufacturer should make an estimate of the quantity of each substance liable to be on site and a decision as to whether the requirements of Sections 4, 5, and 6, apply should be based on the maximum anticipated quantity.

15. The estimation of the quantity of a substance at a site should include all the amounts which are likely to be on the site under the control of the same manufacturer. In the case of production and process activities, this will include quantitites in manufacture, use or processing, and associated storage (i.e., the storage that is used in connection with the process). Account should also be taken of any quantities in pipelines on the site and in internal transport operations. These estimates should include all quantities of any dangerous substance whether the substance is in pure form or part of a mixture or present as a by-product. For example, if a chemical plant manufactures a hazardous substance, the estimate of the total quantity should take account of the quantities which are present in reaction mixtures and purification processes together with the quantities which are present in storage. In certain processes there may be circumstances where a significant quantity of a dangerous substance can only be produced if abnormal conditions develop in the plant. If such an event can reasonably be predicted, then this should be taken into account in estimating the overall quantity of the substance on a site. An example of this type of situation was the production of a significant quantity of TCDD (dioxin) when conditions of excess temperature and pressure developed in a plant producing 2,4,5-trichlorophenol at Seveso.

16. It should be noted that when estimating the quantity of hazardous substance to assess whether the site becomes subject to these requirements, it is necessary to add the quantity of substance in process to the quantity in associated storage together with any amounts of the same substance in any installation within 500 metres owned by the same manufacturer. If the nearby installation is more than 500 metres away then it is only necessary to add the quantities if these are such that there could be, in foreseeable circumstances, an aggravation of the major accident hazard. It is realized that in some cases interpretation of this 500 meter requirement might be difficult but reasons for inclusion or exclusion should be clearly specified.

17. Although an industrial activity involves, or is liable to involve, hazardous substances, this does not of itself make the activity subject to these World Bank guidelines. The hazardous substance

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must be present under circumstances which could give rise to a major accident. Thus, it may be possible for a developer to argue that a major accident cannot, in fact, arise. It may be that the physical state of a substance or the way in which it is distributed round the site may avoid the possibility of some types of accidents. This may be particularly relevant to many of the toxic substances which are involatile liquids or solids. These may not have the potential to cause a major accident unless some special factor, such as energy contained in a pressurized system, is present, although spillage into water courses may still remain a problem.

3.2 Threshold Quantities for Notification

18. A list of hazardous substances at quantities above which the World Bank must be notified is presented in Appendix II. This Appendix is divided into four sections, namely:

(A) Very toxic substances;

(B) Other toxic substances;

(C) Highly reactive substances and explosives; and

(D) Flammable substances.

19. The criteria for the two groups of toxic substances, namely groups (A) and (B) of the Schedule are given in terms of the toxic effects on populations of specified experimental animals, though in two cases in addition to fulfilling these criteria the substances must have physical and chemical properties capable of entailing major accident hazards. This is taken to mean that the properties are such that the toxic substance could be easily distributed throughout the environment if containment is breached, for example, a gas or highly volatile liquid or a solid which might be ejected from a pressurized reactor. A substance has to satisfy only one of the three criteria for ingestion, percutaneous (i.e., through the skin) or inhalation toxicity in the tables to qualify. In the case of Class (A) substances indicative criteria are provided and the World Bank should be informed if any such substance is or could be involved, irrespective of the quantity.

20. In the case of Class (B) toxic substances quantities have been specified for some of the more common substances. However, for those unnamed substances which fall into the indicative criteria given in Appendix II, quantities exceeding 1 ton should be notified.

21. Notification also is required for any process using plant at a pressure greater than 50 bars when the product of the volume of the pressure system in cubic meters and the pressure in bars exceeds 10,000.

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3.3 Quantities Requiring Full Safety Case Study

22. A list of hazardous substances, at quantities above which a full safety case study is required is presented in Appendix III. It consists of a list of hazardous substances divided into four groups: toxic substances in quantities of one ton or less, toxic substances in quantities of greater than one ton, highly reactive and explosive substances and flammable substances, and gives quantity thresholds for the purposes of Section 4.2.

23. There are a large number of toxic substances in Appendix III ranging from dioxin at 1 kg to sulphur dioxide at 1000 tons. Many of the substances are pesticides and a typical example is warfarin at 100 kg. The group of highly reactive substances includes materials such as peroxides and ethylene oxide. Typical explosive substances listed are nitrate esters such as nitroglycerine and trinitroaromatic compounds such as trinitrotoluene (TNT).

24. Most of the entries in the Schedule refer to a specific hazardous substance by a chemical name such as hydrogen cyanide or hydrogen sulphide but some entries are in the form of a generic definition. Typical generic definitions used are salts, powders and compounds, and examples of these are the entry for beryllium (which includes powders and compounds) and the entry for arsenic pentoxide (which includes arsenic (V) acid and salts). In other cases the entry in Appendix III refers to a particular concentration of a solution of a hazardous substance such as formaldehyde. Nitrocellulose has an entry in Appendix III which is qualified by the nitrogen content.

25. Hazardous substances in Appendix III are only affected by requirements of Section 4.2 if they are in a state capable of presenting a major accident hazard. For example, nickel powder or cobalt naphthenate stored in drums would not be expected to present a major accident hazard.

4.0 Implementation of the Guidelines

26. The guidelines require that proof of safe operation be available at any time. Developers must show that they have identified the major accident hazards arising from their activities and have taken adequate steps to prevent such major accidents in design, layout and siting will provide adequate steps to prevent such major accidents during operations and will provide people on site with the information, training and equipment to ensure their safety.

27. The activities which are covered fall into one of two categories. The first is wide ranging and covers any industrial process using a substance which is either toxic, flammable or explosive in quantities greater or equal to those given in Appendix II threshold quantities (i.e., a notifiable installation). The second

includes activities involving substances in quantities greater or equal to those in Appendix III (i.e., installations requiring a full safety case study).

4.1 Requirements for Notifiable Installations

28. A developer who has control of a "notifiable installation" to which this guideline applies shall at any time provide evidence including documents to show that he has:

(a) identified the major accident hazards; and has

(b) taken adequate steps to:

(i) prevent such major accidents and to limit their consequences to persons and the environment; and

(ii) provide persons working on the site with the information, training and equipment necessary to ensure their safety.

4.1.1 Identification of Major Accident Hazards

29. The evidence should identify the dangerous substance and the approximate quantity present on the site; i.e, where the substance is held and in what state; and should show the main ways in which it could be released from its normal containment in sufficient quantities and in such a manner as to create a major accident. Guidance on the definition of major accident is given in Section 2. If it is judged that the industrial activity is not capable of creating a major accident, the reasons should be clear from the evidence.

4.1.2 Steps to Prevent Major Accidents and to Limit Their Consequence

30. The evidence should include an outline of the primary preventive measures (proper design, construction, inspection, maintenance and operation of storage vessels and process plant); any special measures which prevent potentially hazardous excursions from normal operating conditions from proceeding to a major accident (e.g. alarms, trips, dump tanks, scrubbers, etc.); and measures aimed at an incipient major accident to limit its consequences (e.g. water curtains, emergency procedures, etc.). The preventive measures should be linked to the appropriate major accident hazards already identified in the evidence. It is not necessary to specify the preventive measures in detail. For example, it will be sufficient to record that storage and process vessels are designed to the appropriate Standard, or Code of Practice, rather than to list each vessel and the particular standard to which it was designed. The important fact is that the ready availability of the evidence demonstrates the commitment of the developer to safe operation.

4.1.3 Steps to Provide Information, Training and Equipment for Persons Working on Site

31. The developer is required by these guidelines to provide his employees and certain others working on his site with the information, training and equipment necessary to ensure their safety. The evidence should refer to the arrangements made to ensure that the necessary information, training and equipment for major accidents are given to persons working on site. As with the evidence on preventive measures, it is not necessary to specify precisely what the relevant information, training and equipment is, but instead the evidence should show the steps taken to ensure that:

(a) persons working on the site have been informed of the major accident hazards of the activity and have been informed of and received training about the relevant emergency procedures;

(b) operators with particular responsibility for the activities that present a major accident hazard have been trained to a level appropriate to those responsibilities; and

(c) any special equipment necessary for use in an emergency (e.g., breathing apparatus, or fire fighting equipment provided to ensure the integrity of a means of escape has been provided).

32. The detail of the presentation will depend on specific circumstances, for example, the potential extent of hazardous impact, the location, population density, meteorology, topography, as well as special local circumstances.

4.2 Requirements for the Full Safety Case

33. For major hazard installations handling dangerous materials in excess of the quantities listed in Appendix III a "full safety case" study is required. A full safety case study must show that the activity will be carried on safely; it includes a description of the major accident hazards that could arise from a manufacturer's activities and the controls that are exercised to prevent them or to limit their consequences. 'Major accident' is defined in Section 2 and guidance is given on the definition in this section. The guidance that follows discusses some of the general issues that bear on the full safety case. There also may be instances when it will be necessary to carry out a full safety case study for quantities of dangerous materials less than those listed in Appendix III, as possibly indicated by the'preliminary assessment study carried out under Section 4.1.

4.2.1 Objectives

34. The objectives of the full safety case are:

(a) to identify the nature and scale of the use of dangerous substances at the installation;

(b) to give an account of the arrangements for safe operation of the installation, for control of serious deviations that could lead to a major accident and for emergency procedures at the site;

(c) to identify the type, relative likelihood, and broad consequences of major accidents that might occur; and

(d) to demonstrate that the developer has appreciated the major hazard potential of the company's activities and has considered whether the controls are adequate.

35. In addition, the work that the developer does in preparing his safety case study should enable him to provide the competent authority responsible for making emergency plans outside the installation with an estimate of the scale and consequences of the realization of the hazards, in accordance with the requirements of these guidelines (seeSection 5).

4.2.2 The Content of the Full Safety Case

36. The full safety case is essentially an abstract of relevant information about the major hazard aspects of the activities from a much more extensive body of information. This body of information will include plant design specifications, operating documents, maintenance procedures, and information derived from the examination of the major hazard potential by means of techniques such as hazard surveys, hazard and operability studies, hazard analysis and risk assessment. (Details of these techniques will be given in a forthcoming World Bank Manual).

37. The information required in the safety case falls into two broad categories: first, factual information about the site, its activities and surroundings, and second, the core of the safety case- reasoned arguments and judgments about the nature, likelihood and scale of potential major accidents which may occur at the installation and the means to prevent these hazards being realized.

38. It is not possible to specify precisely what the second part of the full safety case should contain because the complexity of the potential hazards will vary greatly from site to site; indeed, any such specification would be too elaborate for many installations because it would need to cover the most complex cases. Thus, the

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requirements below are in broad terms, allowing a flexible approach by firms to the discursive and judgmental, as distinct from the factual part of the full safety case. The essence of the full safety case, and the reason behind the choice of that term, is that the onus lies on the developer to assess his own hazards, take measures to control them adequately, and then to present his conclusions.

39. The full safety case should, therefore, contain sufficient information about the major accident potential of the developers activities to enable judgment to be made whether the significant risks have been identified and are being properly managed. In some instances it may be necessary to ask for information in the full safety case to be supplemented by further information, but ideally the aim should be to provide a safety case which stands on its own as a demonstration that major accident hazards are being adequately controlled.

40. The full safety case should provide adequate justification for its conclusions, either by setting out the sources of the evidence for a particular argument, or by recording the principal assumptions in sufficient detail to enable them to be challenged if it emerges that they are critical to the conclusions of the safety case. For example, a full safety case may state that the integrity of pressure vessels has been assured by the strict application of appropriate design codes, operating duties, maintenance and inspection procedures, in support of an assumption that the sudden failure of pressure vessels has been dismissed as a possible cause of a major accident. A safety case may also perhaps say that the risk of an aircraft crashing on the installation is insignificant in comparison with other causes of a major accident, because the site is well separated fom the nearest airport and air traffic lanes. Clearly, the amount of evidence required on each aspect of the safety case will vary according to the importance of that aspect and in particular the consequences of the particular accident being considered.

4.2.3 Information to be Included in a Full Safety Case

41. The report shall contain the following:

4.2.3.1. Information relating to substances listed in Appendix III:

(i) The name of the substance as given in Appendix III or for substances included in Appendix III under a general designation the name corresponding to the chemical formula of the substance;

(ii) A general description of the analytical methods available to the developer for determining the presence of the substance, or references to such methods in the scientific literature;

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(iii) A brief description of the hazards from the substance;

(iv) In cases where the substance may be isolated from process vessels, its percentage concentration, and the main impurities and their percentages.

4.2.3.2 Information relating to the installation:

(i) A map of the site and its surrounding area to a scale large enough to show any features that may be significant in the assessment of the hazard or risk associated with the site;

(ii) A scale plan of the site showing the locations and quantities of all significant inventories of the hazardous substances;

(iii) A description of the processes or storage involving the hazardous substance and an indication of the conditions under which it is normally held;

(iv) The maximum number of persons likely to be present on site; and

(v) Information about the nature of the land use and the size and distribution of the population in the vicinity of the activity to which the safety case relates.

4.2.3.3 Information relating to the management system for controlling the activity:

(i) The staffing arrangements for controlling the activity with the name(s) of the person(s), and if appropriate his (their) deputies or the competent body responsible for safety and authorized to set emergency procedures in motion and to inform outside authorities;

(ii) The arrangements made to ensure that the means provided for the safe operation of the activity are properly designed, constructed, tested, operated and maintained;

(iii) The arrangements for training of persons working on the site.

4.2.3.4 Information relating to the potential major accidents:

(i) A description of the potential sources of a major accident and the conditions or events which could be significant in bringing one about;

(ii) A diagram of any plant or plants in which the activities are carried on sufficient to show the features which are significant as regards the potential for a major accident or its prevention or control;

(iii) A description of the measures taken to prevent, control or minimize the consequences of any major accident;

(iv) Information about the emergency procedures laid down for dealing with a major accident occuring at the site;

(v) Information about prevailing meteorological conditions in the vicinity of the site; and

(vi) An estimate of the number of people on site who may be particularly exposed to the hazards considered in the written report.

Further details on these items are given in Appendix IV, while a flow chart (Figure 1) summarizes the procedures outlined above in Sections 4.1 and 4.2.

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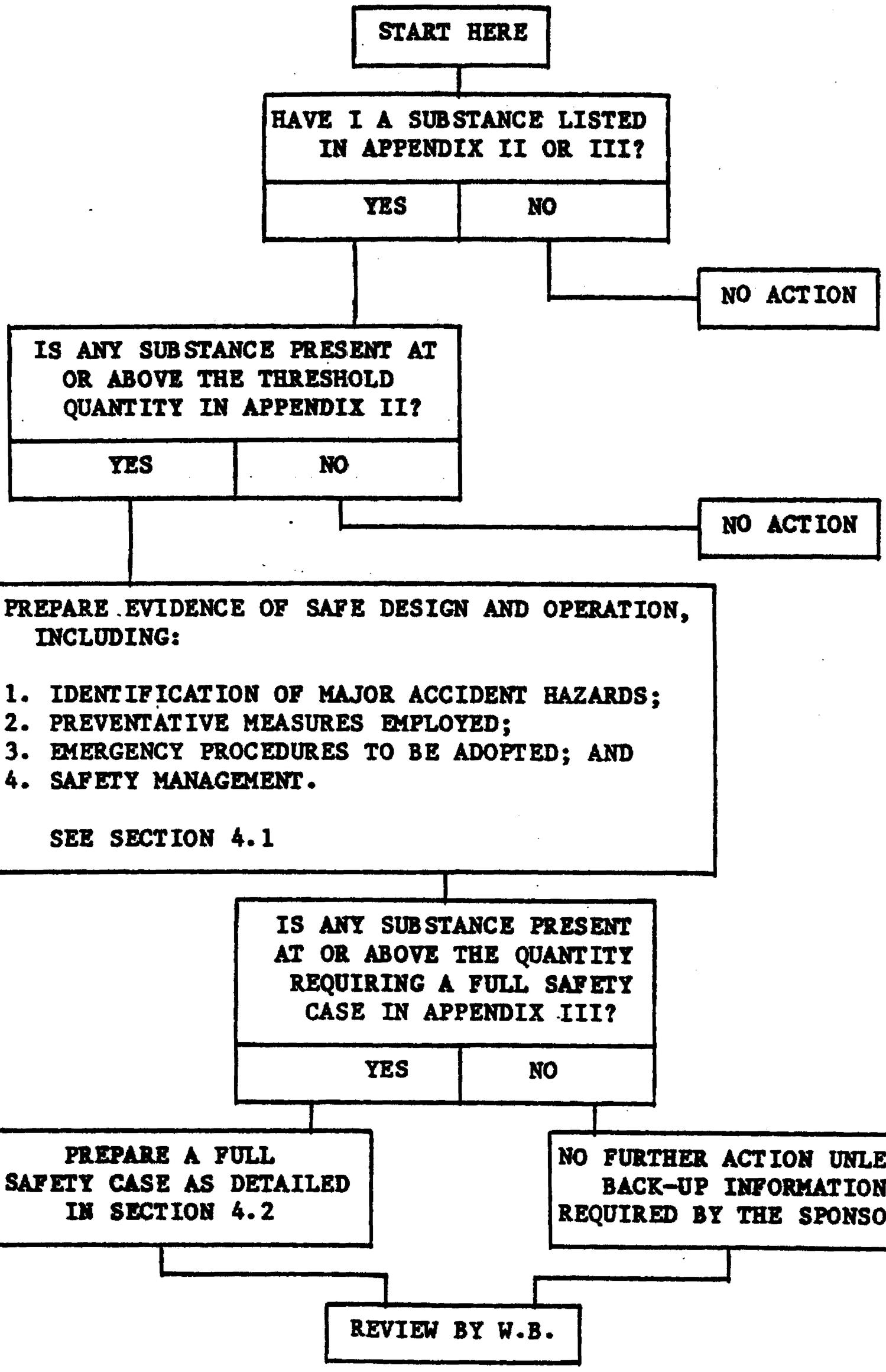
Figure 1: Procedures for Safety Analysis and Control of Major Hazard Installation



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5.0 Emergency Plans

42. The guidelines require developers to prepare an adequate emergency plan for dealing with major accidents that may occur on their sites.

5.1 On-Site Emergency Plans

43. It is not the intention of these guidance notes to explain in detail how to prepare an on-site emergency plan. The detail and scope of the emergency plan will vary according to the complexity of the site and it is, therefore, not appropriate to prescribe here precisely what the plan should cover. The developer will need to consider the potential major accidents which will be identified in the safety assessment (Section 4) to ensure that the plan takes account of them. Useful guidance in preparing the emergency plan may be found in the booklet 'Recommended Procedures for Handling Major Emergencies' published by the Chemical Industries Association.

44. The developer should ensure that the on-site emergency plan is compatible with the off-site emergency plan which should be drawn up by the local authority. The on-site and off-site plans should be interlocked to ensure that they provide a comprehensive and effective response to emergencies.

45. The plan should include the name of the person responsible for safety on the site (usually the site or plant manager) and, if different, the name of the person who is authorized to set the plan in action.

46. The developer should keep the on-site emergency plan up-to-date, and to ensure that it takes account of any changes in operations on the site that might have a significant effect on the plan. The developer is also required to make sure that people on the site who are affected by the plan are informed of its relevant provisions. This should include not only those people who may have duties under the plan, but also those who may need to be evacuated from the site in an emergency, including contractors and visitors.

5.2 Off-Site Emergency Plan

47. The intention is that emergency plans should be drawn up or amended by the local authority after consultation with bodies who might be able to contribute information or advice. Such consultation is seen as an important aspect in the preparation of adequate emergency plans - this has been well demonstrated in the case of plans which are in operation in many areas of the world. Obviously the developer must be consulted about the major accident hazards and the possible consequences, and any special emergency measures.

48. A two-way flow of information is required between the developer and the local authority. Information from the developer is needed to enable the authority to draw up the off-site emergency plan; information from the authority should be available to the developer when he prepares the on-site emergency plan.

6.0 Restrictions on Development in the Vicinity of Major Hazard Installations

49. The extent of the safety buffer zone or restrictive development zone which should be specified for a major hazard installation may be determined using a non-site specific approach, or on a "case-by-case" basis. Regardless of the approach adopted, the great importance of maintaining a restricted development, safety buffer zone is clearly shown by the experience in Mexico and Bhopal in India, as well as at other hazardous installations around the world.

50. A non-site specific approach to setting the limits of a safety buffer zone such as has been adopted in the UK and Europe may provide useful guidance for the full safety case. Using this approach two zones are established at distances of 1 km and 1-2 km from the major hazard installation. Within 1 km no developments are allowed which increases the population at risk (the safety case study determines if the existing land use in the safety buffer zone is acceptable or not at the planning stage of the major hazard installation). Thus, the population at most risk can be controlled. In the 1-2 km zone only limited development is allowed involving a low density of population (such as warehouses and light industry, etc.) and certainly no shanty towns, hospitals, schools, or high-rise developments are allowed.

51. A "case-by-case" approach may be indicated for notifiable installations that do not meet the full case study criteria. For these installations a broad risk assessment taking into account local factors, size and storage, process, management, etc. may indicate that a smaller safety buffer zone is required. A procedure has been developed for estimating local community risk to aid in determining safety buffer zones for notifiable major hazard installation. Suitable procedures will be presented in detail in the forthcoming World Bank Manual on Hazard and Risk Assessment.

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Appendix I

Definition of the Term "Installation"

1. Installations for the production or processing of organic or inorganic chemicals using for this purpose, in particular:

- alkylation
- amination by ammonolysis
- carbonylation
- condensation
- dehydrogenation
- esterification
- halogenation and manufacture of halogens
- hydrogenation
- hydrolysis
- oxidation
- polymerization
- sulphonation
- desulphurization, manufacture and transformation of sulphur-containing compounds
- nitration and manufacture of nitrogen-containing compounds
- manufacture of phosphorus-containing compounds
- formulation of pesticides and of pharmaceutical products

2. Installations for the processing or organic and inorganic chemical substances, using for this purpose, in particular:

- distillation
- extraction
- solvation

- mixing

- drying

3. Installations for distillation, refining or other processing of petroleum or petroleum products.

4. Installations for the total or partial disposal of solid or liquid substances by incineration or chemical decomposition.

5. Installations for the production or processing of energy gases, for example, LPG, LNG, SNG.

6. Installations for the dry distillation of coal or lignite.

7. Installations for the production of metals or non-metals by the wet process or by means of electrical energy.

8. Storage of dangerous materials identified in Appendices II and III.

9. Transportation Distribution Systems:[1]/

- Pipelines (quantities between block valves)
- Shipping and terminal facilities (including in-land waterways)
- Road
- Rail

1/ There may be an overlap between these guidelines and many national and international regulations, and guidelines concerning transfer of hazardous substances. When a national or international regulation applies to a particular installation, the World Bank guidelines should be used only as a check to ensure that all safety aspects have been identified and controlled.

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Appendix II

List of Hazardous Substances Requiring Notification

(A) "Very Toxic" Substances

The following indicative criteria is used to identify any "very toxic" substance requiring notification. These criteria are independent of the quantities of the substance stored, or processed, or may be formed by an unwanted by-product reaction.

Very toxic substances are defined as:

- substances which correspond to the first line of the table below;

- substances which correspond to the second line of the table below and which, owing to their physical and chemical properties, are capable of entailing major-accident hazards similar to those caused by the substance mentioned in the first line:

	LD 50 (oral) (1) mg/kg body weight	LD 50 (cutaneous) (2) mg/kg body weight	LC 50 (3) mg/l (inhalalation)
1	LD 50 ≤5	LD 50 ≤10	LC 50 ≤0.1
2	5<LD 50≤25	10<LD 50≤50	0.1<LC 50≤0.5

Note: (1) LD 50 oral in rats.
Note: (2) LD 50 cutaneous in rats or rabbits.
Note: (3) LC 50 by inhalation (four hours) in rats.

(B) Other Toxic Substances

(1) The following quantities of toxic substances represent the threshold above which notification and compliance with the requirements of Section 4.1 are required.

Named Substances	Notifiable Quantity Tonnes
Phosgene	2
Chlorine	10
Hydrogen fluoride	10
Sulphur trioxide	15
Acrylonitrile	20
Hydrogen cyanide	20

Carbon disulphide	20
Sulphur dioxide	20
Bromine	40
Ammonia (anhydrous or as solution containing more than 50% by weight of ammonia)	100

(2) In addition to the above named substances the following indicative criteria is used to identify other unnamed toxic substances which are stored or processed in quantities of greater than 1 tonne:

LD 50 (oral) (1) mg/kg body weight	LD 50 (cutaneous) (2) mg/kg body weight	LC 50 (3) mg/l (inhalalation)
25 <LD 50 <200	50 <LD 50 <400	0.5 <LC 50<2

Note: (1) LD 50 oral in rats.
Note: (2) LD 50 cutaneous in rats or rabbits.
Note: (3) LC 50 by inhalation (four hours) in rats.

(C) Highly Reactive Substances

(1) The following quantities of "highly reactive" substances represent the threshold above which notification and compliance with the requirements of Section 4.1 are required.

Named Substances	Notifiable Quantity Tonnes
Hydrogen	2
Ethylene oxide	5
Propylene oxide	5
tert-Butyl peroxyacetate	5
tert-Butyl peroxyisobutyrate	5
tert-Butyl peroxymaleate	5
tert-Butyl peroxy isopropyl carbonate	5
Dibenzyl peroxydicarbonate	5
2,2-Bis(tert-butylperoxy) butane	5
1,1-Bis(ter-butylperoxy) cyclohexane	5
Di-sec-butyl peroxydicarbonate	5
2,2-Dihydroperoxypropane	5
Di-n-propyl peroxydicarbonate	5
Methyl ethyl ketone peroxide	5
Sodium chlorate	25
Liquid oxygen	500

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General Groups of Substances	Notifiable Quantity Tonnes
Organic peroxides (not listed above)	5
Nitrocellulose compounds	50
Ammonium nitrates	500

(2) In addition to the above named substances, the following indicative criteria is used to identify potential explosive hazards, irrespective of materials stored or processed.

- Substances which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene.

(D) Flammable Substances

The following quantities of "flammable" substances represent the threshold, above which notification and compliance with the requirements of Section 4.1 are required.

Class of Flammable Substances	Notifiable Quantity Tonnes
1. Flammable Gases:	
Gas or any mixture of gases which is flammable in air and is held as a gas.	15
2. Liquefied Gases and Flammable Liquids in Process at Pressure and/Temperature Above Ambient Levels:	
A substance or any mixture of substances which is flammable in air and is normally held in the installation above its boiling point (measured at 1 bar absolute) as a liquid or as a mixture of liquid and gas at a pressure of more than 1.4 bar absolute. (e.g. LPG's).	25 being the total quantity of substances above the boiling points whether held singly or in mixtures.
3. Refrigerated Liquefied Gas	
A liquefied gas or any mixture of liquefied gases, which is flammable in air, has a boiling point of less than 0°C (measured at 1 bar absolute) and is normally held in the installation under refrigeration or cooling at a pressure of 1.4 bar absolute or less (e.g., LNG).	50 being the total quantity of substances having boiling points below 0°C whether held singly or in mixtures.

4. **Highly Flammable Liquids**

A liquid or any mixture of liquids not included in items 1 to 3 above, which has a flash point of less than 21°C.	10,000

Appendix III

List and Quantities of Hazardous Substances Requiring a Full Safety Case

The quantities set out below relate to each installation or group of installation belonging to the same deveoper/operator (where the distance between the installation is not sufficient to avoid) any aggravation of major accident hazards. These quantities apply in any case to each group of installations/activities belonging to the same developer/operator where the distance between the installations is less than approximately 500 meters.

Group A:

Very Toxic Substances (Quantity < 1 Tonne) (See definition Appendix II, Page 20)	Quantity for Application of Requirements Given in Section 4.2
Aldicarb	100 kilograms
4-Aminodiphenyl	1 kilogram
Amiton	1 kilogram
Anabasine	100 kilograms
Arsenic pentoxide, Arsenic (V) acid and salts	500 kilograms
Arsenic trioxide, Arsenious (III) acid and salts	100 kilograms
Arsine (Arsenic hybride)	10 kilograms
Azinphos-ethyl	100 kilograms
Azinphos-methyl	100 kilograms
Benzidine	1 kilogram
Benzidine salts	1 kilogram
Beryllium (powders, compounds)	10 kilograms
Bis (2-chloroethyl) sulphide	1 kilogram
Bis (chloromethyl) ether	1 kilogram

Carbofuran	100 kilograms
Carbophenothion	100 kilograms
Chlorfenvinphos	100 kilograms
4-(Chloroformyl) morpholine	1 kilogram
Chloromethyl methyl ether	1 kilogram
Cobalt (powders, compounds)	100 kilograms
Crimidine	100 kilograms
Cyanthoate	100 kilograms
Cycloheximide	100 kilograms
Demeton	100 kilograms
Dialifos	100 kilograms
OO-Diethyl S-ethylsulphinylmethyl phosphorotioate	100 kilograms
OO-Diethyl S-ethylthiomethyl phosphorothioate	100 kilograms
OO-Diethyl S-isopropylthiomethyl phosphorodithioate	100 kilograms
OO-Diethyl S-propylthiomethyl phosphorodithioate	100 kilograms
Dimefox	100 kilograms
Dimethylcarbamoyl chloride	1 kilogram
Dimethylnitrosamine	1 kilogram
Dimethyl phosphoramidocyanidic acid	1 tonne
Diphacinone	100 kilograms
Disulfoton	100 kilograms
EPN	100 kilograms
Ethion	100 kilograms
Fensulfothion	100 kilograms

Fluenetil	100 kilograms
Fluoroacetic acid	1 kilogram
Fluoroacetic acid, salts	1 kilogram
Fluoroacetic acid, esters	1 kilogram
Fluoroacetic acid, amides	1 kilogram
4-Fluorobutyric acid	1 kilogram
4-Fluorobutyric acid, salts	1 kilogram
4-Fluorobutyric acid, esters	1 kilogram
4-Fluorobutyric acid, amides	1 kilogram
4-Fluorocrotonic acid	1 kilogram
4-Fluorocrotonic acid, salts	1 kilogram
4-Fluorocrotonic acid, esters	1 kilogram
4-Fluorocrotonic acid, amides	1 kilogram
4-Fluoro-2-hydroxybutyric acid	1 kilogram
4-Fluoro-2-hydroxybutyric acid, salts	1 kilogram
4-Fluoro-2-hydroxybutyric acid, esters	1 kilogram
4-Fluoro-2-hydroxybutyric acid, amids	1 kilogram
Glycolonitrile (Hydroxyacetonitrile)	100 kilograms
1, 2, 3, 7, 8, 9-Hexachlorodibenzo-p-dioxin	100 kilograms
Hexamethylphosphoramide	1 kilogram
Hydrogen selenide	10 kilograms
Isobenzan	100 kilograms
Isodrin	100 kilograms
Juglone (5-Hydroxynaphthalene-1,4-dione)	100 kilograms
4,4' - Methylenebis (2-chloroaniline)	10 kilograms

Methyl isocyanate	1 tonne
Mevinphos	100 kilograms
2-Naphthylamine	1 kilogram
Nickel (powders, compounds)	100 kilograms
Nickel tetracarbonyl	10 kilograms
Oxydisulfoton	100 kilograms
Oxygen difluoride	10 kilograms
Paraoxon (Diethyl 4-nitrophenyl phosphate)	100 kilograms
Parathion	100 kilograms
Parathion-methyl	100 kilograms
Pentaborane	100 kilograms
Phorate	100 kilograms
Phosacetim	100 kilograms
Phosphamidon	100 kilograms
Phosphine (Hydrogen phosphide)	100 kilograms
Promurit (1-(3,4-Dichlorophenyl)-3-triazenethiocarboxamide	100 kilograms
1,3-Propanesultone	1 kilogram
1-Propen-2-chloro-1,3-diol diacetate	10 kilograms
Pyrazoxon	100 kilograms
Selenium hexafluoride	10 kilograms
Sodium selenite	100 kilograms
Stibine (Antimony hydride)	100 kilograms
Sulfotep	100 kilograms
Sulphur dichloride	1 tonne
Tellurium hexafluoride	100 kilograms

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TEPP	100 kilograms
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1 kilogram
Tetramethylenedisulphotetramine	1 kilogram
Thionazin	100 kilograms
Tirpate (2,4-Dimethyl-2,3-dithiolane-2-carboxaldehyde O-methylcarbamoyloxime)	100 kilograms
Trichloromethanesulphenyl chloride	100 kilograms
1-Tri(cyclohexyl)stannyl-1H-1,2,4-triazole	100 kilograms
Triethylenemelamine	10 kilograms
Warfarin	100 kilograms

Group B:

Other Toxic Substances (Quantity > 10 tonnes) (See definition Appendix II, Page 20)

Acetone cyanohydrin (2-Cyanopropan-2-ol)	200 tons
Acrolein (2-Propenal)	200 tons
Acrylonitrile	200 tons
Allyl alcohol (2-Propen-1-ol)	200 tons
Allylamine	200 tons
Ammonia	500 tons
Bromine	500 tons
Carbon disulphide	200 tons
Chlorine	50 tons
Ethylene dibromide (1,2-Dibromoethane)	50 tons
Ethyleneimine	50 tons
Formaldehyde (concentration > 90%)	50 tons
Hydrogen chloride (liquefied gas)	250 tons
Hydrogen cyanide	20 tons

Hydrogen fluoride	50 tons
Hydrogen sulphide	50 tons
Methyl bromide (Bromomethane)	200 tons
Nitrogen oxides	50 tons
Phosgene (Carbonyl chloride)	20 tons
Propyleneimine	50 tons
Sulphur dioxide	1000 tons
Tetraethyl lead	50 tons
Tetramethyl lead	50 tons

Group C.1:

Highly Reactive Substances and Explosives

Acetylene	50 tons
Ammonium nitrate (where it is in a state which gives it properties capable of creating a major accident hazard)	5000 tons
2,2-Bis(tert-butylperoxy) butane concentration > 70%)	50 tons
1,1-Bis (tert-butylperoxy) cyclohexane (concentration > 80%)	50 tons
tert-Butyl peroxyacetate (concentration) > 70%)	50 tons
tert-Butyl peroxyisobutyrate (concentration > 80%)	50 tons
tert-Butyl peroxy isopropyl carbonate (concentration > 80%)	50 tons
tert-Butyl peroxymaleate (concentration > 80%)	50 tons
tert-Butyl peroxyphivalate (concentration > 77%)	50 tons

Dibenzyl peroxydicarbonate (concentration > 90%)	50 tons
Di-sec-butyl peroxydicarbonate concentration > 80%)	50 tons
Diethyl peroxydicarbonate (concentration > 30%)	50 tons
2,2-Dihydroperoxypropane (concentration > 30%)	50 tons
Di-isobutyryl peroxide (concentration > 50%)	50 tons
Di-n-propyl peroxydicarbonate (concentration > 80%)	50 tons
Ethylene oxide	50 tons
Ethyl nitrate	50 tons
3,3,6,6,9,9-Hexamethyl-1,2,4,5-tetroxacyclononane concentration > 75%)	50 tons
Hydrogen	50 tons
Methyl ethyl ketone peroxide (concentration > 60%)	50 tons
Methyl isobutyl ketone peroxide (concentration > 60%)	50 tons
Peracetic acid (concentration > 60%)	50 tons
Propylene oxide	50 tons
Sodium chlorate	250 tons

Group C.2:

Explosive Substances

Barium azide	50 tons
Bis (2,4,6-trinitrophenyl) amine	50 tons
Chlorotrinitrobenzene	50 tons
Cellulose nitrate (containing > 12.6% nitrogen)	100 tons

Cyclotetramethylenetetranitramine	50 tons
Cyclotrimethylenetrinitramine	50 tons
Diazondinitrophenol	10 tons
Diethylene glycol dinitrate	10 tons
Dinitrophenol, salts	50 tons
Ethylene glycol dinitrate	10 tons
1-Guanyl-4-nitrosaminoguanyl-1-tetrazene	10 tons
2,2',4,4',6,6'-Hexanitrostilbene	50 tons
Hydrazine nitrate	50 tons
Lead azide	50 tons
Lead styphnate (Lead 2,4,6-trinitroresorcinoxide)	50 tons
Mercury fulminate	10 tons
N-Methyl-N,2,4,6-tetranitroaniline	50 tons
Nitroglycerine	10 tons
Pentaerythritol tetranitrate	50 tons
Picric acid (2,4,6-Trinitrophenol)	50 tons
Sodium picramate	50 tons
Styphnic acid (2,46,6,-Trinitroresorcinol)	50 tons
1,3,5-Triamino-2,4,6-Trinitrobenzene	50 tons
Trinitroaniline	50 tons
2,4,6-Trinitroanisole	50 tons
Trinitrobenzene	50 tons
Trinitrobenzoic acid	50 tons
Trinitrocresol	50 tons

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2,4,6-Trinitrophenetole	50 tons
2,4,6-Trinitrotoluene	50 tons

Group D:

Flammable Substances

Flammable substances as defined in D.1 below	200 tons
Flammable substances as defined in D.2 below	50,000 tons
Flammable substances as defined in D.3 below	200 tons

D.1 Flammable Gases

Substances which in the gaseous state at normal pressure and mixed with air become flammable and the boiling point of which at normal pressure is 20°C or below.

D.2 Highly Flammable Liquids

Substances which have a flash point lower than 21°C and the boiling point of which at normal pressure is above 20°C.

D.3 Flammable Liquids at High Temperatures and Pressure

Substances which have a flash point lower than 55°C and which remain liquid under pressure, where particular processing conditions, such as high pressure and high temperature, may create a major accident hazard.

Appendix IV

Background Information for the Full Safety Case Study (Section 4.2)

Section 4.2.3 specifies the details required to be included in a full safety case study prepared in accordance with these guidelines.

The details required in Section 4.2.3 are discussed below as separate items but it is for the developer to determine the most appropriate or convenient method of presenting the required information. In particular, general issues (e.g., pressure vessel inspection arrangements) could be referenced and any variations or departures from the generally accepted practice will suffice.

The item-by-item guidance given below in relation to Section 4.2.3 is by example rather than by lists of topics to be covered. The latter approach suffers the twin disadvantages of not being truly comprehensive while at the same time giving the impression that each listed topic is of equal importance. In practice, the depth of information required on each topic will vary according to the circumstances of the individual installation.

Sections 4.2.3.1 and 4.2.3.2 require factual information about the dangerous substances and the installations handling them. Section 4.2.3.3 relates to the management control of the activity. Section 4.2.3.4 requires information about the sources and nature of potential major accidents and the measures taken to prevent and control them.

Section 4.2.3.1 (Substance Name)

The information required under this sub-heading is concerned with identifying the dangerous substance which qualifies the activity or storage for the requirement to make a full safety case study; the wording should be self-explanatory.

Section 4.2.3.1 (Monitoring Methods)

Where standard analytical methods are used by the firm this item need only identify the method and any departures from it. Provision of gas detection equipment could be referred to here or left if appropriate to the discussion of preventive measures under Section 4.2.3.4.

Section 4.2.3.1 (Hazards of the Substances)

Information given under this sub-item should cover (a) the route of the harm to man (skin contact, inhalation or ingestion for toxic substances, and flame contact, thermal radiation or blast for flammable or explosive substances); (b) the dose-response relationship, where known, citing standard published references as appropriate (e.g., the Chemical Industries Association's table of the toxic effects of chlorine at various concentrations); and (c) the nature of the trauma, where this is not obvious (e.g., chloracne from exposure to dioxin).

In relation to the hazards from the substance to the environment, information is not required about the obvious effects of flame or blast from explosive or flammable substances. For toxic substances such information as is readily available should be given or be referred to, including the route of the harm (e.g., the pollution of water courses); the effect on flora and fauna which may be exposed; and an indication of the substance's persistence.

Section 4.2.3.1 (Composition of Process Streams)

This item requires information about the composition of the substance so that the effects of diluents or impurities which have a significant effect on the hazard can be assessed. For example, where an organic peroxide is present in an activity, the name and percentage of any stabilizer should be given.

The presence of significant quantities of impurities could also affect the behaviour of a substance and these impurities and their percentages should also be identified. An example would be the alteration of the toxic properties of chloromethyl methyl ether by the presence of bis (chloromethyl) ether. It is not necessary to list the minor components of mixtures being processed where these have an insignificant effect on the potential hazard (e.g., a hydrocarbon mixture might be described as 70% butane, 25% propane, 5% higher hydrocarbons).

Section 4.2.3.2(1) (Location)

This map is required to indicate where the installation is located, showing its position in relation to local geographic features, such as roads and towns. In general it will be sufficient to use the latest available map or maps on a scale which includes both the site and the surrounding features. Changes (such as a new motorway) which have occured since the printing of the map and which are known to the firm should be shown; it is not intended that this should involve any extended research effort. For many sites a scale of 1 to 10,000 will be appropriate.

Section 4.2.3.2(ii) (Plot Plan)

The intention of this item is to identify clearly, both in location and quantity, the main parts which contribute to the total inventory of the dangerous substance. In addition, the plan should be annotated to indicate the lesser quantities which make up the stated total. For example, an estimate of the quantity of the substance which is present in pipework around a particular plant should be made.

It may be convenient to combine the response to this item with that to Section 4.2.3.4, and in particular, Section 4.2.3.4 item (ii).

Section 4.2.3.2(iii) (Process/Flow Description)

The intention of this requirement is that a sufficient description of the process be given to enable discussion on later items to be understood and placed in context. The amount of description required will depend on the complexity of the process. For example, a water treatment plant using chlorine will require only a brief account of the water dosing process, whereas a chemical plant producing qualifying quantities of a very toxic substance as an intermediate will require sufficient information to enable the critical aspects of the process chemistry to be understood. In this latter example, the information will be supplemented by the information given under Section 4.2.3.4 and it will be for the manufacturer to determine the most appropriate method of presentation.

The conditions under which the substance is normally held should be stated, including the physical state and pressure and/or temperature at the main stages of storage and process, e.g., butane is held in storage as a refrigerated liquid at 0°C; vaporized in a direct-fired evaporator and fed as a gas to a process vessel at 10 bar, 90°C.

Section 4.2.3.2(iv) (Personnel on site)

The number given should be accompanied by sufficient explanation to show how it was derived. Account should be taken of the number of people who may be present at shift changeover; people who may be employed from the site but who may be present only for short periods (e.g., sales staff or delivery drivers); regular visitors to the site (e.g., contractors); and casual visitors. Exact numbers are not required.

Section 4.2.3.2(v) (Local Land Use and Population Distribution)

The information required is about the use of land or water surrounding the activity and the location of people who may be affected in the event of a major accident. This can be provided by

annotations on a suitable map, indicating broad categories of land use (e.g., dwellings, other factories, schools, sports facilities, agricultural land, etc.). It is not necessary to give numerical estimates of population in the areas covered by each category, though any unusually high densities such as shanty towns, blocks of flats should be marked as such.

The choice of the phrase 'in the vicinity of' rather than definite distances is intended to allow for flexible interpretation in relation to the potential hazard. For example, for a flammable liquid tank farm the 'vicinity' might be less extensive than for bulk chlorine storage. A degree of judgment is thus called for and a brief explanation should be given of the choice of vicinity illustrated on the map.

Section 4.2.3.3 (Management)

The aim of this item is to demonstrate that the developer has a proper management system and technical staff to control the major hazard aspects of his activities. The required information is general, insofar as it relates to the management control of the site as a whole, in contrast to the greater detail that may be needed under Section 4.2.3.4 to demonstrate that there are adequate arrangements to prevent and control particular hazardous events. The extent of the response to this item should be seen against its importance in providing a framework in which the rest of the safety case may be set and which will to some degree color the credibility of the whole submission.

Section 4.2.3.3(i) (Responsible Person and Staffing)

A description of the management structure should be given which covers reporting relationship and the experience and qualifications of staff at the different levels. It is important to show how accountability for decisions which affect the potentially hazardous activity is assigned to staff who have the appropriate level of expertise and the relevent professional discipline. Reference should also be made to the developer's policy towards the appointment of competent deputies to cover key positions.

This section should also cover the arrangements which management have set up for identifying and dealing with safety issues arising from the potentially hazardous activity, with references as appropriate to the group, division and site safety policies, and the role of safety representatives and safety committees. This section should include an account of how management decisions about the potentially hazardous activity are made with due regard for their safety implications, and how these decisions are monitored.

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Section 4.2.3.3 (ii) (Quality Control for Safety)

The importance of the containment of dangerous substances is such as to require an adequate account of the management of the engineering system. This should include a discussion of the manufacturer's approach to the design of important plant items and safety systems (e.g., use of standard or company codes); the arrangements for quality assurance; the inspection and testing procedures (who carries them out? how frequently? who decides on the necessary action in the event of deficiencies being discovered? who monitors these actions and how?); the provision of operating manuals and instructions and the procedures for revising them in the event of process changes; the procedures for ensuring that plant modifications are adequately designed, installed and tested; and the system for general maintenance.

The response to this item should not contain lengthy abstracts from written company procedures, but should aim to give a coherent justification for the system of engineering controls exercised over the potentially hazardous activity.

Section 4.2.3.3(iii) (Training)

Information should be given about the standards of relevant training, both on- and off-the-job, for people on site with a significant role in the control or operation of the major hazard activity, including the senior management and engineering staff involved. A brief account should also be given about how training needs are identified and met.

Section 4.2.3.4 (Potential Major Accidents)

The response to this item will provide the heart of the full safety case. Though the information required is specified in some detail, it will be essential for developers to interpret this item with commonsense and flexibility. As noted above in the general discussion of the term, 'full safety case', it will be for the developer to judge which potential major accidents should be investigated and discussed in his safety case, and then to decide the extent of the evidence necessary to support his conclusions.

Section 4.2.3.4(i) (Identification of Potential Major Hazard Events)

This item requires the manufacturer to identify the ways in which a major accident might occur. "Major accident" is defined in Section 2 and guidance on its interpretation is given in this section. Suitable techniques for identification are hazard and operability studies, engineering flow chart review, and review of past accidents and near misses. The concept of the safety case allows the developer the opportunity to argue in the response to this item that

his activities are not capable of giving rise to a major accident, provided that they are satisfied that such an argument can be fully and properly justified. In some cases, a submission of this sort may be relatively easy to support. For example, a toxic hazardous substance may be stored in separate cylinders, and the quantity in each one may not be sufficient to give rise to a major accident. If the cylinders were disposed around the site so that the possibility of of an incident affecting them simultaneously could be ruled out, then the argument that a major accident cannot arise on the site may be reasonably straightforward. In other cases the evidence necessary to justify such an argument may prove to be as extensive as a response to this item which accepts that major accidents may occur, and then goes on to describe how they are prevented; it will be for the manufacturer to decide initially which option better fulfills the objectives of the safety case. If it can be shown that the activity is not capable of giving rise to a major accident, then the remaining parts of Section 4.2.3.4 need not be answered. It is in this section that the quantification of the magnitude of hazardous events and their frequency by means of hazard and risk analysis techniques are required.

In most cases it will be necessary to describe the potential sources of a major accident. Storage and process vessels which contain significant quantities of the dangerous substance should be examined for the most probable ways in which their inventories may be released, and these should include consideration of, spontaneous failure (due to original defects or those arising in the course of operation); failure due to excursions from normal operating conditions (including such matters as operator error, loss of services, and failure of control devices); failure due to events elsewhere on site (e.g., fire, explosion); and failure due to external events (e.g., flooding, seismic activity). For a complex chemical or petrochemical works or a refinery, where the number of vessels and pipes for individual plants may be very large (but built to common standards), it may be appropriate to be more selective in examining the potential sources of a major accident by considering only the largest vessels in detail and then referring to smaller vessels or groups of vessels in general terms.

<u>Section 4.2.3.4(ii) (Process Flow Diagrams)</u>

This item calls for judgment by the developer as to which sections of the plants containing the dangerous substance need to be illustrated in diagrammatic form. Such diagrams should show the process vessels, storage facilities and instrumentation on the plants concenred in sufficient detail to enable the discussion under Section 4.2.3.4 (i) and (iii) to be readily understood. For vessels in the plants which have been identified in Section 4.2.3.4(i) as significant as regards the potential for a major accident, details should be shown on the diagram of their designed maximum working capacities, their

design temperatures and pressures, and their normal operating conditions. It may be convenient to combine this with the response to Section 4.2.3.2(ii). For example, a large vertical cylindrical storage vessel containing the dangerous substance would require a diagram showing the vessel, its connections, instrumentation and external safety features such as water sprays and bunds; for complex plants diagrams of only the largest or most significant vessels are required.

Section 4.2.3.4(iii) (Preventative and Control Systems)

The third part of Section 4.2.3.4 requires a response in two parts. First, relating to the preventive and control measures which check any sequence of events which could foreseeably result in a major accident, and secondly, relating to measures which may be taken after such a hazardous outcome to minimize its adverse consequences. It is important to realize that it is better to prevent a release occurring rather than trying to control the consequences, which may, in part, be impracticable.

The first part of the response should concentrate on those preventive or control measures which are critical in counter-acting significant hazards, though many of these measures will also be appropriate to preventing or controlling lesser events.

The interpretation of certain key words in this part of Section 4.2.3.4 may usefully be discussed in relation to examples; say, a large pressure storage sphere of LPG, representing the risk of fire and explosion, and for an example of toxic risk, a large pressure storage sphere of ammonia.

"Measures taken to prevent" relate to ensuring the safe operation of the plant under normal operating conditions or within specified process limits. They are those measures which are intended to prevent the initiation of a sequence of events which could lead to a significant hazardous outcome and would include consideration of design, engineering standards, constructional and quality assurance, inspection and maintenance, and control systems insofar as these were concerned with controlling the process during normal operation. These preventive measures derive their validity from the way in which the overall management of the plant and company exercises control over them and ensures their effectiveness. Thus, a sufficient account of the relevant parts of the management system, expanding on the general information given in Section 4.2.3.3 will be needed to support any arguments about the probability of initiating a sequence of events with a hazardous outcome. In relation to the ammonia sphere example, "measures taken to prevent", would include a discussion of the arrangements for checking ammonia purity and special vessel inspections in connection with the problem of stress corrosion cracking.

"Measures taken to control" relate to the interventions permitted by the design of the plant (e.g., valves) or safety hardware (e.g., dump tanks) which may counter an event so that the dangerous substance is retained within the plant. The operation of a "measure taken to control" assumes that a sequence of events has been initiated and the control is intended to prevent the sequence proceeding to a major accident. In relation to the LPG sphere example, a spillage of LPG near the tank which ignited, could be prevented from escalating to a BLEVE (boiling liquid expanding vapour explosion) of the whole sphere by the effective operation of a water spray system on the sphere. The discussion of this control measure should include reference to the the capacity of the water storage system, the water application rate; how the company ensures that the system will in fact operate effectively when required to do so; and the system reliability.

The second part of the response to this item covers "Measures to minimize the consequence", which relate to those measures which can be taken after the major accident has actually occurred. Examples of minimization include: bunding, water curtains, foam blankets, and emergency procedures. In relation to the ammonia sphere, the effects of a release of ammonia from a pipe at a sufficient rate to lead to a lethal concentration of gas at (say) the nearest domestic dwellings might be minimized by the application of a water curtain around the sphere, and, through the emergency services, by evacuation of those people who are downwind of the escape.

Section 4.2.3.4 (iii) refers to the prevention or control of major accidents identified in Section 4.2.3.4(i). It is therefore not necessary to include information about measures directed solely at preventing small releases or those which have only minor consequences, unless these have the potential to escalate to a major accident.

Section 4.2.3.4(iii) by concentrating on preventive measures, is intended to draw out discussion on the positive aspects of the full safety case. However, because the sequence of cause, effect and consequence are closely intertwined, it is not possible in practice to confine such a discussion to prevention without mentioning the potential consequences of the potential major accidents discussed in the safety case. Estimates of consequences will in any case be required in order to formulate adequate advice to the authority responsible for drawing up off-site emergency plans (see Section 5).

<u>Section 4.2.3.4 (iv) (Emergency Procedures)</u>

Section 5 requires the developer to produce a plan for dealing with emergencies on-site. The operator/developer should be able to present the whole document for examination if necessary, but that is not the intention of this part of the safety case. On the other hand, it will not be sufficient merely to state that the

emergency plan exists. The response to this item should describe the procedures in outline; indicate the nature and extent of emergencies with which the plans are intended to cope, drawing as necessary on the information in other parts of the safety case; mention those arrangements which may be critical to the success of the plans such as access for emergency services, the provision of adequate supplies of fire-fighting water, the remote siting of emergency control points and the evacuation of non-essential site personnel; and confirm that the plans have been discussed with the relevant outside bodies and practiced with them.

Section 4.2.3.4 (v) (Meteorological Conditions)

Data should be obtained from the nearest Meteorological Office weather station as to the prevailing weather conditions in the vicinity of the site, and if necessary confirmed by actual measurements on the site.

Section 4.2.3.4 (vi) (Numbers at Risk)

This estimate should include those people normally working on the plant concerned and any major concentrations of people in the immediate vicinity of the plant, e.g., office buildings. As for Section 4.2.3.2 (iv), exact numbers are not necessary.