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COMPUTERIZED PROCESSING OF THORNEY ISLAND TRIAL DATA FOR COMPARISON WITH MODEL PREDICTIONS

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Summary

This paper describes a user's experience of the computer processing of the data tapes from Phase I of the Thorney Island trials and the graphical techniques used to present and compare the trial results with model predictions. Six of the sixteen sets of trial data were selected for the comparisons, based on categorization of the trials by wind speed and stability. Both trial data and model results were converted to downwind and crosswind coordinates. In addition to horizontal and vertical concentration contours, plots were produced for maximum concentration versus time and distance. A method was developed to compare, as a function of time, the co-current areal coverage of horizontal concentration contours of the trial results with the predicted results.

1. Introduction

The computerized processing used to compare experimental and predicted results on the dispersion of heavier than air gases is described. Data from the Thorney Island series of large-scale tests were used for the experimental results and four state-of-the-art computer models were used for the predicted results. The ability to predict gas dispersion with a model is one of the primary concerns of project designers and government regulators because the amount of toxic and flammable gases being transported and stored throughout the world is increasing. In the event of a massive release of flammable or toxic vapor, the physical dimensions of the cloud and the distance the cloud is translated by the wind are required to define the area which will be exposed to the gas cloud. The ability of the models to accurately predict such distances for various atmospheric and terrestrial scenarios is important in the siting and routing of materials which exhibit this behavior.

To determine the predictive capabilities of models, reliable and comprehensive data are required for large-scale spills of heavy gases. The United Kingdom Health and Safety Executive (HSE) organized a test program, financed by a group of international organizations. The main task of the HSE was to acquire and document the data for the sponsoring organizations to be used for analysis and testing of the predictive capabilities of available models.

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The trials were conducted in two phases. Phase I had no obstructions in the release path, and Phase II was conducted to record the effects of obstructions both upwind of the release point and in the dispersion path. Phase I data were analyzed for this study and included sixteen trials conducted in the summers of 1982 and 1983. From the sixteen trial data sets, the data were divided into six wind speed and stability categories and the most suitable data within each category were selected for comparison with predicted results of the four heavy gas dispersion models.

2. Trial data processing

The processing of the data for the Thorney Island trials was organized into four phases: collection and validation of the sensor data, sampling and time-averaging data from tapes of each trial, graphical presentation of the trial data to aid in selection of six trial sets, and generation of input information for the models. The collection and validation of the data were performed by the National Maritime Institute and HSE before release of the data to the sponsors. The results of validation and plots of sensor responses were reported for each trial in a series of reports by the United Kingdom Health and Safety Executive [1].

2.1. Data processing organization

A flow chart depicting the overall data flow within the analysis is shown in Fig. 1. The raw data on the tapes received from the HSE were initially processed with a program called SAMPLER. The information output was divided into two streams. One stream contained the experimental results at the sensor locations for the selected times after release of the gas. The second stream contained the initial conditions required by the various models.

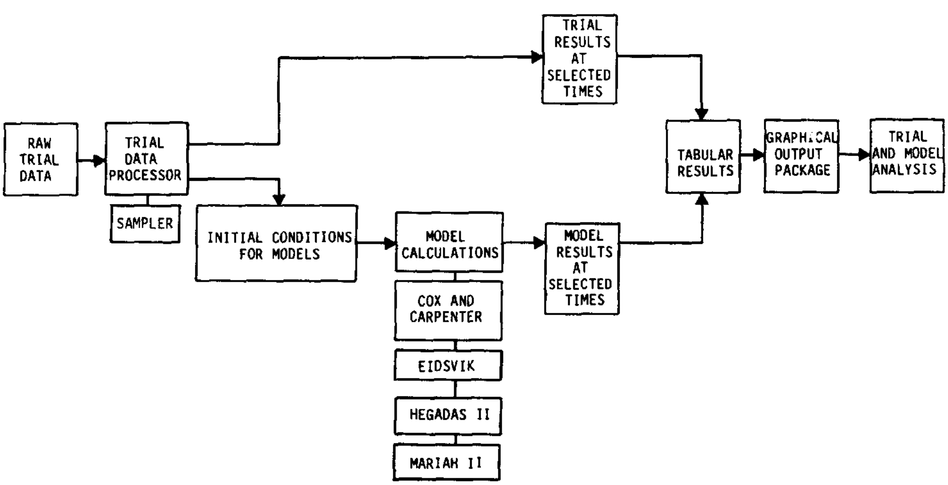

Fig. 1. Data organization.

Once the initial conditions for the models were determined, the models were used to predict the concentrations for each time at each sensor location. At this point in the analysis, concentration values for the experimental results and model predictions at identical coordinates at identical times exist. The concentration/coordinate/time data are coupled in tabular form. The tabular results for the trial and model results were used as the input data base to the graphical output package. The trial results and individual model results were processed through the five graphical representations.

2.2. Averaging and sampling of the data

A description of the data presentation used by HSE was given by Roebuck [2]. The first stage of processing prior to model comparisons was the averaging of the data and the sampling of this averaged data at specific times. Due to the large amount of data, fifteen specific times after the release were selected to examine the trials. The time interval and distribution of times within the interval were varied for each test. The sample times were more frequent (15 s spacing) in the earlier part of the interval. Since the clouds dispersed more slowly at lower wind speeds, longer time intervals were chosen for the trials at these speeds.

The collection rate for the data was 20 Hz and the bulk of the gas sensors had a response time of 1 Hz. The time period used for averaging the gas sensor data was a compromise between retaining the shape of the sensor response and eliminating the noise of the sensor response. For the Thorney Island trials, a time interval of 0.6 to 1.0 s was satisfactory for the standard gas sensors. A time-averaging interval of 0.6 s was used as a matter of convenience since the data were recorded in blocks of 0.6 s (twelve samples). Also, the HSE data books [1] plotted concentration versus time for individual gas sensors based on 0.6 s time interval averaging which permitted comparison of time-averaged values on the same basis.

2.3 SAMPLER

A computer program, SAMPLER, was written to read the data tapes and to average the data over 0.6 s intervals at selected times in the cloud dispersion scenario. SAMPLER required two files as input: a sensor position/sensor type mapping file, and the raw sensor data file. It also required some ambient initial conditions, such as gas cloud composition, to be input. These values were necessary to fully define the initial conditions to be used by the models. The output of the program was multiple versions of the sensor maps. The maps were defined as follows:

(a) A complete sensor map, including sensor location (x,y,z) and sensor description for each location.

(b) A complete map, as in (a), but with the x,y,z coordinates translated/rotated about the cloud release point to align with wind direction.

(c) A list of the trial initial conditions and a sensor map using the downwind and crosswind x,y,z coordinate system. (This was the input file to the heavy gas models.)

(d) A file of sensor outputs for use in conjuction with the full map file (a) for graphic data presentation.
(e) A file containing locations and gas concentration values for the sensor locations in downwind and crosswind coordinates for comparison to the model predictions.

A flow chart of the trial data processing described in this section is presented in Fig. 2.

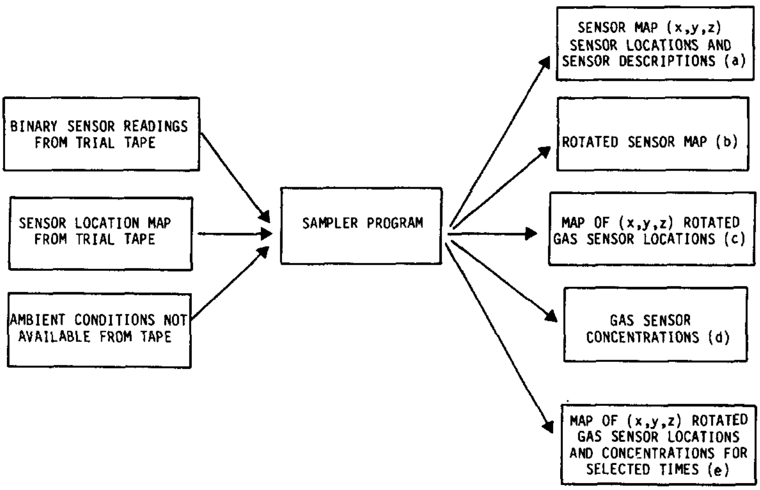

Fig. 2. Trial data processing through SAMPLER program.

2.4 Trial data plots

After processing of the trial data, several graphical methods were developed to analyze the trial data independent of model predictions. Five forms of plotting were used in this analysis, and a brief description of the graphical methods used is presented here. A description of the usefulness of these methods in analyzing the trial and model data co-currently is described in Section 5.

The first method was the formulation of horizontal concentration contours at the four sensor levels for the specified time. The concentration levels chosen were 1.0, 3.0, 5.0, 7.0, and 9.0 mole percent. The horizontal contours are developed for each trial for each time step specified at various heights above 0.4 m. Figures 3(a) and 3(b) represent the horizontal contours for Trial 8 at 60 s after release for the 0.4 m and 1.2 m heights.

A second plot available from the processed trial data was vertical concentration contours along the downwind axis for selected times. Figure 4 presents the vertical concentration contours for Trial 8 at 60 s after release.

In addition to the two-dimensional plots created above, techniques for three-dimensional plotting have been developed for the trial data. Figure

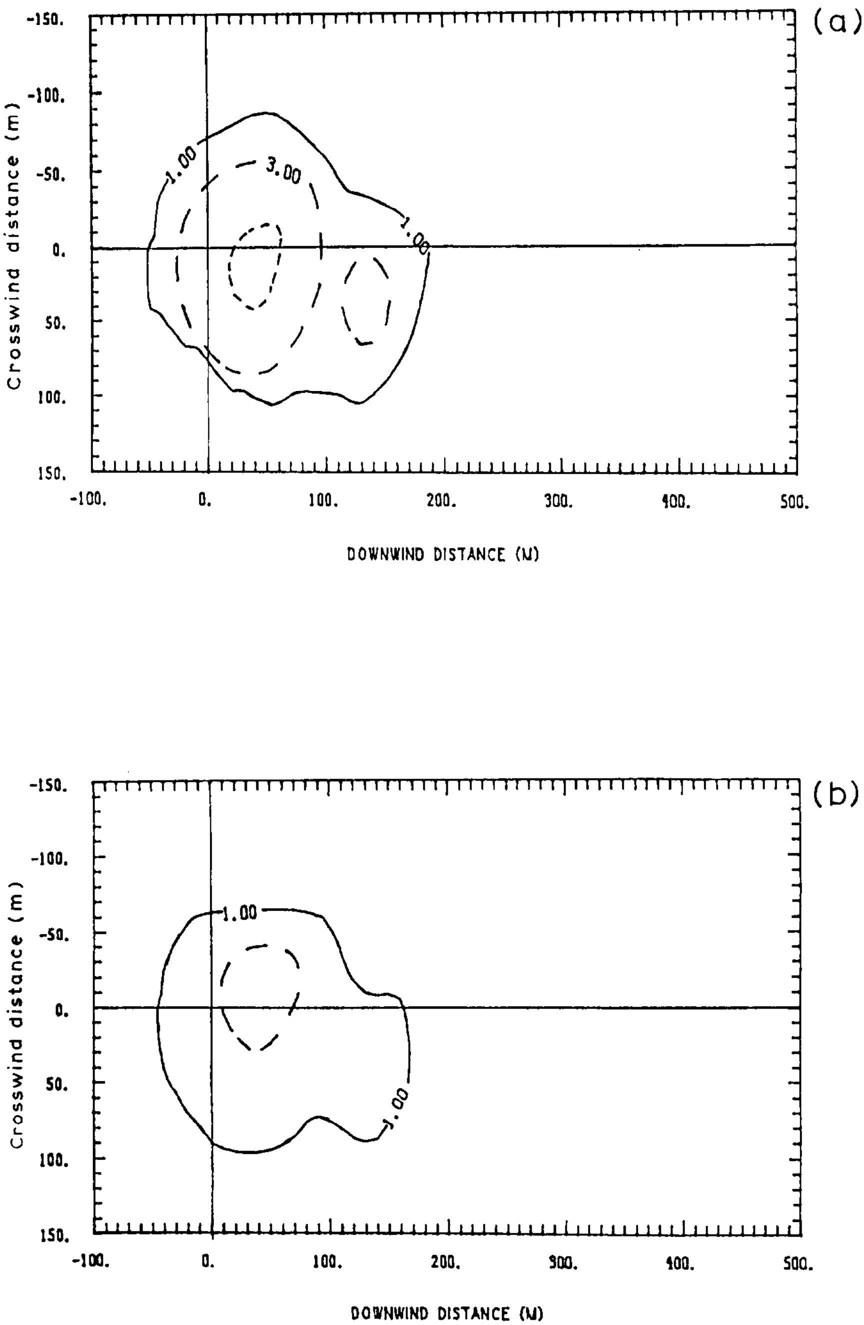

Fig. 3. Examples of concentration contours in horizontal plane derived from the trials data. Trial 8 at 60 s. (a) Height above ground = 0.4 m. (b) Height above ground = 1.2 m.

5 presents a plot of the 1.0 and 3.0 mole percent contours for Trial 8 at 60 s after release. The origin of release is represented as the black circle on the grid system, and Fig. 5 is a view of the cloud from the downwind direction.

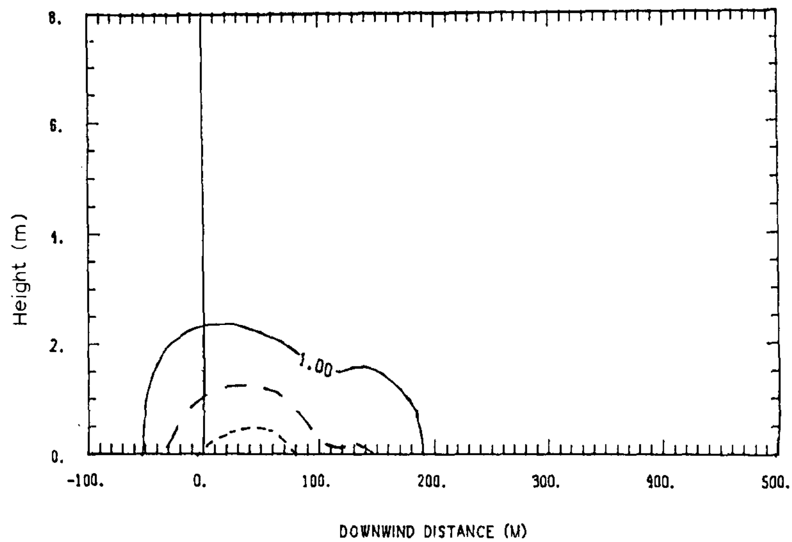

Fig. 4. Example of concentration contours in vertical plane derived from the trials data. Trial 8 at 60 s. Crosswind distance = 0.

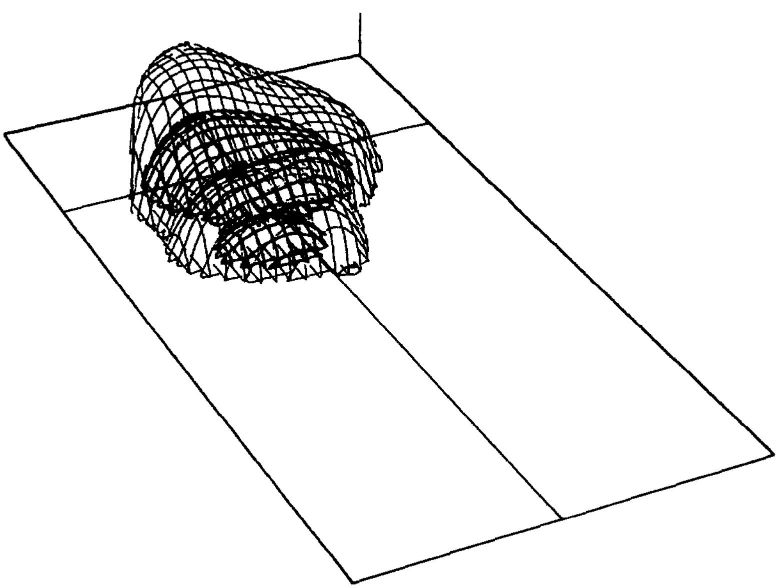

Fig. 5. Three-dimensional plot of concentration contours derived from the trials data. Trial 8 at 60 s. Thin lines 1% concentration. Heavy lines 3% concentration.

Two summary type plots were also created for each trial analyzed. The plots were maximum concentration versus time and maximum concentration versus distance. The maximum concentration versus time plot in Fig. 6 was for Trial 8. Similarly, the maximum cloud concentration versus distance plot for Trial 8 is shown in Fig. 7.

2.5 Definition of trial initial boundary conditions

Initial conditions for the models were extracted at the data processing step. The initial conditions were assumed to be the average values of the trial parameters over the duration of the trial. The parameters extracted from the test data are listed in Table 1, as well as the models that use a particular parameter as an initial boundary condition. Other boundary conditions were determined using other sources. Relative gas density and

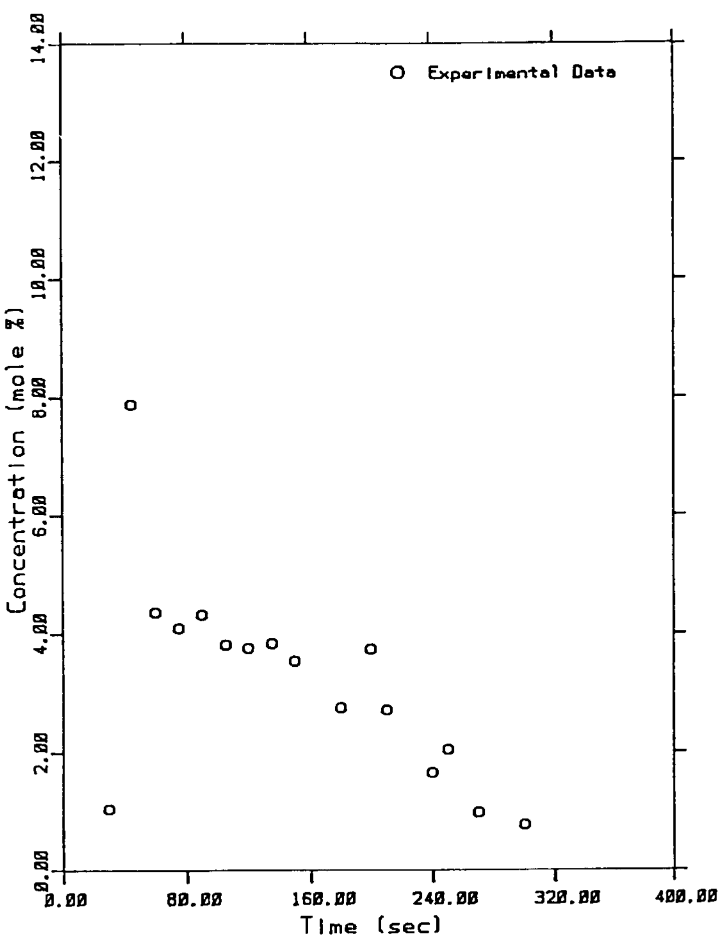

Fig. 6. Maximum concentration versus time for Trial 8.

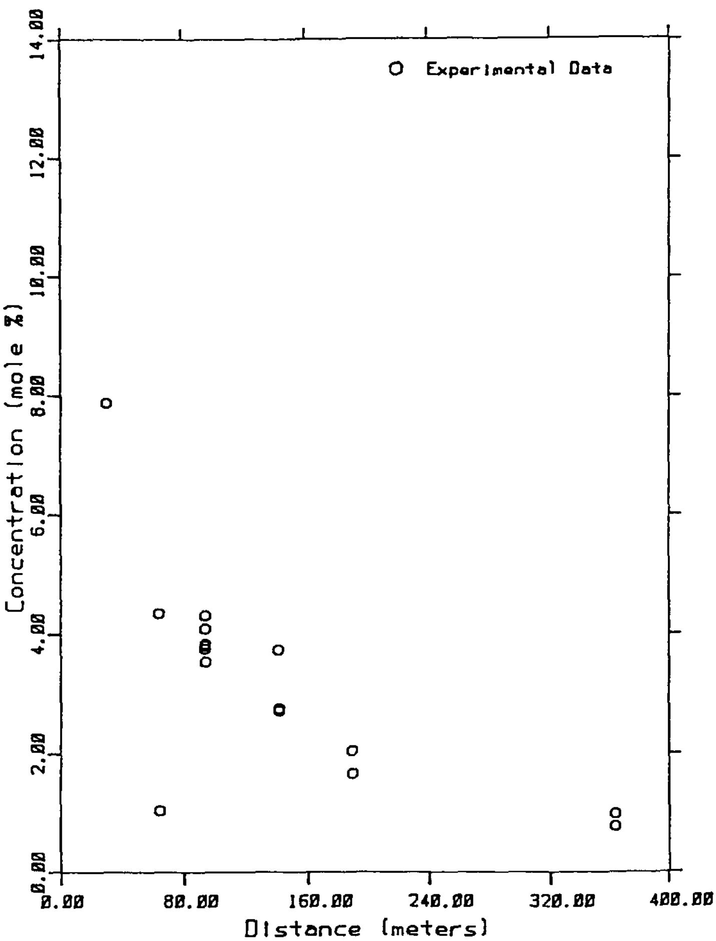

Fig. 7. Maximum concentration versus distance for Trial 8.

atmospheric stability classification were derived from information presented in [1]. Terrain conditions (surface roughness and drag coefficients) were obtained through on-site observations. The method used to define each initial condition is also defined in Table 1.

3. Thorney Island test results

The Phase I Thorney Island trials consisted of sixteen tests of unobstructed instantaneous gas spills. Table 2 is a summary of the trial number, average wind speed, Pasquill stability, initial relative density, and the number of gas sensors responding to the gas clouds. The data in Table 2 were taken from McQuaid [3]. Figure 8 shows the distribution and grouping of tests by wind speed versus stability.

TABLE 1

Model initial boundary conditions

Variable	Obtained from			Initial conditions for			
	Trial tapes	Ref. [1]	On-site observations	Cox and Carpenter	Eidsvik	HEGADAS II	MARIAH II
Wind speed	x			x	x	x	x
Wind direction	x						
Relative humidity	x			x	x	x	x
Air temperature	x			x	x	x	x
Surface temperature		x		x	x		x
Atmos. pressure	x			x	x	x	x
Atmos. stability		x		x		x	x
Mole fraction N_2		x		x	x	x	x
Mole fraction F-12		x		x	x	x	x
Mole fraction air		x		x	x	x	x
Surface drag coefficient			x				
Surface roughness			x	x		x	x
Mass of gas		x		x	x	x	x
Gas cloud radius		x		x	x	x	x
Gas cloud height		x		x	x	x	x

TABLE 2

Summary description of Heavy Gas Trials Phase I

Trial number	Wind speed (m/s)	Pasquill stability category	Initial relative density	Number of gas sensors which responded to gas
004	3.8	B	0.97	22
005	4.6	B	1.69	26
006	2.6	D/E	1.60	46
007	3.2	E	1.75	57
008	2.4	D	1.63	73
009	1.7	F	1.60	62
010	2.4	C	1.80	11
011	5.1	D	1.96	26
012	2.6	E	2.37	65
013	7.5	D	2.00	47
014	6.8	C/D	1.76	50
015	5.4	C/D	1.41	38
016	4.8	D	1.68	45
017	5.0	D/E	4.20	62
018	7.4	D	1.87	60
019	6.4	D/E	2.12	67

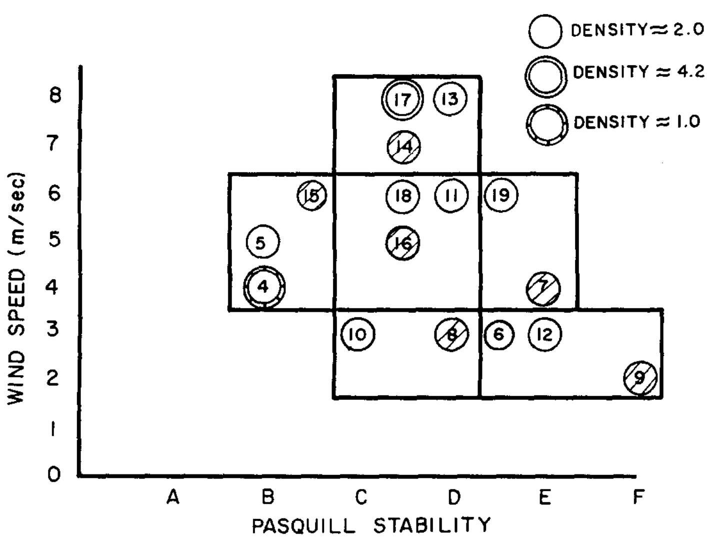

Fig. 8. Grouping of trials by wind speed and Pasquill stability.

3.1 Selection of trials for model comparisons

Six trial data sets were selected for comparisons with model predictions. The data were grouped into wind speed categories of low (1.0—3.0 m/s), midrange (4.0—6.0 m/s), and high (7.0—8.0 m/s) and stability categories of moderately to slightly unstable (Pasquill B—C), slightly unstable to neutral (Pasquill C—D), and slightly to moderately stable (Pasquill E—F) to include as many combinations of conditions as possible that are commonly used in risk assessment studies. The tests within each category were compared with each other, and one test within each category was selected for comparison with model predictions. Plots of the horizontal and centerline vertical concentration contours and the summary information were used in the selection of the six trial results for further analysis. The six sets are marked with diagonal lines in Fig. 8 for each wind speed—stability category, and the selection process for each data set is described below.

Midrange wind speed (4.0—6.0 m/s) and moderately to slightly unstable (Pasquill B—C) category

This category contained Trials 4, 5, and 15. Trial 15 was chosen as the best trial within the category. Trial 15 had thirty-eight gas sensors recording gas during the dispersion, compared to twenty-two for Trial 4, and twenty-six for Trial 5. Trial 5 was released with a relative density of 0.97, and the gas release was delayed due to a squall at the site. In the Trial 5 release, the gas container dropped in two stages.

High wind speed (7.0—8.0 m/s) and slightly unstable to neutral (Pasquill C—D) category

This category included Trials 13, 14, and 17. Trial 14 was chosen as the best data set. Trial 17 was eliminated from consideration because of its initial relative density of 4.2, and the release was made when the gas container was three-fourths full. In choosing between Trials 13 and 14, Trial 14 was chosen because the cloud travel was nearly down the centerline of the sensor field and had a few more sensors recording gas during the dispersion. For Trial 13, the wind speed was increasing during the release and dispersion. Gas filling problems existed with both trials.

Midrange wind speed (4.0—6.0 m/s) and slightly unstable to neutral (Pasquill C—D) category

This category contained Trials 11, 16, and 18. In Trial 11, the wind direction changed after the gas container was filled and the gas cloud traveled to the side of the sensor field. Trial 18 had more gas sensors in the dispersion path than did Trial 16. Some problems were encountered in filling the gas container in both tests, and the plots of the horizontal and centerline vertical concentration contours were comparable. Since Trial 18 had wind speed and conditions similar to Trial 14 (the trial selected for the high wind speed—slightly unstable to neutral category), Trial 16 was chosen because of the lower wind speed and the path of the cloud travel was more nearly down the centerline of the sensor array.

Low wind speed (1.0—3.0 m/s) and slightly unstable to neutral (Pasquill C—D) category

This category contained Trials 8 and 10. Trial 8 was selected due to the large number of sensors that recorded gas during the dispersion. For Trial 10, the wind direction changed after the gas container had been filled and the cloud intersected only a few of the sensors.

Midrange wind speed (4.0—6.0 m/s) and slightly to moderately stable (Pasquill E—F) category

Trials 7 and 19 were included in this category. Trial 7 was selected as the representative trial based mainly on the horizontal and vertical concentration contours, even though Trial 19 had ten more gas sensor responses than did Trial 7. The wind direction for both tests was from the same direction, causing the cloud to move to the right of centerline of the sensor array as the cloud was advected downwind.

Low wind speed (1.0—3.0 m/s) and slightly to moderately stable (Pasquill (E—F) category

Included in this category were Trials 6, 9, and 12. Trial 9 was selected for additional analysis based on its lower wind speed and more stable conditions in order to increase the range of conditions for model comparisons. Trial 6 was rejected because the gas container was only two-thirds full at the time of release. Trials 9 and 12 were comparable in the number of gas sensors that saw gas during the dispersion. Both sets of data produced reasonable (no apparent anomalies) horizontal and centerline vertical concentration contours.

4. Heavy gas dispersion models

For this study, four models were selected that we believe represent state-of-the-art techniques. The models can be roughly divided into three categories: box, K-theory, and three-dimensional hydrodynamic models. From the box model group, we selected the Cox and Carpenter [4] model with modifications by Bradley et al. [5], and the Eidsvik [6,7] model. The label, box, is derived from the uniform distributions assumed in the gas cloud which yield a box type profile for any cross-sectional concentration profile. The two models differ in the way coefficients are specified for the top and frontal air entrainment of the spreading cloud, and in the way the models make the transition to passive scalar dispersion. The Cox and Carpenter model uses a Gaussian method to account for the passive scalar dispersion, and the Eidsvik model makes the transition by the continuous adjustment of the air entrainment coefficients. The Colenbrander [8] model, HEGADAS II (with extensions reported by Puttock et al. [9]), was selected because it is an extension of the box model concept, considers concentration and velocity profiles, and uses the eddy diffusivity approach. From the

K-theory models, the model developed by Taft [10], MARIAH II, was selected as the representative model for this study.

Of the four models selected to be analyzed in this project, all but the MARIAH II three-dimensional hydrodynamic model were coded from literature descriptions by Energy Analysts, Inc. The results from the MARIAH II model were supplied to Energy Analysts, Inc., by Spectra Research Systems. The other three heavy gas dispersion models, Cox and Carpenter, Eidsvik, and HEGADAS II, conform exactly to the literature descriptions available.

4.1 Model input parameters

In order for a heavy gas dispersion model to be useful as a tool for predicting the cloud location and concentration as a function of time after a release, the model should require input information that is readily available. The readily available information commonly employed by a model defines the average atmospheric and surface conditions and the initial amount and thermodynamics of the released gas. Other information, such as the variance in wind speed and wind direction as a function of time, is not normally available and, as such, often cannot be used as input for a predictive model calculation.

In addition to requiring readily available information as input to the models, it would also be desirable from the user point of view if the models were not overly sensitive to parameters within the model which cannot be accurately defined by the user. An example of such a sensitive variable is the air entrainment coefficient, α_5, contained in the Eidsvik model. The variance in the predicted results from the Eidsvik code is sensitive to the value of α_5 employed in the code. In general, the user does not have access to information which could be used to define the air entrainment coefficient for different release cases.

Following this approach of requiring only commonly available information as input to the dispersion models required forcing certain parameters to be "fixed" within the models. The "fixed" model parameters, such as α_5 (the Eidsvik air entrainment coefficient), were defined as they were presented within the original author's literature description. This was done even though the type of release the model was originally scaled for may be quite different than the Thorney Island trials.

4.2 Model output

The output from the vapor dispersion models required for this analysis can be divided into two categories: the location of the gas cloud, and the composition of the gas cloud. The values associated with these two categories are continuously evaluated by the models during the dispersion history. The model results can then be matched directly with the trial results. The times selected for comparison were divided into two groups. One group contained a series of fifteen time values ranging from fifteen to seven hundred seconds after the release of gas. This group was used when analyzing the low wind speed trials (Trials 7, 8, and 9). The other group of times contained values ranging from fifteen to four hundred seconds after the release of the gas. This group was used when analyzing the higher wind speed trials (Trials 14, 15, and 16).

In order for the model results and the trial results to be compared at exactly the same location at the same time, the models had to produce concentration values at specified locations at the required times. The procedure to do this was two-fold. The first portion of the matching process was to translate and rotate the trial results from their original coordinates to coordinates which would match the model's coordinate system, since the model results were calculated based upon a downwind axis with the release point defined as (0.0, 0.0) in the crosswind and downwind directions. The translation of the coordinates was straightforward as each sensor location was translated two hundred meters in the downwind direction and four hundred meters in the crosswind direction. This translation then put the origin (0.0, 0.0) at the location of the gas bag. The rotation of the coordinate system was based upon the average wind direction measured during the course of the trial. After rotation of the sensor locations, the trial data and model results now have matching coordinate systems. The second portion of the matching process was to define the model results at the specified sensor locations. This was accomplished by requiring the model to evaluate the concentration at the specified sensor locations at the specified times.

5. Comparisons

Tabular results of the trial data were merged with tabular results of model predictions. Also, several graphical methods were developed to compare the results.

5.1. Tables of x,y,z coordinates

The results of the trial coordinate system translation/rotation and the model evaluations were presented in a table for each trial which listed the gas sensor locations, the trial concentration at that location, and the model concentration predictions at that location for each specified time. Since for each specified time most of the gas sensors employed during the trial did not "see" gas and the associated locations for the models did not predict that gas would be present, a condensed table of results was produced. This condensed table contained each location at which any one of the models or the trial results reported a gas concentration greater than one-half of one mole percent for each time specified. Table 3 is a portion of such a condensed table for Trial 8 showing the times of 15, 30, 60, and 90 seconds after the release. The location of each sensor is defined as: x = crosswind; y = downwind; and z = height. The mole percent concentrations are defined as: cexp = trial data, ceid = Eidsvik, cheg = HEGADAS II, ccox = Cox and Carpenter, and cmar = MARIAH II. For each of the trials, a complete map of the translated/rotated coordinate system was produced.

TABLE 3

Trial 8 sensor concentrations over 0.5 percent by volume

CW (m)	DW (m)	HT (m)	cexp (%)	ceid (%)	cheg (%)	ccox (%)	cmar (%)
Time after release (s) = 15.00							
Zero sensors report concentrations above 0.5 percent							
Time after release (s) = 30.00							
−34.31	61.83	0.40	1.04	25.50	0.	7.07	0
61.83	34.31	0.40	0.	25.50	0.	7.07	0.
27.51	96.14	0.40	0.	25.50	0.	7.07	0.
Time after release (s) = 60.00							
41.27	144.20	0.40	3.39	15.63	0.	4.68	0.
−34.31	61.83	0.40	4.35	15.63	6.35	4.68	0.
−61.83	−34.31	0.40	0.	0.	6.35	0.	0.
−68.63	123.70	0.40	0.	15.63	0.	4.68	0.
34.31	−61.83	0.40	0.	0.	6.35	0.	6.87
34.31	−61.83	1.40	0.	0.	0.	0.	2.07
96.14	−27.51	0.40	0.	0.	0.	0.	3.57
96.14	−27.51	1.40	0.	0.	0.	0.	2.03
96.14	−27.51	2.40	0.	0.	0.	0.	1.00
61.83	34.31	0.40	4.39	15.63	6.35	4.68	9.76
61.83	34.31	2.40	1.65	0.	0.	0.	0.65
27.51	96.14	0.40	2.91	15.63	0.	4.68	0.
Time after release (s) = 90.00							
41.27	144.20	0.40	3.14	10.29	0.	3.66	0.
41.27	144.20	2.40	0.84	0.	0.	0.	0.
−96.14	27.51	0.40	0.	0.	5.19	0.	0.
−34.31	61.83	0.40	1.40	10.29	5.19	3.66	0.
−61.83	−34.31	0.40	0.	0.	5.19	0.	0.
−41.11	219.80	0.40	0.	10.29	0.	3.66	0.
55.03	192.30	0.40	2.01	10.29	0.	3.66	0.
−68.63	123.70	0.40	1.56	10.29	0.	3.66	0.
123.70	68.63	0.40	0.	0.	0.	0.	1.53
34.31	−61.83	0.40	0.	0.	5.19	0.	0.
96.14	−27.51	0.40	0.	0.	5.19	0.	5.00
96.14	−27.51	1.40	0.	0.	0.	0.	1.86
96.14	−27.51	2.40	0.	0.	0.	0.	0.55
−54.87	171.70	0.40	0.	10.29	0.	3.66	0.
61.83	34.31	0.40	0.60	10.29	5.19	0.	7.56
61.83	34.31	2.40	0.	0.	0.	0.	0.59
27.51	96.14	0.40	4.31	10.29	5.19	3.66	0.
27.51	96.14	2.40	0.76	0.	0.	0.	0.

5.2 Graphical representation of model results

A total of five graphical representations have been developed for the Thorney Island trial data and the applied model results. The five methods are interrelated through the time after gas release variable, yet each of the five demonstrates different phenomena occurring within the gas cloud. A description of each graphical method and its usefulness in analyzing the trial/model results is presented.

5.2.1 Graphical method No. 1: Horizontal gas concentration contours versus time

For specific times during the course of the dispersion testing, the data for each gas sensor were extracted from the trial data and plotted on an x,y rectilinear grid (see Section 2.4). In addition to the test data, the model results for gas concentration were calculated at the same point in time. The model predictions were then plotted in the same rectilinear grid as the trial results.

Such a plot can be used to observe the location of the model as a function of time. The hydrodynamic phenomena worthy of observation resulting from this type of presentation were the radial gravity spreading and how it related to a specified cloud concentration boundary, and the advection of the total cloud mass with the passage of time.

In the analysis presented here, the horizontal level of interest is that of 0.4 m. The reason for this choice is two-fold. First, this was the lowest sensor location for acquiring experimental results. The ideal location would be ground level; however, the structure of the tests was such that this was not possible. In addition, extrapolation from 0.4 m down to ground level by using other sensor location data (2.4 m, 4.4 m, and 6.4 m) could prove

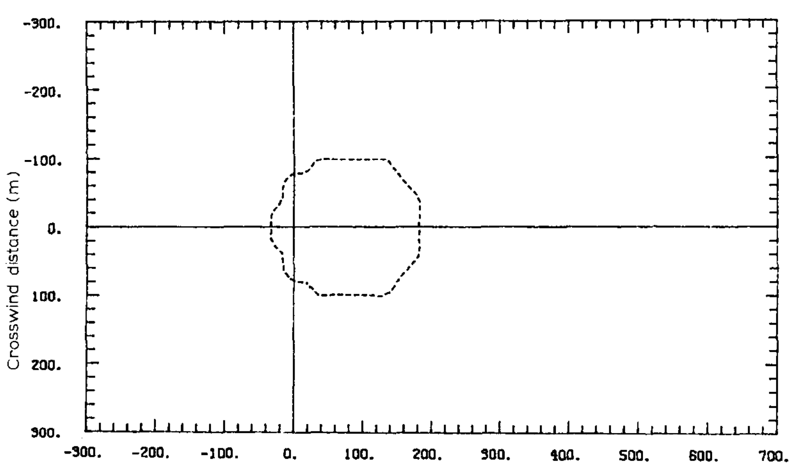

Fig. 9. Example of model concentration contour in the horizontal plane. Model of Eidsvik [6] for concentration of 1% and conditions of Trial 8. Time = 60 s. Height above ground = 0.4 m.

erroneous based upon how the models treat concentration versus height. Second, most of the data acquired from the tests were located along the 0.4 m plane. This allowed for a more accurate representation of the cloud at any point in time. An example of such a plot is presented in Fig. 9. The plot is for the one percent contour and drawn for the Eidsvik model results for Trial 8 at 60 s after release.

5.2.2 Graphical method No. 2: Vertical gas concentration contours versus time

Analogous to the contour mapping performed in method No. 1 was that of plotting the vertical contours of the cloud over the duration of the test. Several problems arose when developing these contours, primarily in the model predictions of concentration. In the Eidsvik and Cox and Carpenter models, cloud height was used as the "floating" variable which was used to satisfy the mass balance once the radius and air entrainment values for a particular point in time were evaluated. In addition to this, due to the nature of these two box models, there was no concentration gradient in the vertical direction; thus, any predictive distribution arising from an interpolation scheme will not accurately reflect the model results.

The definition of cloud height in the HEGADAS II model, once the gas cloud was removed from the source location, was defined with a Gaussian distribution with respect to the ground level gas mass concentration. An example of the vertical concentration is presented in Fig. 10, drawn for the Eidsvik model predictions for Trial 8 at 60 s after release.

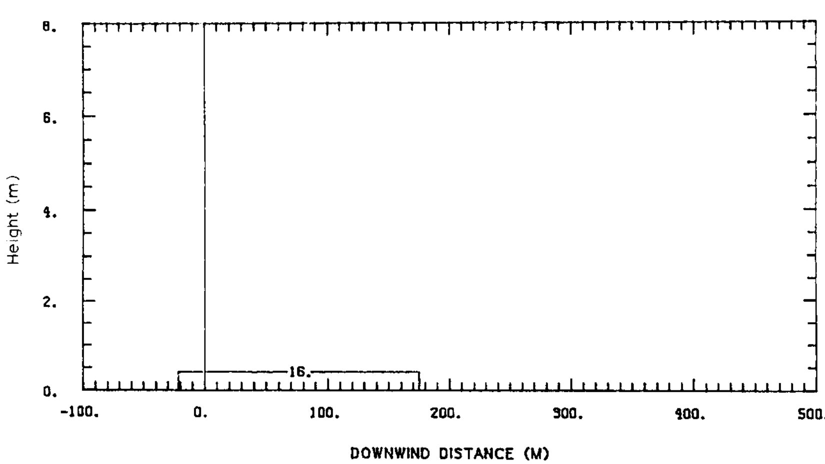

Fig. 10. Example of model concentration contour in the vertical plane of symmetry. Model of Eidsvik [6] for concentration of 1% and conditions of Trial 8. Time = 60 s.

5.2.3 Graphical method No. 3: Maximum gas concentration versus time

The variation of maximum gas concentration versus time is an important measure of how the predictive values of the models compare with the trial data. This representation demonstrated how the rate of air entrainment affected the dilution of the gas cloud. An example of such a plot is presented in Fig. 11. Although the model predictions of maximum concentration versus time are smooth curves, the test data oscillate due to movement of the cloud off the centerline and the non-uniform mixing of gas within the cloud. The plot was drawn from the Eidsvik model predictions and experimental results for Trial 8.

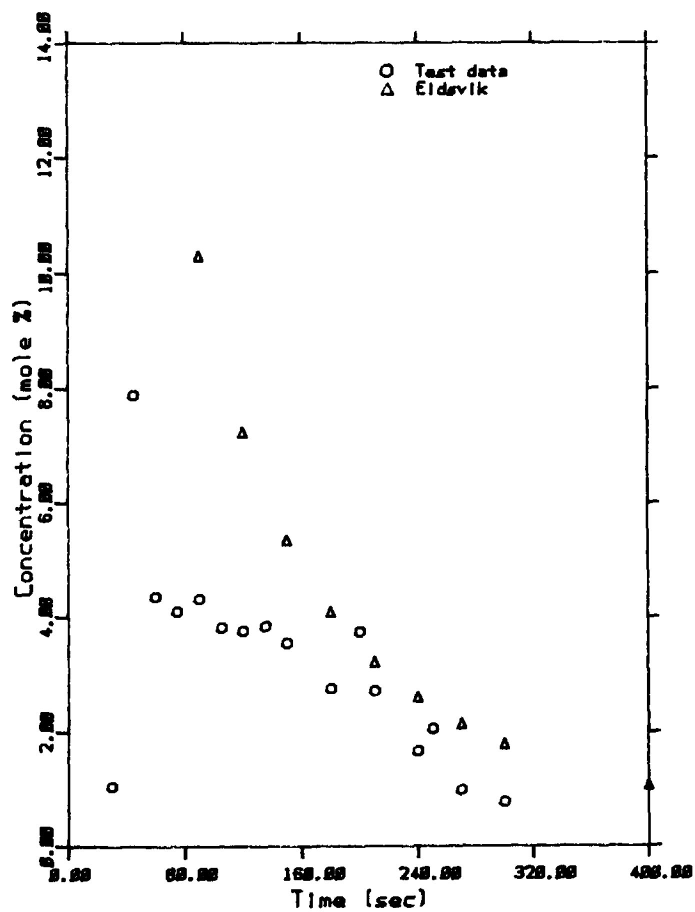

Fig. 11. Example of model predictions and experimental results of maximum centerline concentration versus time. Model of Eidsvik [6] for conditions of Trial 8.

5.2.4 Graphical method No. 4: Maximum gas concentration versus distance

The companion plot to the maximum concentration versus time plot was that of maximum concentration versus distance. This representation showed how the downwind movement of the cloud was related to the dilution of the gas cloud without regard for the time elapsed. An example of such a plot is presented in Fig. 12 for Trial 8. Once again, the curves resulting from the model predictions are smooth, whereas the curves resulting from the experimental results oscillate slightly due to non-uniformity of the cloud.

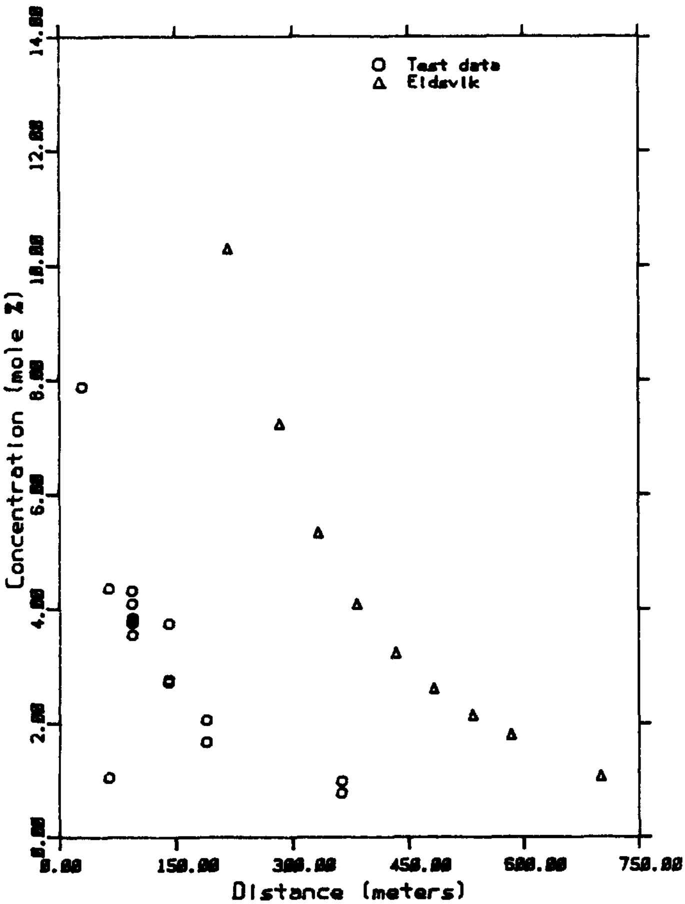

Fig. 12. Example of model predictions and experimental results of maximum centerline concentration versus distance. Model of Eidsvik [6] for conditions of Trial 8.

5.2.5 Graphical method No. 5: Co-current areal coverage of model results with trial results

A method was developed to produce a factor which measured, in part, how well a particular model prediction matched the trial data. The factor was a measure of how well a particular model matched the trial data areal coverage of the x,y horizontal plane at the lowest trial gas sensor readings (0.4 m) extrapolated out to a 1 percent contour. The factor ranged from 0.0 (no co-current areal coverage of the model and trial results) to 1.0 (identical coverage). Figure 13 shows an example calculation for the predicted

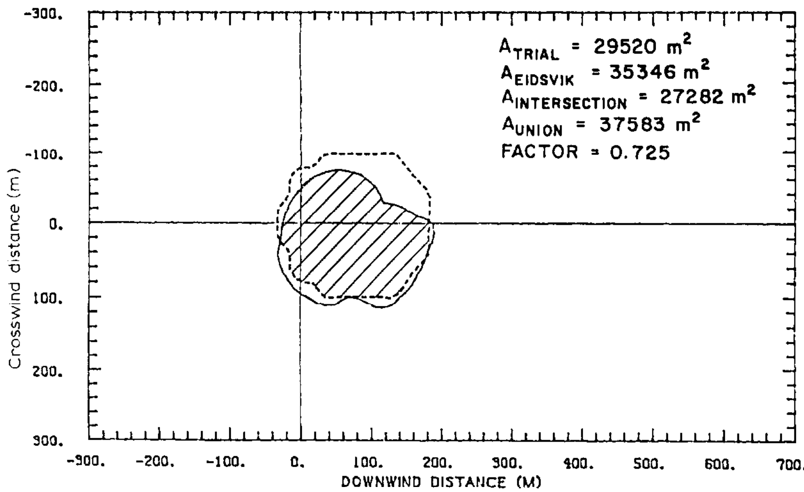

Fig. 13. Example of comparison of areal coverage of 1% concentration of model and trial results. Model of Eidsvik [6] for conditions of Trial 8. Time = 60 s. Height above ground = 0.4 m. Experiment ——. Eidsvik prediction -------.

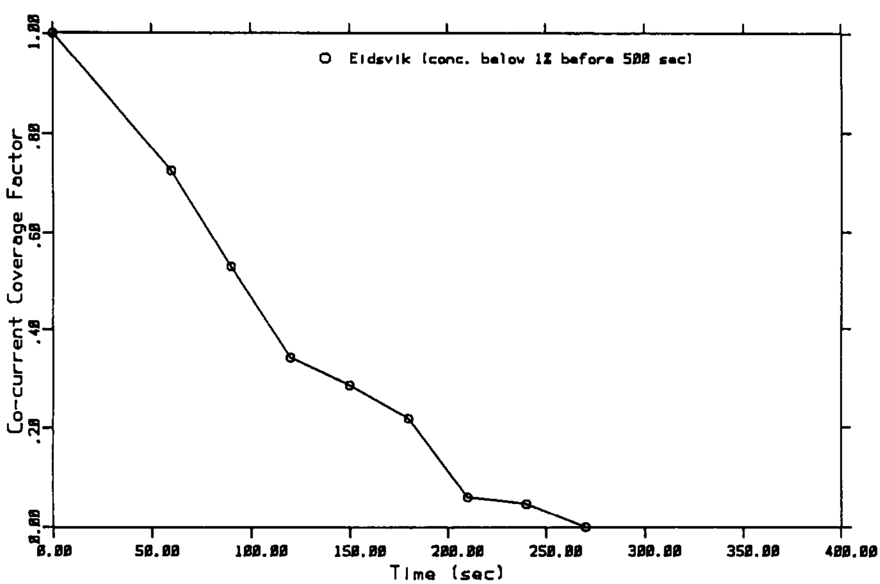

Fig. 14. Variation of coverage factor for 1% concentration with time for Eidsvik [6] model and conditions of Trial 8. Height above ground = 0.4 m.

Eidsvik cloud and the cloud from Trial 8 at 60 s after the release of the bag gas. The coverage is computed from:

$$f = \frac{[A_{\text{model}} \cap A_{\text{trial}}]}{[A_{\text{model}} \cup A_{\text{trial}}]}$$

where: f = factor defining co-current areal coverage, with f = 0.0: no intersection of the cloud, f = 1.0: identical model and trial cloud; A_{model} = area of model cloud; A_{trial} = area of trial cloud; $\cap$ = intersection; $\cup$ = union.

After all time steps are computed and the factors for the model are computed, a composite graph can be created, as shown in Fig. 14. As shown in the figure, the co-current areal coverage is zero after 270 s, the time the recorded trial cloud concentration dropped below 1 percent.

6. Conclusions

For this study, we were primarily interested in the ability of four models to predict the maximum downwind concentration and areal coverage of the cloud. Due to the massive amount of data collected, automation of the data reduction was necessary. The reduction of the data and graphical presentations were developed to display the horizontal and vertical concentration contours of the trial results in a downwind and crosswind coordinate system. Also, plots were produced for maximum concentration versus time and distance. Using the data presentations, six of the sixteen trials were selected as representative trials for comparisons with model predictions.

The model predictions were made at gas sensor locations that had been translated to the downwind and crosswind coordinate system. The graphical techniques that had been used for the trial results were then available to make comparisons of the model predictions and the trial results. In addition, a method was developed to compare co-current areal coverage of horizontal concentration contours. For this study, the 1 percent horizontal concentration contours at 0.4 m height were compared at several time steps during the dispersion of the gas cloud. A summary of areal coverage was presented as a fraction of coverage versus time.

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