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ABSTRACT

This paper summarizes the major model evaluation studies conducted for the MATHEW/ADPIC atmospheric transport and diffusion models used by the U. S. Department of Energy's Atmospheric Release Advisory Capability. These studies have taken place over the last 15 years and involve field tracer releases influenced by a variety of meteorological and topographical conditions. Neutrally buoyant tracers released both as surface and elevated point sources, as well as material dispersed by explosive, thermally bouyant release mechanisms have been studied. Results from these studies show that the MATHEW/ADPIC models estimate the tracer air concentrations to within a factor of two of the measured values 20% to 50% of the time, and within a factor of five of the measurements 35% to 85% of the time depending on the complexity of the meteorology and terrain, and the release height of the tracer. Comparisons of model estimates to peak downwind deposition and air concentration measurements from explosive releases are shown to be generally within a factor of two to three.

INTRODUCTION

The United States Department of Energy and Department of Defense have funded the development of the Atmospheric Release Advisory Capability (ARAC) by the Lawrence Livermore National Laboratory. The ARAC has been designed to provide a real-time service to emergency response managers by supplying computer generated isopleths of radionuclide air concentrations and surface deposition resulting from atmospheric releases of radioactive material [1]. The atmospheric transport and diffusion codes MATHEW [2] and ADPIC [3] are the primary modeling tools used to generate these isopleth products. Over their 15 year lifetime, the MATHEW and ADPIC codes have been applied in an operational emergency response environment to a variety of accident scenarios. These operational applications include those for DOE weapons and fuel processing laboratories, DOD nuclear weapon storage facilities, launches and atmospheric re-entries of nuclear-powered satellites, as well as nuclear power plant releases with consequences from the local to hemispheric scales.

Because the ARAC service must respond to a variety of accident scenarios at any number of different sites involving the simulation of a wide range of possible meteorological conditions, the MATHEW/ADPIC models must be quite flexible and site transferrable. To allow a better understanding of the models' accuracy under a variety of conditions, several MATHEW/ADPIC evaluation studies have been completed over the last 15 years [3,4,5,6,7,8,9,10,11,12,13]. Previous papers have summarized the results of these studies [14,15,16].

The purpose of this paper is to present the results of recent MATHEW/ADPIC evaluation efforts along with previously summarized results in a single report.

The field data used in the evaluations to date are from field campaigns conducted with a wide variety of terrain types, tracers, tracer release heights, sampler placement, and meteorology. The specific data sets used are listed in Table 1. The spatial scales of these studies range from several hundred meters to tens of kilometers. Included in these studies are those conducted by Italy and Sweden, two of approximately ten other countries which use MATHEW/ADPIC in the development and implementation of their emergency response capabilities.

BRIEF MODEL DESCRIPTION

The MATHEW model interpolates temporally averaged point measurements of surface and vertical profiles of wind speeds and directions, and generates a diagnostic, mass conservative, three-dimensional, spatially varying mean wind field. The interpolation is based on a least squares adjustment of the wind observations while accounting for the effects of local terrain [2]. The technique allows for the simulation of atmospheric stability effects in the solution of the mass-adjusted wind field.

The resultant wind field is then used by the particle-in-cell ADPIC model to simulate the transport and diffusion of the tracer, or pollutant. ADPIC simulates the temporal and spatial dispersal of pollutants under complex conditions by representing the pollutant with thousands of Lagrangian "mass" particles which are transported inside a fixed Eulerian grid [3]. The flux conservative form of the three-dimensional diffusion-advection equation is solved through finite difference approximations in a Cartesian coordinate system, and a K-theory closure scheme.

Pollutant concentrations are determined by the volumetric "mass" average of each grid cell, as calculated from the number of "mass" particles contained within the cell. Particles which represent particulate matter may be marked as deposited as they intersect the lower grid boundary through the application of a deposition velocity. Contours of concentration may then be constructed in units of mass, activity, or equivalent dose.

STATISTICAL COMPARISON METHOD

Several statistical methods of comparing field observations (Co) with model predicted concentrations (Cp) are available for use. These include difference methods, correlation coefficients, vector subtractions, and ratio methods [18]. Most of the MATHEW/ADPIC model evaluation studies have presented results using a ratio method.

In this method the ratio of time-averaged concentrations, Cp/Co, is used as a measure of model performance. The relative number of comparisons between modeled and observed concentrations whose ratios, r (= Cp/Co), fall between two chosen values, such as 2 and 1/2, may be expressed as a percentage of the total number of concentration comparisons. For example, Figure 1a indicates a hypothetical set of results which indicate 5 of 10 comparisons have ratios between $r = 2$ and $r = 1/2$, 3 more of the 10 ratios between $r = 5$ and $r = 1/5$, and 2 more of the ratios between $r = 10$ and $r = 1/10$.

In presenting the evaluation results we have defined R = (Co+B)/(Cp+B), where B is the backgroud concentration. If R is less than 1, then R = 1/R. The percentage of comparison pairs within a factor R may then be plotted as a function of R, as in Figure 1b.

An advantage of this method is that field data spanning wide ranges of release and sampling times, sampling distances, terrain, and meteorological conditions, which yield a large range in concentration magnitudes, may be easily presented and compared. Disadvantages occur because of the strict space-time correlation constraints imposed by this method. Namely that 1) An error of a few degrees in the transport wind direction can result in relatively large displacement errors when compared to the distance between the plume centerline and plume edge, and 2) this method can result in exaggeration of the relative importance of fractional errors for low concentrations, especially near the edge of the plume. Therefore, reasonably small absolute errors may translate to relatively large r values. This is partially compensated for through the addition of background concentrations, if any, in the ratio R. An expanded discussion of this and other methodologies of evaluating the MATHEW/ADPIC models is found in Dickerson and Ermak, 1988 [16].

EVALUATION STUDIES

INEL (1971) and SRP (1974)

The first evaluation studies for MATHEW/ADPIC were completed in 1978 using a near-surface, three-hour release of I-131 at the Idaho National Engineering Laboratory (INEL), and six-hour Ar-41 releases from 60 meter stacks at the Savannah River Plant (SRP) in Aiken, South Carolina [3]. The INEL data consist of three-hour integrated air samples from 36 monitors arranged in four downwind arcs. The SRP data are 40 ten-minute surface samples and nine helicopter samples. Rolling hills to almost flat terrain predominate at both INEL and SRP. Atmospheric stability ranged from unstable class B to stable F conditions. Comparisons to measurements were made from a few kilometers to approximately 80 kilometers from the source.

Results of these comparisons are given in Figure 2a. Results shown for these two studies are the best obtained by MATHEW/ADPIC to date, and reflect the capabilities of the models to reproduce dispersion patterns in relatively straight-forward meteorological and simple terrain conditions. On average, the ratios, R, fall within a factor of two for 50% of the comparisons, a factor of five for 85% of the comparisons, and a factor of ten for 95% of the comparisons. The resultant curve given by these percentages represents the expected upper bounds of statistical performance for the models.

ASCOT (1980), ASCOT (1981), and ASCOT (1984)

In contrast, the most challanging conditions were encountered as part of the Atmospheric Studies in Complex Terrain (ASCOT) program. In 1980 and 1981 separate experiments were completed in The Geysers geothermal area of Northern California to study nocturnal drainage flow in areas of complex terrain (local variations of up to 800 meters) [4,6]. These conditions typically produce very localized turbulence and wind shears with accompanying strong vertical motions.

Multiple near-surface one-hour releases of two fluorocarbon tracers were conducted under stable nighttime drainage conditions, as well as one-hour elevated releases of a heavy methane in 1980 and a fluorocarbon in 1981. Most concentration measurements were made at the surface from 500 meters to ten kilometers from the release point. Approximately 1600 one-hourly and two-hourly averaged air concentration samples were used for the evaluation study.

In 1984 ASCOT moved to the Brush Creek Canyon area of Colorado [5]. The experiments were carried out in a steep-walled, V-shaped, deep canyon cut into a flat mesa. Differences in terrain elevation approach 1000 meters in this region. Again, both surface and elevated releases of fluororcarbon tracers were conducted; however, to date, only one night of the 1984 surface release data have been used for a MATHEW/ADPIC evaluation study.

The results of these studies are given in Figure 2b. As shown, the combination of an elevated tracer release and the difficulties produced by complex terrain and meteorology lead to the lower bounds of model performance. In these conditions only about 20% of the ratio comparisons are within a value of R equal to two, about 35% are within R equal to five, and about 45% are within R equal to ten. One major reason for the degradation in performance results under these conditions is the lack of represeritivity of the "point" measurement locations in reproducing a clearer description of local area concentrations. Analysis of the 1980 tracer data showed, for example, variations in the two-hour measured concentrations greater than a factor 20 for samplers 50 to 60 meters apart [19]. This variation challenges the physical basis and resolution of these models, and is enhanced by the elevated releases into shallow vertical atmospheric stratifications.

To gain further insight into the models' capabilities under these demanding conditions, relaxation of the stringent spatial requirements of the ratio statistical method is appropriate. An area of uncertainty may be defined about each sampler location. As shown in Figure 3, the size of the area, A, is determined from an angle of uncertainty, $\pm \int \Theta$, and the distance from the source point. The maximum (Cp+) and minimum (Cp-) concentrations predicted by the model to occur within the area A may then be determined. An error bar is thus defined by the Cp+ and Cp- limits. The ratio R (as previously defined) is set equal to one if the observed sampler concentration (Co) falls between the limits of Cp+ and Cp-. This adjusted ratio is noted as R/and is used only in Figure 4 to demonstrate the dramatic improvement in the selected September 2, 1980 and September 30, 1984 ASCOT comparisons when $\pm \int \Theta = 5°$.

The 1980 ASCOT data was further used to study the effects of the density of the meteorological data used in MATHEW [16]. Since an increase in wind shear is likely in areas of complex terrain, limiting the use of surface and upper air data in areas such as The Geysers is expected to degrade model performance. Five successively diminished data sets were used to quantify the degradation: (1) the complete data set of 47 surface stations and eight vertical profiles of wind speed and direction, (2) 47 surface stations but only one profile nearest the center of the grid, (3) one profile and only 25 surface stations, (4) one profile and twelve surface stations, and finally (5) no measured vertical profile (using instead an estimated power law profile) with only one surface station at each of the three tracer release points.

Results of the five cases are shown in Table 2. The percentage of modeled and measured values within a factor of five are given, ranging from 53% for case (1) to 32% for case (5). As expected, the percentages decrease with the amount of data available to MATHEW. Although no other data sets have been used for a similar comparison, it is expected that corresponding effects under simpler terrain and meteorological conditions would be less than illustrated in this example.

TMI (1980), EPRI (1980-1), Øresund (1984), and PG&E (1986)

With the upper and lower model performance limits defined by the above studies, many additional evaluations have been completed for a variety of environments. In 1980 Kr-85 was purged from the Three Mile Island (TMI) containment vessel [7]. A wide range of atmospheric stabilities influenced the dispersion during the continuous twelve-day release. The TMI plant is located in a shallow river valley, with rolling hill terrain variations of up to 100 meters in the immediate area. From 1980 to 1981 the Electric Power Research Institute (EPRI) conducted sulfur hexafluoride (SF6) releases from a 187 meter stack situated in the flat terrain of central Illinois [9]. Data were collected during unstable daytime dispersion conditions, as well as both a morning and evening transition period. And in 1984 SF6 was released in a series of experiments over the Øresund strait between Denmark and Sweden to explore dispersion processes over the interface between a cold water surface and a warm land surface in a coastal environment [10]. The tracer was released from approximately 100 meters above the surface on the upwind coast. Terrain on either side of the strait ranges from flat to rolling hills with no more than a 100 meter variation. Finally, in 1986 the Pacific Gas and Electric (PG&E) company conducted both surface and elevated (70 meter) SF6 releases in the rugged coastal terrain around the Diablo Canyon Nuclear Power Plant near San Luis Obispo, California [20].

Most samples were hourly averaged air concentrations ranging from two to 40 kilometers from the release points. Evaluation results for these data sets are shown in Figure 5. It is evident that these results fall within the limits of the previously described curves. As expected, the TMI comparisons reflect the relatively simple terrain and meteorology encountered during the twelve-day release period. Since neither the EPRI nor Øresund studies were in areas of complex terrain, some explanation of the degraded results is warranted.

Since the tracer in the EPRI study was associated with a power plant plume significant thermal and momentum plumerise was a complicating factor. Effective stack heights were from 400 to 600 meters. The added uncertainties in modeling the correct plumerise and deriving the appropriate stability parameterizations during the morning and evening transition periods for such elevated plumes can have a strong influence on the estimated surface concentrations. It is evident that under these conditions the model performance approaches that of elevated plumes in areas of complex terrain.

Although the Øresund results better approach the upper performance curve, an uncharacteristic bias to overpredict the measured maximum surface air concentrations was detected. The probable cause of the overprediction can be illustrated from Figure 6 which is derived from Gudiksen and Gryning [10]. The formation of a shallow stable layer over the cool waters of the strait reduces mixing of the tracer much below the top of this layer (this was confirmed by measurements of the vertical SF6 concentration profile). The fraction of the SF6 which is entrained downward is additionally subjected to an increased upward motion as it approaches the warmer downwind land mass. Since the MATHEW/ADPIC models do not currently have the ability to spatially vary the effects of atmospheric stability, they are likely to bring the tracer to the surface too quickly under these conditions.

MATS (1983) and Montalto (1984)

As mentioned earlier, the ratio method employed in these comparisons can sometimes mask the ability of a model to properly reproduce the diffusion of a plume if there are relatively small errors in 'he mean wind direction. Two tracer studies, the Mesoscale Atmospheric Transport Studies (MATS) conducted at SRP in 1983 [11] and a series of seabreeze experiments conducted at the Montalto nuclear power plant outside of Rome, Italy in 1984 [12], are used to illustrate this point.

Both experiments involved multiple releases of SF6 over simple terrain. Release heights varied from ten to 60 meters, and measurements were made with arcs of samplers positioned from one to 30 kilometers from the source. Typical atmospheric stability ranged from class B to class D. Model estimates were compared to the time-integrated concentration measurements for the entire plume passage over the arcs of samplers.

Figure 7 shows the measured and calculated results for one of the 14 MATS experiments. The SF6 concentrations are plotted by the sampler number of those monitors in the portion of the arc affected by the plume passage. This reflects how well the model reproduces the plume's shape and peak concentration. By applying a 7.7 degree rotation in the mean transport wind, ratios of computed to measured values are reduced from in the hundreds to a factor of two. This reduction is most notable near the plume's edges where concentrations are low and gradients are high.

By applying an average rotation of not more than five degrees to the MATS and Montalto results, the adjusted curves in Figure 8 are produced. The apparant difference in modeled and actual mean wind direction (as given by the tracer concentration measurements) may be caused from errors in the modeled wind field or in the limited sensitivity of wind instrumentation used for some data sets.

STABLE (1988)

Recently a third data set collected at the Savannah River Plant was used to evaluate model performance against drastically reduced measurement averaging times [8]. The 1988 Stable Boundary Layer Experiment (STABLE) was conducted over a three-night period by releasing SF6 from a 60 meter stack [21]. The four-hour continuous release of April 14 was chosen for study. Ground level concentration data were collected from a mobile van which intersected the SF6 plume while driving on roads from five to 20 kilometers downwind of the release point. Thirty-second averages of the data were used to compare to model calculations of instantaneous concentration. Local meteorological data were averaged over 15-minute periods for input to MATHEW. Wind direction rotated 35 to 40 degrees during the four-hour period of data collection.

Figure 9 shows the results of 109 comparisons. Although these ratios are paired in space, the measurements were compared with the 15-minute calculated concentration closest to each measurement's observation time. This led to differences in model and observed concentration times of up to 7 and one-half minutes. This inexact temporal pairing, plus the reduction in typical measurement averaging times from 60 minutes (or more) to 30 seconds, degrades the results to the lower limits of model performance.

Roller Coaster (1963)

The MATHEW/ADPIC models are applied to a variety of radionuclide release scenarios. One of the more commonly modeled release mechanisms involves an explosion in which the resulting thermal environment aerosolizes radioactive material. Recently, a computer code developed by Sandia National Laboratory (SNL) was incorporated into the ADPIC model to allow better estimation of the time-dependent cloud rise associated with explosive puff releases. This was followed with an evaluation of MATHEW/ADPIC, using the SNL code, by comparing model results of air concentration and deposition to the Clean Slate 1 and Double Tracks data from the Roller Coaster series of experiments [13].

The Roller Coaster experiments were conducted in 1963 at the Tonopah Test Range in Nevada to investigate the effects of a credible nuclear weapon accident from the inadvertent detonation of the device's high explosive without causing a nuclear yield [22]. Of the four experiments, the Clean Slate 1 and Double Tracks shots are the most applicable for investigation of an open-air high explosive detonation accident. Measurement data of airborne and deposited plutonium were collected by arcs of samplers placed a few hundred meters to several kilometers downwind of the shots. Both shots took place over relatively flat areas of the test range under stable atmospheric stability. The two experiments were conducted using different explosive amounts, 482 and 53 kilograms (TNT equivalent).

The SNL code [23] provides ADPIC with a time evolution of the physical and thermodynamic properties of a buoyant cloud. These properties include the cloud's radius, height, temperature, and vertical velocity. Comparisons of model predictions with observed cloud heights from both Clean Slate 1 and Double Tracks are shown in Figure 10, and are comparable to the results achieved by Boughton and Delaurentis [23].

A relationship between the buoyant cloud velocity and ADPIC's Lagrangian "mass" particles was determined using comparisons to the Clean Slate 1 air concentration and deposition patterns. The transferability of this relationship was evaluated with data from Double Tracks. To date, a complete analyses using all sampler data has not been completed for this evaluation. Figure 11, however, shows the measured and calculated Clean Slate 1 plume centerline integrated air and deposition values when normalized to a one kilogram plutonium release. The equivalent values for Double Tracks are shown in Figure 12. MATHEW/ADPIC calculations are typically within a factor of three of the air concentration measurements, and a factor of two for deposition. A comparison of measured to calculated deposition contour patterns are shown in Figures 13 and 14 for Clean Slate 1 and Double Tracks, respectively.

Chernobyl (1986)

The model evaluations sited to this point have studied performance on the scales of a few hundred meters to several tens of kilometers. The Chernobyl nuclear power plant accident [24] provided an opportunity to use MATHEW/ADPIC on a hemispheric scale and compare results to surface and elevated measurements of Cesium-137. The source was modeled such that approximately 4.5 x 10E16 Becquerels of Cesium was released in a lower level cloud extending from the surface to 1500 meters, and another 4.5 x 10E16 Becquerels was released in an upper level cloud from 1500 meters to 7500 meters above the surface. This geometry and source strength were determined by optimizing the agreement between available observations and ARAC's PATRIC (a simplified version of ADPIC) modeled cloud arrival times and peak concentrations from various locations in Europe, Japan, Kuwait, and the United States. A more complete discussion of the source term assumptions can be found in Gudiksen, et al. 1989 [17].

Comparisons of calculated and measured Cesium concentrations are shown in Table 3. The measured air concentrations were derived by calculating the average daily concentrations and subsequently averaging them over the periods given in the table. Appendix A lists the references for these measurements. Table 3 shows good overall agreement of cloud arrival times with most of the concentration estimates within a factor of five. Rainout and topographical effects were neglected for this particular comparison. The lack of proper treatment of precipitation effects is the likely cause for the underprediction of the Berkeley measurement. The limited number of comparisons are presented here as an illustration of the applicability of MATHEW/ADPIC to a global transport and diffusion problem, and not as a complete evaluation study.

A detailed evaluation study has recently been completed using the Chernobyl data set as part of ARAC's participation in the Atmospheric Transport Model Evaluation Study (ATMES) co-sponsored by the International Atomic Energy Association, World Meteorological Organization, and Commission of European Communities. Results are expected to be published following the ATMES workshop to be conducted in March, 1991.

SUMMARY

The MATHEW/ADPIC transport and diffusion models have been evaluated using data from a variety of tracer release studies and other atmospheric releases of neutrally bouyant and non-reactive species. Performance depends upon the complexity of the topography and meteorology being simulated by the models. When simple terrain and meteorological conditions exist, the models have predicted to within a factor of two of the measurements 50% of the time, and to within a factor of five 85% of the time. These percentages degrade in studies involving complex conditions to 20% and 35%, respectively. Although most of the 14 evaluation studies discussed dealt with passive tracer releases, studies involving explosive release mechanisms have also been completed. In these studies, ground deposition and air concentration calculations were typically within a factor of 2 to 3 of the measurements.

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APPENDIX A: References for Table 3

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TABLE 1
A List of Data Sets Used in MATHEW/ADPIC Evaluation Studies
(in order of following discussion)

STUDY	YEAR	LOCATION	TOPOGRAPHY	ATMOSPHERIC STABILITY	RELEASE HEIGHT
INEL [3]	1971	Idaho Falls, ID	Flat-Rolling	Unstable	Surface
SRP [3]	1974	Aiken, SC	Flat-Rolling	All	Surface, Elevated
ASCOT [4,5,6]	1980	The Geysers, CA	Complex	Stable	Surface, Elevated
ASCOT [6]	1981	The Geysers, CA	Complex	Stable	Surface, Elevated
ASCOT [5]	1984	Brush Creek, CO	Complex	Stable	Surface
TMI [7]	1980	Harrisburg, PA	Flat-Rolling	All	Elevated
PG&E [8]	1986	San Luis Obispo, CA	Complex	Neutral, Unstable	Surface, Elevated
EPRI [9]	1980-1	Kincaid, IL	Flat	All	Elev + Plumerise
Øresund [10]	1984	Øresund Strait, Denmark/Sweden	Flat-Rolling	Neutral (spatially transitional)	Elevated
MATS [11]	1983	Aiken, SC	Flat-Rolling	Neutral, Unstable	Elevated
Montalto [12]	1984	Italy	Flat-Rolling	Unstable	Surface, Elevated
STABLE [8]	1988	Aiken, SC	Flat-Rolling	Stable	Elevated
Roller Coaster [13]	1963	Tonopah, NV	Flat	Stable	Explosive
Chernobyl [17]	1986	Kiev, USSR	----	----	Explosive

TABLE 2
The Sensitivity of MATHEW/ADPIC to Meteorological Database Density
(using data from the 1980 ASCOT study)

Case		1	2	3	4	5
Data	surface stations	47	47	25	12	3
	upper air profiles	8	1	1	1	1*
Percent Samples Within a Factor of R = 5		53	47	43	40	32

*Profile was derived from a power law relationship

TABLE 3
A Comparison Between Measured and Calculated Air Concentrations and Cloud Arrival Times for the Chernobyl Release
(Bq/m3)

Location	Dates	Cs-137 Concentrations		Cloud Arrival Date	
		Meas.	Calc.	Meas.	Calc.
Nurmijarvi	4/29-5/3	0.08	0.8	4/27	4/27
Stockholm	4/28-5/6	0.2	1.4	4/27	4/27
Kjeller	4/28-5/5	0.2	0.2	4/27	4/27
Munich	4/30-5/6	1.7	2.1	4/30	4/30
Budapest	5/1-5/5	0.6	0.8	4/29	4/29
N. Italy	4/30-5/6	0.7	3.1	4/30	4/30
S.E. France	5/1-5/6	0.4	1.0	4/29	4/30
Paris	5/1-5/7	0.2	0.2	4/29	5/1
S. Italy	5/1-5/6	0.6	0.7	5/1	5/1
Berkeley (UK)	5/1-5/3	0.05	0.0005	5/2	5/3

a)

Observed Concentration (Co)	Predicted Concentration (Cp)	Cp/Co = r
1.5	1.2	0.8
2.0	12.0	6.0
5.7	10.4	1.8
8.8	7.2	0.8
1.6	12.9	8.1
5.0	3.1	0.6
7.9	3.4	0.4
3.3	15.2	4.6
0.8	3.7	4.6
2.3	4.1	1.8

b)

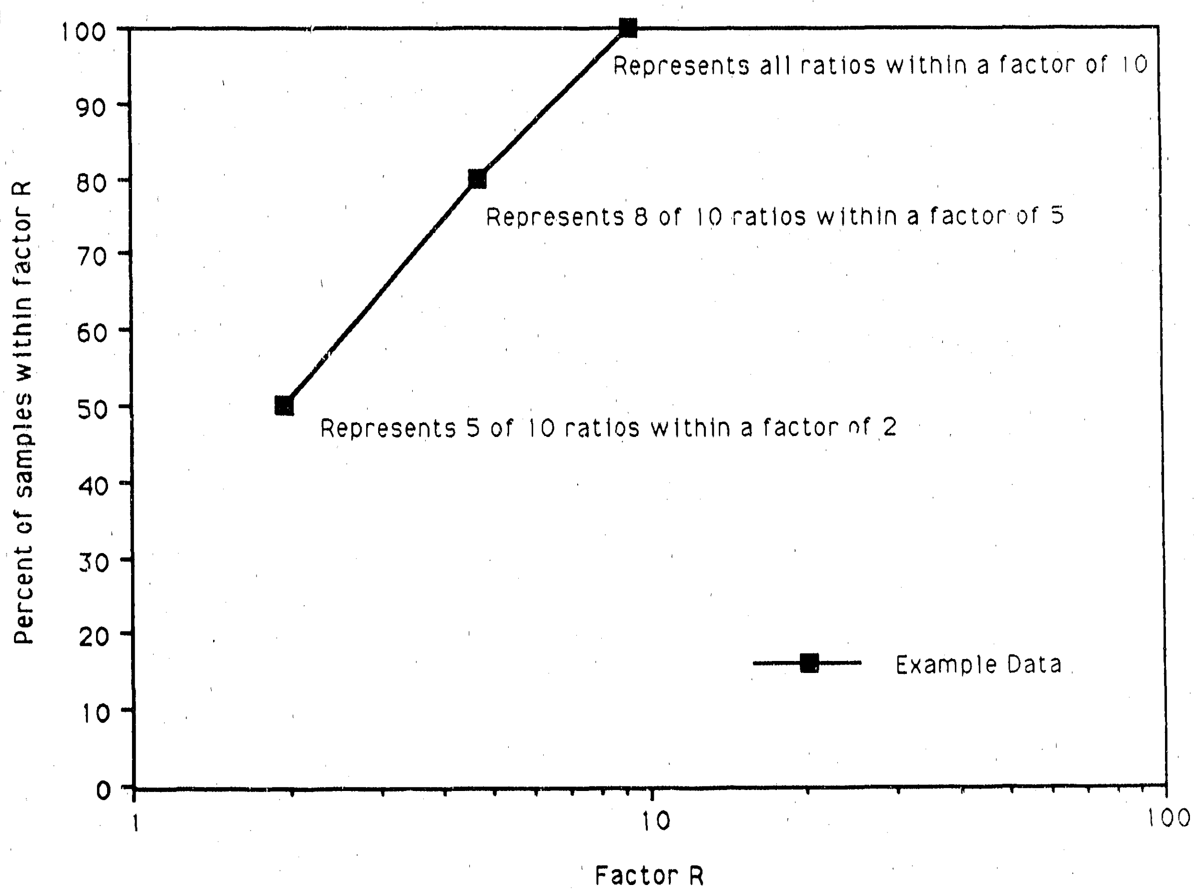


Figure 1: An illustration, using hypothetical data, of the results from the ratio method employed in most MATHEW/ADPIC evaluation studies. This plot would be that derived from the data shown above if background concentration of the tracer were zero.

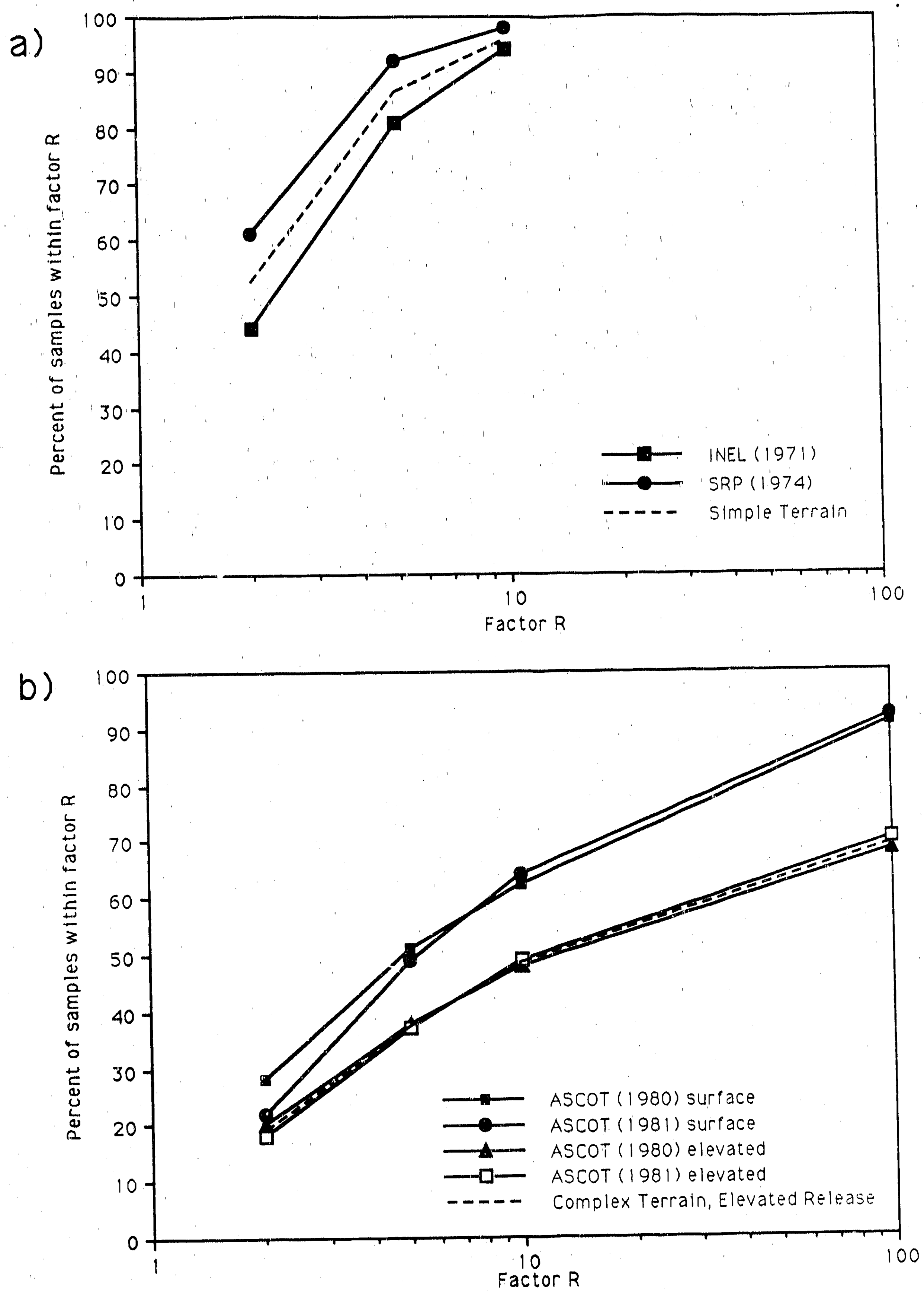


Figure 2: MATHEW/ADPIC evaluation study results in areas of simple terrain (a), and in complex terrain (b). Dashed lines indicate the approximate upper and lower limits of model performance expected in simple and complex terrain, respectively, as derived from these studies.

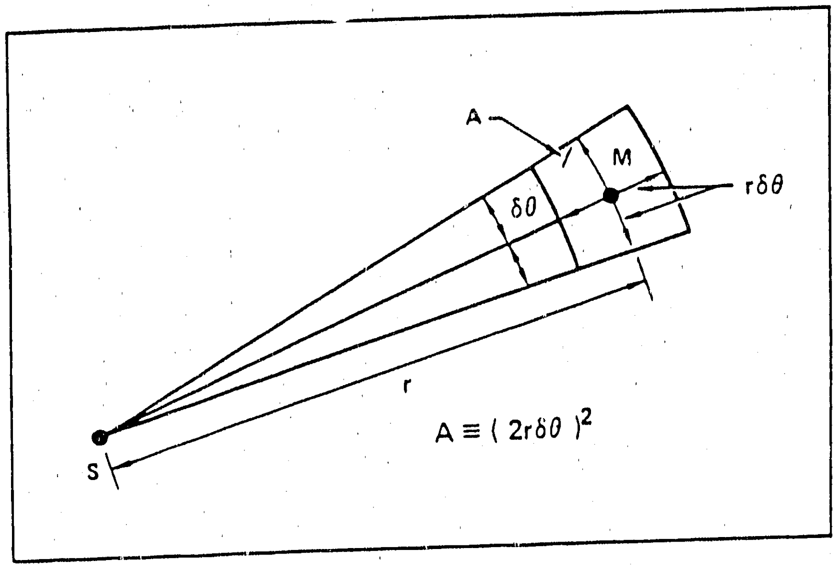


Figure 3: Area of uncertainty A defined by the angular uncertainty $\delta\theta$. M is the location of the sampler and r is the distance of the sampler from the source S.

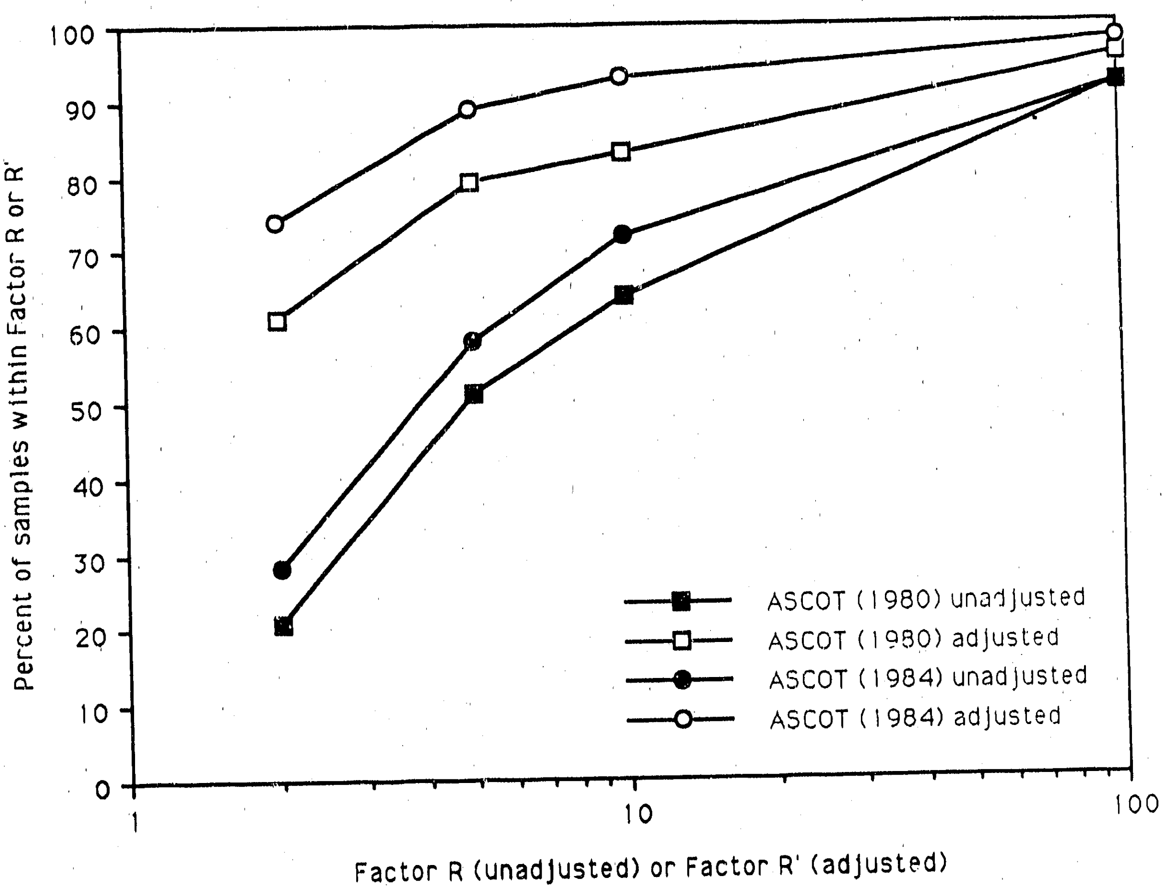


Figure 4: MATHEW/ADPIC evaluation study results for the September 2, 1980 and September 30, 1984 ASCOT experiments. The exact space and time (unadjusted) comparisons are shown, as well as results which allow a five degree directional adjustment for the model calculations.

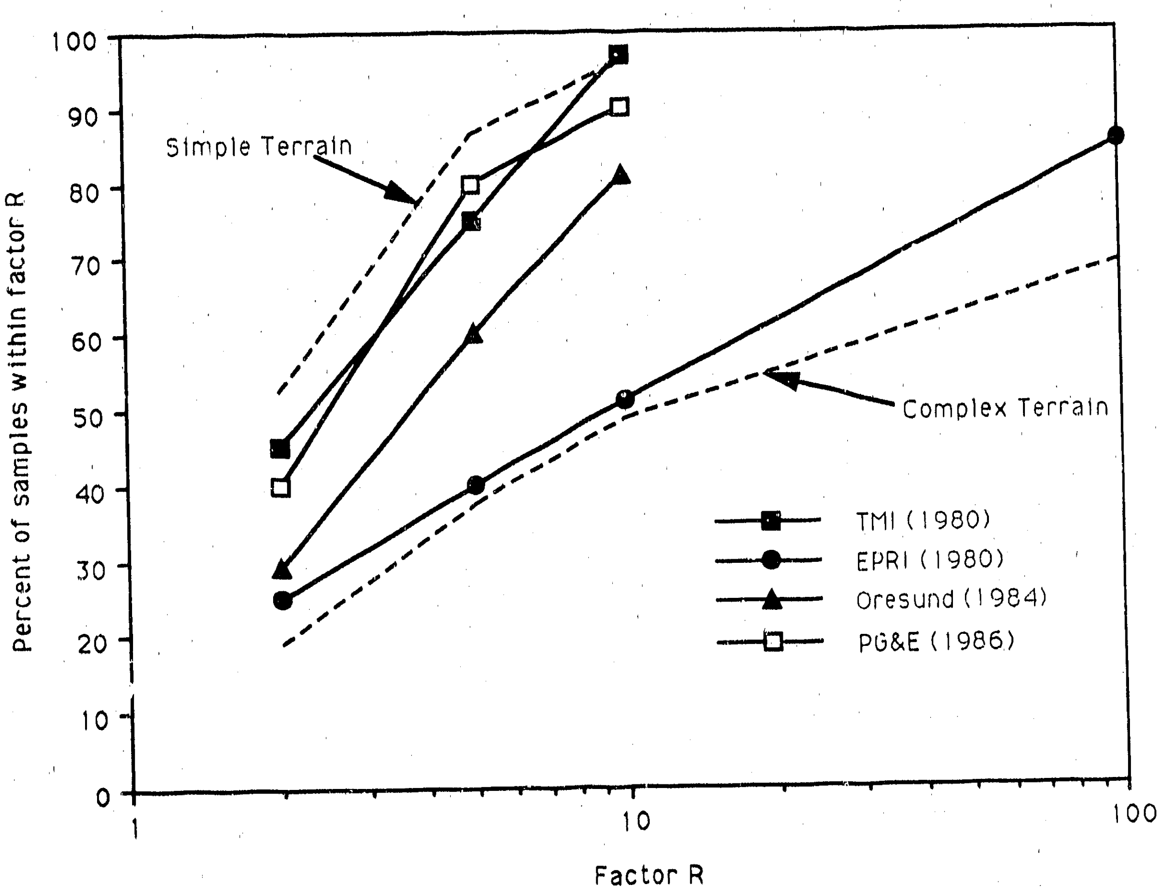


Figure 5: MATHEW/ADPIC evaluation study results from campaigns in a variety of terrain and meteorological conditions. Dashed lines are those from Figure 2.

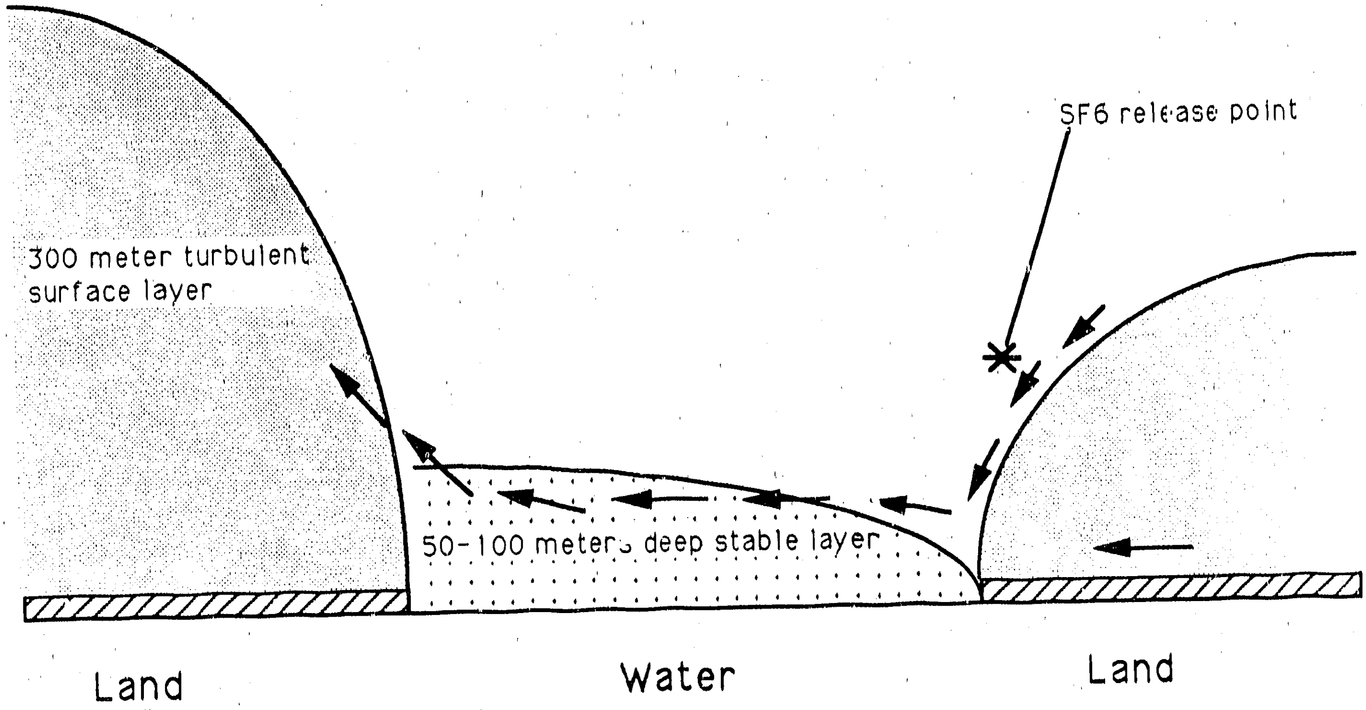


Figure 6: Generalized depiction of the atmospheric bounday layer flows along the east-west cross-section of the Øresund strait. (Arrows indicate wind direction.)

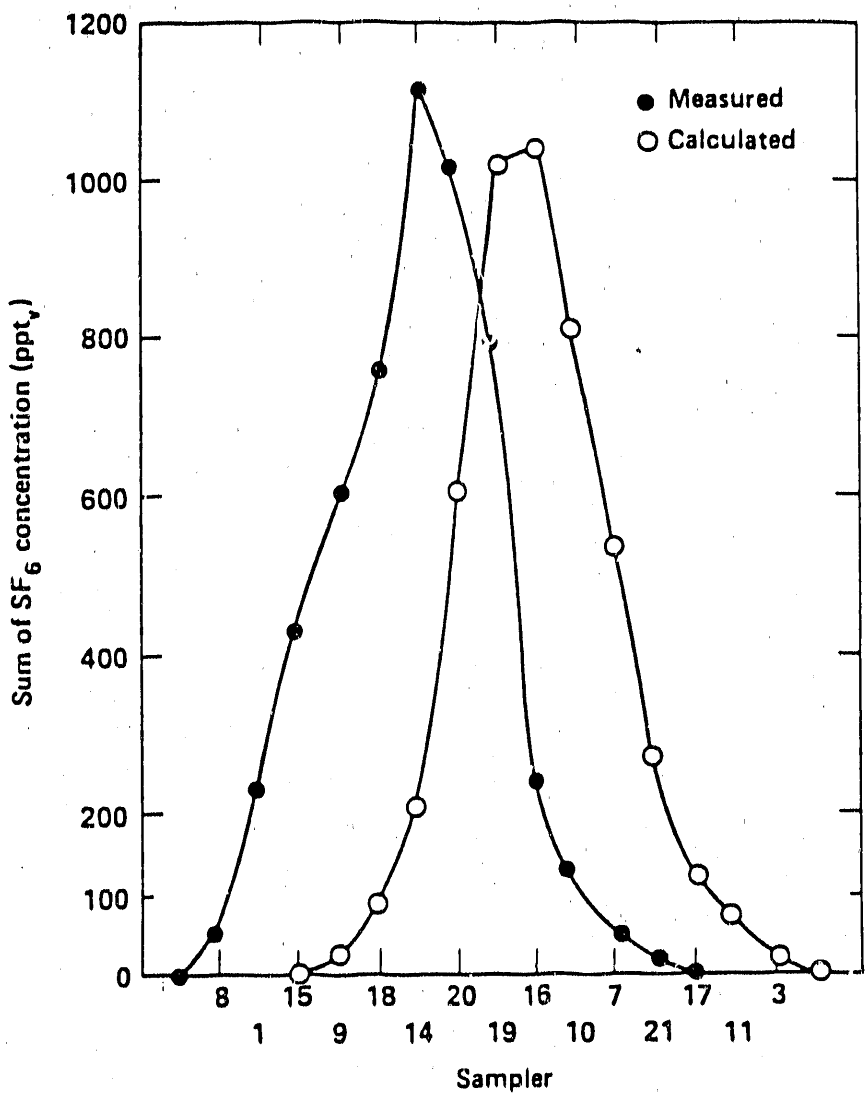


Figure 7: Measured and calculated air concentration values for the SRP 1983 MATS tracer experiment number 7.

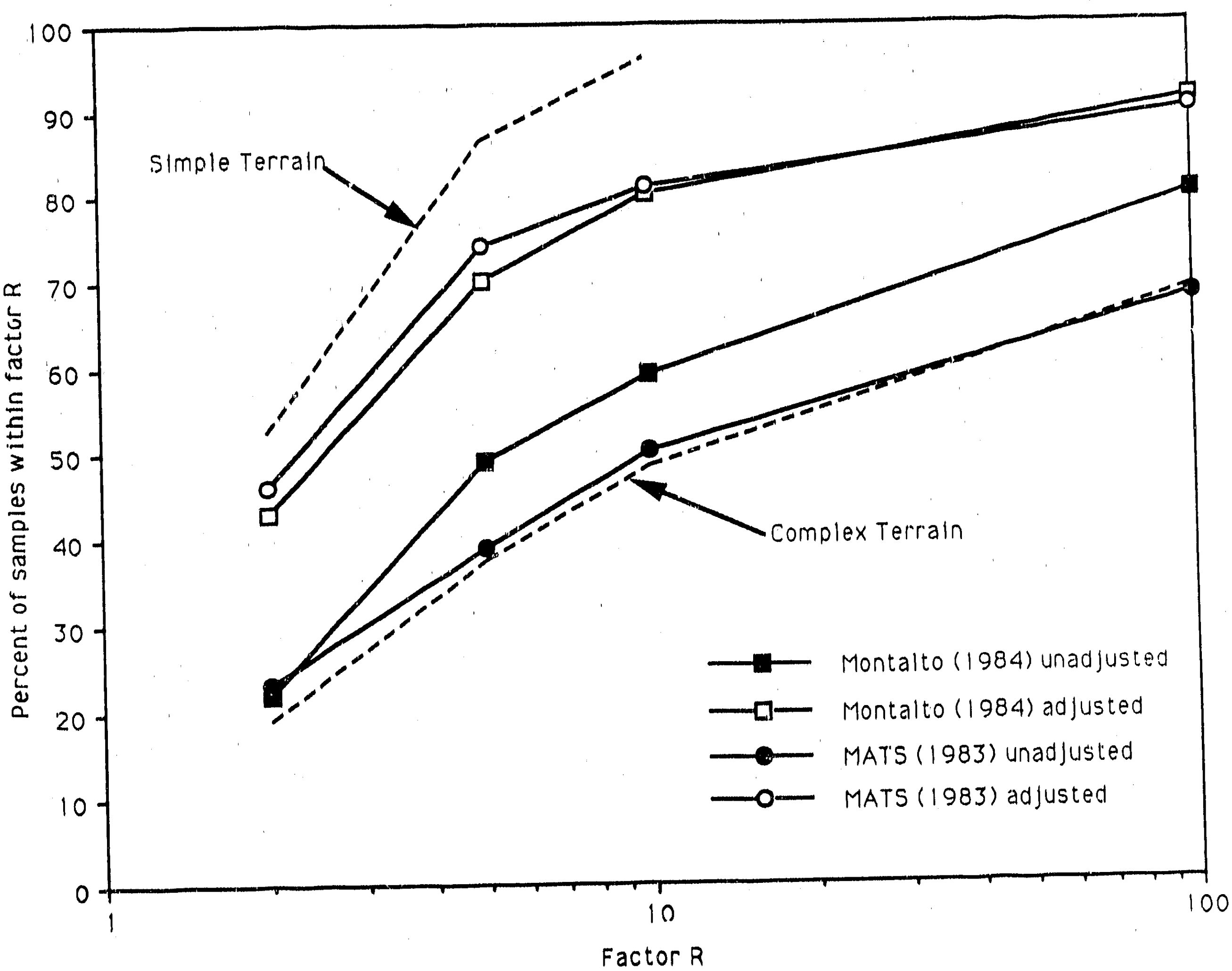


Figure 8: MATHEW/ADPIC evaluation study results for the Montalto and MATS experiments. The unadjusted results are shown, as well as the results (adjusted) when less than a five degree rotation in mean wind direction is made.

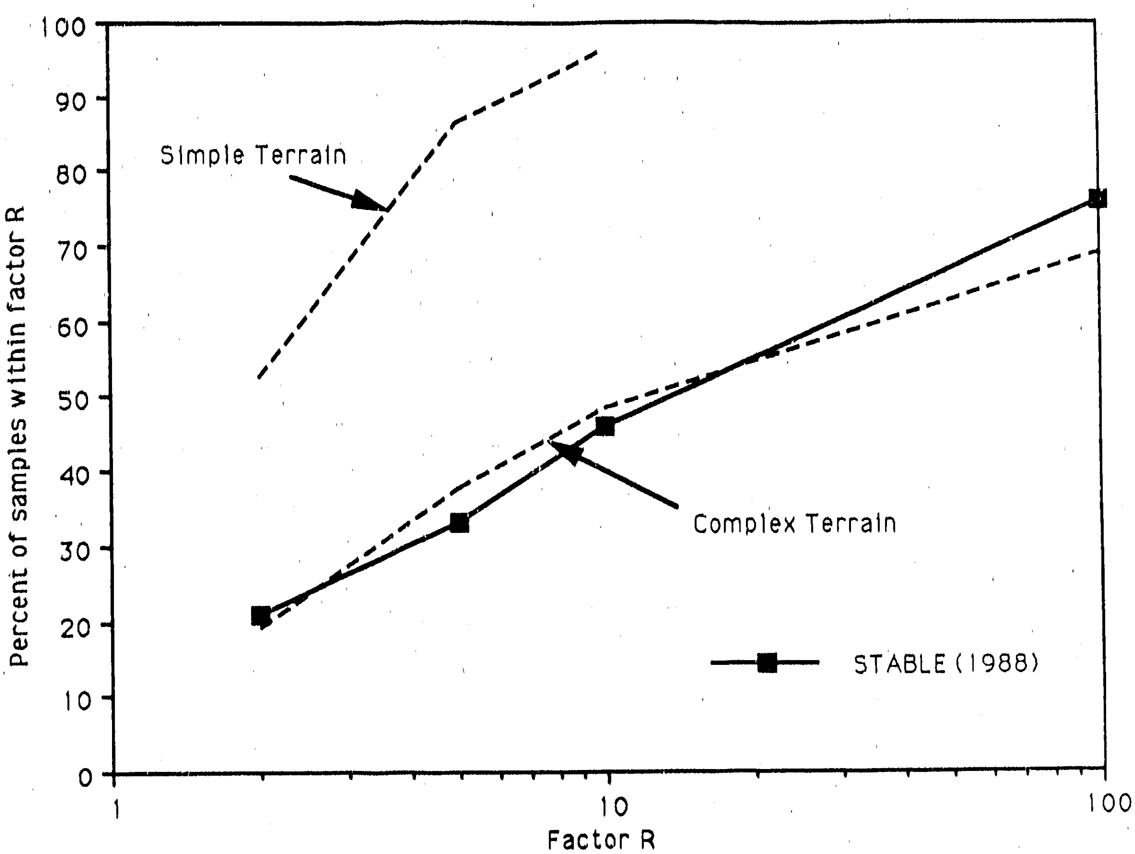
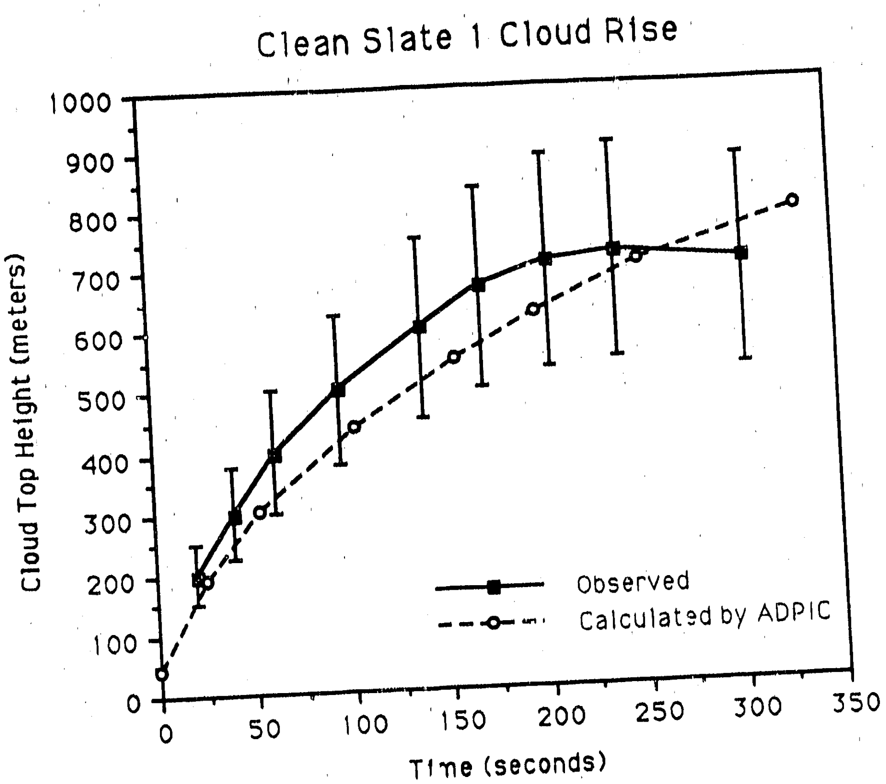


Figure 9: MATHEW/ADPIC evaluation study for the STABLE experiment.



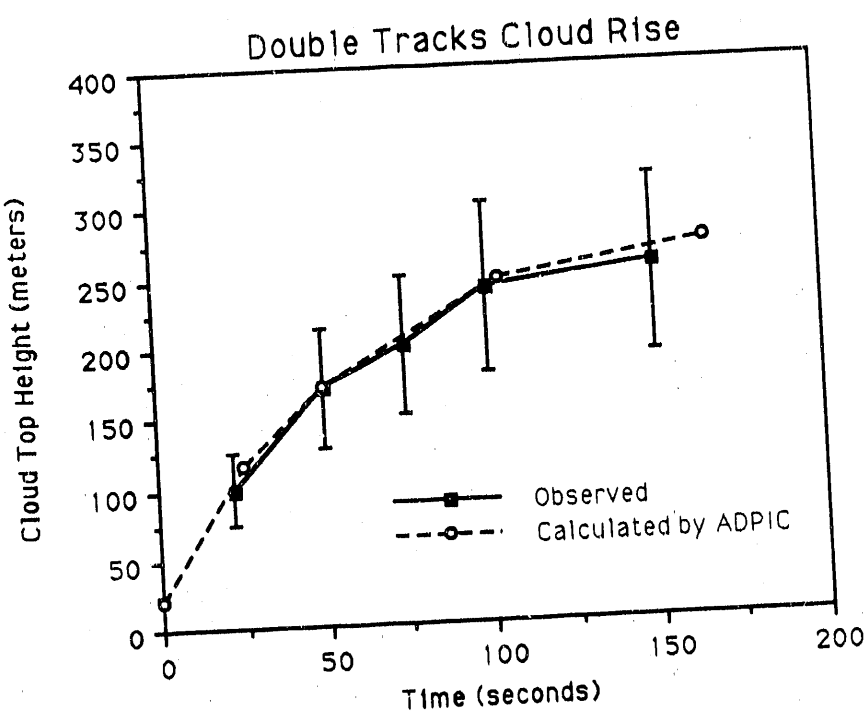
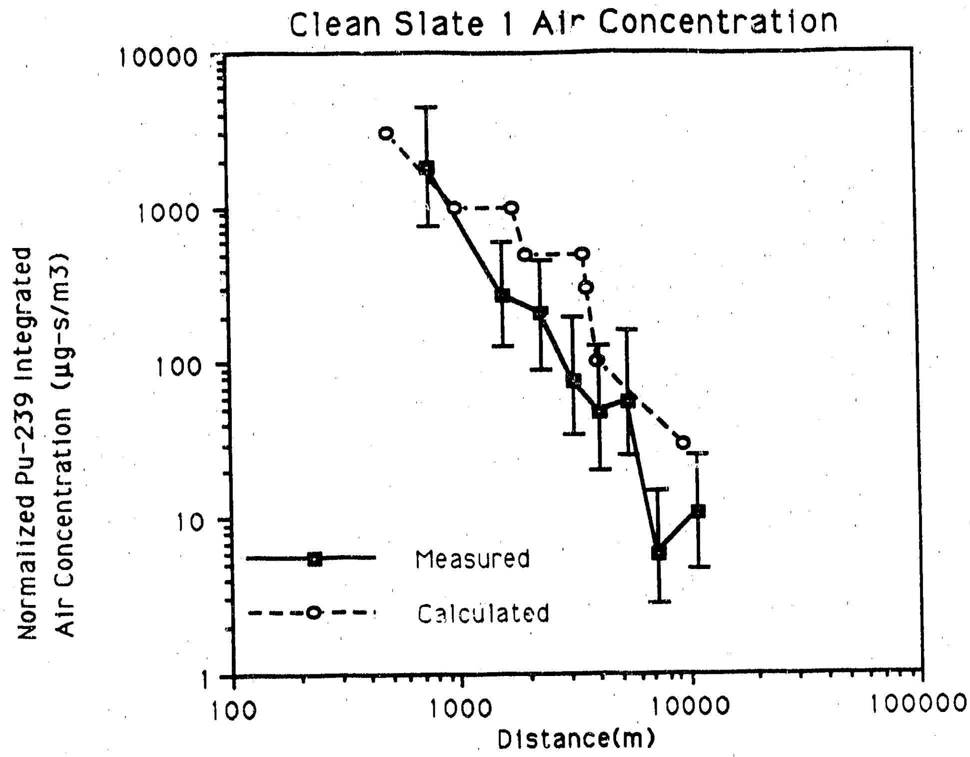


Figure 10: Comparison of observed and calculated cloud top heights for Clean Slate 1 and Double Tracks experiments. (Error bars are 25% of data.)



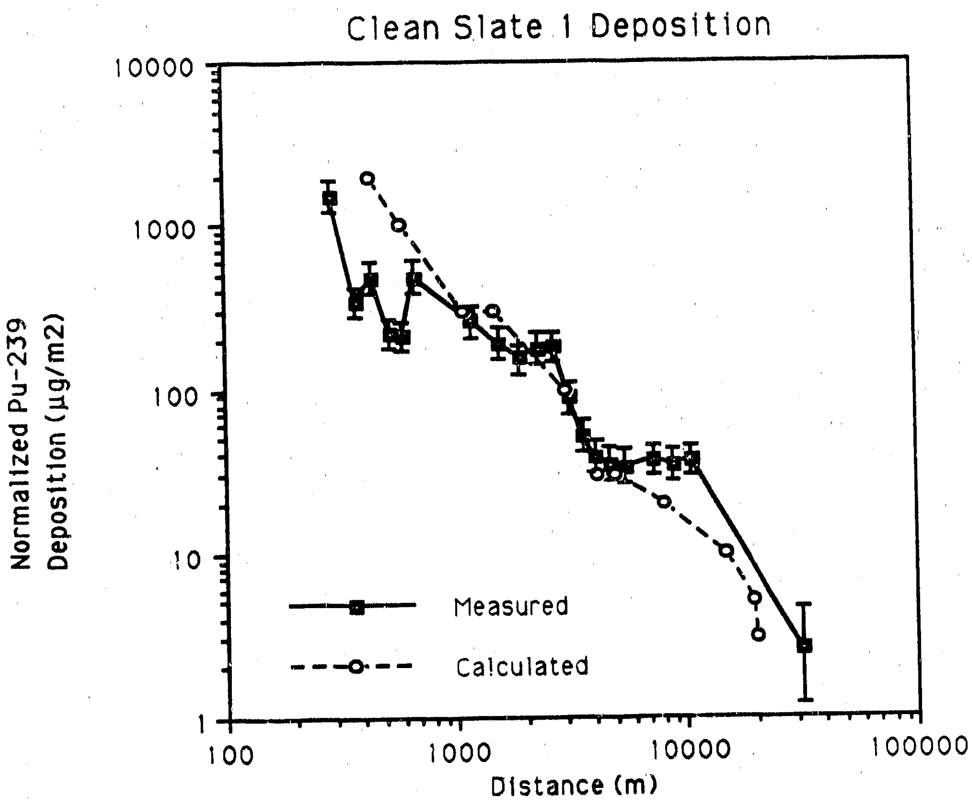
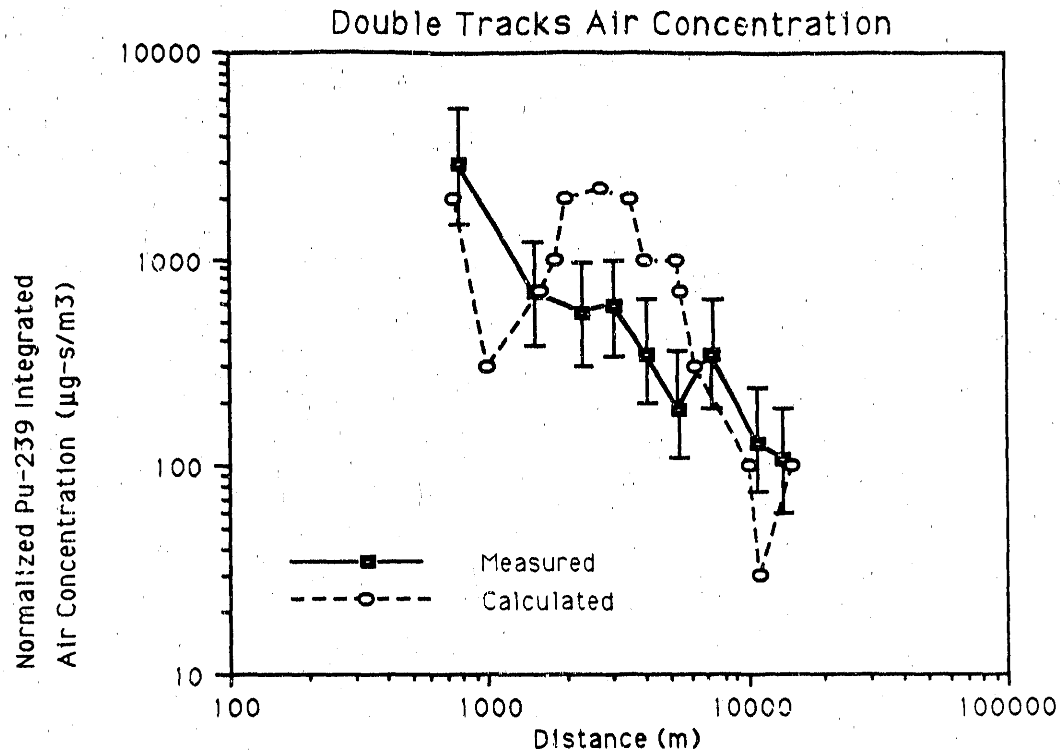


Figure 11: Comparison of measured and calculated centerline air concentration and ground deposition values for Clean Slate 1.



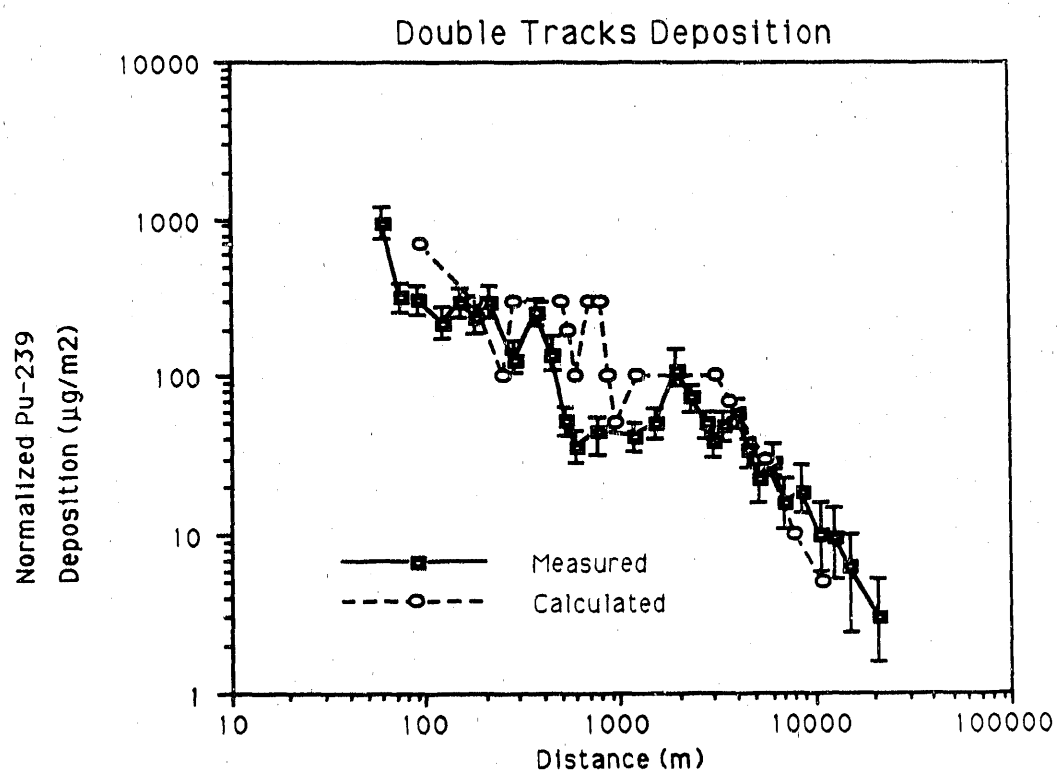
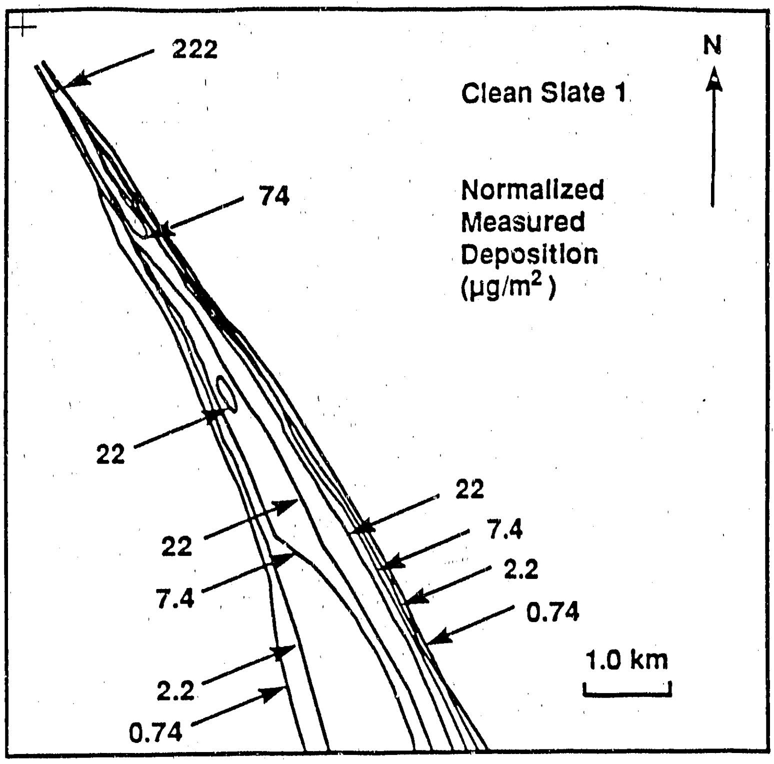


Figure 12: Comparison of measured and calculated centerline air concentration and ground deposition for Double Tracks.

a)



b)

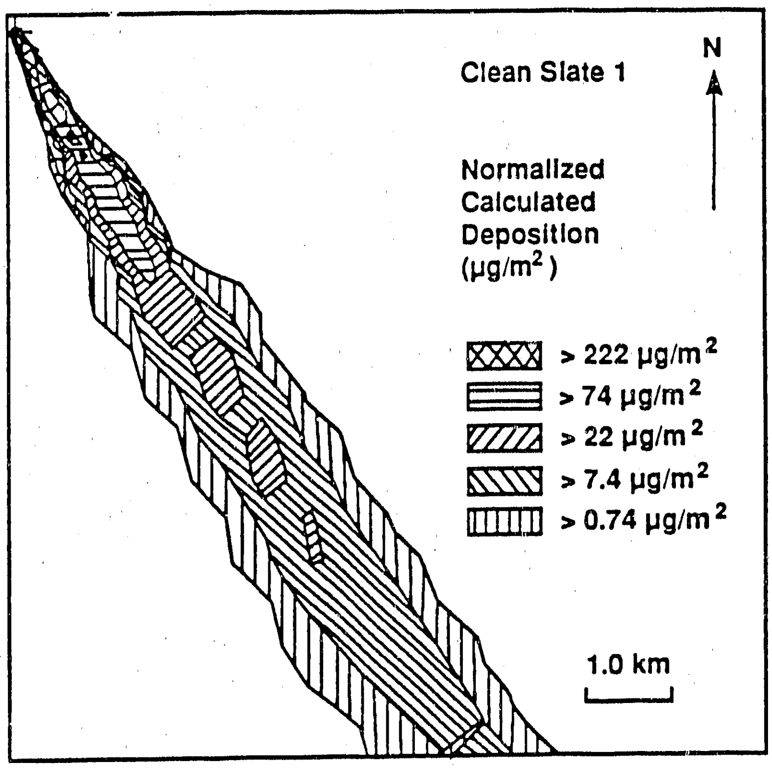
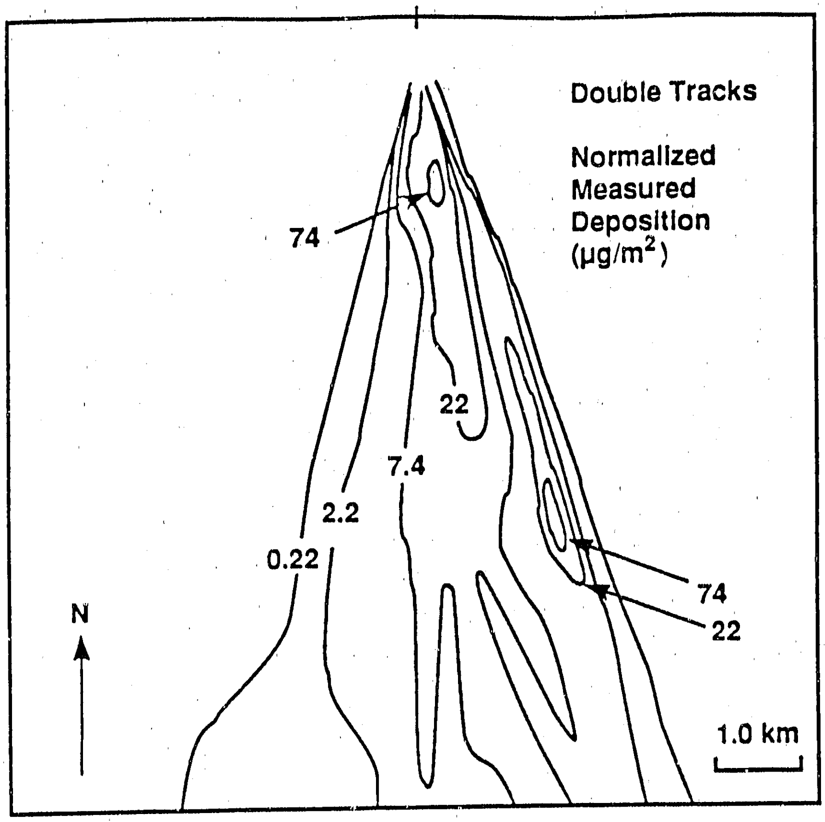


Figure 13: Measured (a) and calculated (b) deposition contours (normalized to a 1 kilogram source release) for the Clean Slate 1 shot. Contours have been subjectively smoothed.

a)



b)

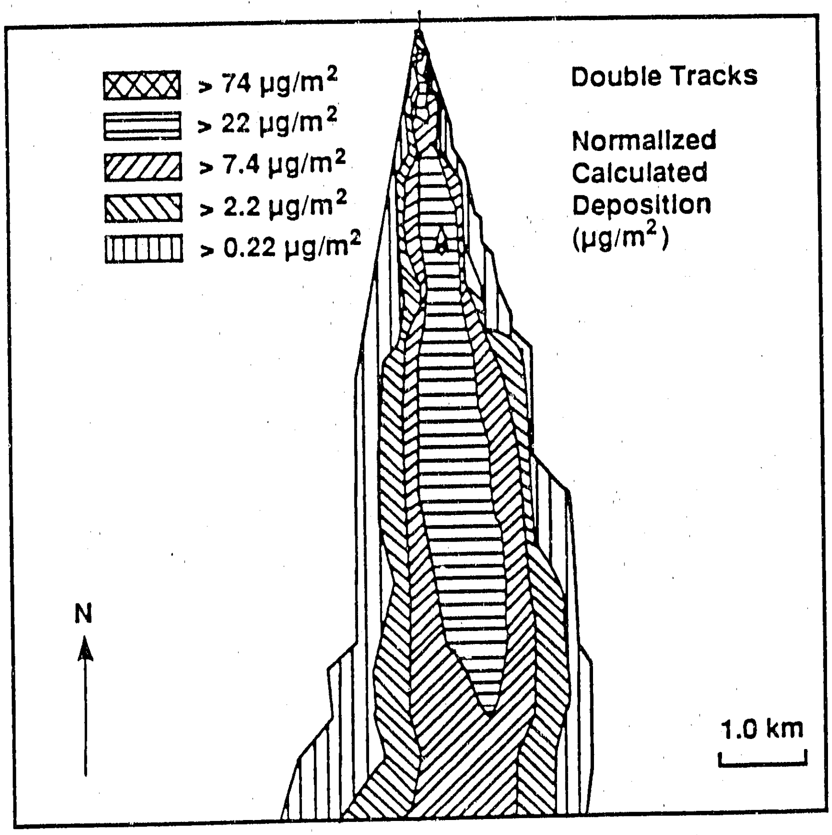


Figure 14: Measured (a) and calculated (b) deposition contours (normalized to a 1 kilogram source release) for the Double Tracks shot. Contours have been subjectively smoothed.

END

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