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A TRACER STUDY OF DISPERSION PATTERNS FROM GRÄNGES ALUMINIUM SMELTER IN SUNDSVALL

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SUMMARY AND CONCLUSIONS

Dispersion experiments using SF_6 as a tracer were carried out during June 1980 in the Sundsvall area. SF_6 was released from the Gränges Aluminium smelter to simulate PAH releases to:

- investigate the transport and dispersion patterns of PAH in the area
- recommend locations for representative measurements of ambient PAH in the Sundsvall area.

Ten SF_6 dispersion tests were conducted during 3-6 June 1980, under wind directions and meteorological dispersion conditions typical for the summertime in the area. During the 4-day test period the plumes from the Gränges Aluminium smelter tended to follow the natural channels of wind flow across downtown Sundsvall, sweeping the northern slopes of the Selånger valley across Norrmalm towards Granlo and Bergsåker. On a couple of occations the paths were more northerly, leading across the western tip of Sundsvallsfjärden passing between Haga and Skönsberg northwards along E4.

On the basis of the measured SF_6 concentration patterns and wind frequency distributions from 13 March - 31 August 1980 PAH sampling stations were selected to represent areas of severe impact, average impact and slight impact.

1. Tivolivägen near Västergatan (residential, severe impact)
2. Kubikenborg (local centre, school, severe impact)
3. Köpmansg./Skolhusallé (downtown, average impact)
4. Sidsjön (residential, slight impact)
5. Mobile unit.

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1 INTRODUCTION

Polycyclic aromatic hydrocarbons (PAH) are among the largest single group of chemical carcinogens known (NAS, 1972). Because of the many sources of PAH, and their stability and long range air transport possibility, these compounds are widely distributed in the environment (Suess, 1976). PAH are largely the undesired, and sometimes unexpected byproducts of the activities of an industrialized society. They are formed by pyrolysis and incomplete combustion of coal, tar, oil and other organic matter (NAS, 1972). Because of their demonstrated carcinogenic effect, PAH are likely to remain the cause of great concern, unless major technological changes can be foreseen.

The Norwegian Institute for Air Research (NILU) was asked by Gränges Aluminium, Division Metall to:

(a) investigate the transport and dispersion patterns of PAH from their Sundsvall smelter operations, and
(b) recommend locations for representative measurements of ambient PAH in the Sundsvall area.

Figure 1 shows the topographical features of the study area.

In the assessment of potential air pollution problems in the aluminium industry, atmospheric tracer simulation techniques have been applied to a wide varity of situations over a wide range of length scales (Lamb et al., 1980). In the Gränges, Sundsvall, study the gaseous tracer sulphur hexafluoride (SF_6) and electron capture gas chromatographic (GC) analysis were selected to achieve the above objectives.

This report describes the experimental procedures used, and presents the results and recommendations of the study.

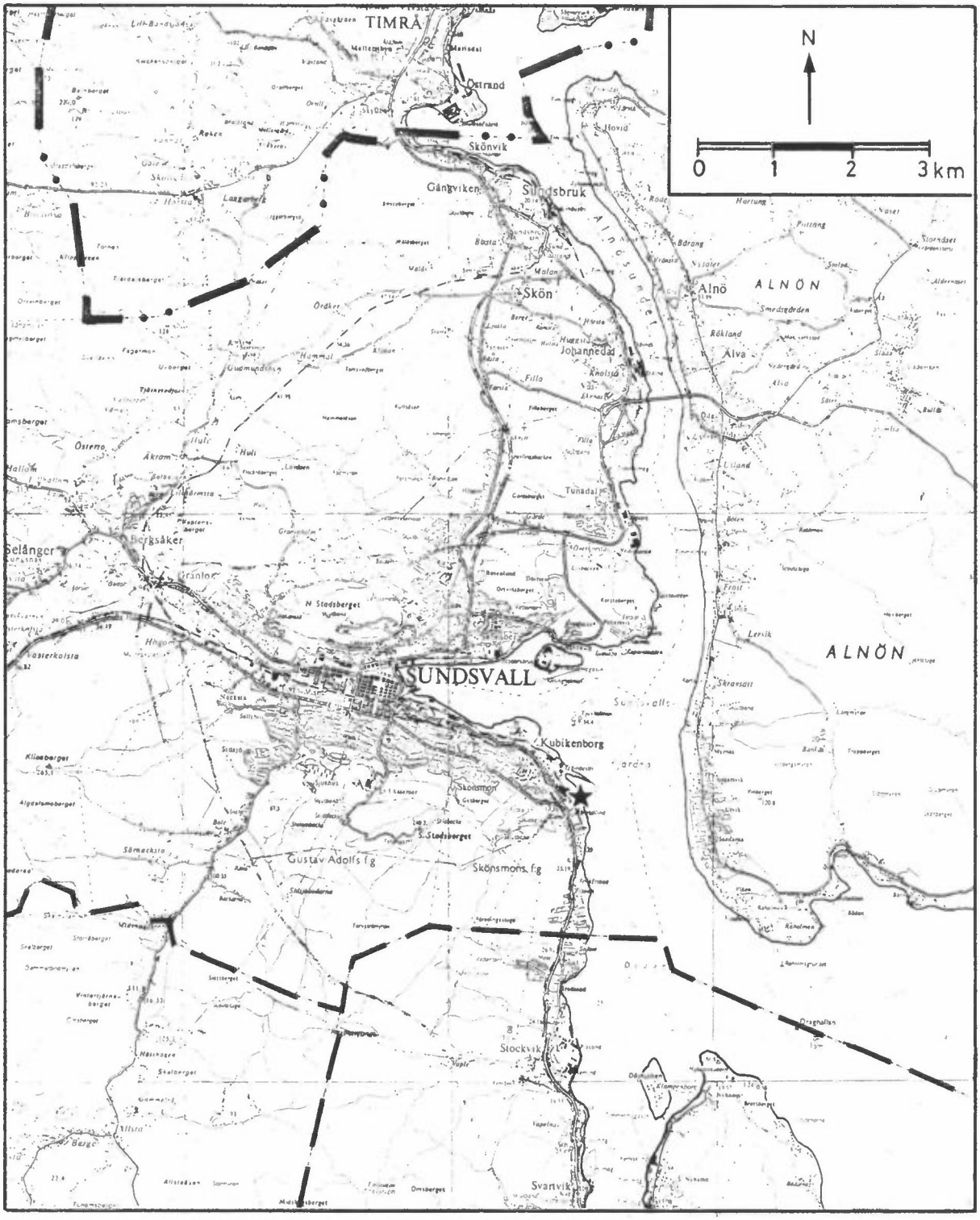


Figure 1: Topographical features of Sundsvall and surrounding area. The location of Gränges Aluminium smelter is indicated by ★

2 INSTRUMENTATION AND EXPERIMENTAL PROCEDURES

Ten SF_6 dispersion tests were conducted in Sundsvall during 3-6 June, 1980. The methods employed in these tracer studies included the continuous release of a known amount of SF_6, collection of air samples at various points and times using inexpensive, plastic syringes, and rapid analysis of the samples with electron capture gas chromatography. SF_6 is an inert non-toxic, colourless, and odourless gas which can be detected at concentrations as low as 10^{-12} p SF_6/p air by electron capture gas chromatography (Lamb, 1978). SF_6 does not occur naturally, and its uses have been confined to high-power electrical equipment (as electrical insulation medium in switching gear and transformers) and lately to certain metallurgical operations (as inert flame-quenching gas). Background levels of SF_6 in Scandinavia are less than 10^{-12} p SF_6/p air (de Bortoli and Peechio, 1976).

The equipment and procedural details have been previously described (Lamb and Sivertsen, 1978), and are only briefly reviewed here.

2.1 Tracer release

In the study described in this report, the SF_6 tracer was released from compressed gas cylinders through 2-stage pressure regulators and flowmeters. The rotameter-type flowmeters had been individually calibrated using SF_6 gas and a precision wet test meter.

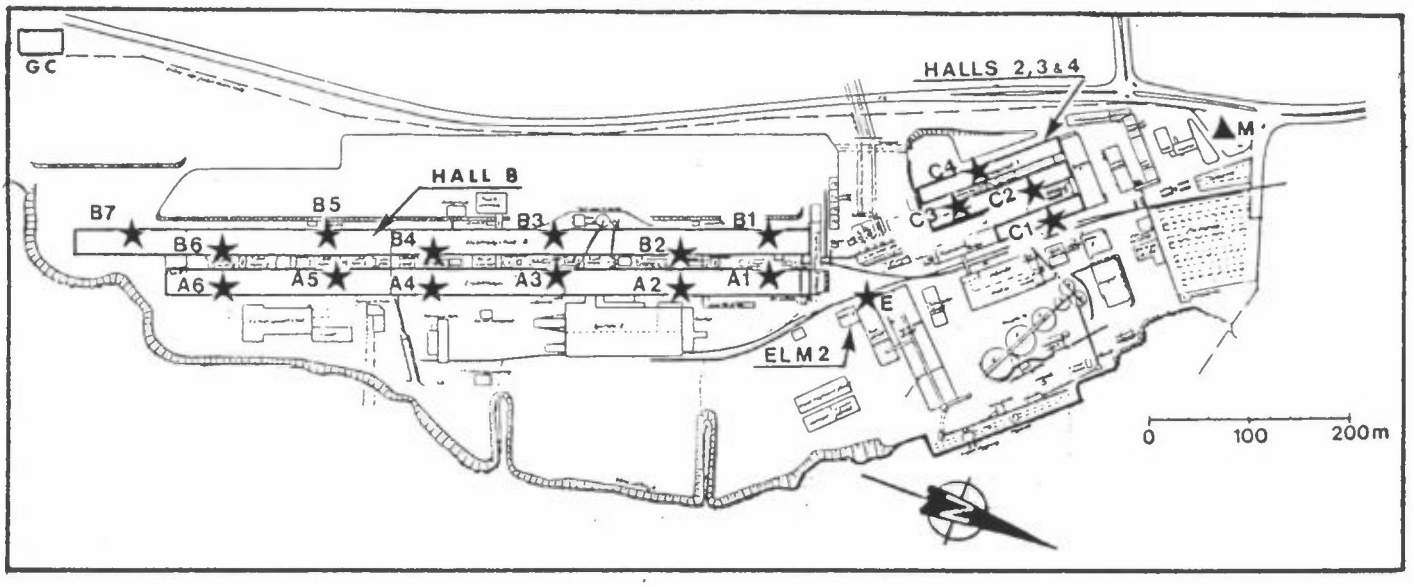


Figure 2: *SF_6 release points - Hall A: A_1-A_6; Hall B: B_1-B_7 Halls 2,3&4: C_1-C_4; Anode paste plant (ELM2):E. Meteorological tower: M. Gas chromatograph for SF_6 analysis (GC).*

The approximate locations of all the release points are shown in Figure 2. In reduction halls A (points Al-A6), B(points Bl-B7), and 2,3 and 4 (points Cl-C4), the SF_6 was released simultaneously at all points about 50 cm above the potroom floor to simulate emissions from the reduction pots. To simulate the diffuse and stack emissions from the anode paste plant (ELM 2), SF_6 was released from a single cylinder, through a flowmeter and a vertical plastic tube, on the roof of one of the buildings of the plant approximately 20 m above ground.

In each of the ten tests, SF_6 was released continuously and at a constant rate for the duration of the releases, and all releases were continually monitored. A summary of the overall release rates for the various tests is given in Table 1.

Table 1: Summary of SF_6 release data during the tracer tests at Gränges Aluminium smelter, Sundsvall.

Test No.	Date of test	Time of test	Total SF_6 release rate, q $SF_6 s^{-1}$		
			Verk 1* (Halls 2,3&4)	Verk 2* (Halls A&B)	ELM 2*
1	030680	1415-1430	0.27	0.87	0
2	030680	1700-1715	0.27	0.87	0
3	040680	1100-1115	0.27	0.80	0
4	040680	1350-1405	0.27	0.87	0.11
5	040680	1615-1630	0	0	0.33
6	050680	1410-1425	0.27	0.87	0.11
7	050680	1630-1645	0.27	0.87	0.11
8	050680	1815-1830	0	0	0.33
9	060680	1100-1115	0	0.87	0
10	060680	1415-1430	0.46	1.35	0.22

* cf Figure 2 for locations.

2.2 Air sampling

Air samples were collected in 20 cm^3 plastic disposable syringes. Fifteen-minute averaged samples were collected at fixed points using automatic, battery-powered syringe samplers. The sampler is shown in Figure A1 in Appendix A. Detailed, quasi-instantaneous descriptions of the tracer plume could also be obtained with grab samples collected in syringes during walking, cycling or automobile cross- and along-wind traverses.

Small diameter hypodermic needles were used on the syringes to prevent back-diffusion of the sample air after collection. Data from Lamb (1978) indicate that samples collected in the syringes do not change in concentration more than 5% over approximately one to two weeks. In this study, sample analyses were completed within a few hours of collection.

The samplers were placed along several traverses downwind and at distances ranging from 200 m to ∿ 4 km from the source area. In addition to these (approximately perpendicular to the expected plume path) sampler arrays, samples were also collected alongside Verk 1 and Verk 2 to detect possible fugitive emissions from the reduction halls and/or downwash from the stacks.
The locations of the sampling arrays are shown separately for each test in Figures 5 through 15 in Section 4.

2.3 Analysis of samples

All air samples were analyzed using electron capture gas chromatography. The gas chromatograph was calibrated with SF_6 at NILU immediately prior to the field study using the exponential dilution method. The analysis and calibration system is shown in Figure A2 in Appendix A.

Analysis for SF_6 was achieved using a stainless steel column (106 cm x 0.6 cm OD, 0.5 cm ID) packed with 80-100 mesh Alumina F-1 (Supelco Inc, Crans, Switzerland) and N_2 as the carrier gas. The gas chromatograph was equipped with 6-port gas sampling valve (Valco, Inc, Houston, Texas) and a 1.0 cm^3 sampling loop.

During the study the chromatograph was housed and all analyses were performed in a caravan, located upwind of the smelter. The tracer concentrations in the air samples were determined from the output peak heights on the strip-chart recorder, using calibration factors.

2.4 Meteorological measurement

Gränges Aluminium Sundsvall smelter has a 40 m meteorological tower located about 20 m north of the laboratory/office building (cf. Figure 2). The tower is instrumented with wind speed and direction sensors at the 40 m level, and with air temperature sensors at 10 m and 40 m. Thus temperature difference between 40 m and 10 m is also available. The sensor outputs are continually recorded by strip-chart recorders housed in the nearby Analytical lab building.

To estimate atmospheric stability from temperature differences between the 40 m and 10 m levels (ΔT 40-10) the following criteria were used:

Unstable	:	$\Delta T \leq 0.5^{o}C$
Neutral	:	$-0.5 < \Delta T \leq 0^{o}C$
Slightly stable	:	$0 < \Delta T \leq 0.5^{o}C$
Stable	:	$\Delta T > 0.5^{o}C$

A discussion of stability measurements can be found in Appendix E.

3 METEOROLOGICAL CONDITIONS DURING TESTS

Average wind and air temperature data from the 40 m meteorological tower at the Gränges, Sundsvall smelter for the actual test periods are summarized in Table 2.

Table 2: Summary of SF_6 release and meteorological data during the tracer tests at Gränges Aluminium smelter, Sundsvall.

Test No.	Date of test	Time of test	Meteorological conditions				
			Wind dir. (deg)	Ave.wind speed (ms^{-1})	Range of wind dir. fluctu-ations (deg)	Air temp. 40 m (^oC)	Temp.diff. ΔT 40-10 (^oC)
1	030680	1415-1430	160	4.5	25	20.4	-1.4
2	030680	1700-1715	165	4.4	38	18.0	-0.9
3	040680	1100-1115	160	4.9	55	20.8	-1.1
4	040680	1350-1405	160[1)]	5.2	66	21.2	-1.0[4)]
5	040680	1615-1630	155	3.4	90	22.0	-1.3
6	050680	1410-1425	166	6.1	50	18.0	-1.4
7	050680	1630-1645	165[2)]	3.9	60	18.6	-1.1
8	050680	1815-1830	155[3)]	3.6	62	19.8	-0.8
9	060680	1100-1115	175	5.8	45	17.8	-1.5
10	060680	1415-1430	175	5.9	50	18.9	-1.4

1) turned from 150 to 170 deg. during test.

2) turned from 170 to 160 deg. during test.

3) turned from 150 to 160 deg. during test.

4) change in stability (increase) during test due to temperature decrease (> 1.5^{o}C).

Hourly wind and temperature data for the four daus of the SF_6 tests (3-6 June 1980) are given in Table B1 in Appendix B. Synoptic weather maps for the same period are shown in Figure 3.

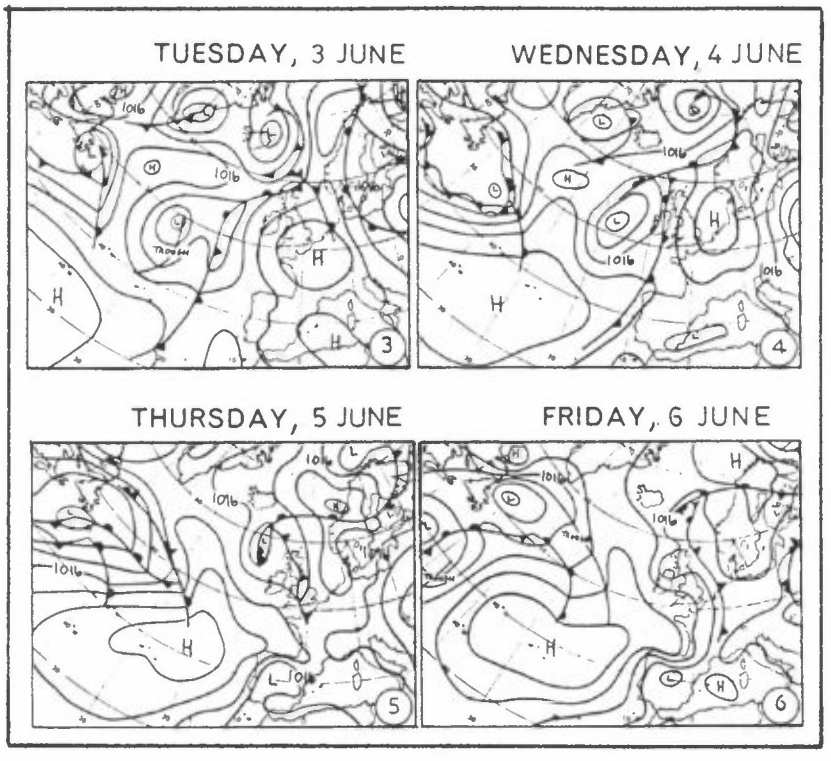


Figure 3: Weather maps (at 1200 GMT), 3-6 June 1980.

The test period was characterized by weak geospheric wind conditions over the Sundsvall area. Except for a cold front with showers passing over the area on the morning of 5 June, the weather was fair and favourable for land/sea breeze development.

During the year two predominant wind directions are present in the Sundsvall area, i.e., winds from northwest (winter and nighttime winds) and winds from south-southeast (summer and daytime winds).

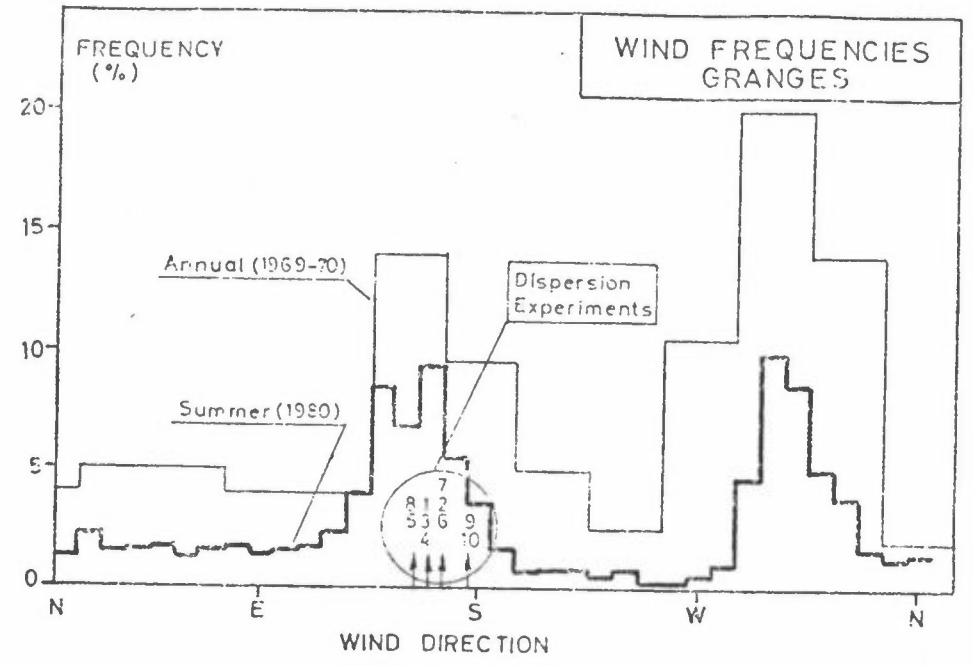


Figure 4: Wind frequency distributions at Gränges for the summer season 1980 and for one year 1969-70. The wind directions during the dispersion experiments are also indicated.

Figure 4 shows that the dispersion experiments were conducted under wind condition typical for the summertime in the Sundsvall area.

4 TRACER EXPERIMENTS

In all tests, SF_6 releases at the selected release points were begun approximately 25 min. before the scheduled start of air sampling to allow sufficient time for tracer dispersion and transport to the sampling sites.

All 15-min. automatic samplers were assamled, the pre-sampling period timers set and then started at the same time, just before they were taken to and placed along the various sampling traverses. Thus all automatic samplers would begin and end their 15-min. sampling runs at exactly the same time. The end of SF_6 releases and end of the air sampling runs were approximately coincident.

After the completion of a test the samplers were collected, the sample syringes removed and capped, and immediately taken to the caravan for GC analysis.

The measured SF_6 concentrations, in $\mu g\ SF_6 m^{-3}$ air, for all tests and sampling locations are listed in Appendix C. The concentration distributions along the various sampling traverses are shown in Appendix D. Descriptions of all the individual tests (and discussion of the plume dispersion patterns) follow.

4.1 Test 1: 1415-1430 hrs., 3 June 1980

SF_6 was released inside Halls 2,3 and 4 (Verk 1) and Halls A and B (Verk 2) at each of the release points (cf. Figure 2), at a rate of 0.067 g SF_6 s^{-1}, to study dispersion patterns from the 70 m tall stacks of the reduction halls.

The wind during the test period blew from SSE (160 deg.) at an average speed of 4.5 m s^{-1}. Air reaching the meteorological tower (point M, Figure 2) was unstable ($\Delta T = -1.4^{o}C$).

The 15-min automatic samplers were placed mainly along Enhörningsv. (Traverse A-B), Skarpskytterv. - Oljevägen (Traverse C-D), and Skolhusallén - Tivolivägen - Medborgargt. (Traverse G-L), as shown in Appendix C. Figure 5 shows the estimated SF_6 concentration isopleths.

The emissions appeared to emerge from the reduction hall stacks only, since the plume did not reach the ground for some distance downwind, with no SF_6 detected near the ground along Verk 1 and 2.

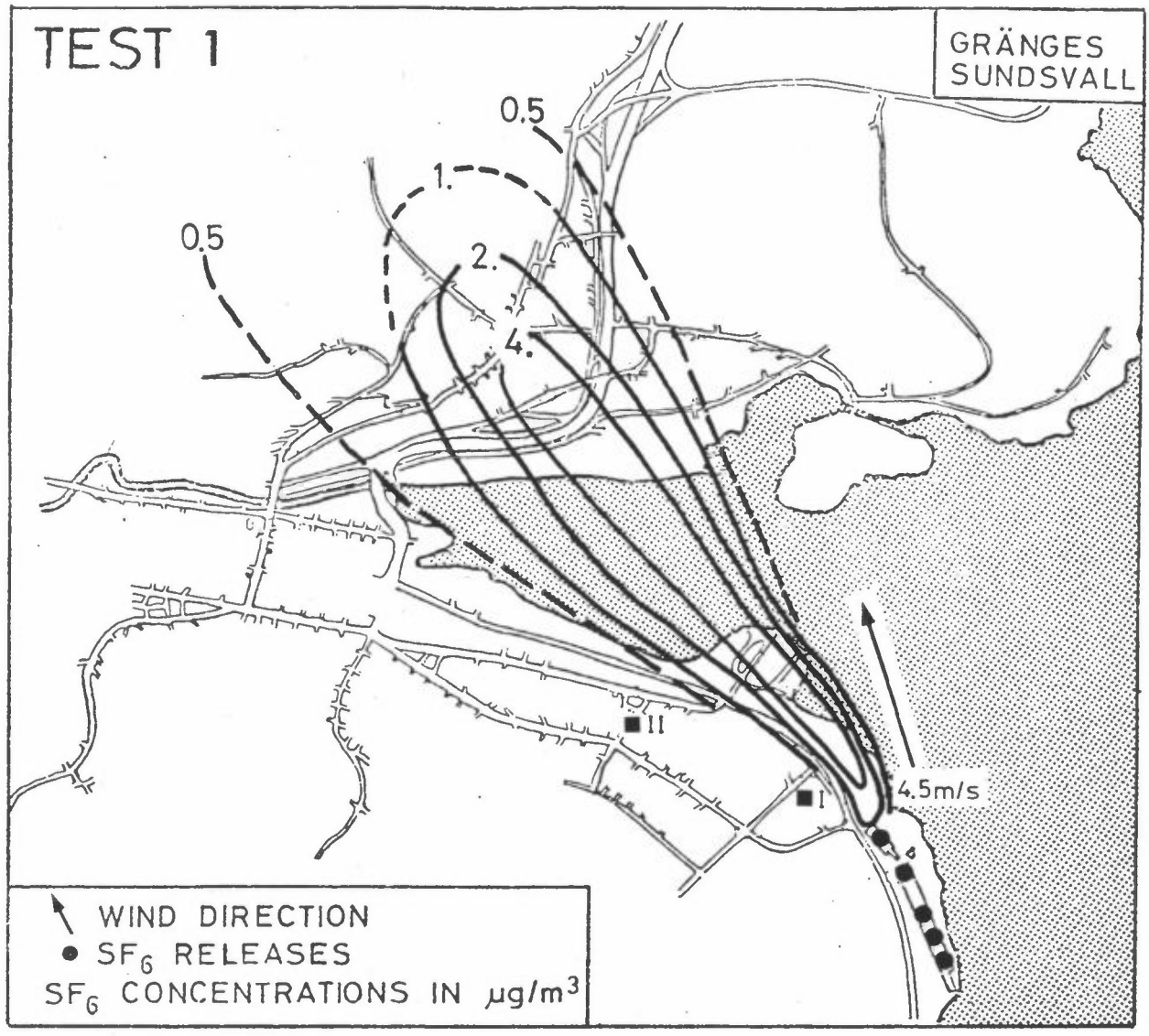


Figure 5: 15-min average SF_6 concentrations.
Test 1; 3 June 1980, 1415-1430 hrs.
Measurements of PAH and fluorides taken
at I: Kubikenborg
II: Brenner

The wind direction during Test 1 was quite steady (cf. wind direction fluctuations, in Table 1), and the plume was relatively narrow in the horizontal. It turned slowly away from the wind direction (as recorded at point M) to the west across the western tip of Sundsvallsfjärden, and passed over the Haga area of Sundsvall. A typical feature of this concentration pattern was the elongated, streched out maximum concentration area. More than 4 $\mu g/m^3$ was detected from about 400 m downwind to about 3 km downwind. One reason for this is the source configuration with 5 tall stacks located at points stretched out over a distance of almost 1 km parallell to the wind direction.

4.2 Test 2: 1700-1715 hrs, 3 June 1980

SF_6 release and wind conditions (4.4 m s^{-1}, 165 deg.) during this test were essentially similar to those of Test 1. The air was slightly cooler and somewhat less unstable ($\Delta T = -0.9^{o}C$). More 15-min automatic samplers were placed closer to the source area to help define better the distance of plume touchdown. The ground level SF_6 concentrations were somewhat more dilute, and the plume turned even more west, passing over the downtown area of Sundsvall (cf. Figure 6).

There appears to have been a slight downwash or escape of SF_6, since some SF_6 was detected near the ground on the west side of Verk 1.

4.3 Test 3: 1100-1115 hrs., 4 June 1980

SF_6 was released inside the halls of Verk 1 and 2 at each of the release points, at the usual rate (0.067 g $SF_6 s^{-1}$). Because of a broken flowmeter, release at point A4 was terminated before actual sampling had begun. At the meteorological tower (point M) wind blew during the test from SSE (160 deg) at an average 4.9 m s^{-1}, and the atmosphere was unstable ($\Delta T = -1.1^{o}C$). At 1100 hrs the plume from the smelter stacks was visually observed to pass north of the Björneborgsgt. - Landsvägsallén intersection at Oljevägen.

The path of the SF_6 plume was the same as during Test 2, but it appeared to reach ground nearer the source area (cf. Figure 7). There were not fugitive emissions or downwash of SF_6 detected from the reduction halls.

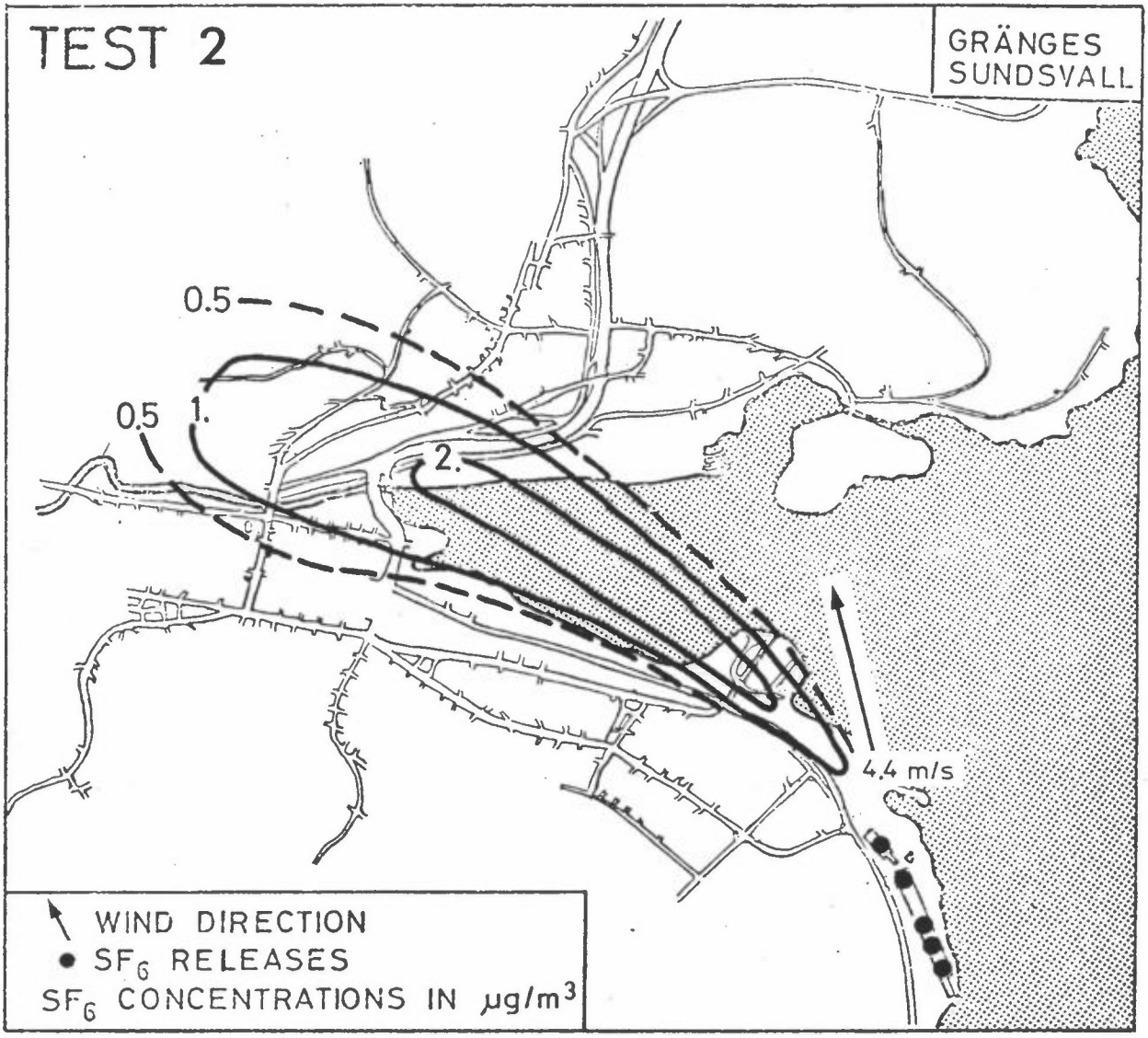


Figure 6: 15-min average SF_6 concentrations. Test 2; 3 June 1980, 1700-1715 hrs.

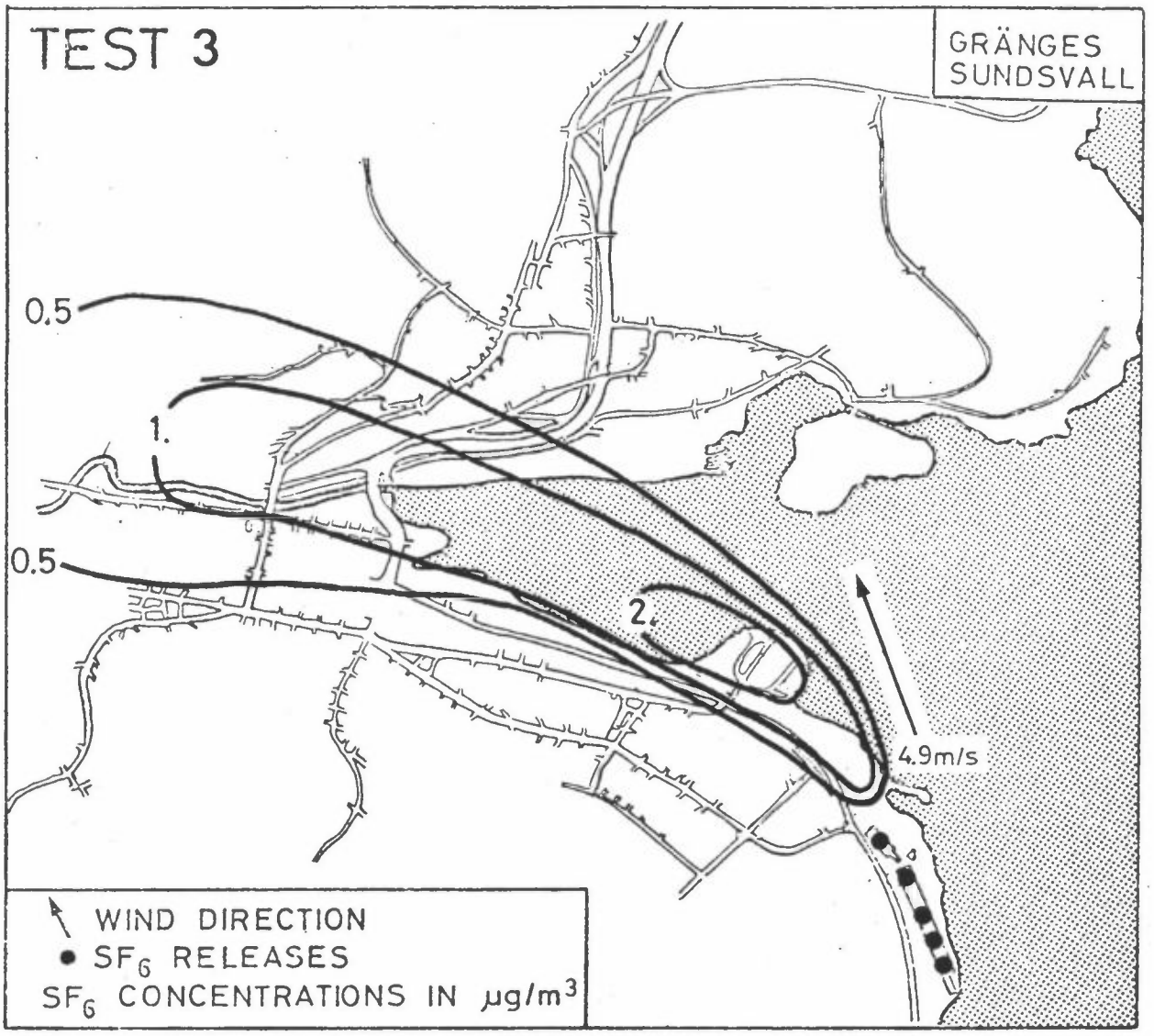


Figure 7: 15 min average SF_6 concentrations. Test 3; 4 June 1980, 1100-1115 hrs.

4.4 Test 4: 1350-1405 hrs., 4 June 1980

SF_6 was released at all of the release points to simulate dispersion of combined emissions from the reduction halls and the electrode plant.

The releases in the reduction halls were held at the usual 0.067 g SF_6 s^{-1}; release at point E, on the roof of one of the buildings of the anode paste plant (ELM 2) was 0.11 g $SF_6 s^{-1}$.

While the wind speed during the test remained relatively constant (at 5.2 m s^{-1}), wind direction turned from 150 deg to 170 deg, and air temperature dropped 1.5°C. The latter resulted in a slight increase in atmospheric stability during the 15 minute of the test.

Within the smelter complex the wind appeared to be channelled alongside and between the large buildings, and continued blowing from south-southeast (150 deg) throughout the test. From visual observation of the behaviour of the white plume from the stack of ELM 2, it was apparent that intense turbulence was generated in the wake of the plant. The plume was rapidly entrained in the wake, down-washed and transported laterally along the sides of the various nearby structures, at places almost perpendicular to the main wind direction.

The SF_6 dispersion pattern in Figure 8 confirmed this observation. SF_6 was now detected in substantial concentrations near the ground alongside the reduction halls, apparently due to downwash of SF_6 from release point E.

The average SF_6 plume had turned even further to the west, and apparently made its furthest incursion into the southern portions of Sundsvall during this test, passing over the Södermalm area of the town. Unfortunately, not enough samplers had been placed in the southerly direction along Traverse G-H, and the full spread of the plume cannot be defined with certainty.

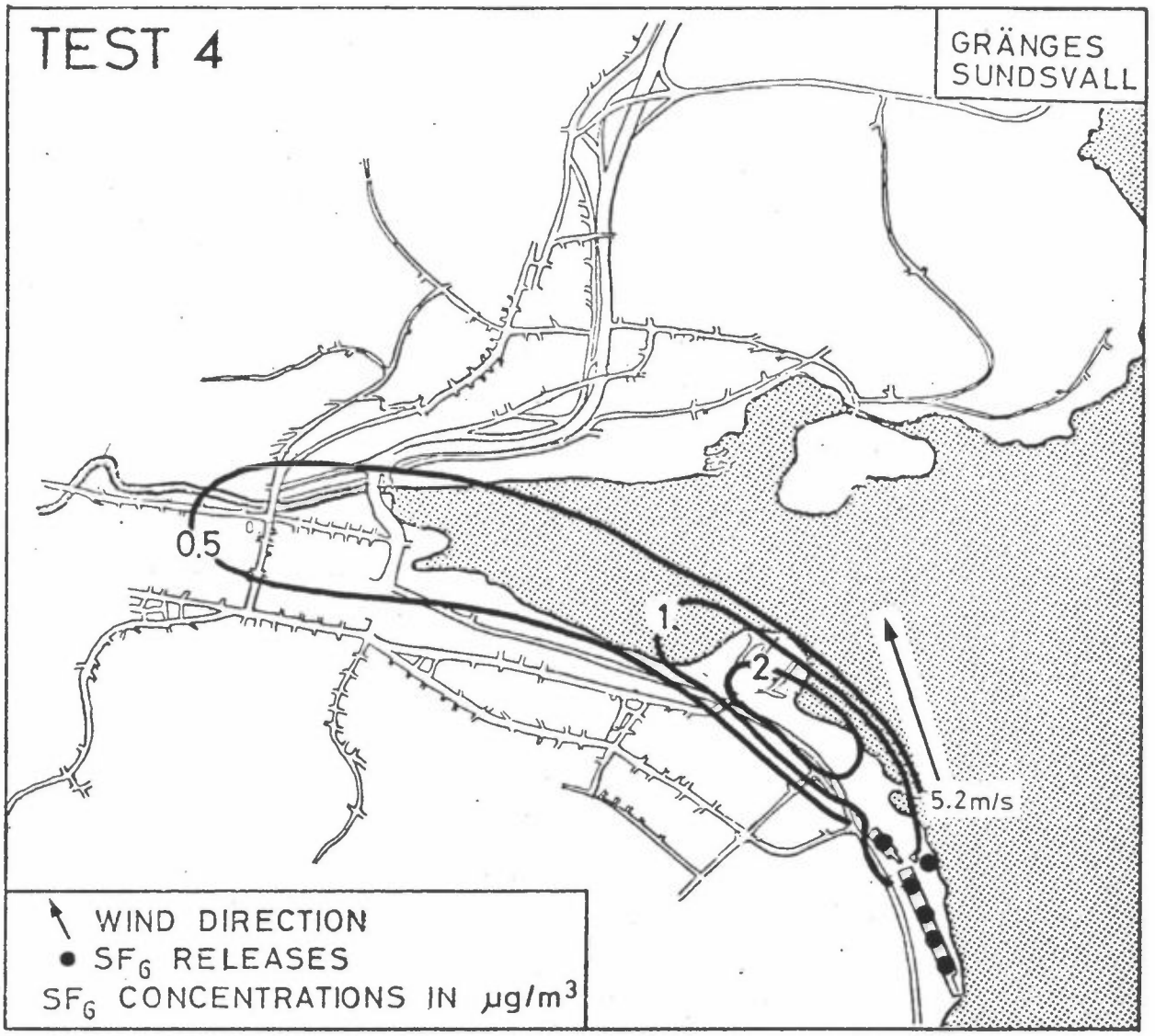


Figure 8: 15 minute average SF_6 concentrations. Test 4; 4 June 1980, 1350-1405 hrs.

4.5 Test 5: 1615-1630 hrs., 4 June 1980

During this test SF_6 was released at a rate of 0.33 g $SF_6 s^{-1}$, at point E only to assess the dispersion from the anode paste plant (ELM 2) alone. The wind at 3.4 m s^{-1} was weaker than during the previous release at point E in Test 4, but the direction (155 deg) at point M was more along the channelled flow between the buildings, although quite unsteady and widely fluctuating. The temperature was slightly warmer and the air somewhat more unstable.

The previously noted plume downwash from the ELM 2 stack was again present. SF_6 concentration patterns in Figure 9 show that emissions from point E do indeed become rapidly downwashed and dispersed laterally as well as downwind. Relatively high concentrations within the confines of the smelter complex and in the immediate area downwind can result. Despite its broadness near the SF_6 release point, the plume, under the conditions existing during this test, remained quite narrow and retained relatively high SF_6 concentrations as it passed across the western tip of Sundsvallsfjärden and the Norrmalm area of Sundsvall.

4.6 Test 6: 1410-1425 hrs. , 5 June 1980

The start of this test had to await the passage of a very well-defined cold front with showers (see Figure 3).

SF_6 was released at all points in the halls and at ELM 2 at the usual rates (as in Test 4). While the wind direction was again from SSE (166 deg), the air was quite unstable ($\Delta T = -1.4^{o}C$) and the wind speed average of 6.1 m s^{-1} was the highest of any encountered during these tests. The path of the SF_6 plume, in Figure 10, was the most northerly, passing over the Skönsberg area of Sundsvall. With the moderate wind direction fluctuations, the plume remained quite confined horizontally, with relatively high SF_6 concentrations measured at ground level on its centre-

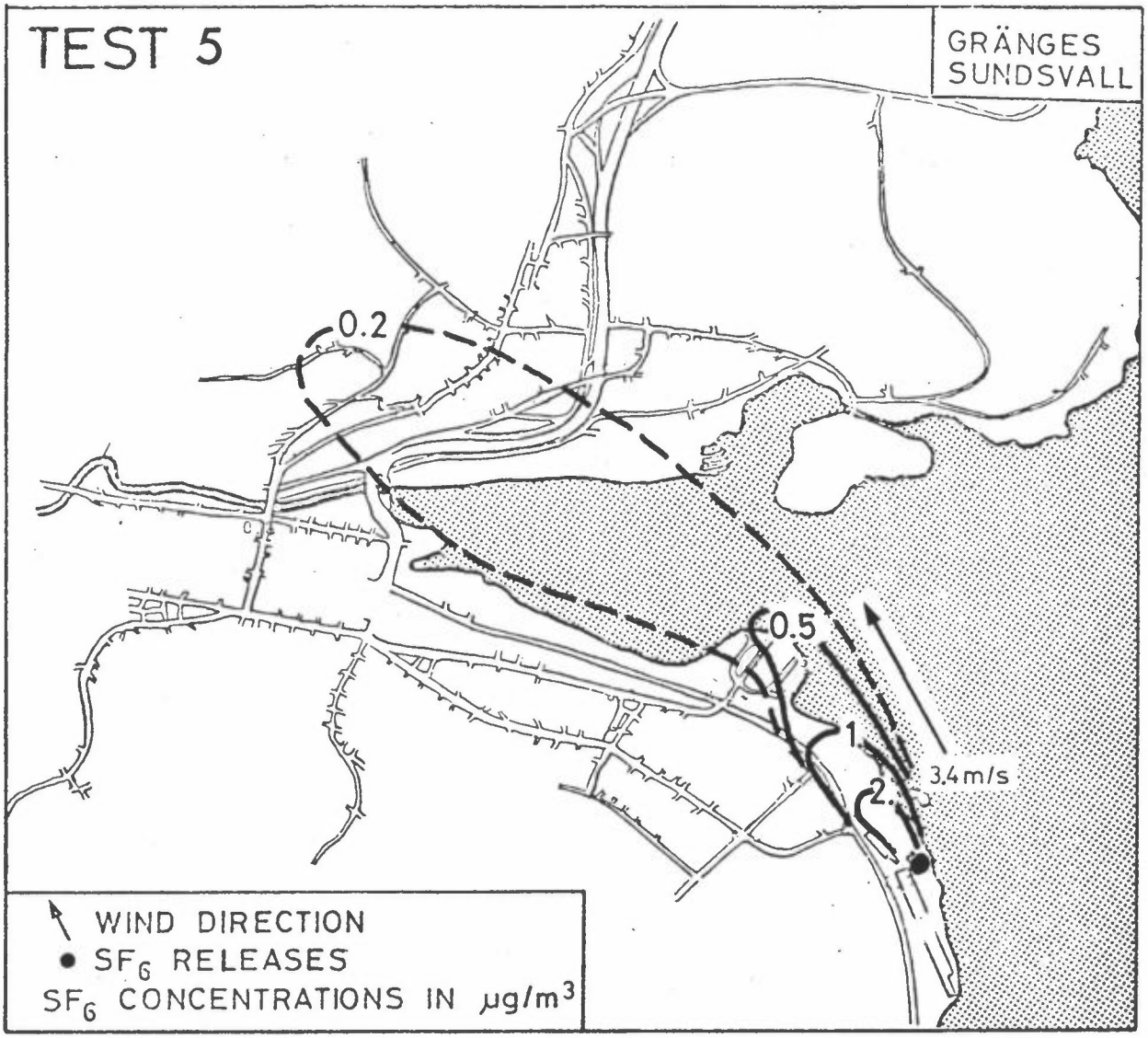


Figure 9: 15 minute average SF_6 concentrations. Test 5; 4 June 1980, 1615-1630 hrs.

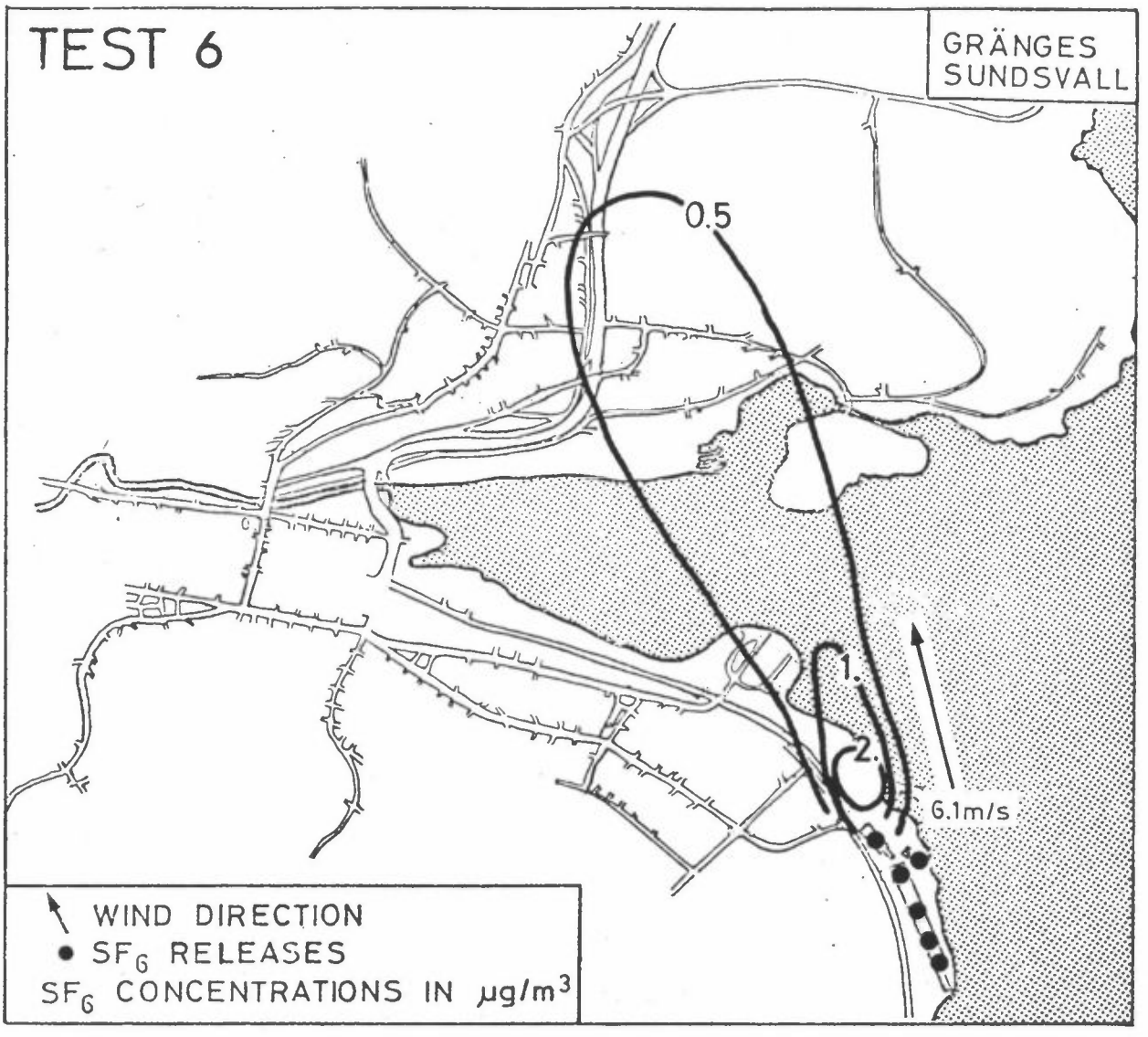


Figure 10: 15 minute average SF_6 concentrations. Test 6; 5 June 1980, 1410-1425 hrs.

line along Traverse G-L. The near-dispersion pattern of SF_6 from ELM 2 among the smelter buildings in again evident.

4.7 Test 7: 1630-1645 hrs., 5 June 1980

This test was conducted only 2 hours after the completion of Test 6, but the meteorological conditions had changed noticeably. The average wind speed was now only 3.9 m s^{-1}, and the air was slightly less unstable. The wind turned to blow from a more south-easterly direction during the test (from 170 deg to 160 deg) and the direction fluctuations increased.

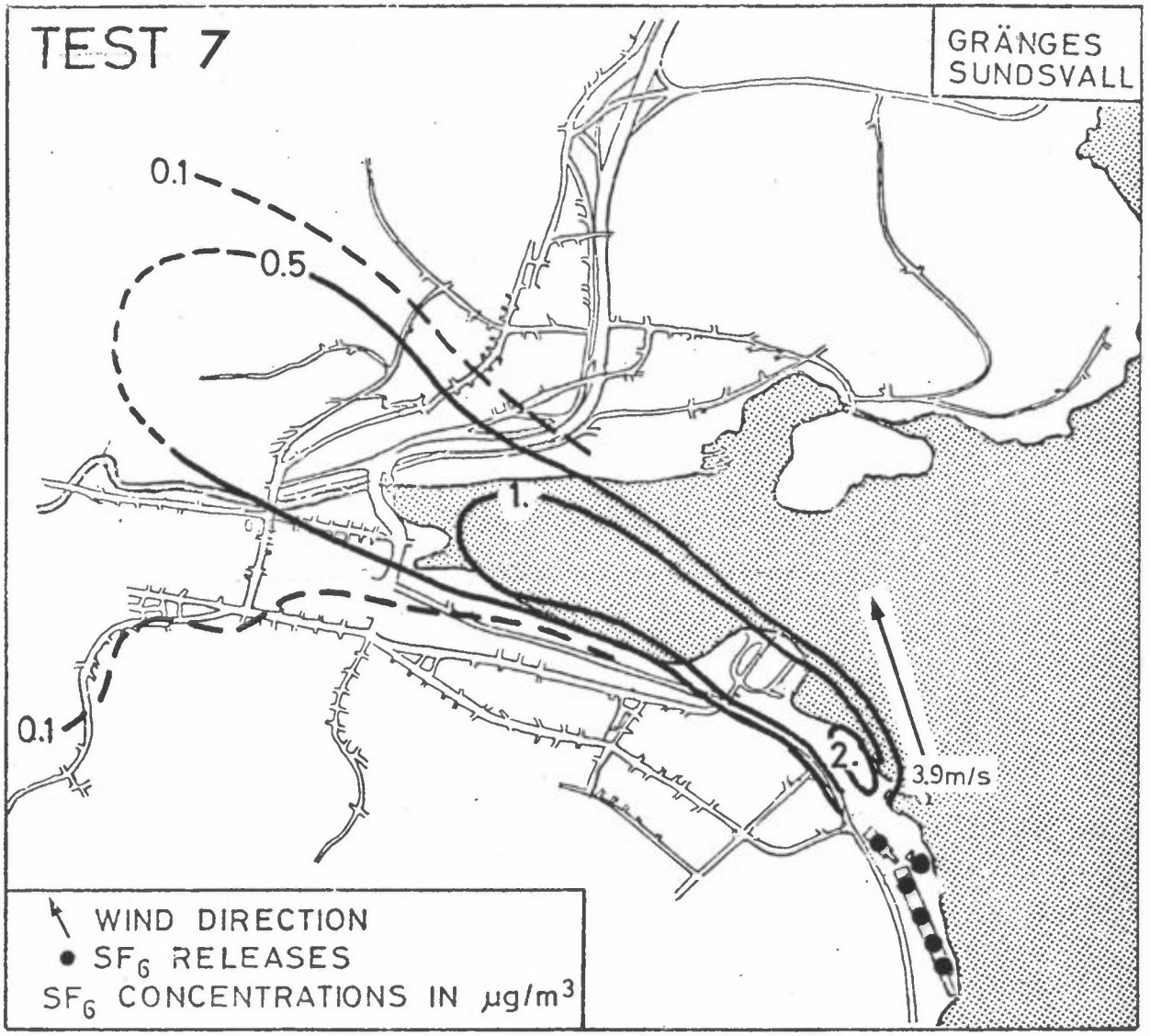


Figure 11: 15 minute average SF_6 concentrations. Test 7: 5 June 1980, 1630-1645 hrs.

SF_6 was released from all points at the usual rates (same as in Tests 4 and 6). The shift in wind direction, as well as afternoon warming of ground surfaces by the sun, caused the plume to turn away from the wind at the meteorological tower towards west, and follow a path similar to those in Tests 2 and 3.

Probably bacause of the wind shift, the plume was the broadest, with SF_6 detected as far south as Sallyhill and as far north as the Haga areas (cf. Figure 11). In spite of the lower wind speed, this still resulted in substantial plume dilution, with SF_6 concentrations only about half of those measured at corresponding locations during Tests 2 and 3.
Low-level dispersion of SF_6 among the smelter buildings was again present.

4.8 Test 8: 1815-1830 hrs, 5 June 1980

This was a repeat test to measure SF_6 dispersion from point E at ELM 2. The tracer was released at 0.33 g SF_6 s^{-1}.
There was considerable similarity in weather conditions during this test and Test 5 in terms of wind and atmospheric stability (cf. Table 2).

As seen from Figures 12 (for this test) and 9, the plume shapes were also quite similar, and substantial concentrations of SF_6 were measured among the smelter buildings. SF_6 samples were not taken along travers EF and GH in this experiment.

Although wind direction fluctuations during this test were much smaller than in Test 5, there was a wind shift towards the north (from 150 deg to 160 deg).This, however, did not result in effective dilution of the plume, and SF_6 concentrations remained high at downwind points up to beyond 1 km from the release point.

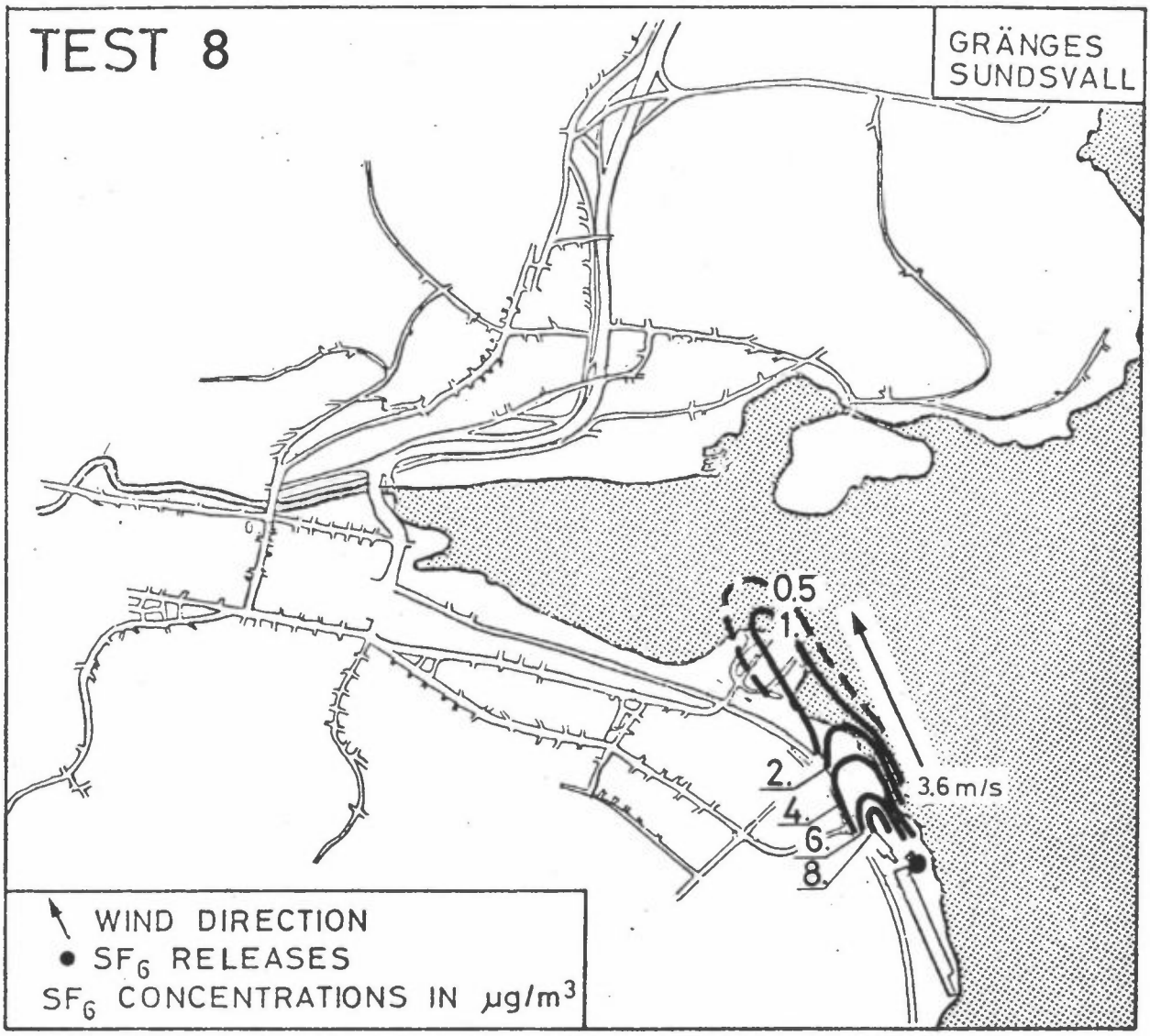


Figure 12: 15 minute average SF_6 concentrations.
Test 8: 5 June 1980, 1815-1830 hrs.

4.9 Test 9: 1100-1115 hrs., 6 June 1980

The phase-out of Gränges Aluminium, Verk 1 (Halls 2,3 and 4) at Sundsvall is expected in the future. To estimate dispersion patterns from Verk 2 alone, SF_6 was released during this test at 0.067 g SF_6 s^{-1} at each of the 13 points in Halls A and B. The wind at the metoeorological tower was more southerly (175 deg) than during any of the other tests, brisk at 5.8 m s^{-1}, and unstable ($\Delta T = -1.5^{o}C$). Direction fluctuations were moderate.

The SF_6 plume turned only slightly to the west and was carried north along E4 in the Skönsberg area. In the unstable air, the plume was probably looping and apparently brought down to the ground, with higher concentrations of SF_6 detected at various distances from the source. From the SF_6 concentration isopleths in Figure 13, this may have occurred at the north end of Oljevägen and near the intersection of E4 and Medborgargt. at some time during the test. This would then explain the elevated 15-min average concentrations at these particular places in comparison with the surrounding locations. Some escape or downwash of SF_6 was also detected alongside Hall B.

In order to quantify the effectiveness of ventilation in the reduction halls, SF_6 concentration decay rate measurements were attempted in Hall B. For this, instantaneous air samples were collected at regular intervals, after the termination of SF_6 releases, at 2 locations: about 3 m above potroom floor at B5 (on top of pot 491), and near the floor level between pots 469 and 470.

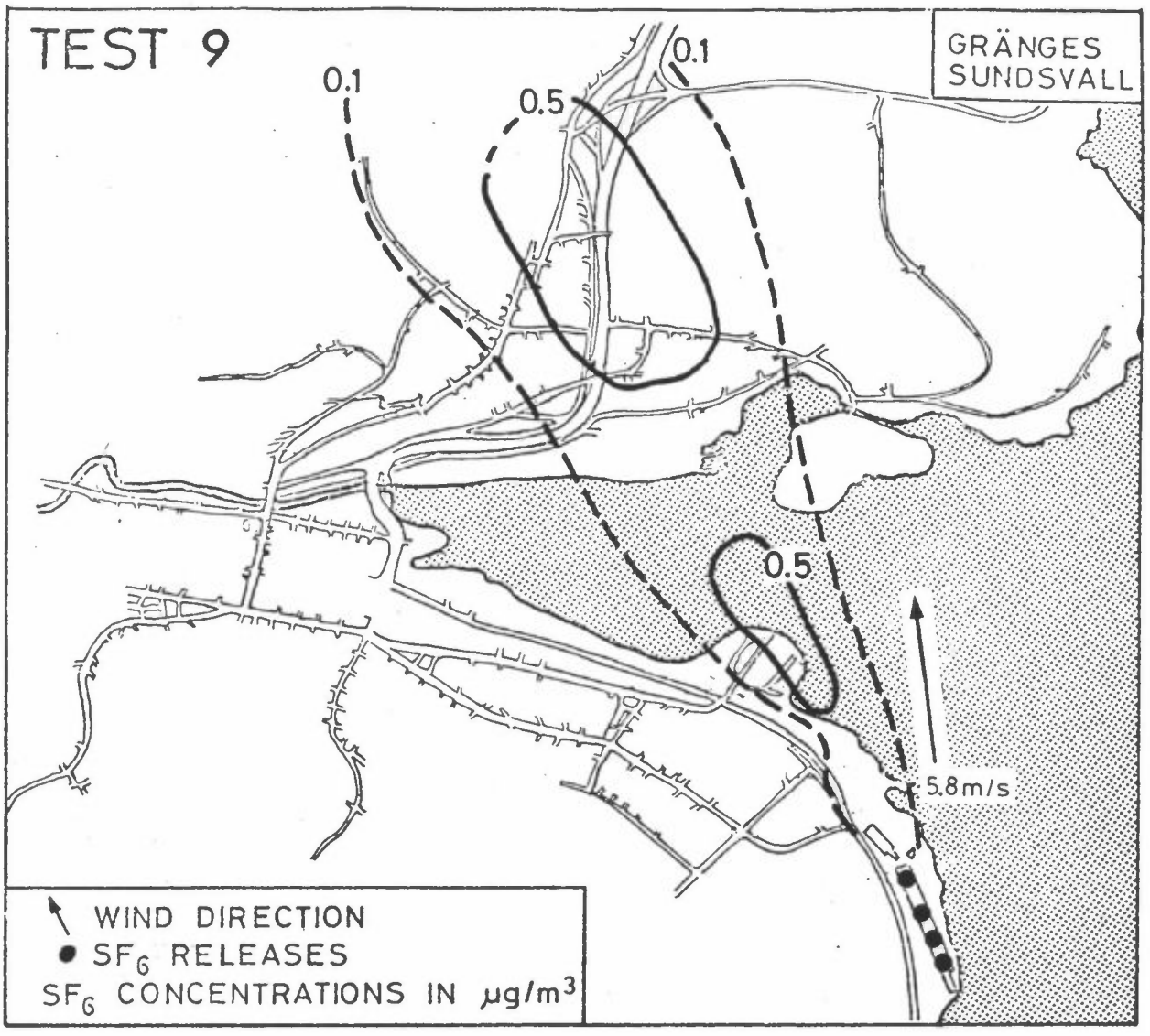


Figure 13: 15 minute average SF_6 concentrations. Test 9; 6 June 1980, 1100-1115 hrs.

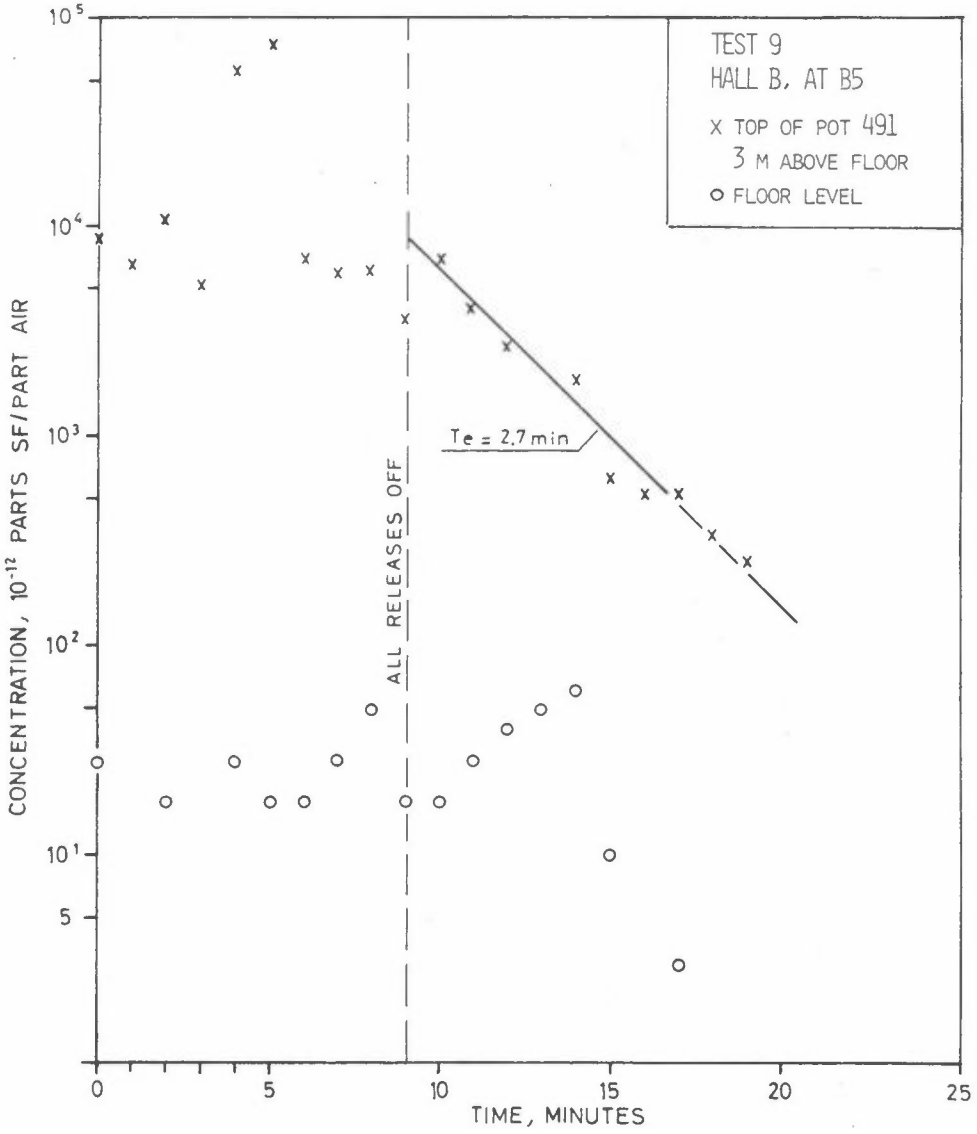


Figure 14: Instantaneous SF_6 concentrations as a function of time during Test 9.

The results are plotted in Figure 14, and an experimental concentration decay constant of about 3 min is estimated for the B5 sampling location from the slope of the decay curve. This means, that at this location one complete air change took place approximately every 3 minutes. At the floor-level location, the decay pattern is not well defined, probably due to the very intense air turbulence, but here the decay rate seems to be even more rapid. The concentration fluctuations (and even an apparent increase at floor-level) after the termination of SF_6 releases (which were not simultaneous at all release points in the hall) are probably due to the "clearing" of SF_6 from the SF_6 cylinder pressure regulators.

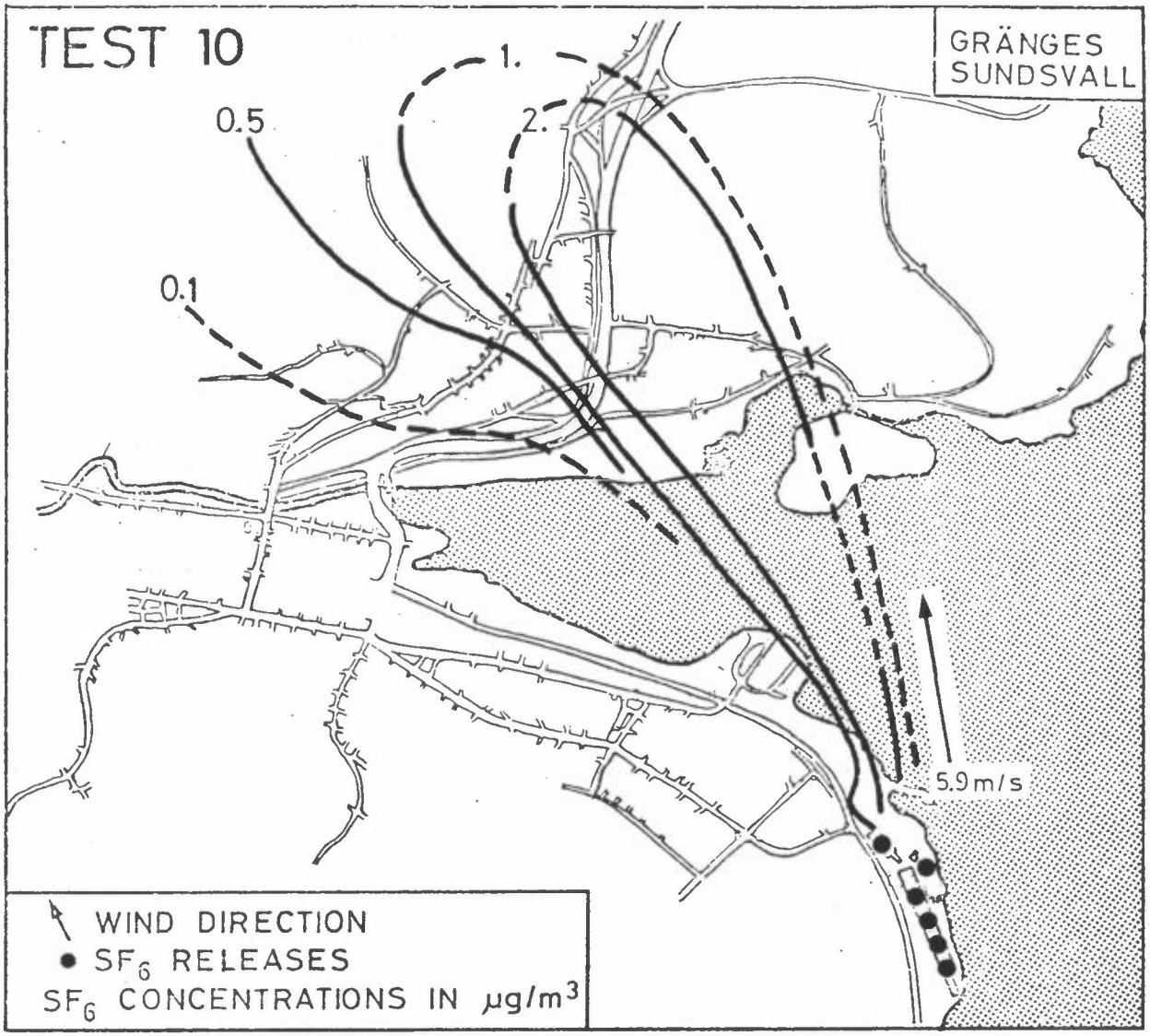


Figure 15: 15 minute average SF_6 concentrations. Test 10: 6 June 1980, 1415-1430 hrs.

4.10 Test 10: 1415-1430 hrs, 6 June 1980

Test 10 was conducted approximately 3 hours after Test 9. The wind and stability conditions had remained essentially the same.

For this test, SF_6 was released at all release points in the halls and at ELM 2, at higher rates than used earlier, in an attempt to better define the horizontal extent of the merged plumes from the smelter. Figure 15 shows, that the path of the plume was virtually the same as in Test 9, but with the almost doubled total SF_6 release rate, the measured concentrations at points across Sundsvallsfjärden were considerably higher. As in Test 9, the concentrations closer to the sources were not pronounced, probably due to good dilution by the brisk wind and unstable air.

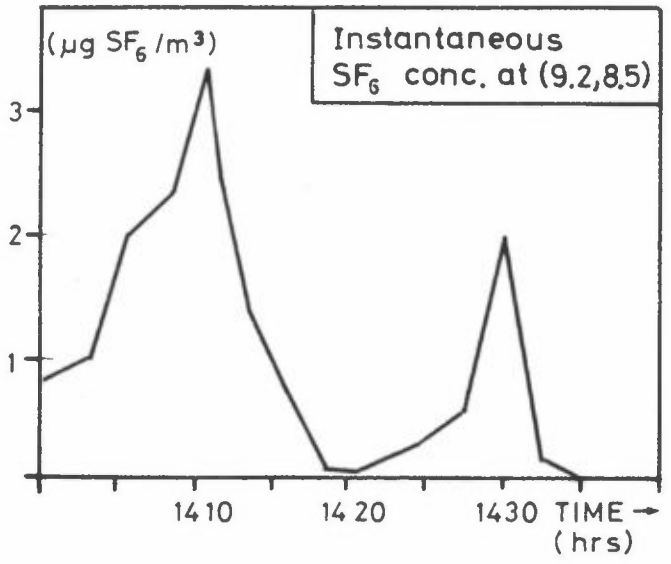


Figure 16: Variation with time of SF_6 concentrations during Test 10. Location: North end of Petroleumsvägen (Traverse C-D, point 9.2, 8.5).

Instantaneous air samples collected at the north end of Petroleumsvägen at 2½ min. intervals, show considerable variations in SF_6 concentration (cf. Figure 16) with time at this fixed location. The sampling point was at the very edge of the average plume, and the variation is therefore most likely the result of the horizontal meander of the plume.

5 DISCUSSION

During the 4-day test period and the prevailing daytime sea-breeze wind regime, the plumes from the Gränges Aluminium smelter in Sundsvall tended to follow the natural channels of wind flow. It is apparent from Figure 4 that the experiments were carried out during wind directions and meteorological conditions typical for the summertime in the area. For the most part, the plume paths were to the WNW over downtown Sundsvall, along the Selångersån river towards Granlo and Bergsåker. On a couple of occasions the paths were more northerly, leading across the western tip of Sundsvalls-fjärden, north along E4 and towards Skön.

For fixed SF_6 release rates in the reduction halls, the plume concentrations appear to be more influenced by horizontal spread than by the average wind speed. Thus, when the wind direction fluctuations were the lowest during Tests 1 and 2, the plumes were the narrowest and had the highest ground-level centreline concentrations, as shown in the summary of SF_6 concentrations across traverse GH in Figure 17. (The SF_6 concentration distributions for each of the sampling traverses and each test are illustrated in Appendix D.)

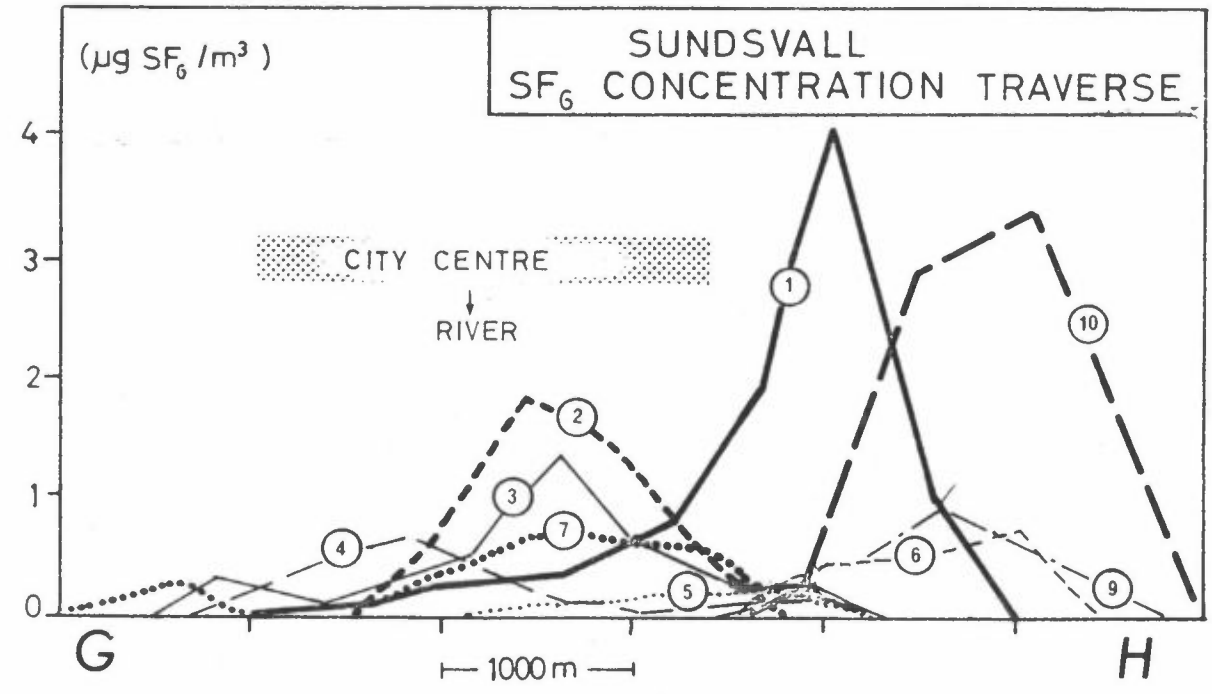


Figure 17: SF_6 concentrations measured along traverse GH during Tests 1-10.

When SF_6 was released in the potrooms only, the plumes from the 70 m high reduction hall stacks contained virtually all the released SF_6 (only minor fugitive emissions and/or stack effluent downwash may have occurred during Tests 2 and 9). Thus, the existing ventilation/gas cleaning facility of Gränges Sundsvall smelter appears to be efficient in collecting essentially all potroom emissions and preventing fugitive releases at ground level from all reduction hall. Evidence of very efficient ventilation rates, obtained from the few tests in Hall B (cf. Section 4.10 and Figure 14), supports this conclusion.

Figure 18 summarizes the plume centreline SF_6 concentration distributions with distance from the sources under situations with releases from the high stacks and low releases from the ELM 2 factory.

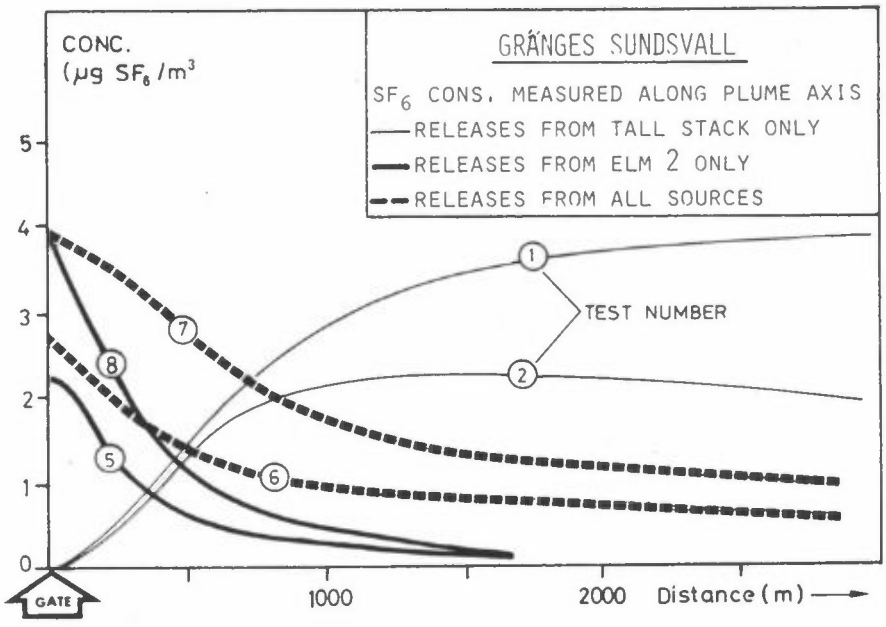


Figure 18: Centre plume SF_6 concentrations as a function of distance from the Gränges Aluminium plant during different dispersion tests.

SF_6 concentrations in the high plumes from the reduction hall stacks reach maximum ground-level concentrations only some 1-3 km from the source (cf. Figures 5,6,7 and 13). Because the emissions from the electrode plant (ELM 2) occur much closer to the ground and because of the complex air flow patterns around ELM 2 and the adjoining building, effluents from ELM 2 would be rapidly, and within a short distance downwind, brought to the ground, even from the ELM 2 stack. With the southwesterly winds prevailing during late spring and in summertime, as well as the apparently strong channelling of air flow effect by the smelter buildings, the plume from the relatively short ELM 2 stack is likely to be entrained in the wake on the north side of the ELM 2 buildings. This is just as likely on the south side with northerly winds dominating in wintertime. The emissions from ELM 2 collect then in a broad, low-level plume, with the highest concentrations occurring in the immediate surroundings of the source (cf. Figures 9 and 12).

The merged plume, combining the high and the low plumes from the reduction hall and ELM 2 stacks, affects areas both near and far downwind from these sources (cf. Figures 8,10,11 and 15) .

Rough estimates of SF_6 concentrations as a function of distance from the aluminium smelter have been carried out using simple Gaussian type dispersion models (Sivertsen, 1980).

A comparison of estimated and measured centreline concentrations during Tests 1 and 2 is shown in Figure 19.

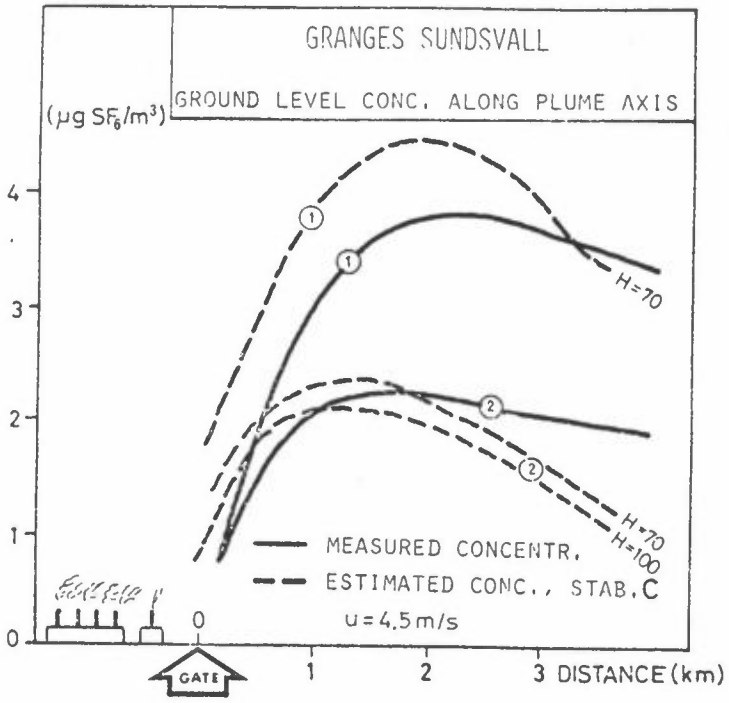


Figure 19: Ground level concentrations of SF_6 measured along the plume axis in Tests 1 and 2 compared to estimated concentrations assuming slightly unstable conditions, 4.5 m/s wind speed and plume height (H) of 70 m or 100 m.

From Figure 19 it can be seen that a simple Gaussian type model reasonably well estimates the ground level concentration along the plume axis, from the wind speed and stability data measured at the meteorological tower at Gränges. If the wind direction data, measured at the tower, are used to specify where in the Sundsvall area these concentrations will occur, it is easy to realize that such estimates in most cases will lead to large errors.

More than one wind station is needed to specify the position of the plume, or to estimate the plume trajectory (wind field).

Instead of analyzing data from several wind stations (which do not exist) in the area, the measured SF_6-concentration distributions can be applied to specify the most probable positions of plumes from Gränges Aluminium.

6 RECOMMENDATIONS FOR PAH SAMPLER PLACEMENT

On the basis of the measured SF_6 concentration patterns during the 3-6 June 1980 period, and wind frequency distributions from 13 March - 31 August 1980 and for the 1969/70 and 1975 periods, the Gränges Aluminium smelter emissions can be expected to have:

I) severe impact
II) average impact
III) slight impact

on air quality in the various areas of Sundsvall and its surroundings.

To insure representative measurement of ambient PAH concentrations and to assess the relative contribution of Gränges Aluminium smelter operations to the overall PAH burden in Sundsvall, locations for seven sampling stations were proposed.

Following a meeting on 17 June 1980 between NILU, Gränges Aluminium, SNV, Sundsvall kommun, hälsovårdskontoret, Härnösand länsstyrelsen, and Stockholm universitet representatives, five locations for sampler placement were recommended.

Station 1: Tivolivägen near Västergatan
Area characteristics:

- residential
- severe impact (I), frequently affected by plumes from Gränges smelter
- relatively unaffected by heavy motor vehicle traffic.

Station 2: Kubikenborgsskolan
Area characteristics:

- residential
- local centre for public activities (library, school, sports/recreation facilities)
- severe impact (I) frequently affected by low-level plumes from Gränges smelter.

Station 3: Corner of Köpmansgatan/Skolhusalléen
Area characteristics:

- downtown business/commerce
- average impact (II), variably affected by Gränges smelter plumes
- strongly affected by motor vehicle traffic.

Station 4: West of Sidsjön district
Area characteristic:

- suburban residential /open-space
- slight impact (III), likely to be only occasionally affected by Gränges smelter plumes
- somewhat sheltered topographically from direct air pollutant transport.

Station 5: Mobile unit.

In addition to the above four fixed sampling locations, a mobile station is proposed. It would enable PAH measurements where possible impact occurs during different seasonal/weather conditions. Such flexibility is particularly desirable because, with wintertime winds, areas along the western coast of the island Alnön and around Klampenborg/Nyhamnsudden could conceivably be affected by plumes from the Gränges smelter. The relative impacts of industry (e.g. Gränges Aluminium, Ortvikens Pappersbruk) and motor vehicle traffic in the Ortviken/Petersvik area then could also

be assessed. The placement of permanent sampling stations in these areas would probably not be cost/benefit effective. One sampler located close to the smelter area (i.e. at Forskningslab, SCA) would give information on the contribution of PAHs from the electrode plant.

7 ACKNOWLEDGEMENTS

The whole-hearted help and cooperation of L. Wikström and the personel of Gränges Aluminium contributed greatly to the successful conduct of the SF_6 tests and is gratefully acknowledged.

8 REFERENCES

de Bortoli, M.
Peechio, E.
Measurement of some halogenated compounds in air over Europe. *Atmos.Environ.* 10, 921-923 (1976).

Lamb, B.K.
Development and application of dual atmospheric tracer techniques for the characterization of pollutant transport and dispersion. Ph. D. Thesis, California Institute of Technology, Pasadena, CA, 1978.

Lamb, B.K.
Sivertsen, B.
Atmospheric dispersion experiments using the NILU automatic weather station and SF_6 tracer techniques.
Norwegian Institute for Air Research, Lillestrøm 1978.
(NILU TN 12/78.)

Lamb, B.K.
Vitols, V.
Skogvold, O.F.
Atmospheric tracer techniques and gas transport in the primary aluminium industry.
J.Air Poll.Control. Assoc. 30, 558-566 (1980).

National Academy of Sciences (NAS)

Particulate polycyclic organic matter. Washington, DC, 1972.

Suess, M.J.

The environmental load and cycle of polycyclic aromatic hydrocarbons. *Sci. Total Environ.* 6, 239-250 (1976).

Sivertsen, B.

The application of Gaussian dispersion models at NILU. Lillestrøm 1980. (NILU TN 11/80.)

APPENDIX A

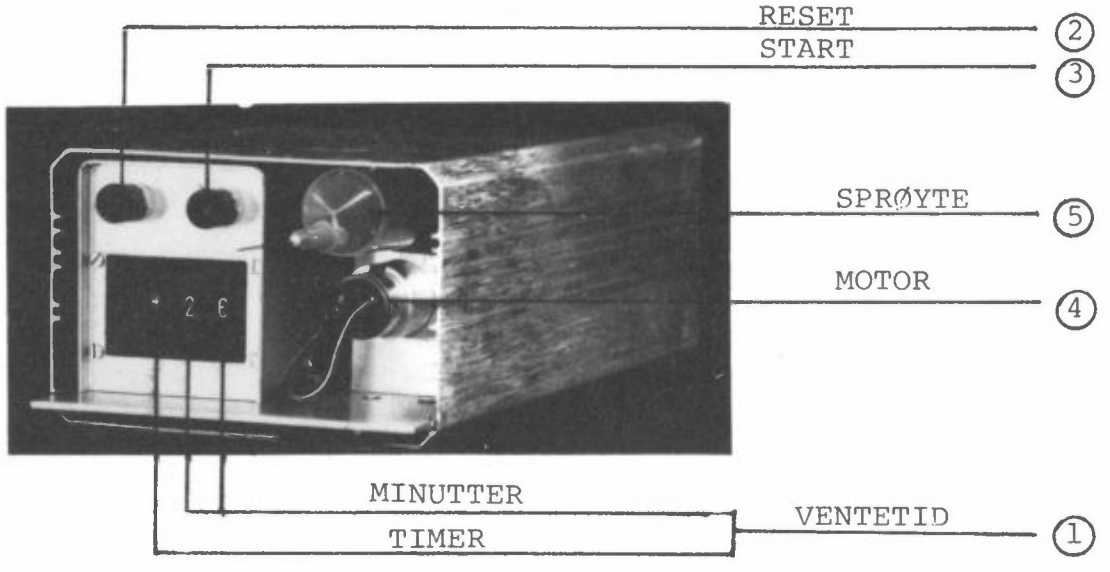
AUTOMATIC SF_6 SAMPLER
SF_6 ANALYSIS AND CALIBRATION SYSTEM

NORSK INSTITUTT FOR LUFTFORSKNING

Telefon (02) 71 41 70
Adresse:
Elvegaten 52
2000 Lillestrøm
Postadresse:
Postboks 130
2001 Lillestrøm

PRØVETAKER FOR SF_6 TRACERGASS

Prøvetakeren består av en elektronisk klokke med flere funksjoner og en motordrevet plastsprøyte (engangs-sprøyte). Det hele rommes i en aluminiumboks, 10x7x21 cm. Klokken kan innstilles til å vente en ønsket tid, opptil 10 timer, før den setter sprøytemotoren i gang. Sprøyten trekkes ut i 15 minutter og fylles med prøveluft, hvoretter motoren snur og går tilbake til utgangspunktet, mens sprøyten forblir uttrukket.

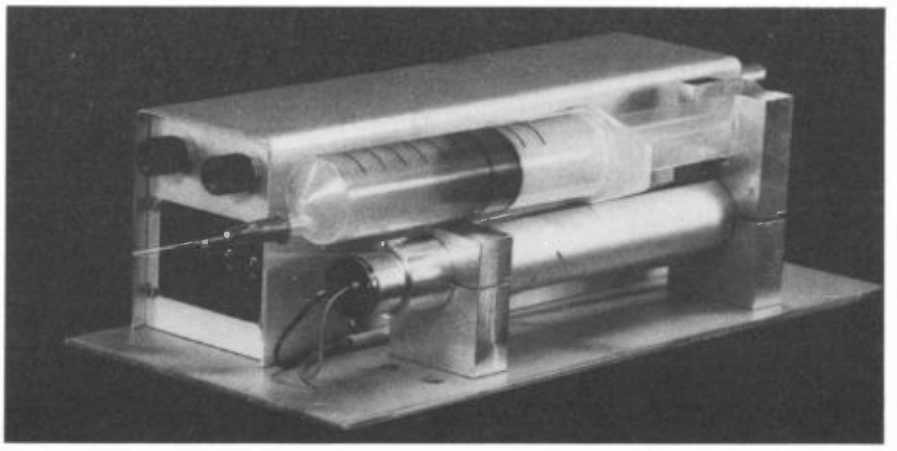


① "Ventetiden" (tiden fra start til prøvetaking begynner) settes i timer og minutter.

② "RESET"-knappen trykkes inn for å sikre at motor og klokke er i startposisjon.

③ START-knappen trykkes inn og ventetiden begynner å løpe.

④ ⑤ Etter utløpt ventetid starter motor ④ og prøveluft trekkes inn i sprøyta ⑤ i 15 min.



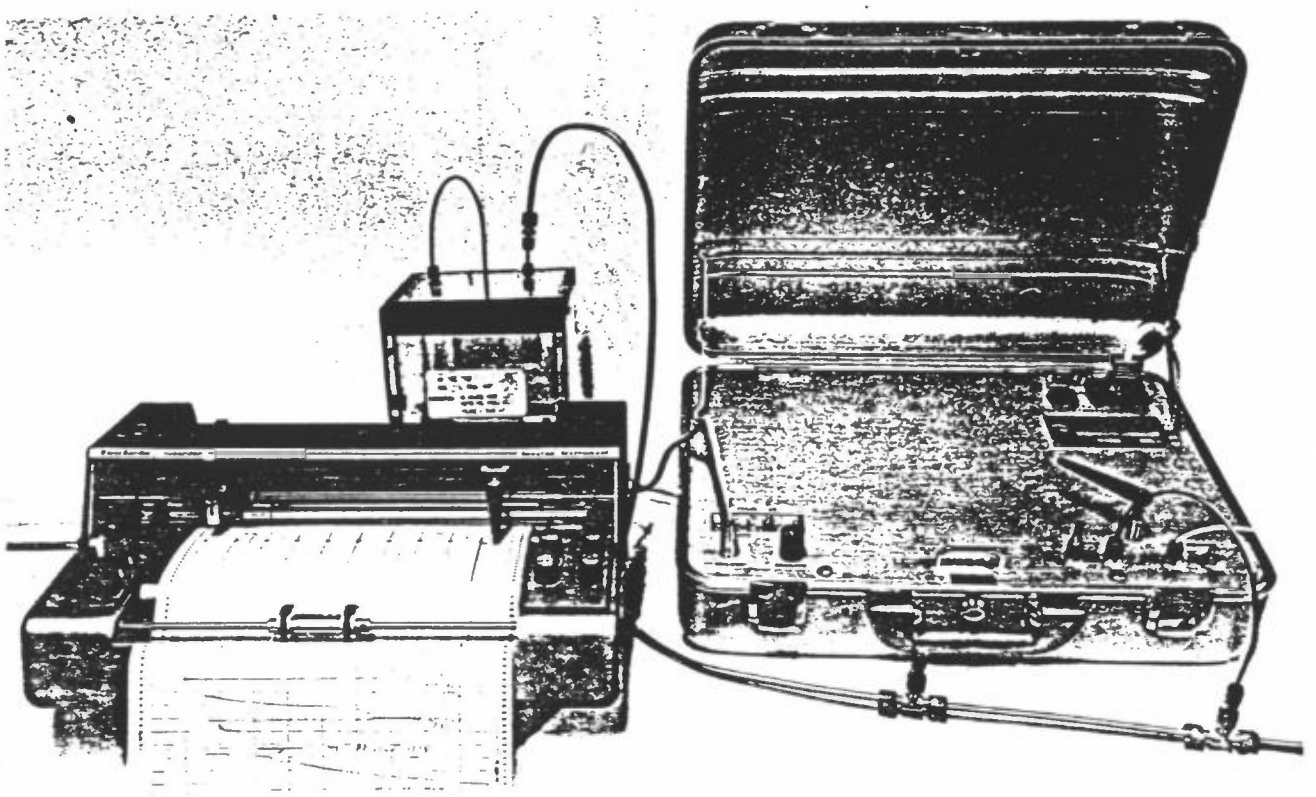


Figure A2: Tracer analysis and calibration system: portable electron capture gas chromatograph, strip-chart recorder, and exponential dilution cube.

APPENDIX B

HOURLY METEOROLOGICAL DATA FROM THE TOWER AT GRÄNGES

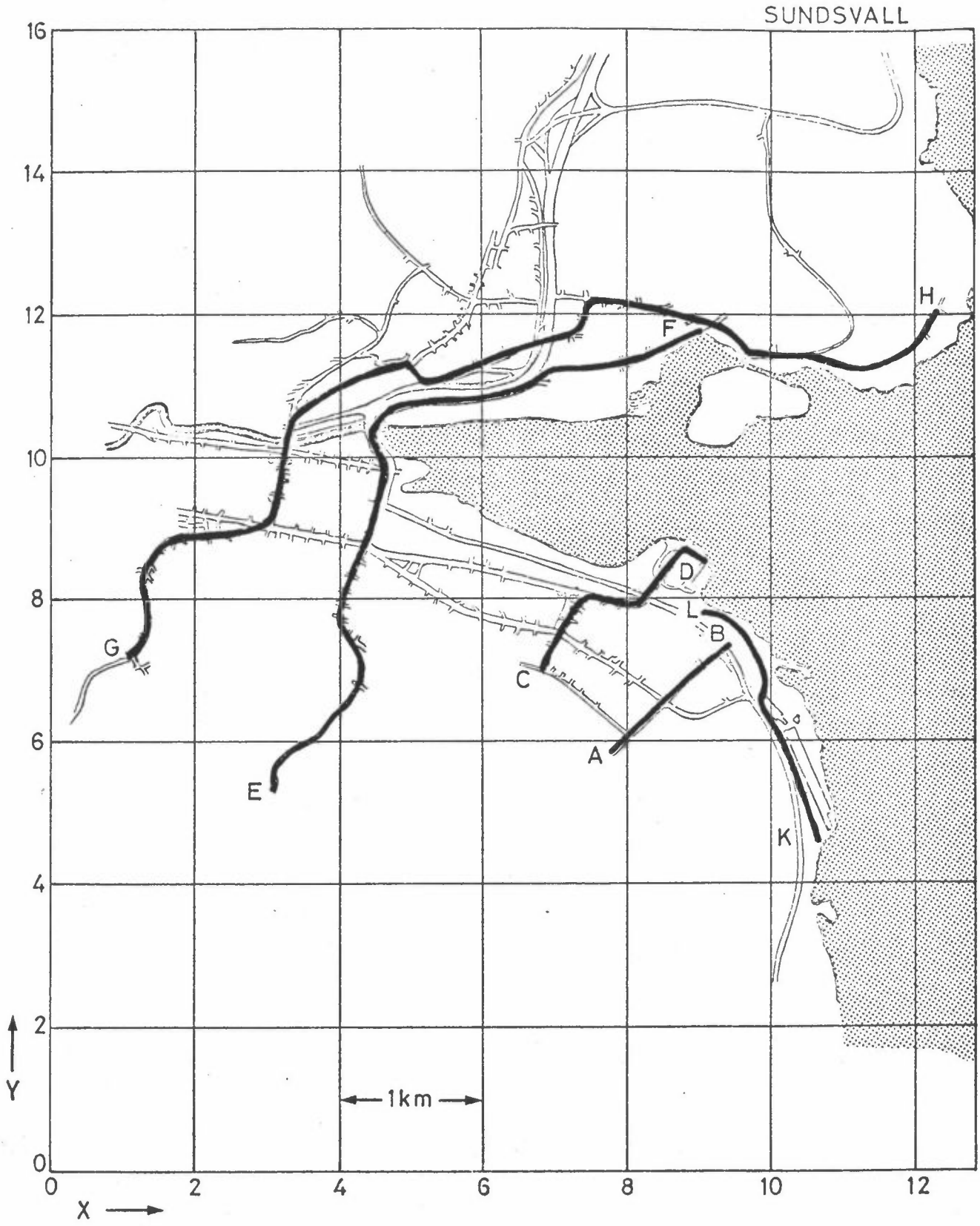
1 - 6 JUNE 1980

				TEMP	DFL. T	FF	DD
1	6	80	1	9.2	.4	1.6	12.
1	6	80	2	9.3	.8	1.5	14.
1	6	80	3	9.7	.7	1.9	17.
1	6	80	4	9.0	.1	1.8	22.
1	6	80	5	9.5	.7	1.7	21.
1	6	80	6	10.0	.6	1.2	26.
1	6	80	7	10.3	.4	1.7	18.
1	6	80	8	11.2	.4	1.8	28.
1	6	80	9	11.9	.5	1.6	16.
1	6	80	10	12.0	.4	1.4	17.
1	6	80	11	12.2	.4	4.5	25.
1	6	80	12	11.1	0.0	3.8	32.
1	6	80	13	13.0	-.3	4.0	32.
1	6	80	14	13.2	-.1	3.8	32.
1	6	80	15	13.8	0.0	3.3	32.
1	6	80	16	14.1	.1	2.0	13.
1	6	80	17	14.8	.2	1.5	23.
1	6	80	18	14.7	0.0	2.3	12.
1	6	80	19	14.6	.1	2.4	19.
1	6	80	20	15.0	0.0	3.7	31.
1	6	80	21	14.9	-.1	4.4	30.
1	6	80	22	15.0	.1	4.0	31.
1	6	80	23	15.0	.1	4.7	31.
1	6	80	24	15.0	0.0	5.0	30.
2	6	80	1	14.3	-.1	4.9	30.
2	6	80	2	14.8	0.0	5.3	30.
2	6	80	3	14.9	-.3	6.1	30.
2	6	80	4	14.8	-.3	5.2	30.
2	6	80	5	15.1	-.2	5.0	30.
2	6	80	6	15.0	-.1	4.7	30.
2	6	80	7	15.6	-.4	5.9	31.
2	6	80	8	15.6	-.4	5.0	32.
2	6	80	9	16.5	-.6	6.0	21.
2	6	80	10	16.8	-.5	5.0	32.
2	6	80	11	17.3	-.5	4.8	33.
2	6	80	12	17.2	-.6	4.3	18.
2	6	80	13	15.0	-.1	3.0	18.
2	6	80	14	17.9	.6	3.7	33.
2	6	80	15	18.8	-.2	3.0	34.
2	6	80	16	19.9	.1	2.9	28.
2	6	80	17	20.6	-.1	3.0	22.
2	6	80	18	20.4	-.2	3.7	18.
2	6	80	19	20.0	-.2	2.9	31.
2	6	80	20	19.2	-.1	2.8	18.
2	6	80	21	19.0	0.0	3.7	17.
2	6	80	22	16.8	.4	3.0	21.
2	6	80	23	16.6	.2	4.0	31.
2	6	80	24	16.2	.1	3.2	29.
3	6	80	1	16.1	1.1	1.1	18.
3	6	80	2	14.2	1.3	1.5	14.
3	6	80	3	13.8	1.1	2.3	33.
3	6	80	4	14.1	.5	4.0	31.
3	6	80	5	15.0	.1	4.7	30.
3	6	80	6	15.7	-.3	4.2	31.
3	6	80	7	16.2	-.1	2.7	32.
3	6	80	8	18.1	.4	1.8	26.
3	6	80	9	19.8	-.7	3.5	14.
3	6	80	10	18.2	-.4	1.2	13.
3	6	80	11	19.0	-.7	3.3	15.
3	6	80	12	20.1	-1.1	4.2	16.
3	6	80	13	20.8	-1.2	4.9	16.
3	6	80	14	23.2	-1.5	5.6	16.
3	6	80	15	18.2	-1.4	4.7	16.
3	6	80	16	18.1	-1.2	4.3	16.
3	6	80	17	18.9	-.9	4.0	15.
3	6	80	18	17.6	-.7	3.2	16.
3	6	80	19	17.7	-.1	1.9	15.
3	6	80	20	17.2	.7	1.1	17.
3	6	80	21	15.5	1.2	.7	17.
3	6	80	22	15.0	1.3	.9	16.
3	6	80	23	14.7	.7	1.9	32.
3	6	80	24	14.6	.8	1.0	31.

				TEMP	DELT	FF	DD
4	6	80	1	14.0	.6	.9	17.
4	6	80	2	13.8	1.6	.7	17.
4	6	80	3	13.6	1.1	1.8	29.
4	6	80	4	14.1	.4	2.7	32.
4	6	80	5	15.5	.6	1.6	32.
4	6	80	6	16.2	1.3	.8	10.
4	6	80	7	18.3	.4	2.3	14.
4	6	80	8	18.0	-.8	4.0	15.
4	6	80	9	19.2	-.5	4.2	16.
4	6	80	10	20.1	-1.1	4.9	16.
4	6	80	11	21.0	-1.1	4.6	16.
4	6	80	12	20.0	-1.1	4.0	15.
4	6	80	13	21.5	-.8	4.0	15.
4	6	80	14	20.8	-1.0	4.2	16.
4	6	80	15	22.3	-1.3	3.9	15.
4	6	80	16	22.1	-1.3	4.3	15.
4	6	80	17	21.0	-.9	3.9	15.
4	6	80	18	21.2	-.7	4.3	16.
4	6	80	19	20.1	-.4	3.5	15.
4	6	80	20	19.0	0.0	2.8	15.
4	6	80	21	16.2	.4	1.7	13.
4	6	80	22	15.0	.4	1.0	18.
4	6	80	23	13.7	-.4	3.8	16.
4	6	80	24	13.0	.4	1.7	27.
5	6	80	1	13.6	.7	.7	19.
5	6	80	2	14.1	.4	1.9	29.
5	6	80	3	16.0	1.5	2.3	29.
5	6	80	4	16.6	1.1	2.8	32.
5	6	80	5	17.1	.7	2.0	21.
5	6	80	6	18.8	.1	2.3	18.
5	6	80	7	19.2	0.0	3.0	17.
5	6	80	8	19.5	-.1	3.0	16.
5	6	80	9	20.1	-.5	4.0	5.
5	6	80	10	19.6	-.6	4.2	3.
5	6	80	11	18.0	0.0	1.3	14.
5	6	80	12	19.1	-.4	2.7	13.
5	6	80	13	18.0	-1.5	5.3	16.
5	6	80	14	17.9	-1.4	5.0	16.
5	6	80	15	17.2	-1.1	4.8	16.
5	6	80	16	18.5	-1.2	4.2	16.
5	6	80	17	19.9	-1.1	3.7	16.
5	6	80	18	20.0	-.8	3.9	16.
5	6	80	19	19.5	-.6	3.5	15.
5	6	80	20	19.0	-.3	2.0	14.
5	6	80	21	17.6	1.1	1.9	19.
5	6	80	22	16.1	1.5	.7	18.
5	6	80	23	15.0	1.1	.8	32.
5	6	80	24	15.0	.5	4.2	30.
6	6	80	1	15.0	1.1	4.3	30.
6	6	80	2	15.1	.7	5.0	30.
6	6	80	3	16.8	.4	4.2	29.
6	6	80	4	16.0	1.3	3.8	30.
6	6	80	5	18.9	.4	2.4	31.
6	6	80	6	20.0	.4	1.7	31.
6	6	80	7	20.6	.7	1.4	18.
6	6	80	8	21.2	-.7	3.8	13.
6	6	80	9	19.9	-1.4	6.0	17.
6	6	80	10	18.4	-1.5	6.1	18.
6	6	80	11	18.0	-1.5	5.9	17.
6	6	80	12	17.8	-1.8	6.0	17.
6	6	80	13	17.2	-1.5	6.0	17.
6	6	80	14	17.7	-1.4	5.8	17.
6	6	80	15	17.2	-1.4	6.2	17.
6	6	80	16	17.0	-1.4	4.8	16.
6	6	80	17	16.8	-1.4	5.0	17.
6	6	80	18	17.0	-1.1	4.0	16.
6	6	80	19	16.4	-.4	3.3	16.
6	6	80	20	15.6	-.4	1.7	14.
6	6	80	21	14.3	.7	2.5	16.
6	6	80	22	12.1	1.9	1.8	17.
6	6	80	23	11.4	2.2	.8	15.
6	6	80	24	11.2	1.6	.4	18.

APPENDIX C

SF_6 TRACER DATA


SUNDSVALL
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
X
Y
1km
A
B
C
D
E
F
G
H
K
L

GRANGES SUNDSVALL VERK 1 OG 2

NO. OF DATA SETS 1
IPLOT 0 WIND ANGLE (DEG) 0.
XO,YO 10.6 5.5

TEST 1 DATA SET NO 1 DATE 030680 TIME 1415-1430
GRENGES SUNDSVALL VERK 1 OG 2
NO. OF POINTS 35

CONCENTRATION IN (UG/M)

X	Y	C
2.8	9.0	.1
3.2	10.0	.1
3.6	10.9	.3
4.6	11.3	.9
5.4	11.4	1.8
6.3	11.5	4.1
7.2	11.8	1.2
8.0	12.2	0.0
9.0	12.0	0.0
1.9	8.9	.1
10.8	4.9	0.0
10.6	5.5	0.0
10.4	6.0	0.0
9.9	6.6	2.6
9.9	6.8	1.1
9.9	7.2	4.0
9.6	7.4	5.0
9.3	7.7	4.0
5.5	9.0	.1
5.6	9.2	.2
6.6	8.6	.1
7.5	8.2	0.0
8.4	8.1	1.4
8.2	8.5	1.6
8.9	8.8	2.1
8.7	8.5	3.1
8.5	8.3	3.6
7.4	8.2	0.0
7.2	8.0	.0
7.2	7.8	.0
7.0	7.2	.1
6.7	6.5	0.0
8.8	6.8	0.0
9.1	7.0	.0
9.3	7.2	.4

35 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2

NO. OF DATA SETS 1
IPLOT 0 WIND ANGLE (DEG) 0.
XO,YO 10.6 5.5

TEST 2 DATA SET NO 1 DATE 030680 TIME 1700-1715
GRENGES SUNDSVALL VERK 1 OG 2
NO. OF POINTS 37

CONCENTRATION IN (UG/M)

X	Y	C
9.2	8.5	.8
8.9	8.8	.6
8.7	8.5	1.5
8.4	8.1	1.7
8.1	7.9	0.0
7.2	7.8	0.0
8.7	6.6	0.0
9.1	7.0	.0
9.3	7.2	.9
9.5	7.4	1.6
1.9	8.9	0.0
2.8	9.0	0.0
3.2	10.0	.4
3.6	10.9	1.8
4.6	11.3	1.4
5.4	11.4	.3
6.3	11.5	.2
7.2	11.8	.1
8.0	12.2	0.0
9.0	12.0	0.0
10.6	5.5	0.0
10.4	6.0	0.0
9.9	6.6	.2
9.9	6.8	.3
9.9	7.2	.4
9.6	7.4	1.0
9.3	7.7	1.8
9.3	8.0	.4
8.4	8.2	3.2
7.5	8.2	.4
6.0	9.0	.1
4.8	9.2	0.0
5.3	9.9	1.4
5.0	10.8	2.1
4.1	10.9	1.3
7.2	11.3	.3
6.7	11.2	.4

37 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2

NO OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 3 DATA SET NO 1 DATE 040630 TIME 1100- 265
GRENGES SUNDSVALL VERK 1 OG 2
NO OF POINTS 26

CONCENTRATION IN (UG/M)

X	Y	C
9.2	8.5	1.3
8.9	8.8	1.1
8.7	8.5	3.5
8.3	8.0	1.6
7.4	8.5	.2
8.1	7.9	0.0
7.3	8.1	0.0
8.8	6.8	0.0
9.1	6.9	0.0
9.3	7.2	.2
1.9	8.9	.3
2.8	9.0	.1
3.2	10.0	.4
3.6	10.9	1.4
4.6	11.3	.7
5.4	11.4	.5
6.3	11.5	.2
7.2	11.8	.2
8.0	12.2	0.0
9.7	11.5	0.0
10.4	6.0	0.0
9.9	6.6	0.0
9.9	6.8	.1
9.9	7.2	1.3
9.6	7.4	1.9
9.3	7.7	1.7

26 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2

NO OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0
XQ,YQ 10.6 5.5

TEST 4 DATA SET NO. 1 DATE 040680 TIME 1350-1405
GRENGES SUNDSVALL VERK 1 OG 2
NO OF POINTS 27

CONCENTRATION IN (UG/M)

X	Y	C
3.2	10.0	.6
3.6	10.9	.1
4.6	11.3	.1
5.4	11.4	.1
6.3	11.5	.1
7.2	11.8	0.0
8.0	12.2	0.0
9.2	8.5	0.0
8.9	8.8	.1
8.7	8.5	1.3
8.4	8.1	1.9
8.1	7.9	.3
7.3	8.1	0.0
7.2	7.3	0.0
8.7	6.5	0.0
8.8	6.8	.1
9.1	7.0	.8
9.3	7.2	2.0
9.9	7.0	1.9
10.8	4.9	0.0
10.6	5.5	.2
10.4	6.0	1.3
9.9	6.6	.7
9.9	6.8	1.3
9.9	7.2	2.3
9.6	7.4	1.9
9.3	7.7	2.5

27 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL E2

NO. OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 5 DATA SET NO. 1 DATE 040680 TIME 1615-1630
GRENGES SUNDSVALL E2
NO. OF POINTS 26

CONCENTRATION IN (UG/M)

X	Y	C
9.5	7.3	.1
8.6	7.8	0.0
9.2	8.5	.5
8.9	8.8	.6
8.7	8.5	.4
8.4	8.1	0.0
8.1	7.9	0.0
7.4	8.5	0.0
10.0	6.6	6.0
10.1	6.7	4.3
9.9	6.9	3.1
10.1	6.9	3.2
9.9	6.6	0.0
9.9	6.8	.1
9.9	7.2	3.1
9.6	7.4	2.1
9.3	7.7	.2
3.6	10.9	.1
4.6	11.3	.3
5.4	11.4	.3
6.3	11.5	.2
7.2	11.6	0.0
8.0	12.2	0.0
10.9	11.4	0.0
11.9	11.4	.1
11.4	11.4	0.0

26 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2

NO. OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 6 DATA SET NO. 1 DATE 050680 TIME 1410-1425
GRENGES SUNDSVALL VERK 1 OG 2
NO. OF POINTS 24

CONCENTRATION IN (UG/M)

X	Y	C
5.6	9.2	0.0
7.4	8.5	0.0
9.2	8.2	.8
9.2	8.5	.9
8.5	8.3	.3
8.4	8.1	0.0
8.1	7.9	0.0
8.8	6.8	0.0
9.1	6.9	0.0
9.3	7.2	.4
4.6	11.3	0.0
5.4	11.4	0.0
6.3	11.5	.4
8.0	12.2	.8
4.2	11.5	0.0
4.2	12.1	0.0
10.7	5.2	0.0
10.6	5.5	0.0
10.4	6.0	.3
9.9	6.6	1.8
9.9	6.8	2.5
9.9	7.2	2.0
9.6	7.4	1.7
9.3	7.7	.9

24 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2

NO. OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 7 DATA SET NO 1 DATE 050680 TIME 1530-1645
GRENGES SUNDSVALL VERK 1 OG 2 E2
NO. OF POINTS 32

CONCENTRATION IN (UG/M)

X	Y	C
7.4	8.5	.4
9.2	8.2	1.5
9.2	8.5	.5
8.5	8.3	1.8
8.4	8.1	1.2
8.1	7.9	0.0
7.3	8.1	0.0
8.8	6.8	0.0
9.1	6.9	.0
9.3	7.2	.4
1.1	7.2	0.0
1.2	8.2	.2
1.9	8.9	.1
2.8	9.0	.2
3.2	10.0	.4
3.6	10.9	.8
4.6	11.3	.6
5.4	11.4	.3
6.3	11.5	0.0
8.0	12.2	0.0
4.2	11.5	.6
4.2	12.1	.6
3.4	11.8	.7
2.6	11.8	.6
10.7	5.2	0.0
10.6	5.5	0.0
10.4	6.0	.3
9.9	6.6	.4
9.8	6.8	.7
9.9	7.2	3.3
9.6	7.4	1.2
9.3	7.7	1.2

32 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL E2

NO. OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 8 DATA SET NO 1 DATE 050680 TIME 1815-1830
GRENGES SUNDSVALL E2
NO. OF POINTS 18

CONCENTRATION IN (UG/M)

X	Y	C
10.2	7.1	.8
10.2	6.8	3.5
10.1	6.7	11.0
10.0	6.6	10.7
9.9	6.6	0.0
9.9	6.8	.1
9.9	7.2	4.3
9.6	7.4	3.8
9.3	7.7	.1
9.3	7.5	.2
9.2	8.2	1.4
9.2	8.5	.9
8.9	8.3	1.3
8.7	8.5	.6
8.4	8.1	0.0
8.1	7.9	0.0
9.5	7.4	0.0
10.0	6.8	7.5

18 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 2

NO OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 9 DATA SET NO. 1 DATE 060680 TIME 1100-1115
GRENGES SUNDSVALL VERK 2
NO OF POINTS 28

CONCENTRATION IN (UG/M)

X	Y	C
11.0	12.0	0.0
8.8	11.7	.1
7.6	11.3	.3
5.3	9.8	0.0
8.4	8.1	0.0
9.2	8.2	.3
8.9	8.8	.9
8.7	8.5	.4
8.3	11.5	.3
3.6	10.9	0.0
5.4	11.4	0.0
6.3	11.5	.1
7.2	11.8	.9
8.0	12.2	.8
9.7	11.5	0.0
11.9	11.4	0.0
4.3	14.2	.1
4.7	13.3	.1
5.5	12.4	.1
10.8	4.9	.4
10.7	5.2	0.0
10.6	5.5	0.0
10.4	6.0	.1
9.9	6.6	.1
9.9	6.8	.1
9.9	7.2	.3
9.6	7.4	.1
9.3	7.7	0.0

28 DATA POINTS HAVE BEEN PLOTTED

GRANGES SUNDSVALL VERK 1 OG 2 E2

NO OF DATA SETS 1
IFLAG 0 WIND ANGLE (DEG) 0.
XQ,YQ 10.6 5.5

TEST 10 DATA SET NO 1 DATE 060680 TIME 1415-1430
GRENGES SUNDSVALL VERK 1 OG 2 E2
NO OF POINTS 26

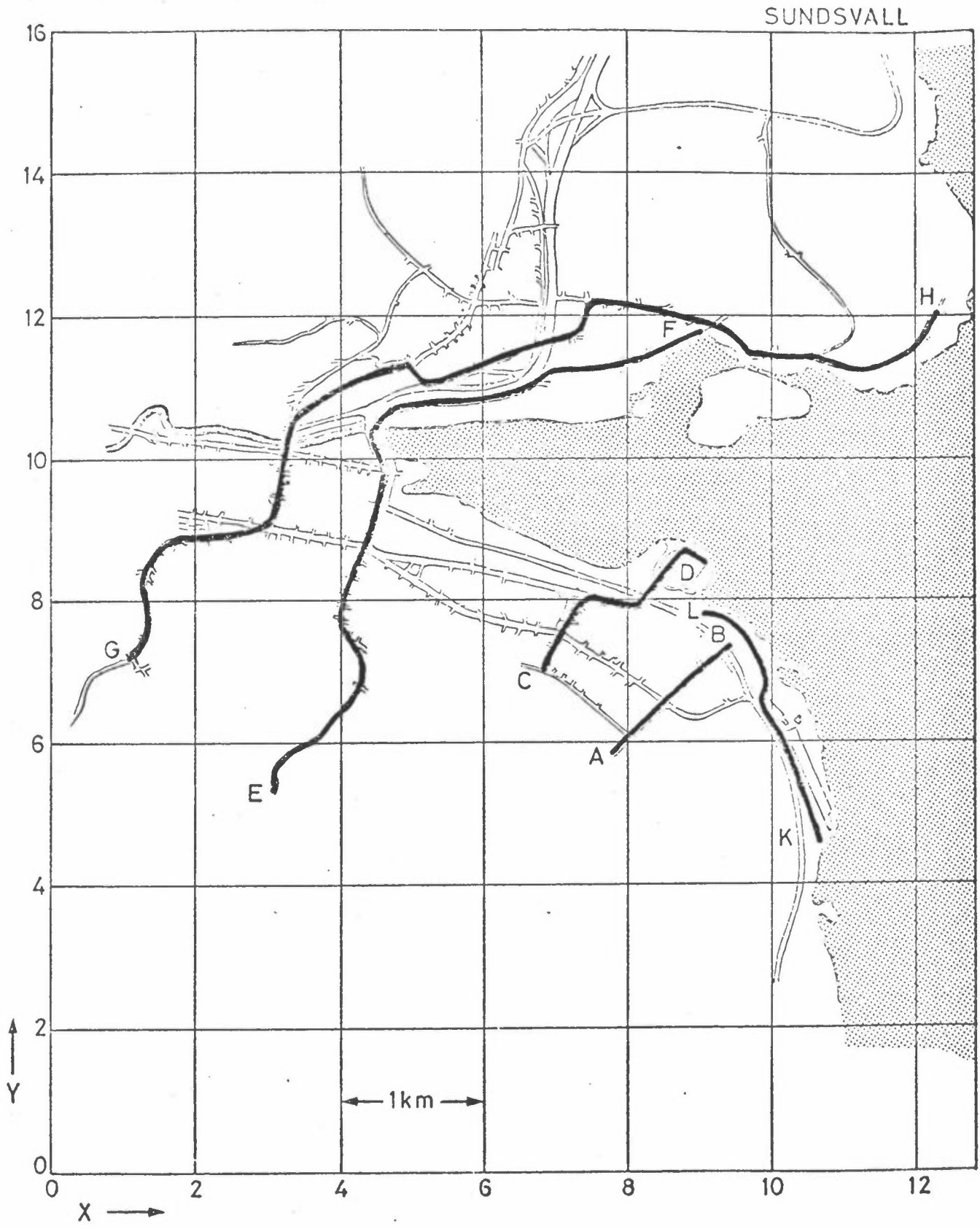
CONCENTRATION IN (UG/M)

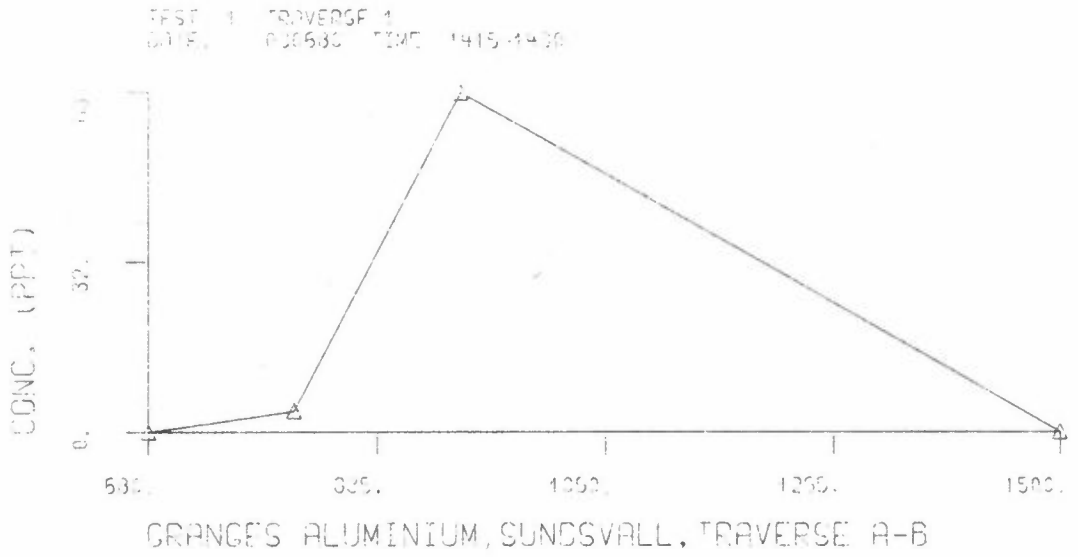
X	Y	C
3.2	10.0	0.0
3.6	10.9	0.0
4.6	11.3	.4
5.4	11.4	.3
6.3	11.5	.3
7.2	11.8	2.9
8.0	12.2	3.4
9.7	11.5	0.0
4.3	14.2	.8
4.7	13.3	.7
5.5	12.4	.7
10.4	6.0	0.0
9.9	6.6	0.0
9.9	6.8	1.8
9.9	7.2	0.0
9.6	7.4	.0
9.3	7.7	0.0
9.2	8.2	0.0
9.2	8.5	1.3
8.9	8.8	.7
8.7	8.5	0.0
8.4	8.1	0.0
7.3	8.1	0.0
6.8	6.9	0.0
8.7	6.5	0.0
9.3	7.2	0.0

26 DATA POINTS HAVE BEEN PLOTTED

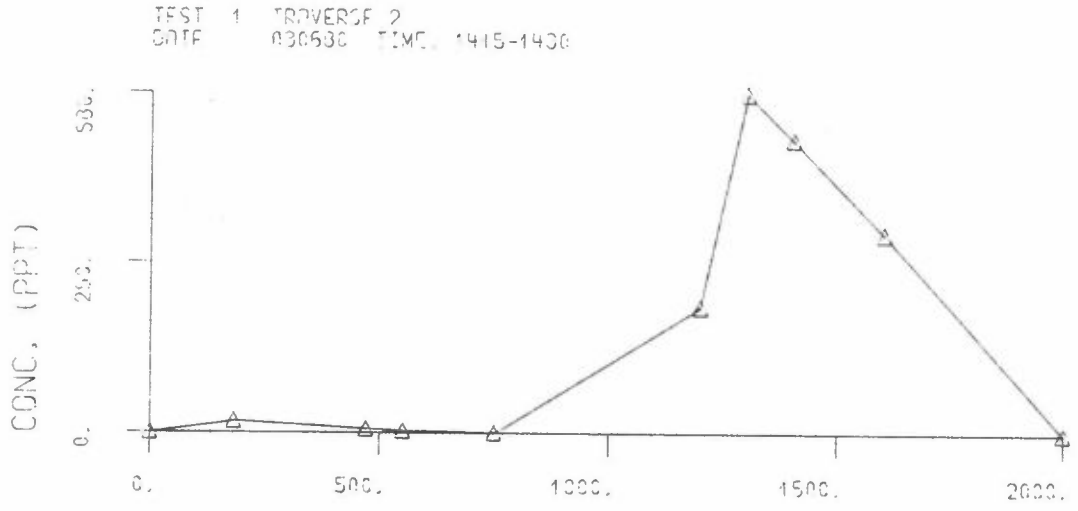
APPENDIX D

SF_6 CONCENTRATION DISTRIBUTIONS ALONG TRAVERSES, GIVEN IN IN PPT $\simeq 6.6 \cdot 10^{-3}$ $\mu g/m^3$

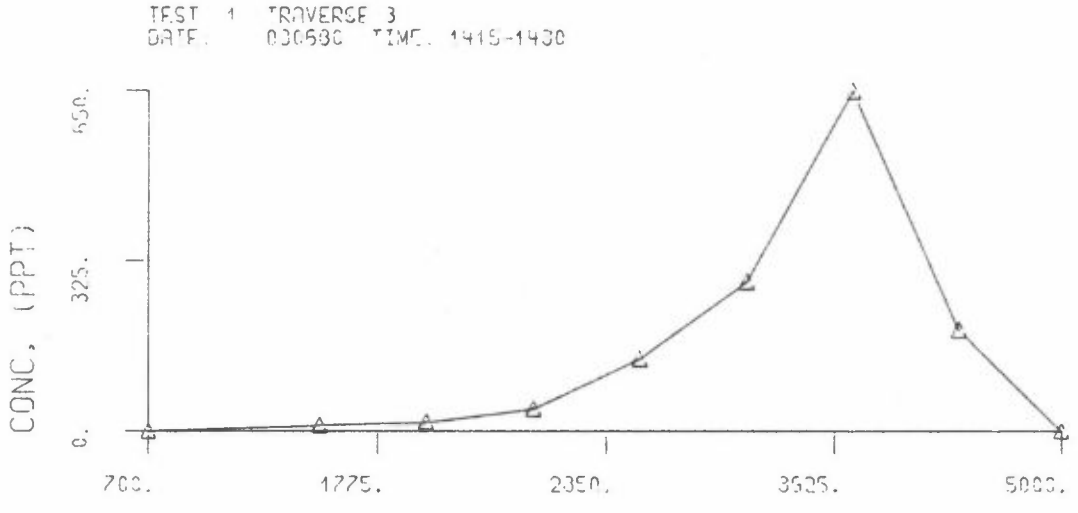

SUNDSVALL
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
X
Y
1km
A
B
C
D
E
F
G
H
K
L



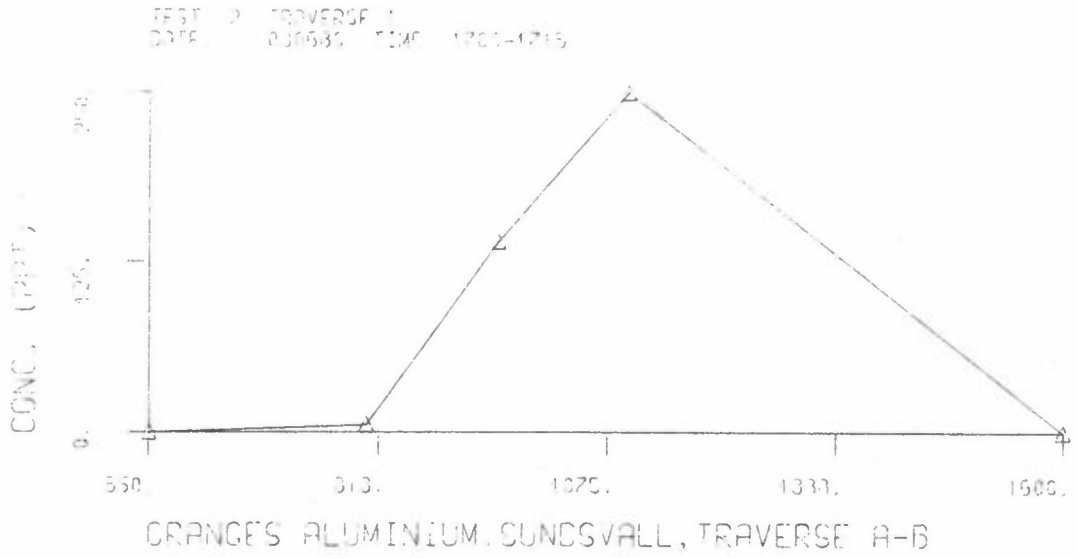
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B

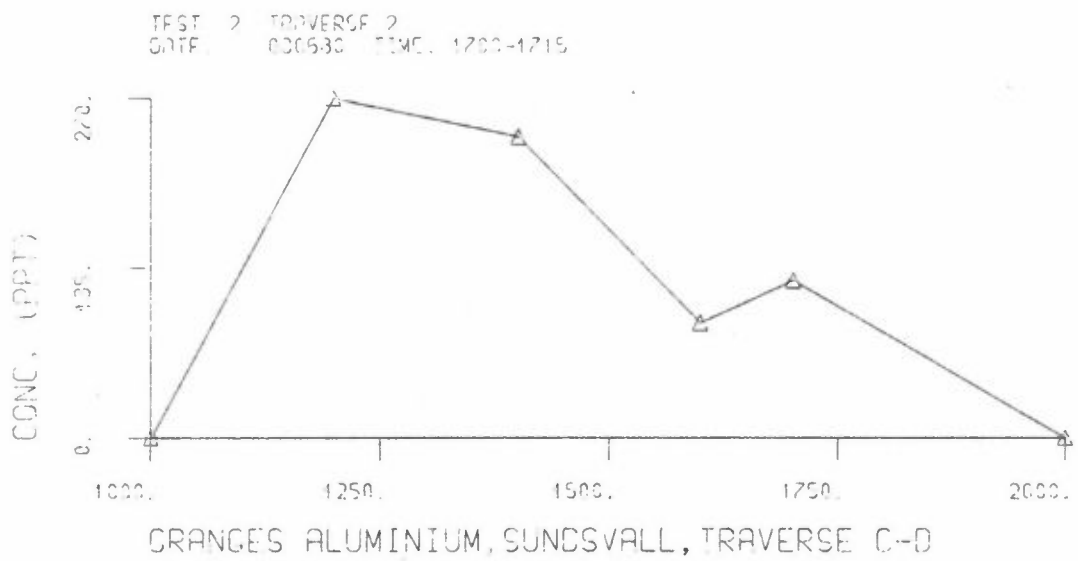


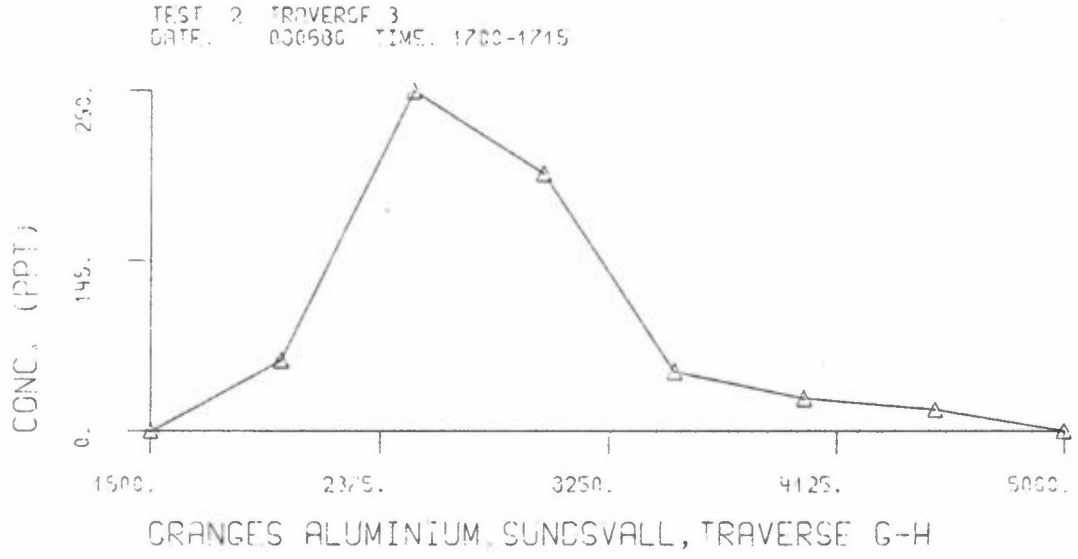
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D

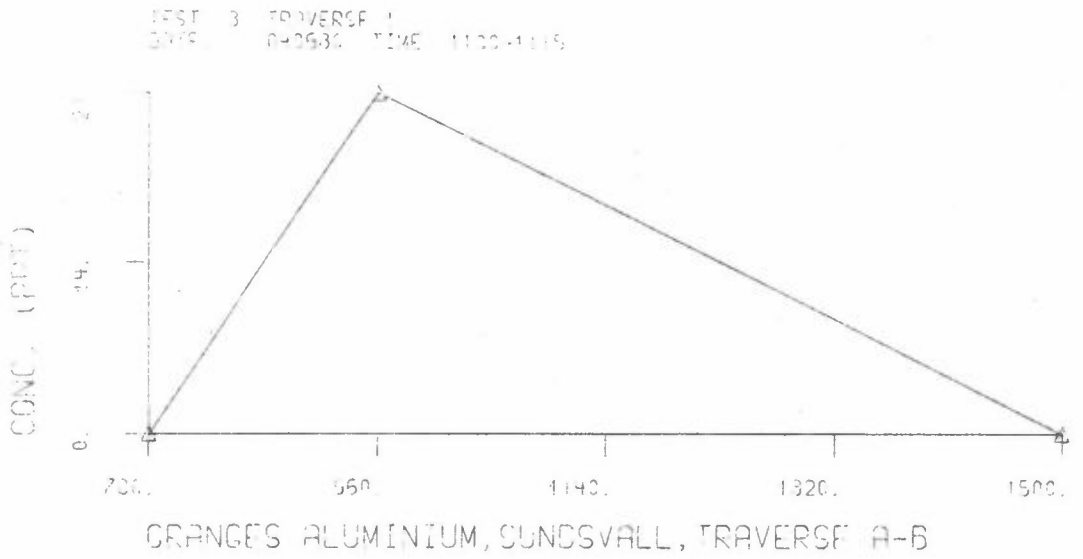


GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H

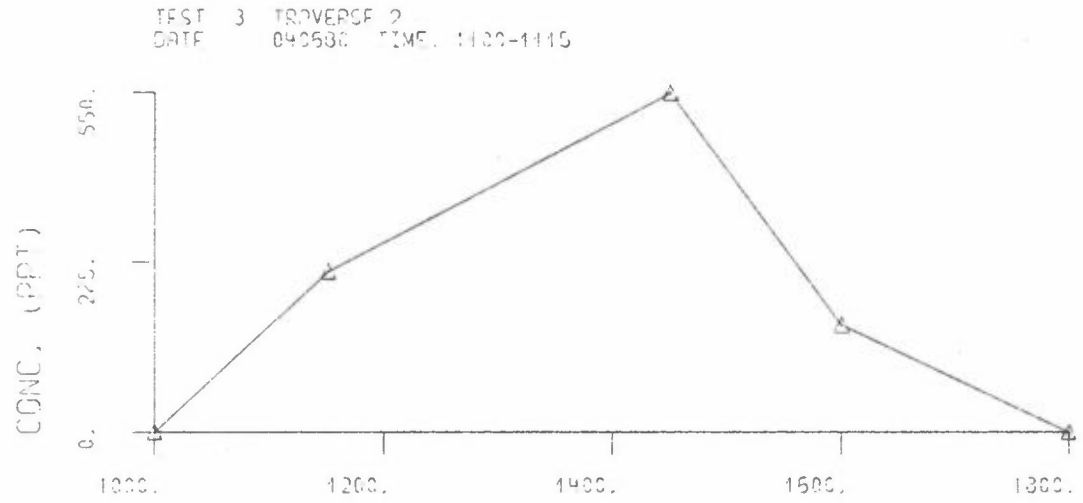

TEST 2 TRAVERSE 1
DATE. 030630 TIME. 1700-1715
CONC. (PPT)
0.
563.
813.
1063.
1313.
1563.
ORRNGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B


TEST 2 TRAVERSE 2
DATE. 030630 TIME. 1700-1715
CONC. (PPT)
0.
1000.
1250.
1500.
1750.
2000.
ORRNGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D

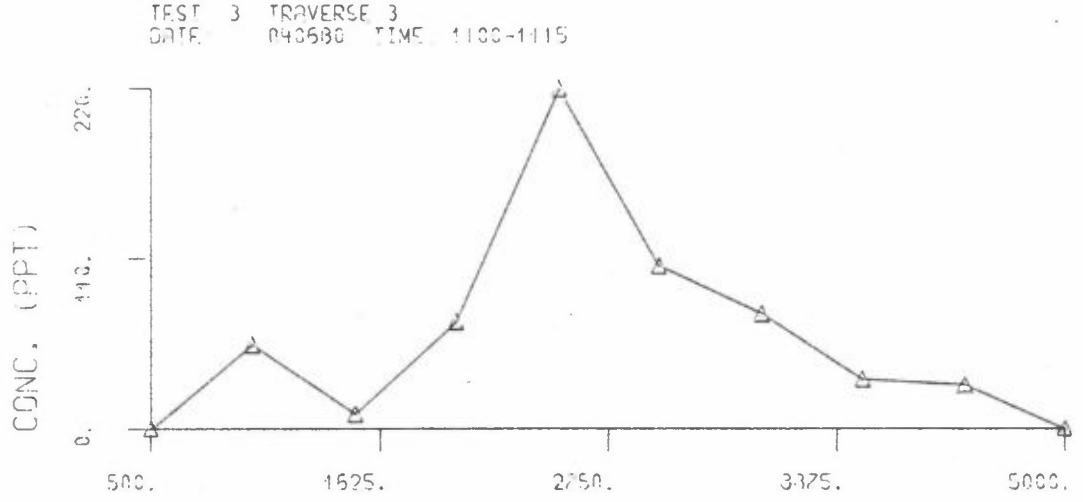

TEST 2 TRAVERSE 3
DATE. 030630 TIME. 1700-1715
CONC. (PPT)
0.
1500.
2375.
3250.
4125.
5000.
ORRNGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H



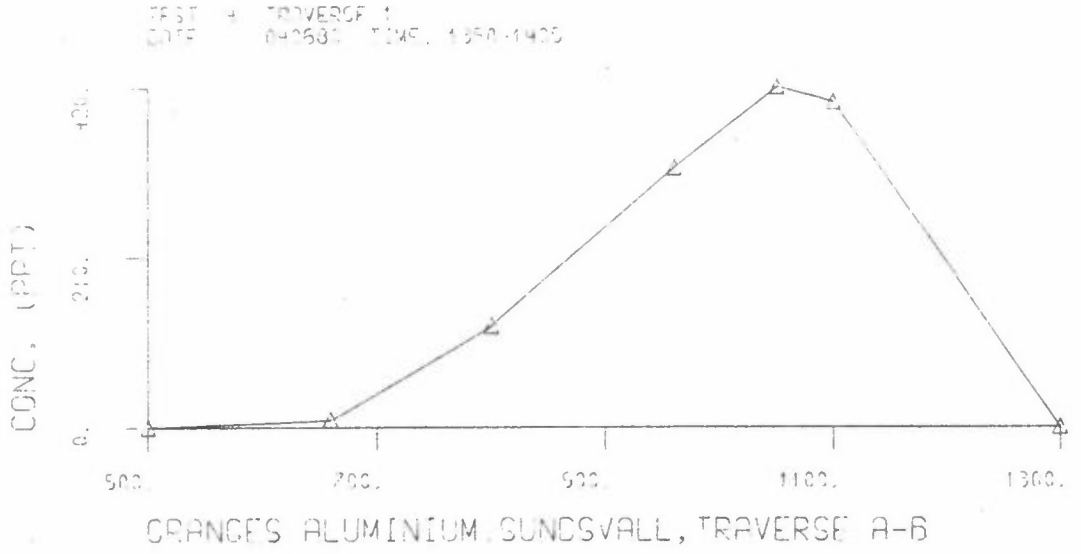
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B



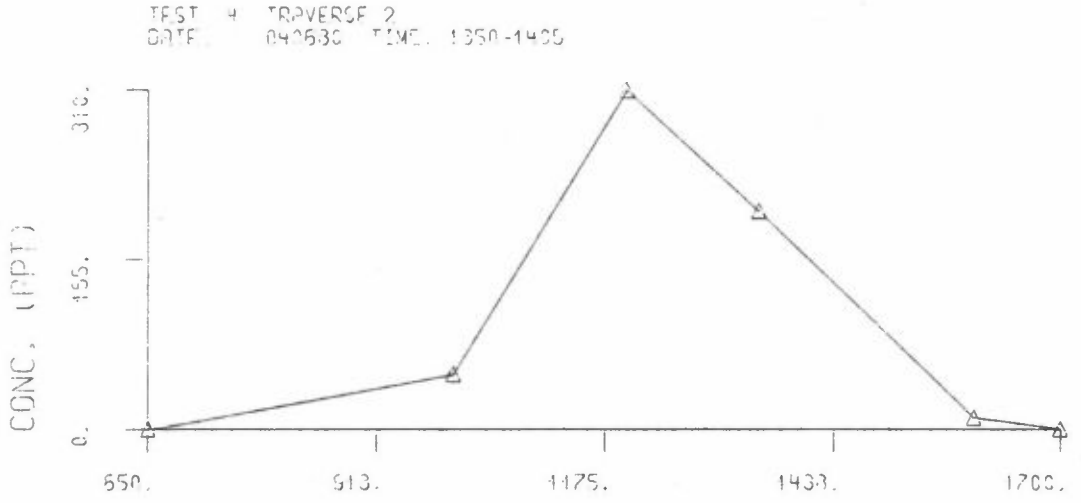
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



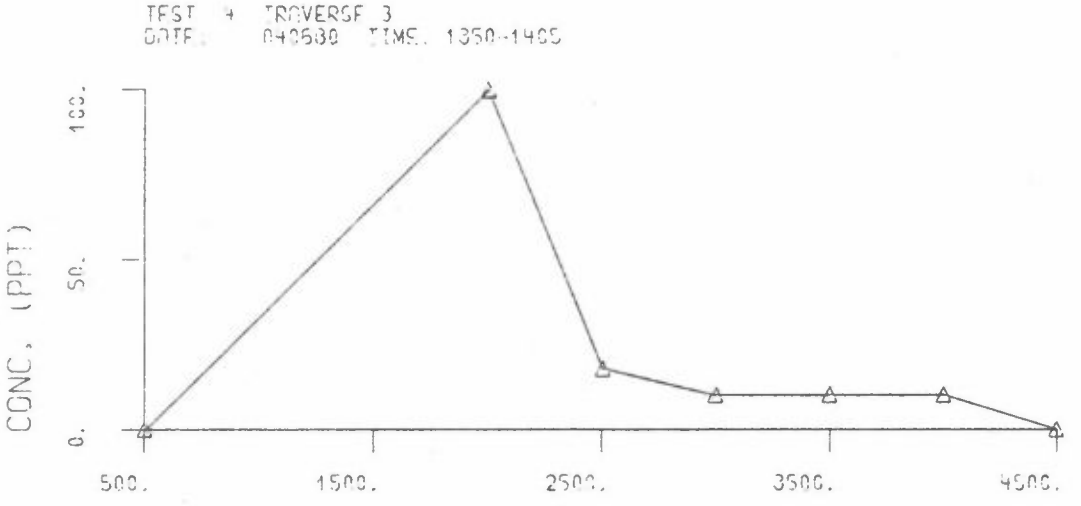
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H



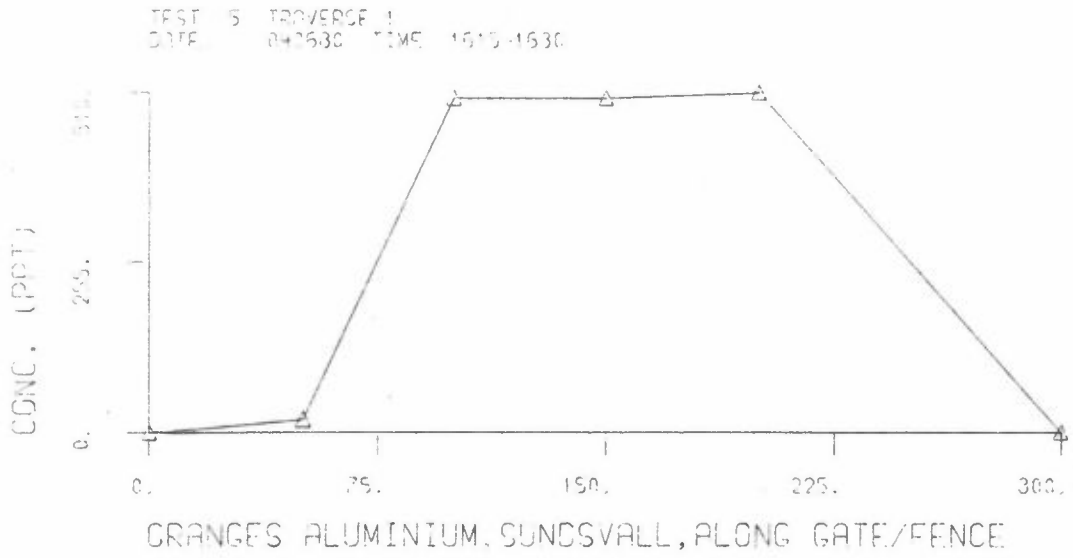
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B



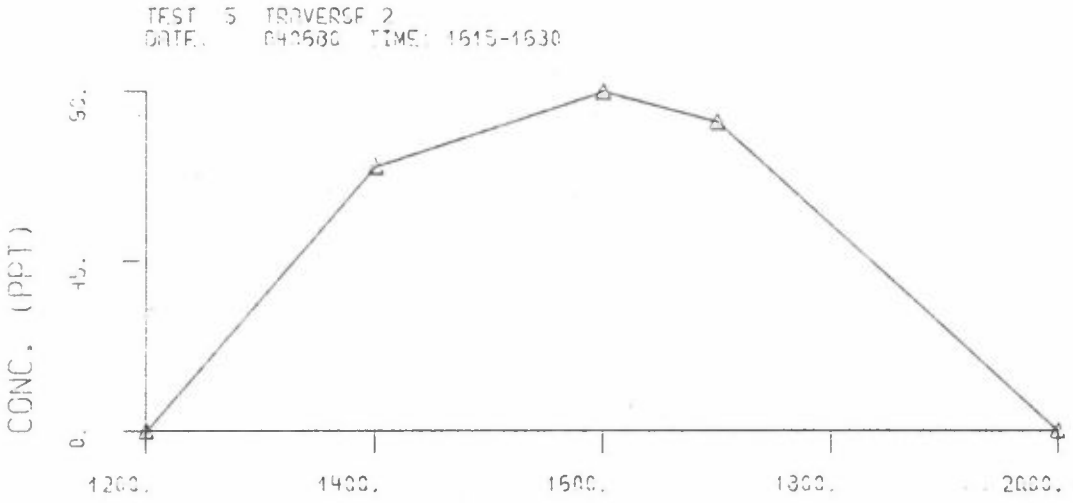
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



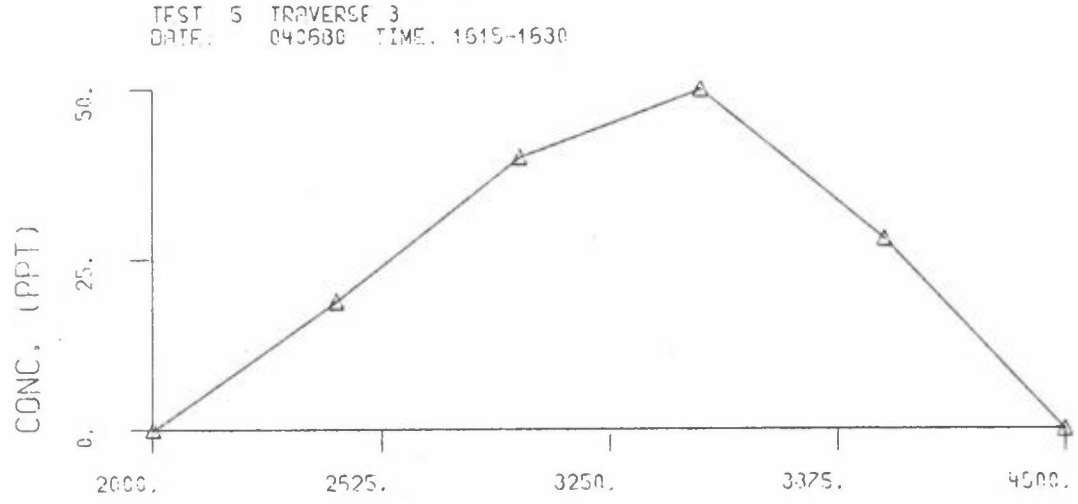
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H



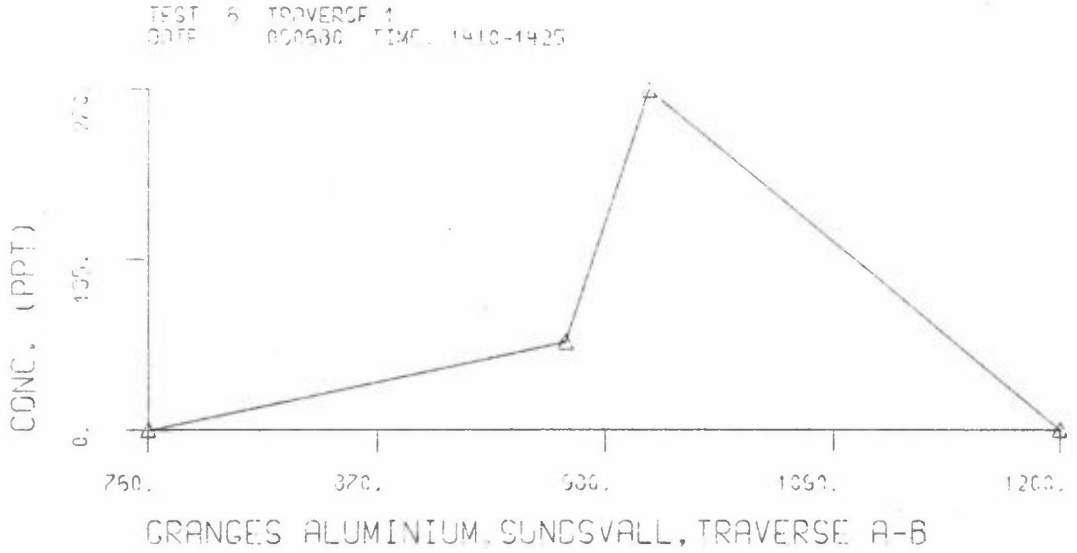
GRANGES ALUMINIUM, SUNDSVALL, ALONG GATE/FENCE

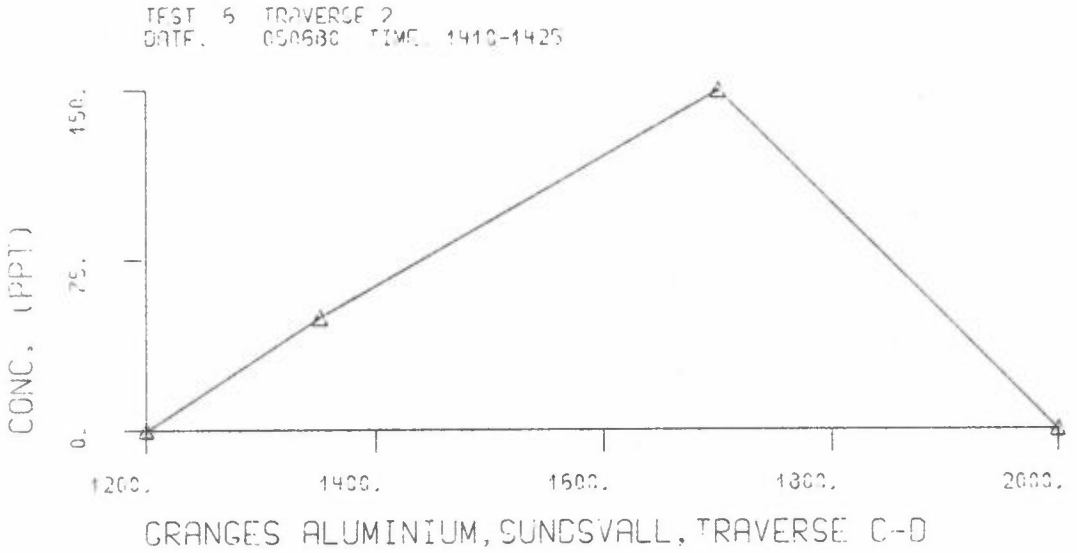


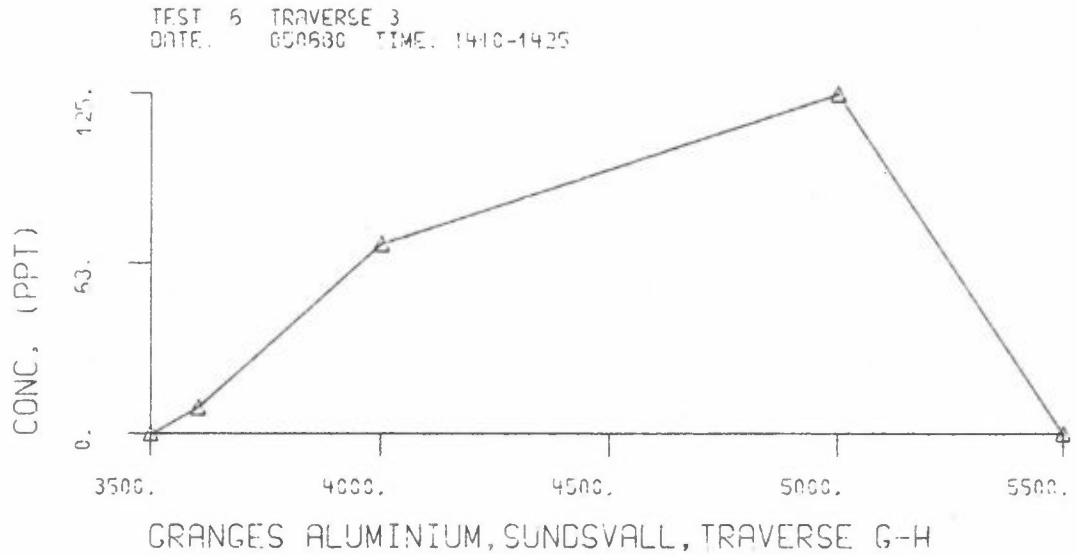
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D

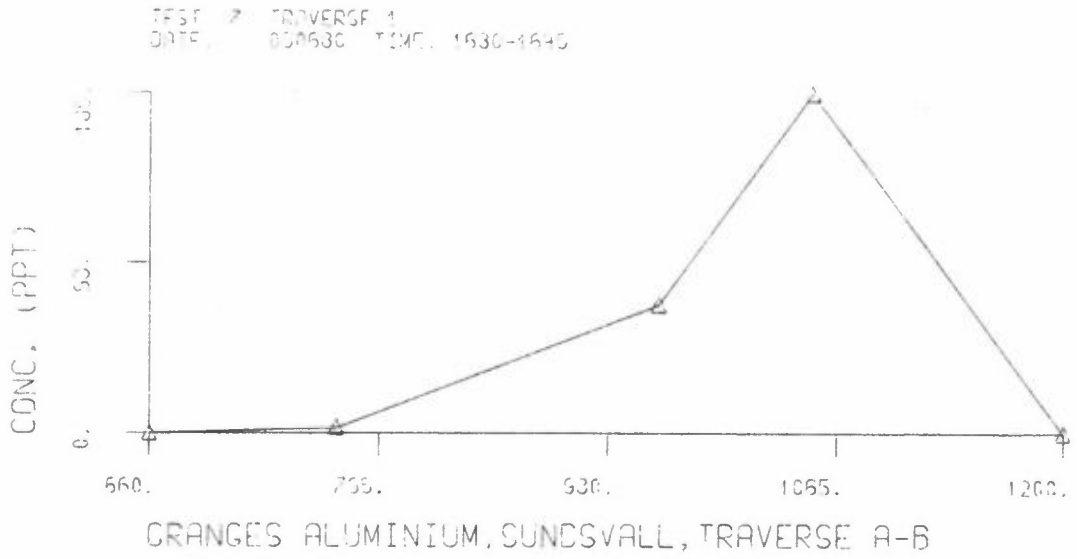


GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H

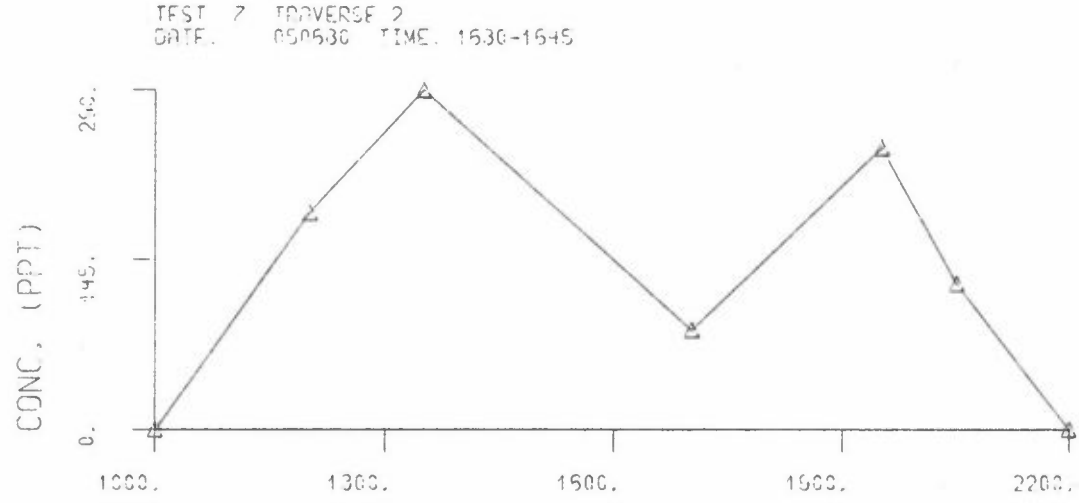

TEST 6 TRAVERSE 1
DATE. 850630 TIME. 1410-1425
CONC. (PPT)
0.
750.
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B


TEST 6 TRAVERSE 2
DATE. 850630 TIME. 1410-1425
CONC. (PPT)
150.
75.
0.
1200.
1400.
1600.
1800.
2000.
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D

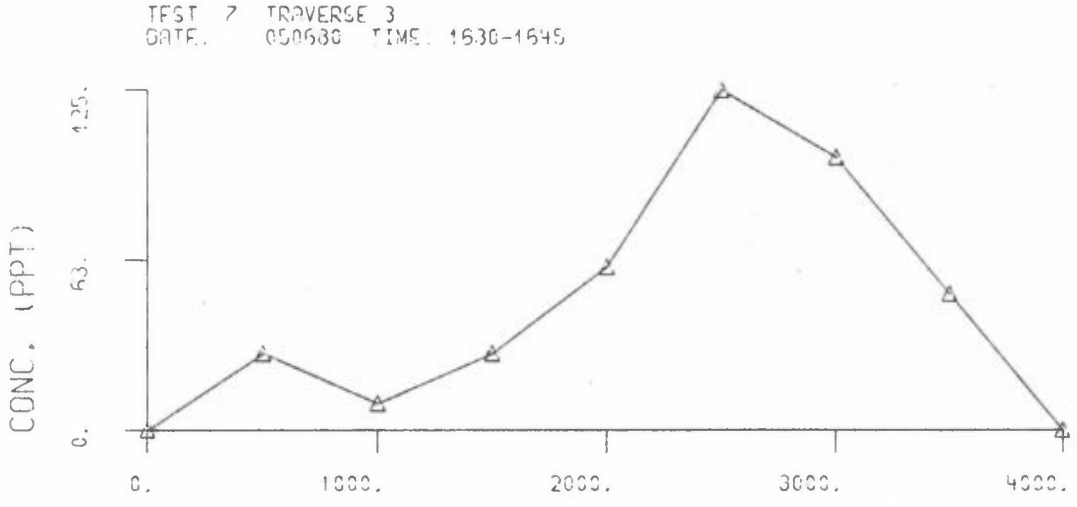

TEST 6 TRAVERSE 3
DATE. 850630 TIME. 1410-1425
CONC. (PPT)
125.
63.
0.
3500.
4000.
4500.
5000.
5500.
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H



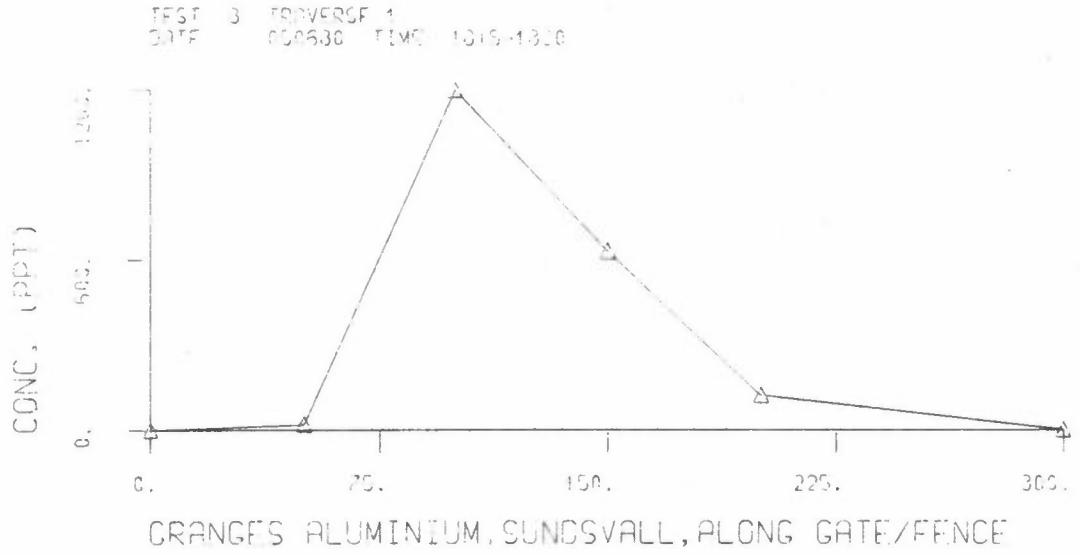
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE A-B

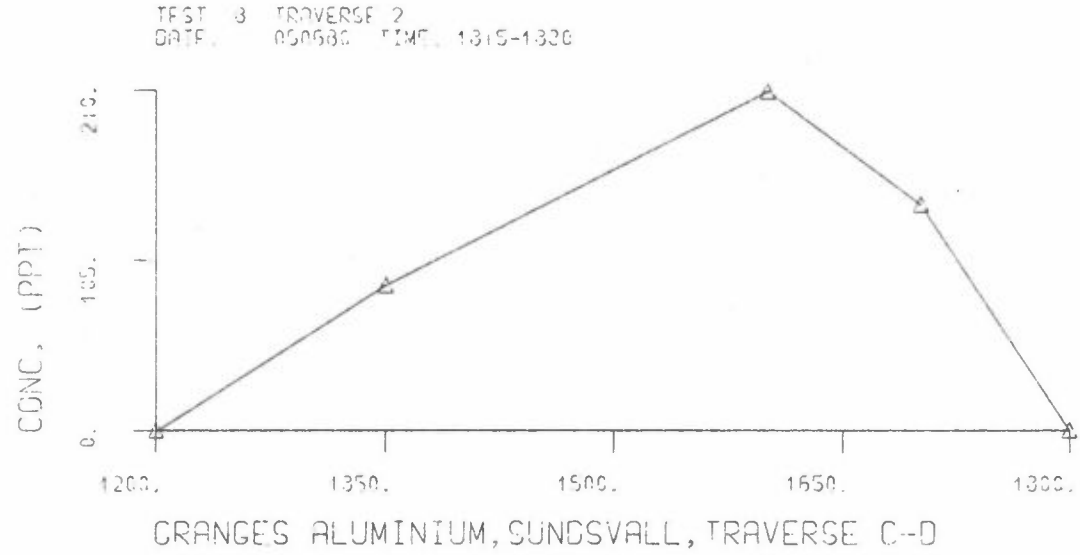


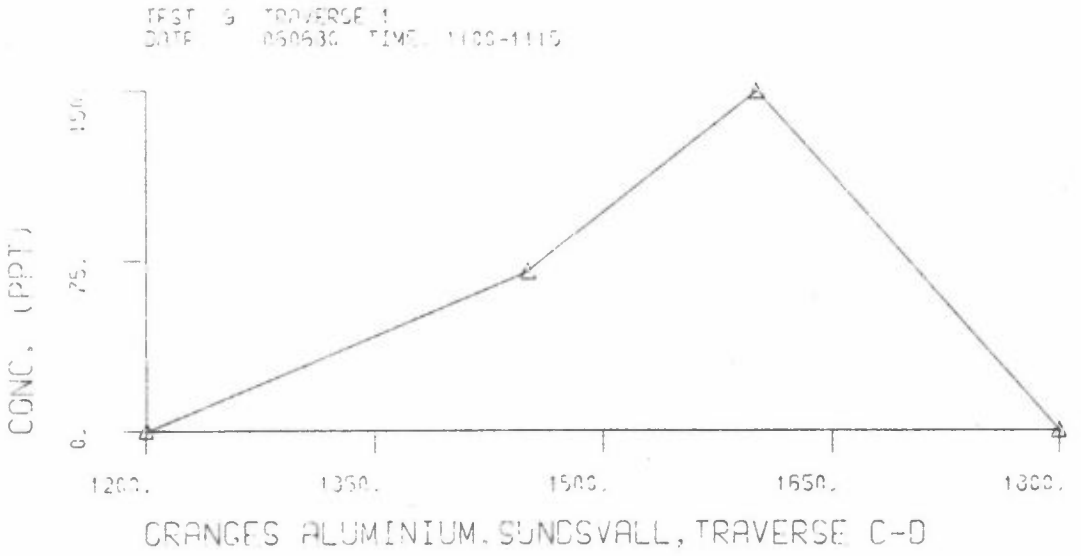
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



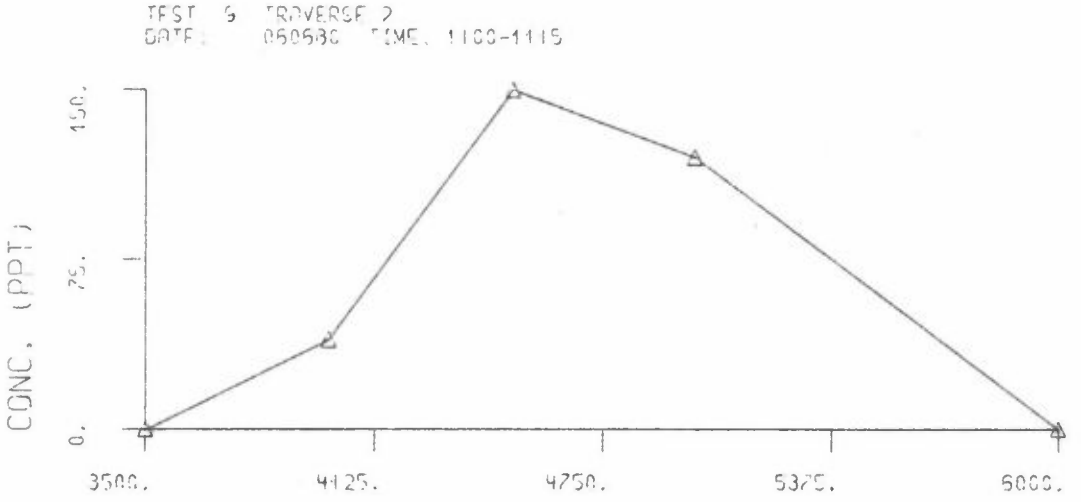
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H


TEST 3 TRAVERSE 1
DATE 850630 TIME 1315-1330
CONC. (PPT)
0.
75.
150.
225.
300.
GRANGES ALUMINIUM, SUNDSVALL, ALONG GATE/FENCE

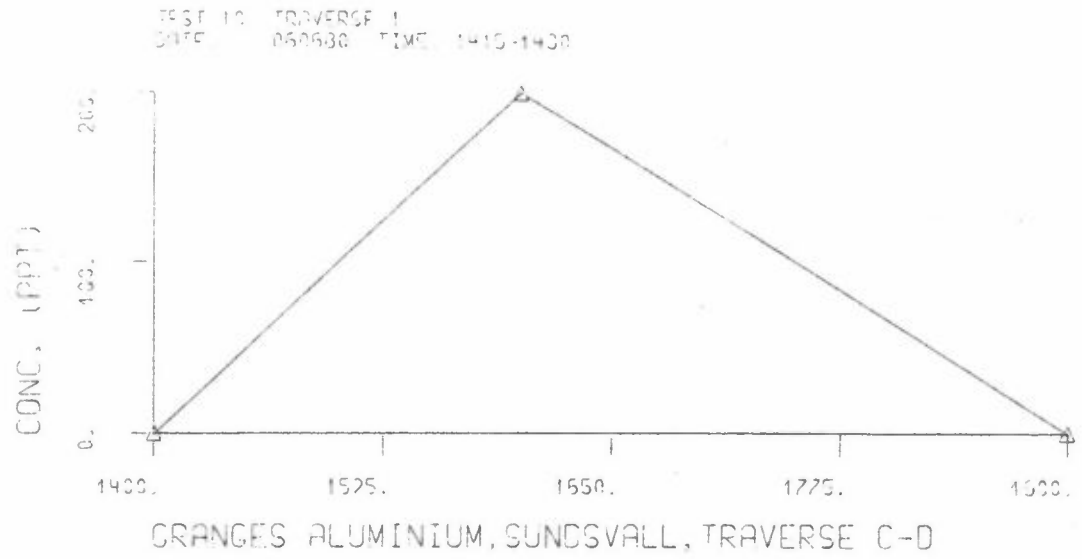

TEST 3 TRAVERSE 2
DATE 850630 TIME 1315-1330
CONC. (PPT)
0.
135.
210.
1200.
1350.
1500.
1650.
1800.
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



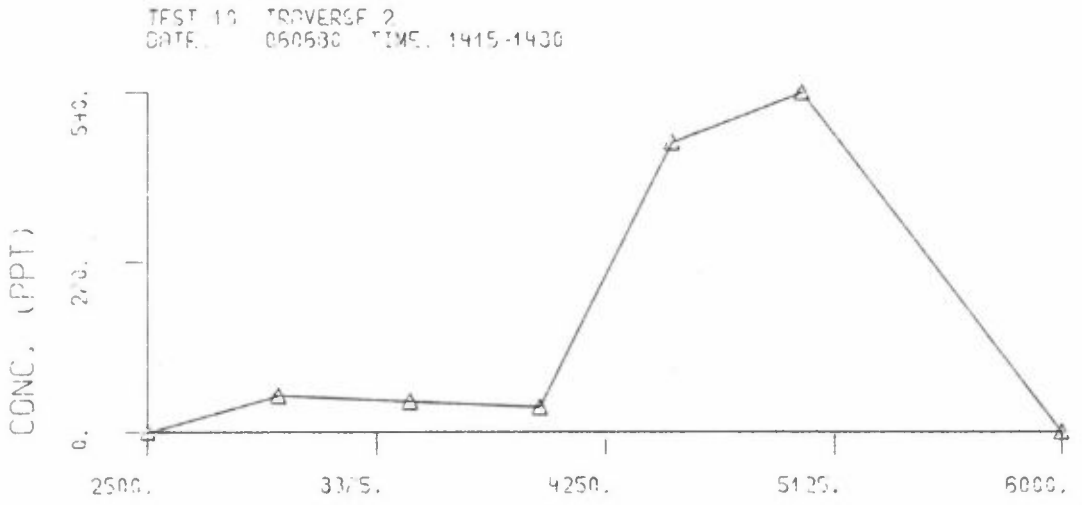
GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



GRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H



CRANGES ALUMINIUM, SUNDSVALL, TRAVERSE C-D



CRANGES ALUMINIUM, SUNDSVALL, TRAVERSE G-H

APPENDIX E

CALIBRATION OF STABILITY MEASUREMENTS ON THE 40 M TOWER AT GRÄNGES

STABILITY

Temperature difference between 40 m and 10 m (ΔT_{40-10}) at the meteorological tower is measured with a platinum resistance thermometer (1000 Ω) to estimate atmospheric stability.

Calibration of the temperature difference measurements has been performed at several occasions.

A statistical treatment of the stability data indicated, however, that:

- the range of temperature differences was too large (the stable cases were too stable and the unstable ones too unstable)
- the zero-temperature difference seemed to be displaced towards positive values producing too many stable cases.

To verify this, a radiosonde was released close to the meteorological tower on 3 June 1980 at 2300 hrs. The radiosonde was slowly lifted to 150 m above the ground by a gas filled balloon. The temperature was continuously recorded. The measured temperature profile is shown in Figure E1, together with a line showing the temperature gradient estimated from ΔT_{40-10} measured at 2300 hrs.

From these profiles,and from the statistical treatment of ΔT_{40-10} data during 13 March-21 Sept 1980, the following correction was introduced:

$$\Delta T_{new} = 0.7 \cdot (\Delta T_{meas} - 1.0)$$

These "new" ΔT data were divided into four stability classes using the following criteria:

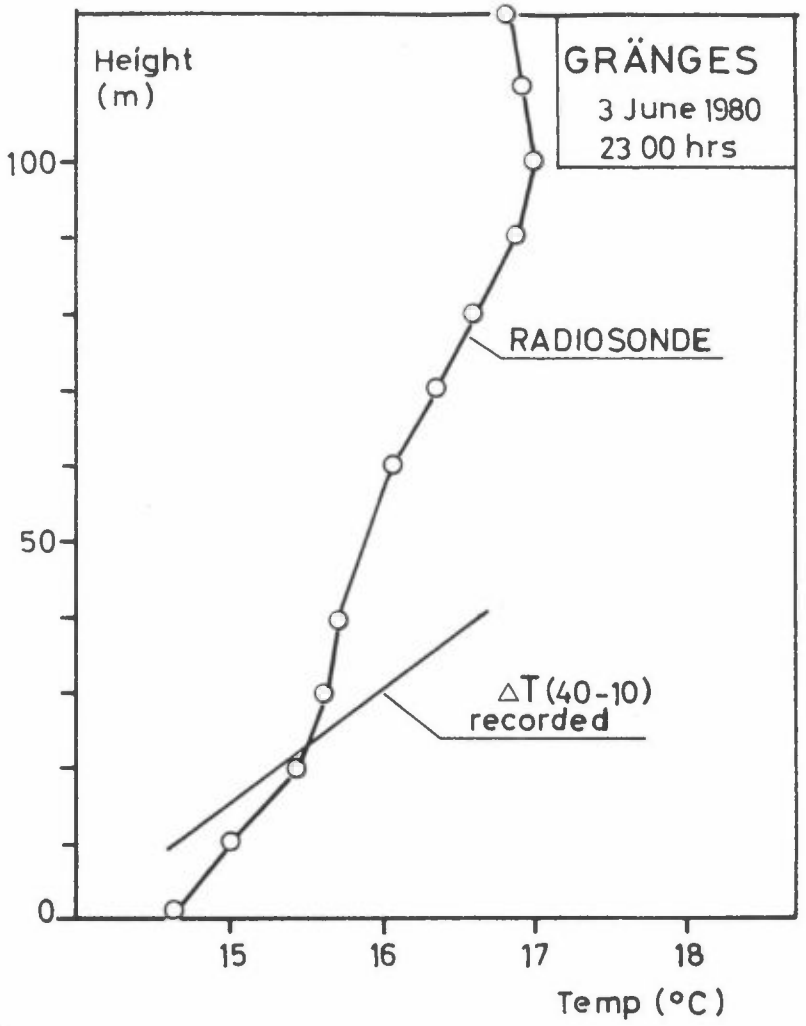


Figure E1: Temperature profiles measured with a radiosonde and from ΔT_{40-10} on 3 June 1980 at 2300 hrs.

Unstable	:	$\Delta T \leq -0.5^{o}C$
Neutral	:	$-0.5 < \Delta T \leq 0^{o}C$
Slightly stable	:	$0 < \Delta T \leq 0.5^{o}C$
Stable	:	$\Delta T > 0.5^{o}C$

Figure E2 show the diurnal variation of these stability classes for the spring (13 March-31 May) and summer (1 June - 31 August) 1980.

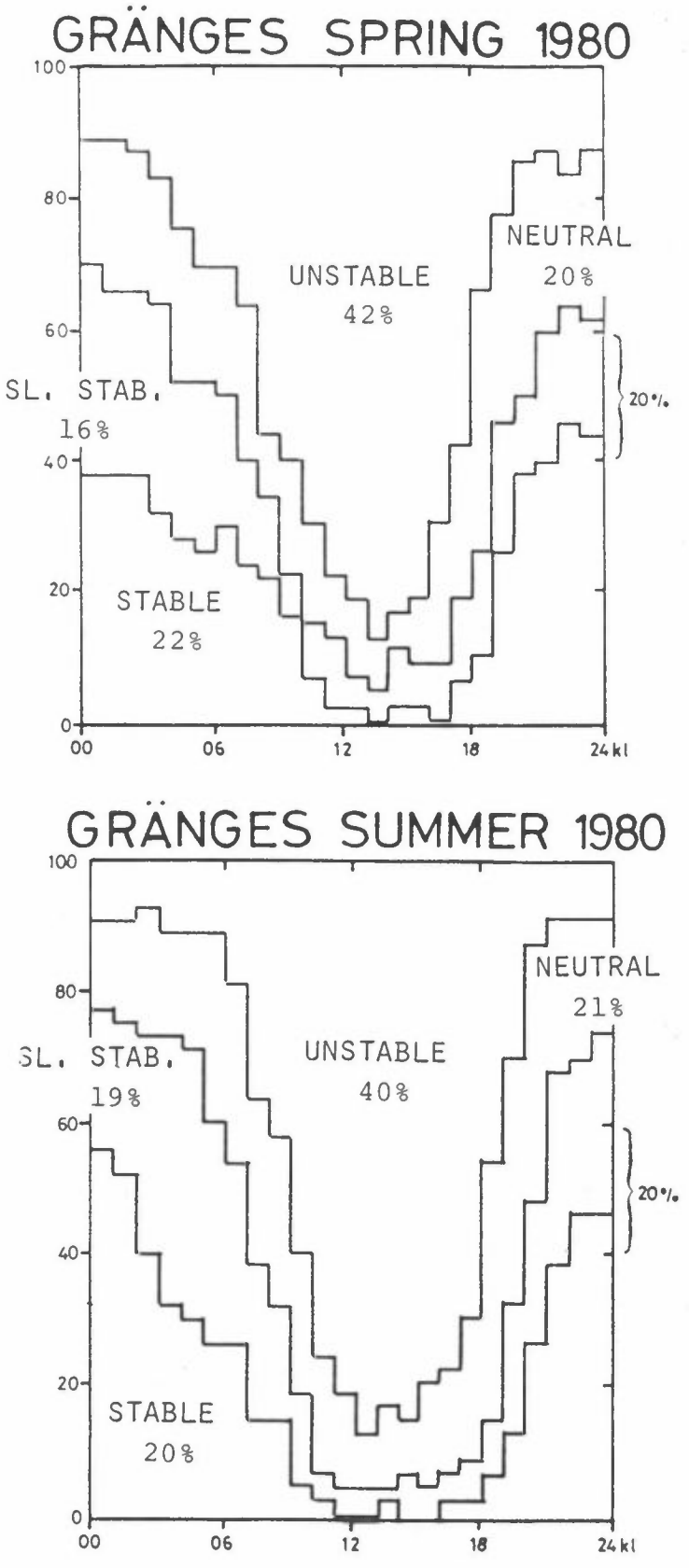


Figure E2: Diurnal variation of stability classes.

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TITTEL A tracer study of dispersion patterns from Gränges Aluminium smelter in Sundsvall		PROSJEKTLEDER B.Sivertsen NILU PROSJEKT NR 24479
FORFATTER(E) Bjarne Sivertsen Val Vitols		TILGJENGELIGHET ** A OPPDRAGSGIVERS REF.
OPPDRAGSGIVER Gränges Aluminium,Metall		
3 STIKKORD (á maks.20 anslag) Dispersion experiments	Tracer SF_6	PAH measurements

REFERAT (maks. 300 anslag, 5-10 linjer)
Spredningsforsøk med SF_6 som sporgass ble utført på Gränges Aluminium i Sundsvall sommeren 1980 for å finne representative stasjonsplasseringer for PAH-målinger. Basert på ti forsøk ble 5 stasjoner valgt for å representere sterkt, middels og lite belastete områder.

TITLE A tracer study of emission patterns from Gränges Aluminium smelter in Sundsvall

ABSTRACT (max. 300 characters, 5-10 lines)
Ten dispersion experiments using SF_6 as a tracer were carried out at the Gränges Aluminium smelter in Sundsvall during 3-6 June 1980 to recommend locations for representative measurements of ambient PAH in the Sundsvall area. Five stations were selected to represent severe, average and slight impact.

**Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C