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A TRACER INVESTIGATION OF THE WAKE DOWNWIND OF AN ALUMINUM SMELTER HALL

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SUMMARY

Nine SF_6 tracer experiments were conducted at the ÅSV Høyanger Aluminium Smelter during April, 1978. The purpose of these tests was to determine the extent to which smelter exhaust gases may become entrained within the wake downwind of a smelter hall and to investigate the effects of increasing the height of the emission point upon the extent of entrainment. Tracer emitted at heights ranging from 1 m to 11 m above the roof of the smelter hall become entrained within the wake and subsequently reentered the hall through the fresh air supply vents. Approximately 1% of the SF_6 released above the roof during southerly winds infiltrated the hall, while as much as 11% of the SF_6 released above the roof during northerly winds infiltrated the hall. The amount of infiltration which was observed during southerly winds was independent of the release height. During northerly winds, the amount of infiltration observed for a 2.5 m release height was twice that observed for an 11 m release height.

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1 INTRODUCTION

The emission of large volumes of polluted air from the ventilation exhaust on the roof of an aluminum smelter hall may contaminate the fresh air supply of the hall or of halls located downwind. In order to avoid entrainment of the polluted exhaust air within the wake of the hall and subsequent reentry of pollutants through floor-level inlet vents, it may be necessary to release the exhaust air through chimneys. The greater effective release height caused by chimneys (as compared to the release height of roof level exhaust ducts) would lift the exhaust gases above the building wake and into the free air stream.

The purpose of this work was to investigate the extent to which exhaust gases may become entrained within the wake downwind of a smelter hall and to determine the effects of increasing the height of the emission point upon the extent of entrainment. The impetus for this investigation was the proposed construction of a new smelter hall beside an existing hall at the ÅSV Høyanger aluminum smelter. The proposed and existing halls, designated hall A and hall C, respectively, lie perpendicular to the axis of the Høyanger valley, as shown in Figure 1. A cross-section of the halls is shown in Figure 3b. All figures are presented in Appendix A. The prevailing winds, which follow the valley axis, may cause the exhaust of one hall to be carried into the second.

In this work, tracer techniques, involving sulfur hexafluoride (SF_6), an inert, nontoxic gas, and electron capture gas chromatography, were employed to characterize the flow of exhaust air immediately downwind of the existing smelter hall.

2 BUILDING WAKE EXPERIMENTS

Previous investigations of pollution near buildings include work by Halitsky (1962, 1963) who found from wind tunnel experiments that a fairly well defined turbulent region exists downwind of a building, as shown in Figure 2. Halitsky proposed a means for calculating pollutant concentrations within this wake caused by emissions from the building. Rummerfield et al. (1967) tested Halitsky's model for a real building by using radioactive tracer methods; they concluded that Halitsky's equations were valid for outdoor conditions. Huber and Snyder (1976) found from wind tunnel tests that for a rectangular building with its width equal to twice its height and breadth, the turbulent cavity extended 2.5 building heights (H_b) from the downwind edge of the building. The peak height of this wake was 1.5 H_b above the ground. The maximum width equaled 3 H_b. These maximum values occurred 0.5 H_b from the downwind edge of the building. Huber and Snyder reported that for stacks slightly above the roof, the effluent was dispersed immediately to the ground and became partially entrained in the cavity. For stacks with heights greater than 1.5 H_b above the ground, the plume was not entrained within the recirculation cavity, but vertical dispersion of the plume was enhanced.

Drivas and Shair (1974) used SF_6 as a tracer to study the wake downwind of a rectangular building. Their results indicated that the recirculation cavity was a well-mixed region which extended 3 H_b downwind. Concentrations within the cavity caused by an instantaneous tracer release decreased exponentially. The time for the concentration to decrease by 1/e equaled approximately 1 minute. Drivas and Shair also found that infiltration of the tracer from the wake into the building ventilation system occurred within 5 minutes after the release of the tracer within the wake.

Obremski et al. (1974) conducted wind tunnel tests to determine the external pressure distribution on a model of the Norsk Hydro Karmøy aluminum smelter. They found that for wind speeds greater than 3 m/s large pressure differences occurred between the windward and leeward sides of the smelter halls. These pressure differences were found to be the result of flow patterns over and around the halls and the presence of a vortex between the halls, as illustrated in Figure 3a. Obremski et al. coupled these findings with results from water tank model studies and on-site ventilation velocity measurements and suggested a number of ventilation modifications, including extensive use of basement fans. The purpose of the changes was to separate the performance of the ventilation system from external wind conditions. These changes were not expected to effect the entrainment of the exhaust gases.

3 EXPERIMENTAL PROCEDURE

3.1 Tracer release procedures

Nine tracer experiments were conducted during the week of 10-14 April 1978, at the ÅSV Høyanger aluminum smelter. During 8 of the tests, SF_6 was released at a steady rate through a calibrated gas flow meter from various heights above the roof of hall C. An 11 m mast was erected temporarily to provide the appropriate heights. During Test 9, SF_6 was released at a steady rate inside hall C at a fresh air inlet near the floor of the hall. The total amount of SF_6 released during these experiments determined from the calibrated flowmeter agreed within 6% of the total amount of SF_6 determined from the weight of the SF_6 gas bottle before and after the field study. Descriptions of each tracer release are listed in Table 1.

TABLE 1

SF_6 TRACER RELEASE DATA

Test	Date	Time	Location	Height *	Release rate
1	10-4-78	1430-1450	85 m from the east end of hall C, north of the roof exhaust duct	1 m above the roof	265 cm^3/min (1.7 g/min)
2	11-4-78	1230-1305	85 m from the east end of hall C, north of the roof exhaust duct	11 m above the roof	480 cm^3/min (3.1 g/min)
3	11-4-78	1345-1405	85 m from the east end of hall C, north of the roof exhaust duct	6 m above the roof	480 cm^3/min (3.1 g/min)
4	11-4-78	1445-1505	85 m from the east end of hall C, north of the roof exhaust duct	2.5 m above the roof	480 cm^3/min (3.1 g/min)
5	12-4-78	1215-1235	85 m from the east end of hall C, north of the roof exhaust duct	11 m above the roof	480 cm^3/min (3.1 g/min)
6	12-4-78	1330-1350	85 m from the east end of hall C, north of the roof exhaust duct	2.5 m above the roof	480 cm^3/min (3.1 g/min)
7	13-4-78	0830-0850	120 m from the east end of hall C, south of the roof exhaust duct	2.5 m above the roof	480 cm^3/min (3.1 g/min)
8	14-4-78	0830-0850	120 m from the east end of hall C, south of the roof exhaust duct	11 m above the roof	480 cm^3/min (3.1 g/min)
9	14-4-78	1045-1115	151 m from the east end of hall C, at a window in the south wall of hall C	1 m above the floor of hall C	480 cm^3/min (3.1 g/min)

* The height of the release was measured from the top of the roof of the hall. An exhaust duct which stands 3 m high covers the entire length of the hall. Thus, a release at 11 m above the roof was 8 m above the top of the roof exhaust duct. Figure 3b shows a cross-section of the hall.

3.2 Air sampling methods

Instantaneous air samples, collected manually, and 15-minute average air samples, collected with automatic samplers, were taken using plastic 20 cm^3 syringes at various points within and downwind of hall C. Between 4 and 7 persons were involved in each test. As many as 17 automatic battery powered single samplers were used. In addition, 3 automatic 220 V powered sequential samplers were used inside hall C; each unit could collect 4 consecutive 15-minute average air samples. A total of 1585 samples were collected during the 5 test days.

3.3 Analytical method

All samples were analyzed using 2 electron capture gas chromatographs. These instruments were located in the chemical laboratory at the Høyanger smelter. Approximately 100 samples could be analyzed per hour; all samples were analyzed within 12 hours of the completion of an experiment. The instruments were calibrated using an exponential dilution method. The calibration results indicate that SF_6 can be detected in concentrations ranging from approximately 10^{-6} parts SF_6 per part air (10^6 parts per trillion, ppt) to 10^{-11} parts SF_6 parts SF_6 per part air (10 ppt). All concentrations presented herein are in units of parts per trillion (ppt). A typical calibration curve and SF_6 chromatogram are shown in Figure 4.

The gas chromatographs were calibrated before and after the field study. The calibration results for the two instruments changed by 5% and 25%, respectively. Degradation of the columns and detectors by atmospheric contaminants in the air samples along with transport to and from Høyanger probably caused the observed changes. Concentrations of a few samples analyzed with both instruments during the tests gave agreement within 5%. Thus, the uncertainty in the tracer concentrations is estimated to range from less than 5% for most of the samples to no more than 25% for a limited number of samples.

3.4 Meteorological observations

Meteorological data were collected at an automatic weather station with wind and temperature sensors on a 25 m mast, and from a recording anemometer located at a 10 m mast. The positions of the masts are shown in Figure 1.

Wind speed and direction measurements were also collected at various points around hall C during each test using a hand-held anemometer and soap bubbles. A summary of the meteorological conditions for each test is given in Table 2.

4 SYNOPSIS OF TRACER TESTS

The results of the tracer tests are described in the following three sections. The locations of sampling points were converted to distances from either the east or west end of hall C using maps of the area. Downwind distances were measured on maps from the downwind edge of hall C.

4.1 Investigation of the wake north of hall C

Six tracer studies were conducted during conditions with winds from south when the wake downwind of the hall formed on the north edge of the aluminium factory. The release point and typical sampling points for Tests 1-6 are shown in Figure 5. The wind direction during these tests was generally from south with speeds between 1 and 3 m/s. Conditions were usually cloudy with some light precipitation. Atmospheric stability conditions ranged from neutral to unstable.

The tracer flow pattern was similar in each of the six tests. The tracer was observed immediately after the start of the release along the outside of hall C close to the leeward intake

Table 2: Summary of meteorological observations.

DATE	TEST	TIME	DATA COLLECTED NEAR HALL C[1]		DATA FROM 10m MAST[2]		DATA FROM 25m MAST[3]		Temp. (°C)	ΔT °C/15m	Stability
			Wind velocity (m/s)	Wind direction (deg)	Wind veloc. (m/s)	Wind direct. (deg)	Wind veloc. (m/s)	Wind direct. (deg)			
10.4.78	1	1430-1450	1-3	S	1.7	210	1.9	180	2.5	-.56	Unstable
11.4.78	2	1230-1305	2-4	S	3.1	220	6.5	190	2.3	-.31	"
11.4.78	3	1345-1405	2-4	S	3.2	220	7.0	190	2.3	-.30	Neutral
11.4.78	4	1445-1505	2-4	S	3.5	220	7.1	180	2.2	-.15	Neutral
12.4.78	5	1215-1235	2	S-SE	2.2	200	6.1	200	1.3	-.32	Unstable
12.4.78	6	1330-1350	2	S-SE	1.5	210	2.6	190	2.2	-.81	Unstable
13.4.78	7	0830-0850	1-2	N	1.0	60	1.4	30	0.1	-.19	Neutral
14.4.78	8	0830-0850	0.5-1.5	N	1.1	60	1.8	40	0.4	.06	Slightly stable
14.4.78	9	1045-1115	-	-	0.6	110	1.2	190	4.0	-.60	Unstable

1 DATA COLLECTED AT VARIOUS POINTS AROUND HALL C USING A HAND-HELD ANEMOMETER AND SOAP BUBBLES.

2 HOURLY AVERAGED DATA COLLECTED AT A 10m MAST 400m NORTHEAST OF HALL C.

3 DATA AVERAGED OVER THE SF_6 RELEASE PERIOD COLLECTED AT A 25m MAST 200m SOUTHEAST OF HALL C.

vents. SF_6 was found west of the release point along 100 m to 150 m of the leeward side of the hall as indicated by the data in the upper graph in Figures 6, 7, and 8. This transport to the west along the hall occurred for all release heights. The instantaneous and 15-minute average profiles of SF_6 given in the upper portion of the figures illustrate that SF_6 observed close to the hall was displaced more to the west of the release, than the plume observed further from the hall.
The maximum instantaneous concentrations observed by the leeward side of the hall ranged from 144 ppt to 2323 ppt. The range of maximum instantaneous concentrations observed during walking traverses 50 m north of hall C was 508 ppt to 2345 ppt. Typical data from these traverses are shown in the center graph of Figures 6, 7, and 8. The maximum values observed in 15-minute average samples collected 23 m and 55 m north of hall C ranged from 168 ppt to 1068 ppt and from 119 ppt to 1015 ppt, respectively. At a distance 200 m north of the edge of hall C, maximum instantaneous concentrations ranged from 152 ppt to 987 ppt. Typical data from these automobile traverses are shown in the lower portion of Figures 6,7, and 8. The widths of the plumes observed along Riksvei 13 ranged from 150 to 300 m.

The appearance of SF_6 at the leeward inlet vents of the building explains the measurement of significant SF_6 concentrations inside hall C and in the exhaust gas at the roof. Figures 9 and 10 show data typical of the patterns observed in every test. The tracer appeared inside the hall and in the exhaust gases at the roof within 5 to 7 minutes after the start of the release. Concentrations reached an apparent steady state during the release and then decreased after the release was stopped. The time for the concentration to decrease by 1/e, known as the characteristic concentration decay time (τ_e), was between 3 and 5 minutes in every test. For a perfectly well-mixed building, this characteristic time is also defined by $\tau=V/Q$ where V is the building volume and Q is the total air flow rate. For hall C, the value of Q ($=2.15 \cdot 10^6$ m^3/hr) was obtained from air flow rate data measured during the summer 1975. The value of V ($=148\ 000$ m^3) was obtained from drawings of hall C. The value of τ, thus, equals 4 minutes. Since τ_e also equals 4 minutes, the tracer data suggest that the hall is relatively well-mixed.

4.2 Investigation of the wake south of hall C

Test 7 and 8 were conducted during conditions with winds from north when the wake formed south of the hall. The locations of the release point and typical sampling points are shown in Figure 11. SF_6 was released from 2.5 m above the roof during Test 7 and from 11 m above the roof during Test 8. Wind conditions were similar during these tests, but a snowfall occurred during Test 7 while the sky was clear during Test 8. The wind speed was approximately 1 m/s. Atmospheric conditions were neutral during Test 7 and slightly stable during Test 8.

The tracer flow patterns observed during both tests were similar to those observed during Tests 1-6. However, as the data in Figures 12 and 13 indicate, maximum concentrations were an order of magnitude greater in Tests 7 and 8 than in Tests 1-6. The maximum instantaneous concentrations observed 2 m, 50 m, and 130 m south of hall C ranged from 12544 ppt to 12725 ppt, from 17015 ppt to 40000 ppt, and from 1058 ppt to 1544 ppt, respectively. The maximum values observed in 15-minute average samples collected 2 m south of the hall during Tests 7 and 8 were 4574 ppt and 1754 ppt, respectively. Maximum 15-minute average concentrations found 50 m south of the hall during the two tests were 5004 ppt and 3360 ppt, respectively.

The tracer data obtained during tests 7 and 8 show that recirculation of the plume back to the building does occur. Peak instantaneous concentrations observed 50 m from the hall were significantly higher than peak instantaneous concentrations found next to the hall. Furthermore, the wind direction on the roof of hall C was from north while the wind direction at ground level in the sampling area was from south. The vertical tracer concentration profile, given in Figure 13, shows a ground level maximum which indicates that the plume had been transported to the ground before reaching 130 m south of the hall. These observations suggest that the tracer plume became entrained in the wake where at least a portion of it was swept back to hall C, possibly in a pattern similar to those shown in Figures 2 and 3.

Personnel at the Høyanger plant have indicated that the ventilation of hall C is worse during conditions with northerly winds than during conditions with southerly winds. The tracer data indicate that exhaust gases infiltrate hall C more during northerly winds than during southerly winds. Differences in the degree of infiltration may be a reason for the observed differences in ventilation. Concentrations of SF_6 found inside the hall and in the exhaust gas were much greater in Tests 7 and 8 than in previous tests. Data from Test 7 are shown in Figure 14. The steady state instantaneous SF_6 concentration in the hall air was 2442 ppt during Test 7 and 2196 ppt during Test 8. The characteristic concentration decay time equaled 5 minutes for both tests. Data from walking traverses taken inside the hall, shown in Figure 15, together with data from 15-min samples taken outside the hall, indicate that SF_6 entered the hall in a pattern similar to that observed immediately outside. SF_6 was found inside the hall over a length of approximately 120 m; the horizontal tracer profile was centered slightly west of the release point.

4.3 Investigation of the air flow within hall C

The purpose of test 9 was to study the flow pattern associated with fresh air entering hall C from inlet vents on the south side. The locations of the release point and sampling points are shown in Figure 16. SF_6 was released inside the hall at an inlet vent 1 m above the floor. Winds during the test were from south at 1-2 m/s.

The highest floor level concentrations were found in instantaneous samples collected in the center of the hall opposite the release point and in 15-minute average samples collected west of the release point. These data are shown in Figure 17. Although most of the tracer was apparently carried upward to the roof exhaust, a portion of the tracer was transported west along the hall. The average instantaneous concentration observed at the roof was 16058 ppt, while the average concentrations observed at the three floor-level points were, from east to west, 15 ppt, 1919 ppt, and 63 ppt. Data from the roof sampling point are shown in the lower portion of Figure 17. Concentrations observed in 15-minute average samples 2 m and 10 m above the floor indicated that the amount of spreading of SF_6 along the length of the hall increased sharply with increasing height above the floor.

5 THE FLOW OF EXHAUST GAS DOWNWIND OF HALL C

Significant levels of SF_6 were observed immediately outside the hall, inside the hall, and in the exhaust air at the roof during each of the outside tests. The average maximum instantaneous concentrations observed at each of the sampling locations are shown in Figure 18. In 5 of the 8 tests, the maximum value was observed 50 m downwind of the hall. These data suggest that the SF_6 plume was brought to the ground approximately 50 m from the hall. A portion of it was recirculated to the hall where it entered the fresh air supply into the hall. The remainder of the plume was carried away from the hall in the direction of the mean wind. Table 3 gives the ratios of the various maximum concentrations. On the average, the maximum concentration observed immediately outside the hall was 1/2 of that observed 50 m from the hall. The maximum concentration inside the hall was approximately 1/3 of that observed just outside the hall. Finally, the maximum concentration found in the exhaust gas was approximately 7/10 of that measured in the hall.

Table 3: Ratios of average maximum instantaneous SF_6 concentrations.

TEST	C_2/C_1 *	C_3/C_2 *	C_4/C_3 *
1	1.34	0.31	-
2	0.55	0.61	0.14
3	1.75	0.31	0.81
4	0.52	0.38	0.67
5	0.66	0.30	0.69
6	0.21	0.30	0.94
7	1.13	0.28	1.00
8	0.52	0.23	0.68
AVE	0.52	0.34	0.70

* Locations of sampling positions are shown in Figure 18.

The path of the plume during Tests 1-6 is shown in the top portion of Figure 19 where the locations of the observed SF_6 maximum concentrations are mapped. This map indicates that the plume curved to the northeast before reaching Riksvei 13, 200 m from hall C. Figure 19 also illustrates the marked displacement of SF_6 to the west which was observed along the side of the hall. The lower portion of Figure 19 shows the probable air stream patterns and the average maximum instantaneous concentrations from Tests 2-6.

Similar data are presented in Figure 20 for Tests 7 and 8. During these tests, the plume was transported slightly towards the southwest. The SF_6 observed next to the hall was not displaced to the side of the release as in Tests 1-6.

6 THE EFFECT OF RELEASE HEIGHT UPON THE FLOW AND ENTRAINMENT OF EXHAUST GASES

The appearance of SF_6 near the leeward inlet vents and inside the hall during every test indicates that tracer was entrained within the building wake for release heights ranging from 1 m to 11 m above the roof (2 m below the roof exhaust duct to 8 m above the exhaust duct). It should be recognized that the 3 m high roof exhaust duct undoubtably has a significant effect upon the structure and dimensions of the building wake. Furthermore, the SF_6 released at 2.5 m above the roof was mixed immediately with the warm exhaust gases. Tracer released at 6 m and 11 m above the roof became mixed with the exhaust gases at some point downwind of the release points. It is very difficult to determine how much the existing release conditions effected the tracer flow patterns. However, it appears that polluted air released at the heights of the tracer releases would also become entrained in the wake of the hall.

The amount of entrainment and subsequent infiltration of polluted air which may occur under existing conditions can be estimated from the tracer data. If it is assumed that all of the tracer observed immediately outside the hall near the inlet vents was drawn into the hall, then the percentage of tracer released which infiltrated the hall will be:

$$\%\ \text{INFILTRATED} = \frac{\overline{C}_{SF_6}}{Q_{SF_6}/\frac{1}{2}\,Q_{AIR}} \cdot 100 \qquad (1)$$

where

$$\overline{C}_{SF_6} = \frac{1}{L}\int_0^L C_{SF_6}(y)\,dy \qquad (2)$$

and where $C_{SF_6}(y)$ is the instantaneous concentration observed during walking traverses along the side of the hall, L is the total length of the hall, Q_{SF_6} is the SF_6 release rate, and ½ Q_{AIR} is one half the total air flow rate through the hall. The value of $\overline{C}_{SF_6}$ represents the average SF_6 concentration which would occur within the hall if the tracer observed near the inlet vents were uniformally mixed over the length of the hall. The maximum % INFILTRATED observed during each test is listed in Table 4. In no case was the amount of infiltration greater than 11%. During tests with winds from south, the amount of infiltration appeared to be independent of the release height. During the two tests with winds from north, the amount of infiltration for a 2.5 m release height was approximately twice that observed for an 11 m release heights. The amount of infiltration was much greater during wind from north than during winds from souths. The large difference in topography on the north and south side of the hall may be the cause for the difference in % INFILTRATED.

Table 4: Percentage of tracer which infiltrated hall C.

TEST	RELEASE HEIGHT (m)	Q_{SF_6} (cm^3/min)	Q_{AIR} (cm^3/min)	$\overline{C}_{SF_6}$ p/p	% INFILTRATED*
1	1	265	$3.58 \cdot 10^{10}$	$1.26 \cdot 10^{-10}$	1
2	11	480	$3.58 \cdot 10^{10}$	$2.04 \cdot 10^{-10}$	1
3	6	480	$3.58 \cdot 10^{10}$	$5.69 \cdot 10^{-10}$	2
4	2.5	480	$3.58 \cdot 10^{10}$	$1.44 \cdot 10^{-10}$	1
5	11	480	$3.58 \cdot 10^{10}$	$3.25 \cdot 10^{-10}$	1
6	2.5	480	$3.58 \cdot 10^{10}$	$2.0 \cdot 10^{-11}$	0.1
7	2.5	480	$3.58 \cdot 10^{10}$	$2.90 \cdot 10^{-9}$	11
8	11	480	$3.58 \cdot 10^{10}$	$1.45 \cdot 10^{-9}$	5

The extent of reentry of pollutants into the hall can be estimated from the results given in Table 4. If the pollutants behave as the tracer gas, the average concentration of pollutant ($\bar{C}_p$) observed inside the hall resulting from reentry will be

$$\bar{C}_p = \frac{\%\ \text{INFILT.}}{100} \cdot \frac{Q_p}{\frac{1}{2}\ Q_{AIR}} \qquad (3)$$

where Q_p is the total pollutant emission rate, Q_{AIR} is the total air flow rate, and the range of % INFILT. is taken from the tracer data in Table 4. In the case of fluoride emissions, data collected during 1975 yield Q_F = 6.6 kg/hr. The corresponding average instantaneous concentration of fluorides in the fresh air supply to the hall ranges from 123 $\mu g/m^3$ for 2% infiltration to 675 $\mu g/m^3$ for 11% infiltration.

Maximum concentrations from the 15-minute average samplers for Tests 1-6 are shown in Figure 21 as a function of release height. These data indicate that for increasing release heights, concentrations increased and, thus, dispersion apparently decreased. This pattern is reflected in the data collected inside the hall, also illustrated in Figure 21. Evidently, greater mixing of the tracer occurred for releases from the exhaust duct than for releases above the exhaust duct. This pattern is probably caused by the turbulence associated with the presence of the exhaust duct. It is difficult to predict if the same pattern would be observed if the exhaust duct were absent. Results from Tests 7 and 8, given in Figure 21, indicate that this pattern also occurred in data collected 50 m south of the hall. However, concentrations observed near the hall and inside the hall during these two tests yield an opposite pattern. The tracer plume was apparently recirculated to the hall to a greater extent during the lower release. These data suggest that, during northerly winds, increasing the release height can cause lower concentrations to occur inside the hall.

7 THE EFFECT OF CHIMNEYS UPON RELEASE HEIGHT

As previously noted, Hyber and Snyder found from wind tunnel tests that stacks higher than 1.5 H_b were necessary to avoid plume entrainment in the wake of a building. To the extent that their results are applicable to hall C, a height greater than approximately 42 m above the ground or 15 m above the roof would be required. In order to obtain a release height greater than the height of the wake as specified by Huber and Snyder, a series of chimneys located on the roof of the hall would be required. The effect of chimneys upon the effective release height would be twofold: to raise the actual release point as high as possible within the wake and to provide an exhaust velocity sufficient to raise the exhaust gases above the wake. For example, channeling the hall air ($Q=2.15 \cdot 10^6 m^3/hr$) through 6 chimneys, each 2.5 m in diameter and 10 m high, would increase the exhaust velocity from the existing value of 0.7 m/s to 20 m/s.

Holland's plume rise formula, which is based upon data taken in the free air stream, is given by

$$\Delta H = 1.5 \frac{V_E d}{u} \qquad (4)$$

where V_E is the exhaust velocity, d is the chimney diameter, and u is the mean wind velocity. Buoyancy effects are not included. For u=3 m/s, the resulting plume rise will be 25 m for each chimney. The combination of a 10 m chimney and a plume rise of 25 m should be sufficient to raise the exhaust gases well above the wake of the hall. This increased release height has the added advantage of reducing maximum pollutant concentrations immediately downwind of the hall.

8 CONCLUSIONS AND RECOMMENDATIONS

The results of these tracer experiments should be accepted with the uncertainty associated with their performance during only 5 days of meteorological conditions. It should also be recognized that the tests were conducted using the existing smelter structures. The results may not accurately reflect conditions that will be present after construction of the new hall or after modification of the roof line of Hall C.

In spite of these uncertainties, the tracer data clearly show that entrainment of gases emitted from the roof and subsequent infiltration of exhaust gases into the hall can occur. It appears that while the main body of the plume traveled along the direction of the mean wind, a portion of the gas became entrained in the wake, and was transported back to the hall. The amount of SF_6 which infiltrated the hall was approximately 1% of that released during southerly winds and between 5% and 11% of that released during northerly winds. The amount of infiltration which was observed during southerly winds appeared to be independent of the tracer release height. During northerly winds, the amount of infiltration observed for a 2.5 m release height was twice that observed for an 11 m release height. The dispersion of gases released above the roof exhaust duct was apparently less than that for gases released at the exhaust duct. Higher concentrations were observed short distances from the hall for 11 m release hights than for 2.5 m release heights.

After the new hall A is placed in operation, gases emitted from the upwind hall may reenter the hall through the leeward inlet vents and may also enter the downwind hall through its windward inlet vents. Exhaust gases from both halls may infiltrate the downwind hall from its leeward side. If the exhaust gases from hall A and hall C are both released at a sufficient height, this entrainment and infiltration may be avoided. Wind tunnel data and, indirectly, the tracer data suggest that a sufficient height would be at least 1.5 H_b above the ground or, for hall C, 15 m above the roof. Releasing the exhaust gas through several 10 m high chimneys on the roof of the hall at the air flow rate which currently exists might yield an effective release height much greater than 1.5 H_b.

In the case of hall A, it may be necessary to use 15 m high chimneys in order to eliminate the effects of the different elevations of hall A and hall C. Careful wind tunnel tests using a model of the proposed structures could be used to specify more exactly the necessary release heights. Additional tracer tests, using greater release heights could be used to determine the height of the wake over the existing structures. Results from existing as well as future tracer tests could be used to validate the results of wind tunnel experiments.

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APPENDIX A

FIGURES

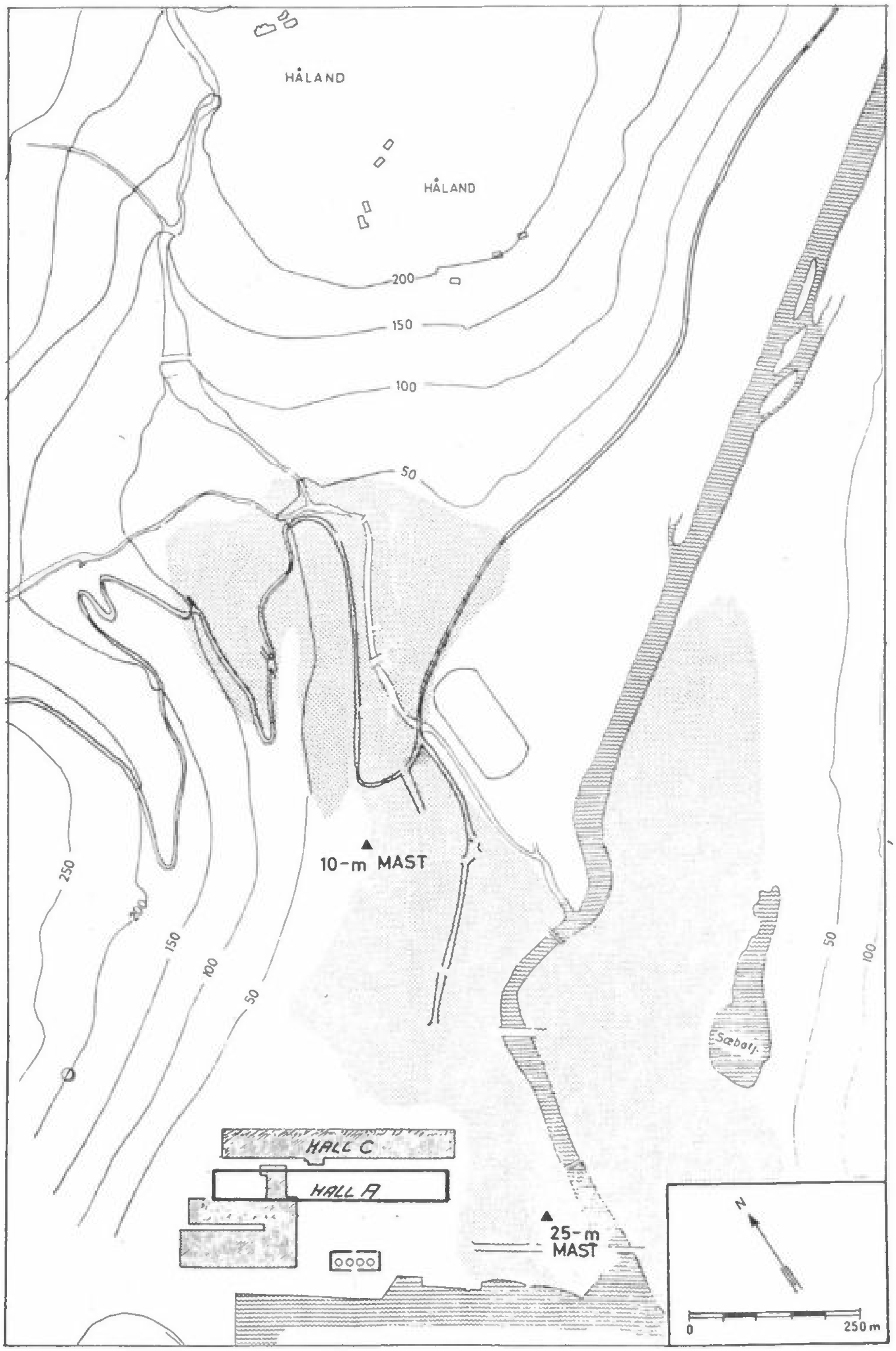


Figure 1: Location of the existing and proposed smelter halls. Meteorological measurement points (▲) are also shown.

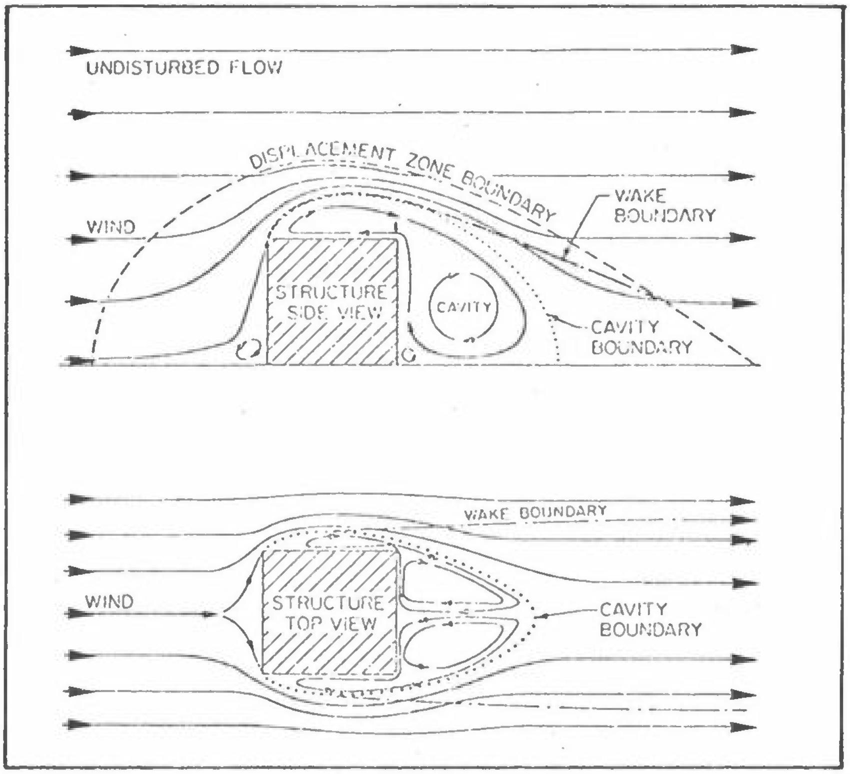


Figure 2: Sketch of the air flow patterns around a building, showing the recirculating cavity region. (Halitsky, 1963).

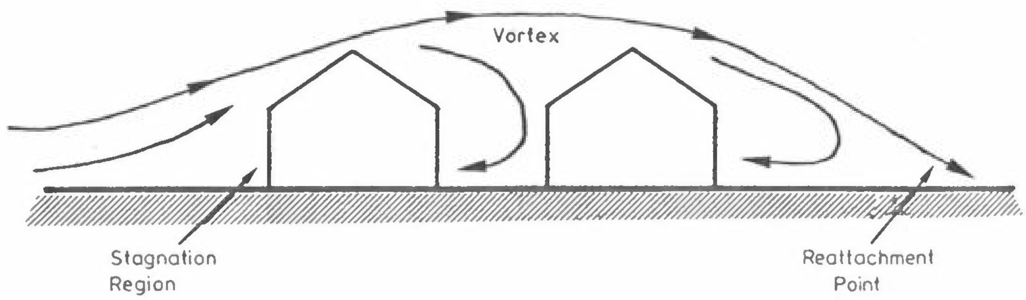


Figure 3a: External flow over potlines (from Obremski et al. (1974)).

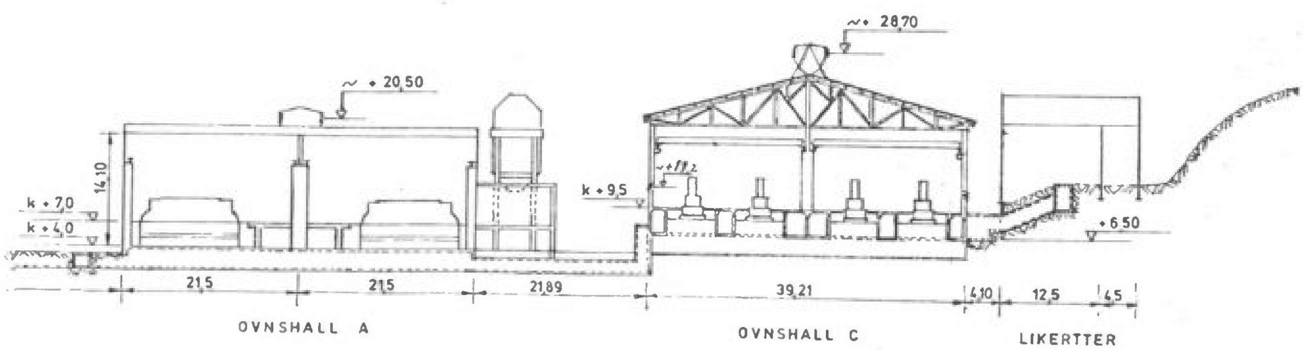


Figure 3b: Cross-section showing location at the proposed hall A and the existing hall C.

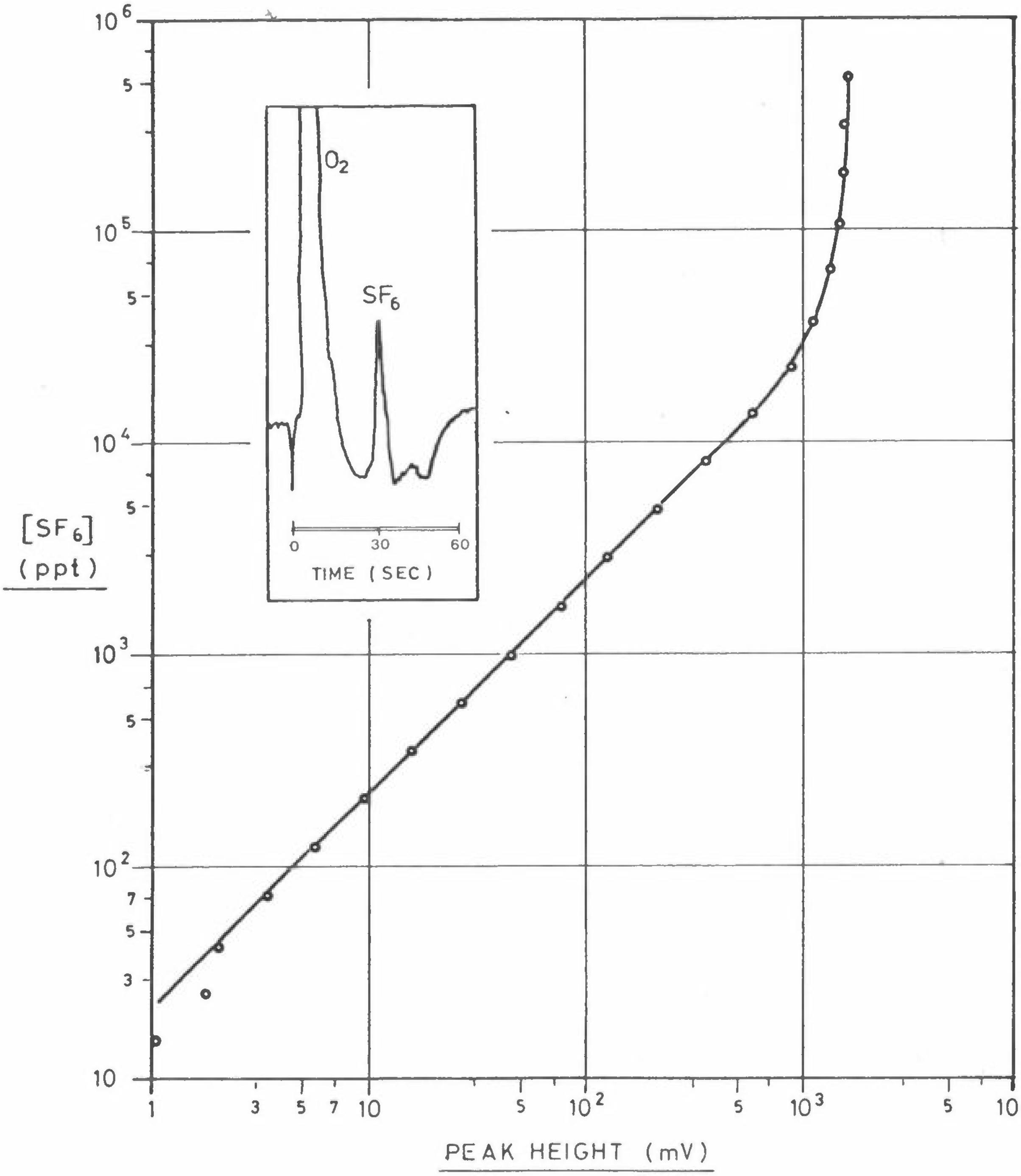


Figure 4: Typical SF_6 calibration curve and typical SF_6 chromatogram, (Inset) (SF_6) = 355 ppt.

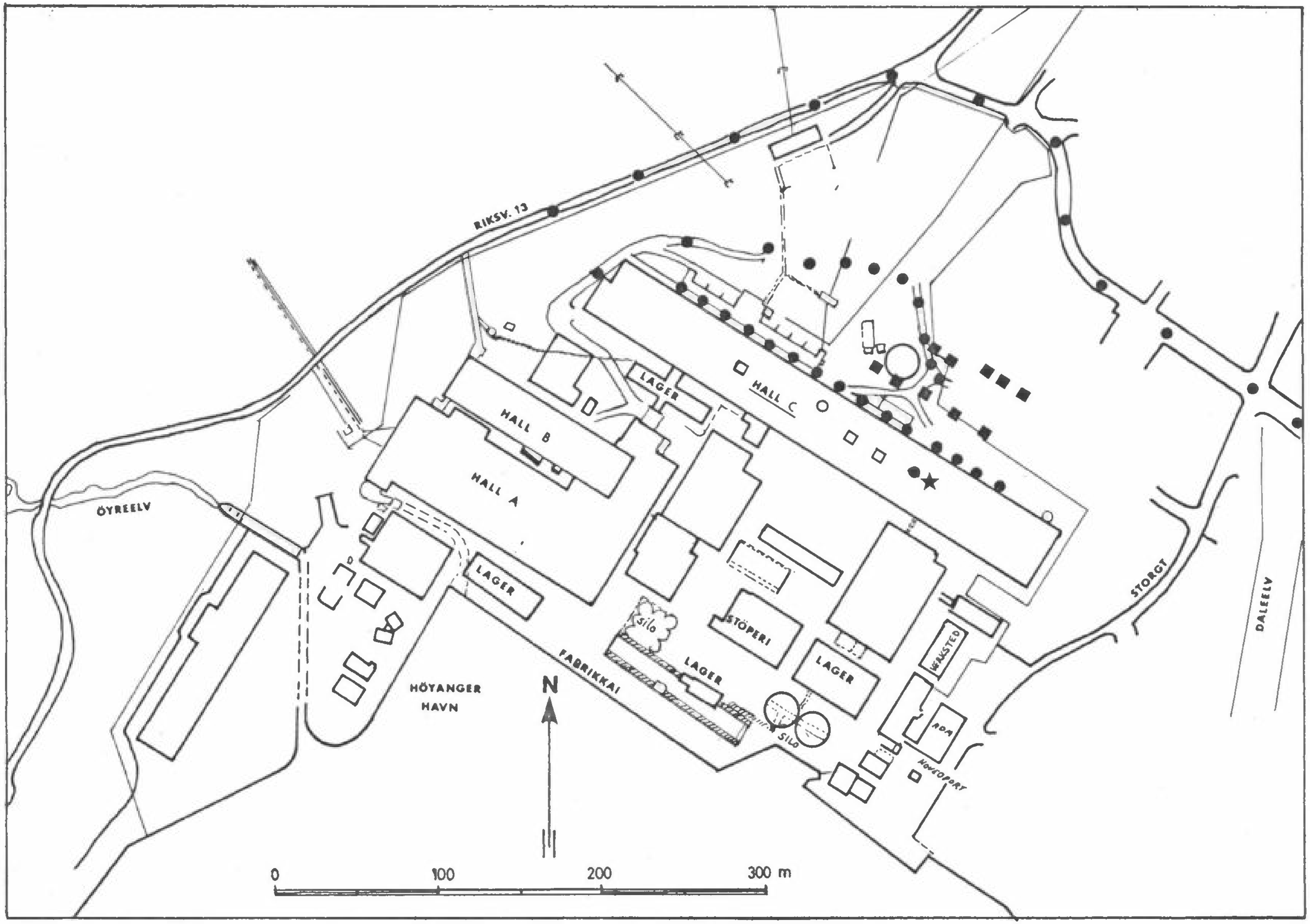


Figure 5: Release point (★) and typical instantaneous (●) and 15-minute average (■) sampling points for tests 1-6. and typical instantaneous (○) and 15-minute average (□) sampling points inside the hall.

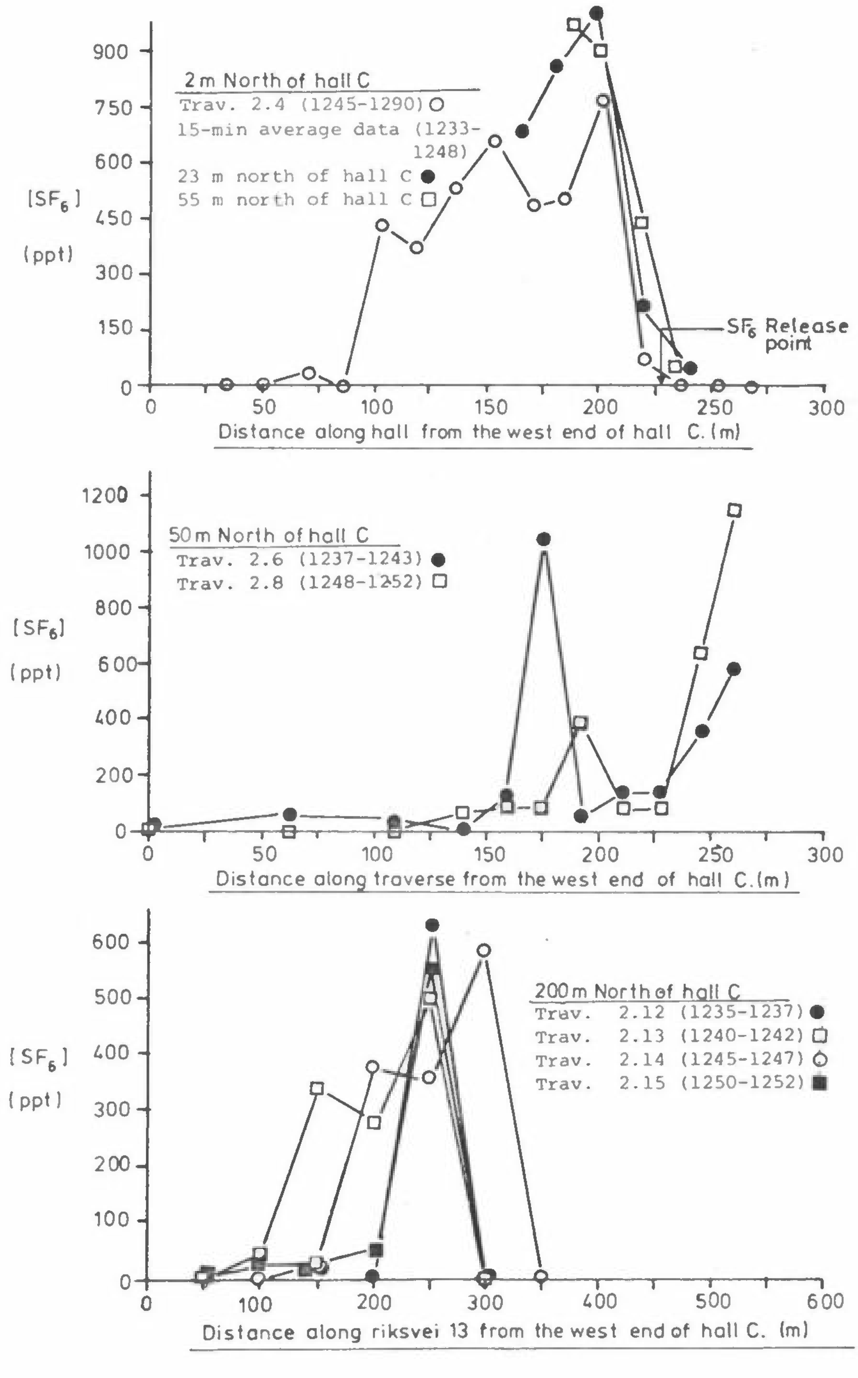


Figure 6: *SF_6 tracer data from test 2. SF_6 was released 11 m above the roof of hall C. Times are shown in parantheses.*

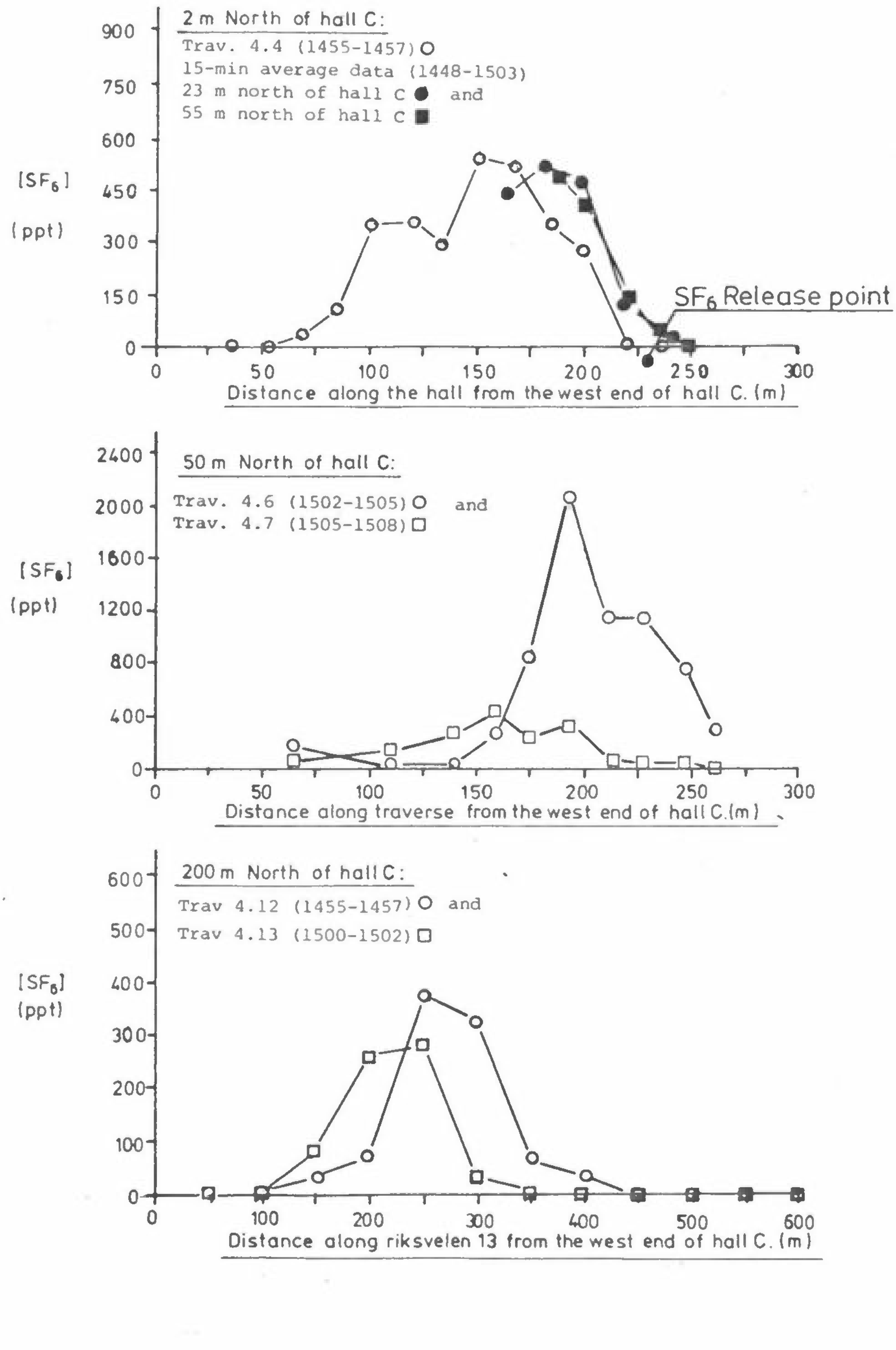


Figure 7: SF_6 tracer data from test 4. SF_6 was released from 2.5 m above the roof of hall C. Times are shown in parentheses.

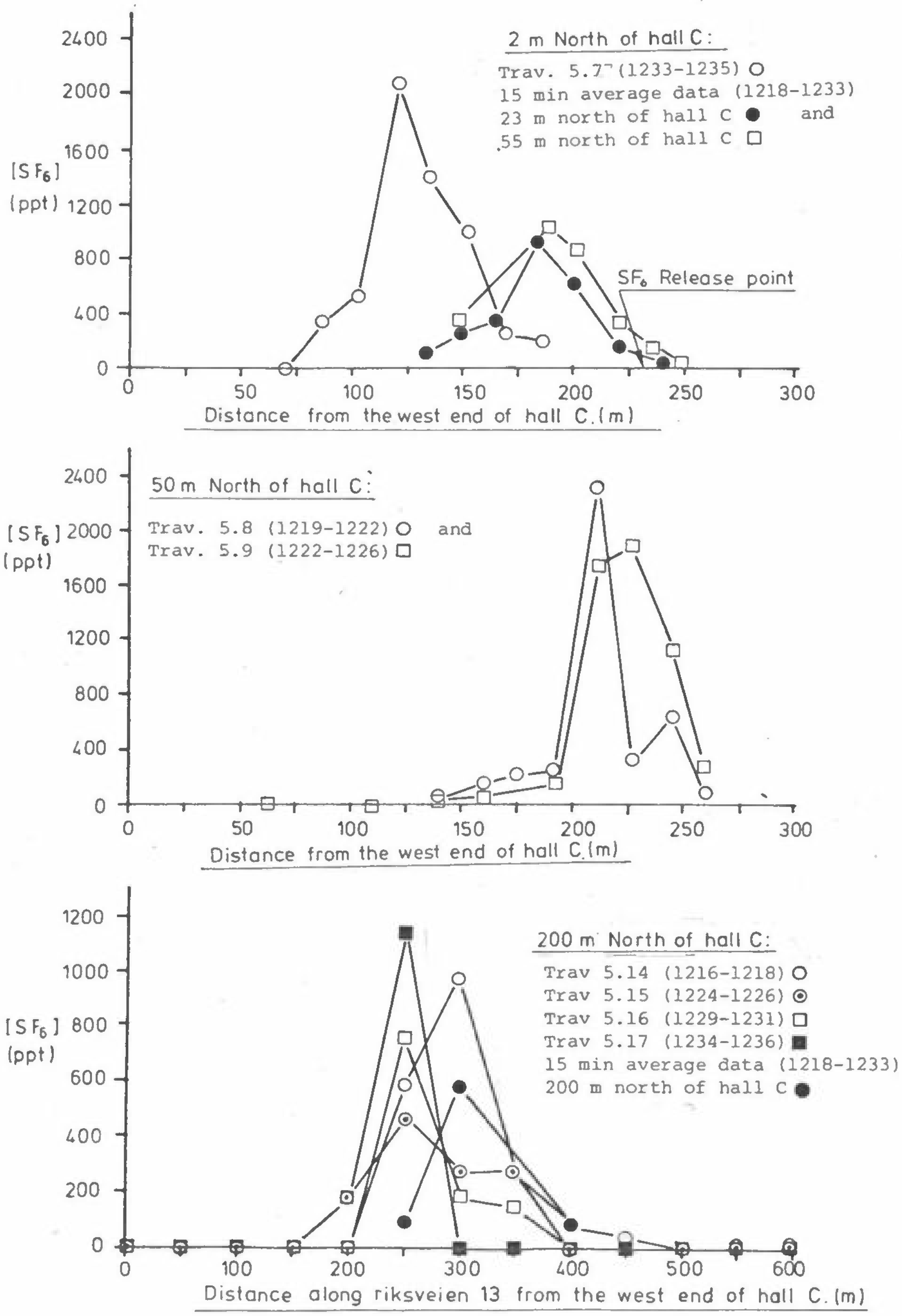
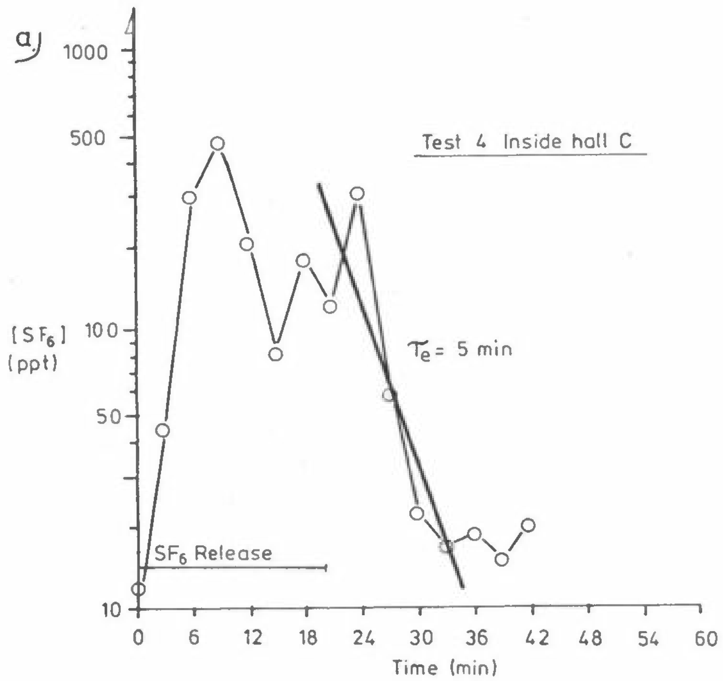


Figure 8: SF_6 tracer data from test 5. SF_6 was released from 11 m above the roof of hall C. Times are shown in parentheses.



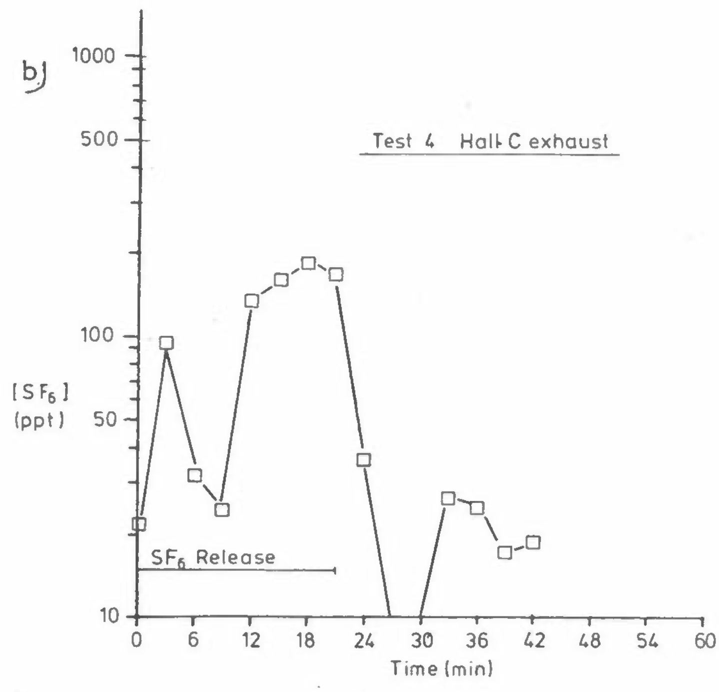


Figure 9 a) Instantaneous SF_6 concentrations collected inside hall C 148 m from the west end of the hall.

b) Instantaneous SF_6 concentrations collected in the exhaust gas at the roof of hall C, 10 m east of the release point, 219 m from the west end of the hall.

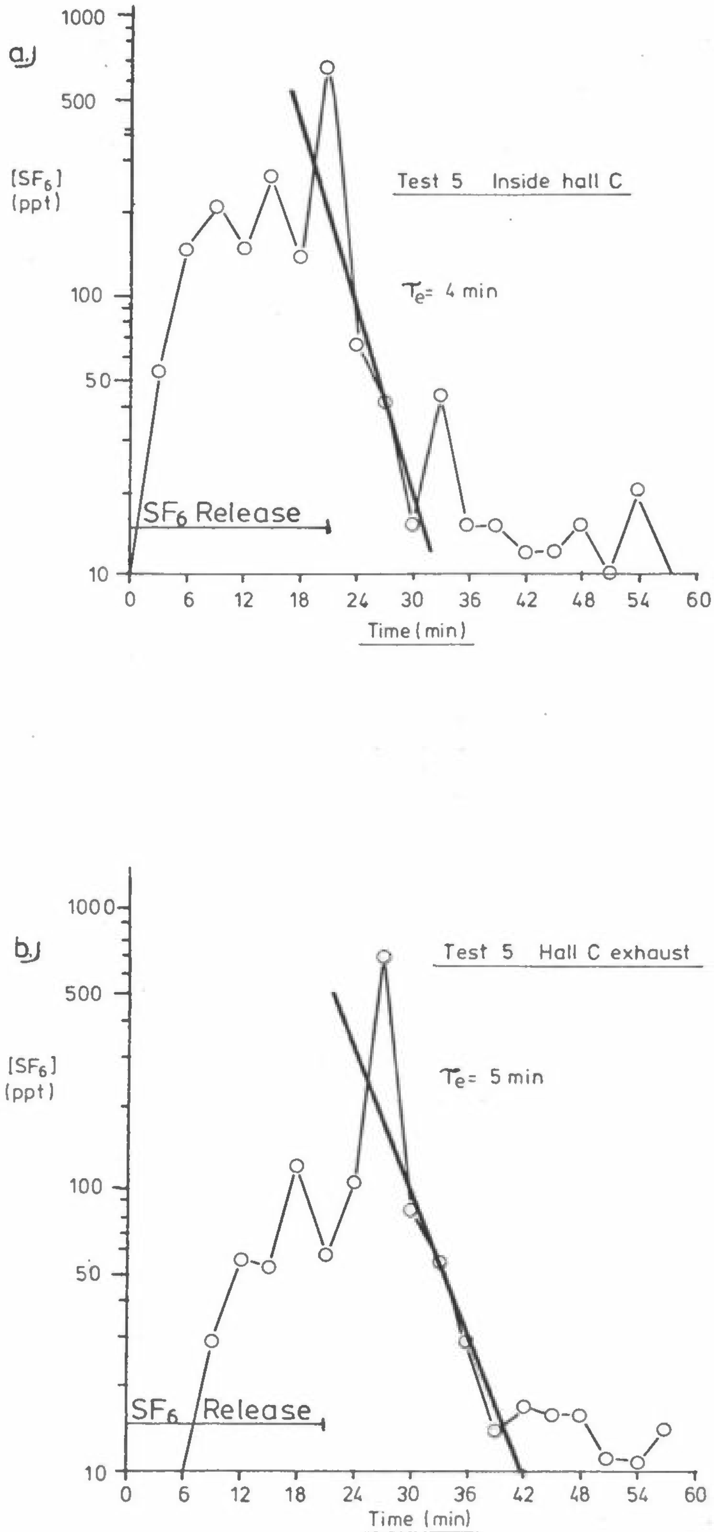


Figure 10 a) Instantaneous SF_6 concentrations collected inside hall C 148 m from the west end of the hall.

b) Instantaneous SF_6 concentrations collected in the exhaust gas at the roof of hall C, 10 m west of the release point, 219 m from the west end of the hall.

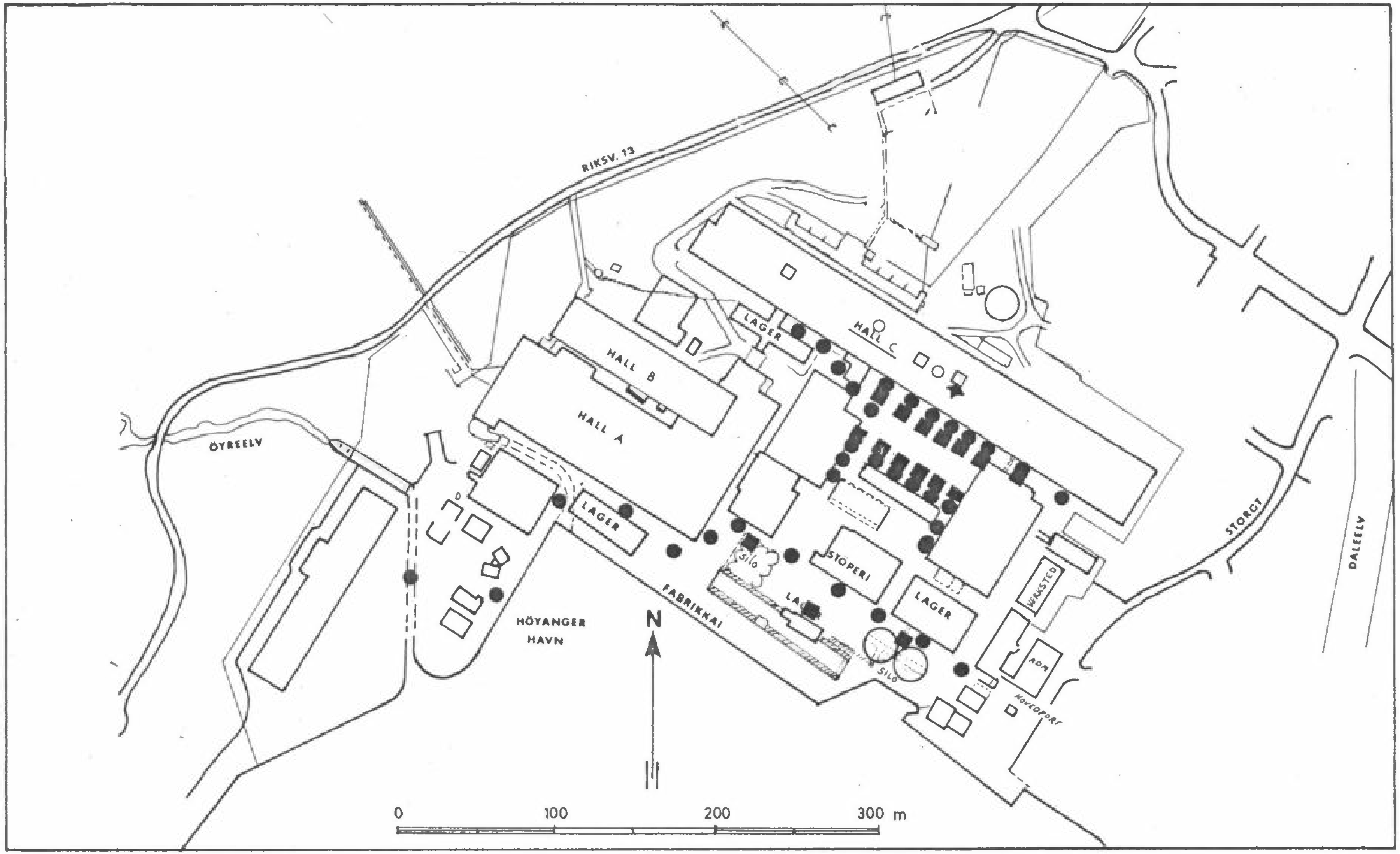


Figure 11: Release point (★) and typical instantaneous (●) and 15 minute average (■) sampling points for test 7 and 8. and typical instantaneous (○) and 15-minute average (□) sampling points inside the hall.

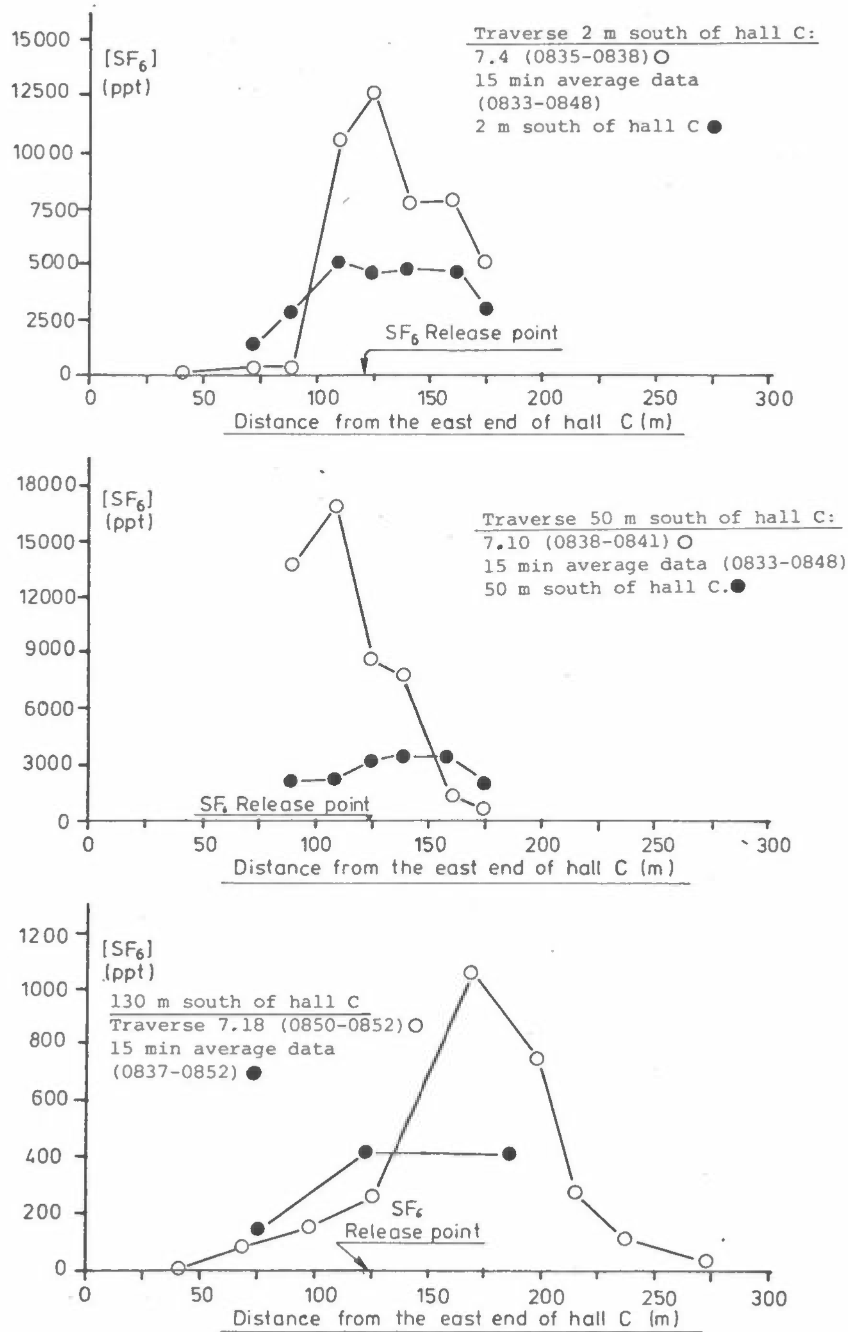


Figure 12: *SF_6 tracer data from test 7. SF_6 was released from 2.5 m above the roof of hall C. Times are shown in parentheses.*

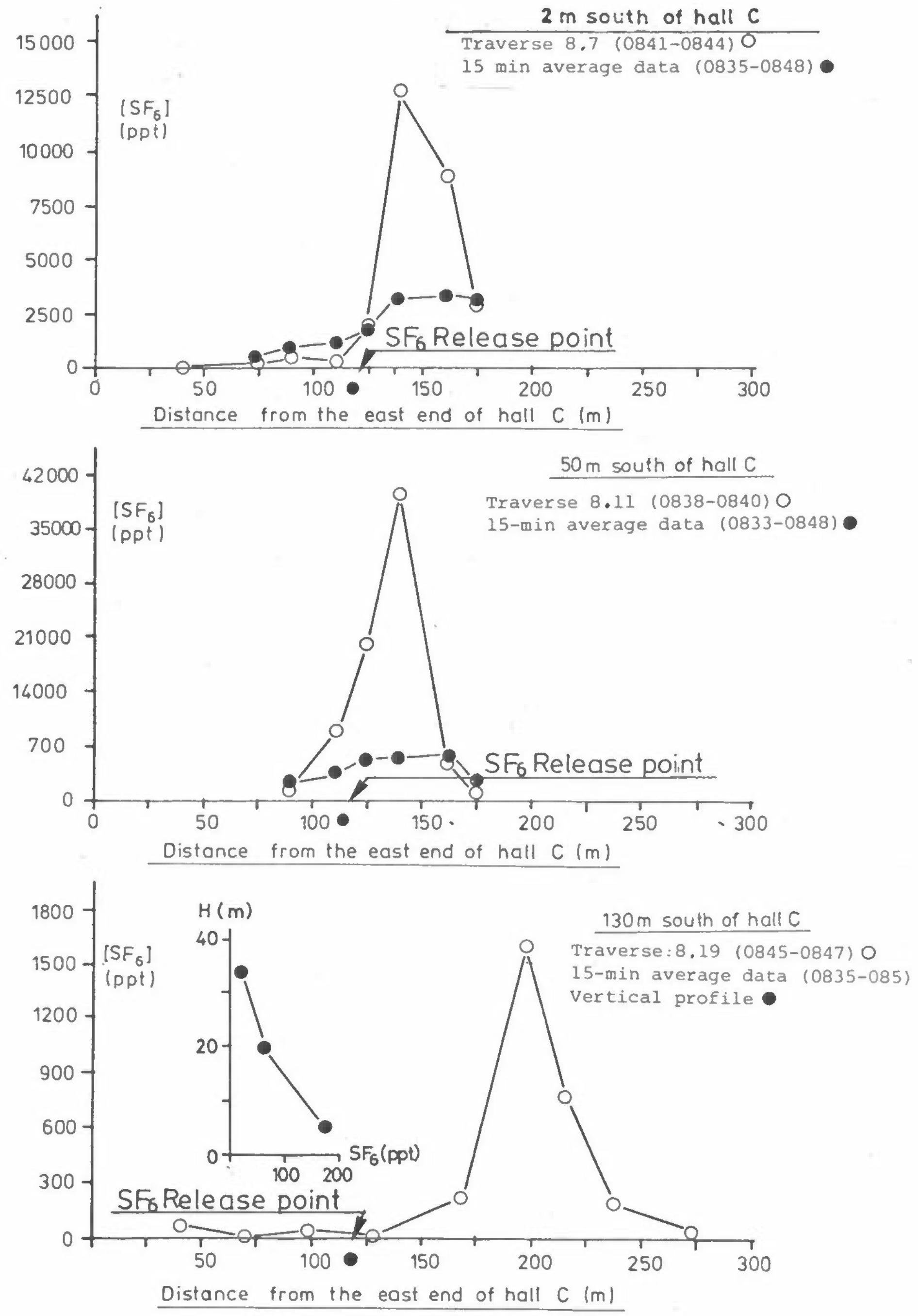


Figure 13: *SF_6 tracer data from test 8. SF_6 was released from 11 m above the roof of hall C. Times are shown in parentheses.*

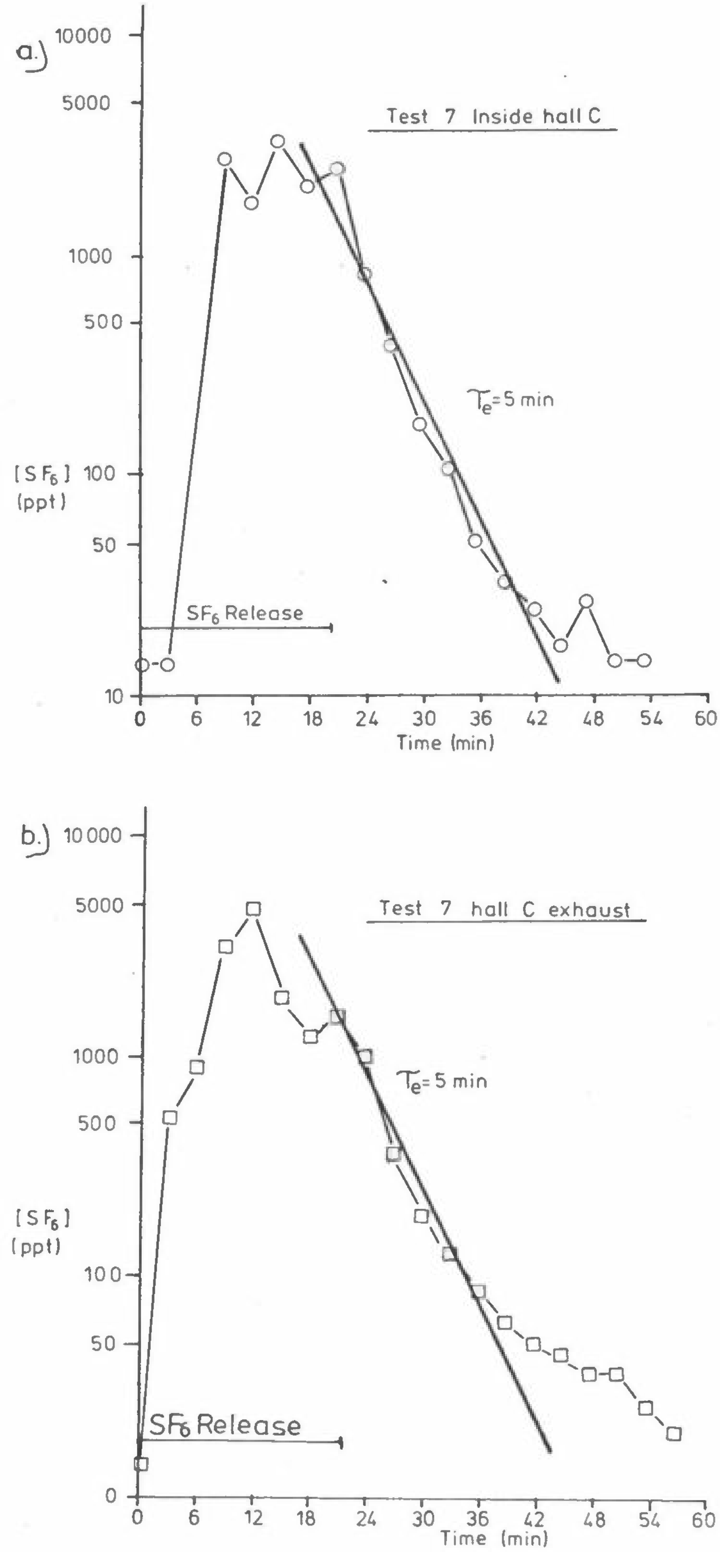


Figure 14: *a) Instantaneous SF_6 concentrations collected inside hall C 173 m from the east end of the hall.*
b) Instantaneous SF_6 concentrations collected in the exhaust gas at the roof of hall C, 10 m west of the release point, 130 m from the east end of hall C.

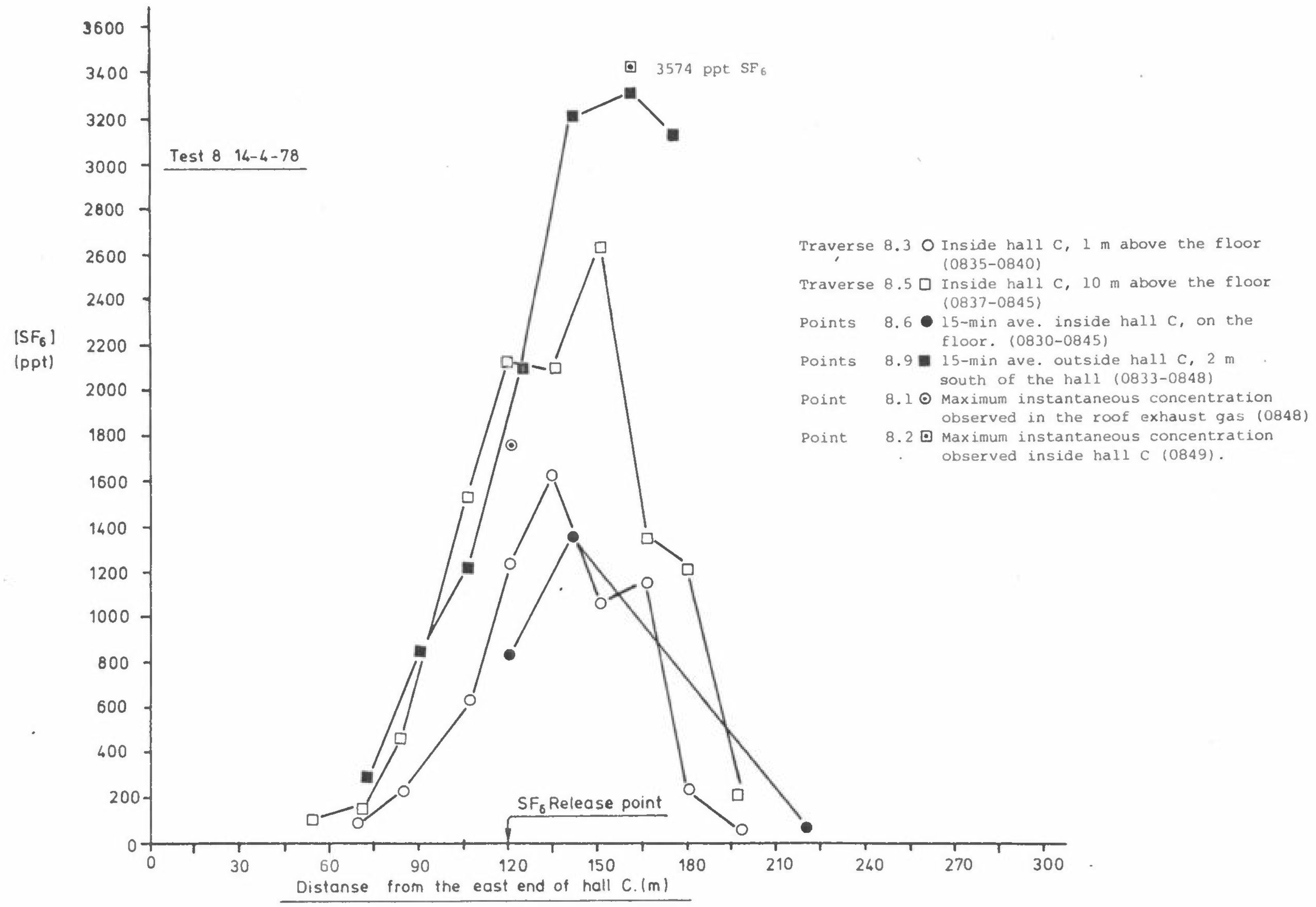


Figure 15: SF_6 tracer data from test 8 collected within and very near hall C. SF_6 was released 11 m above the roof of hall C. Times are shown in parentheses.

HALL C

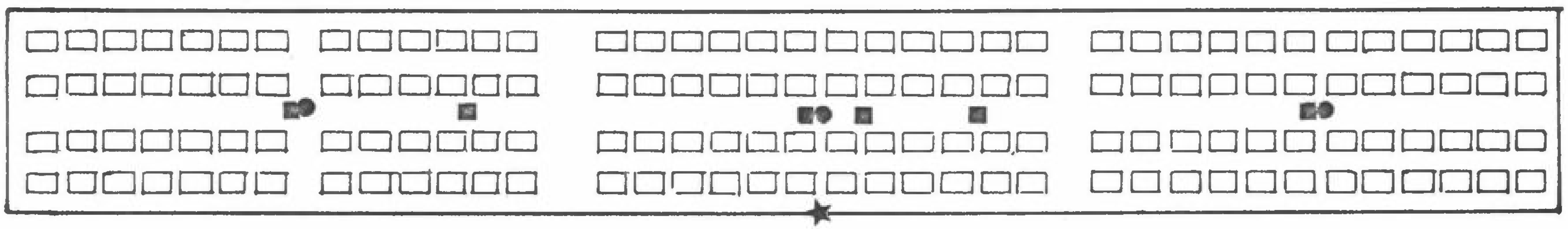
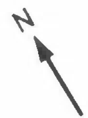
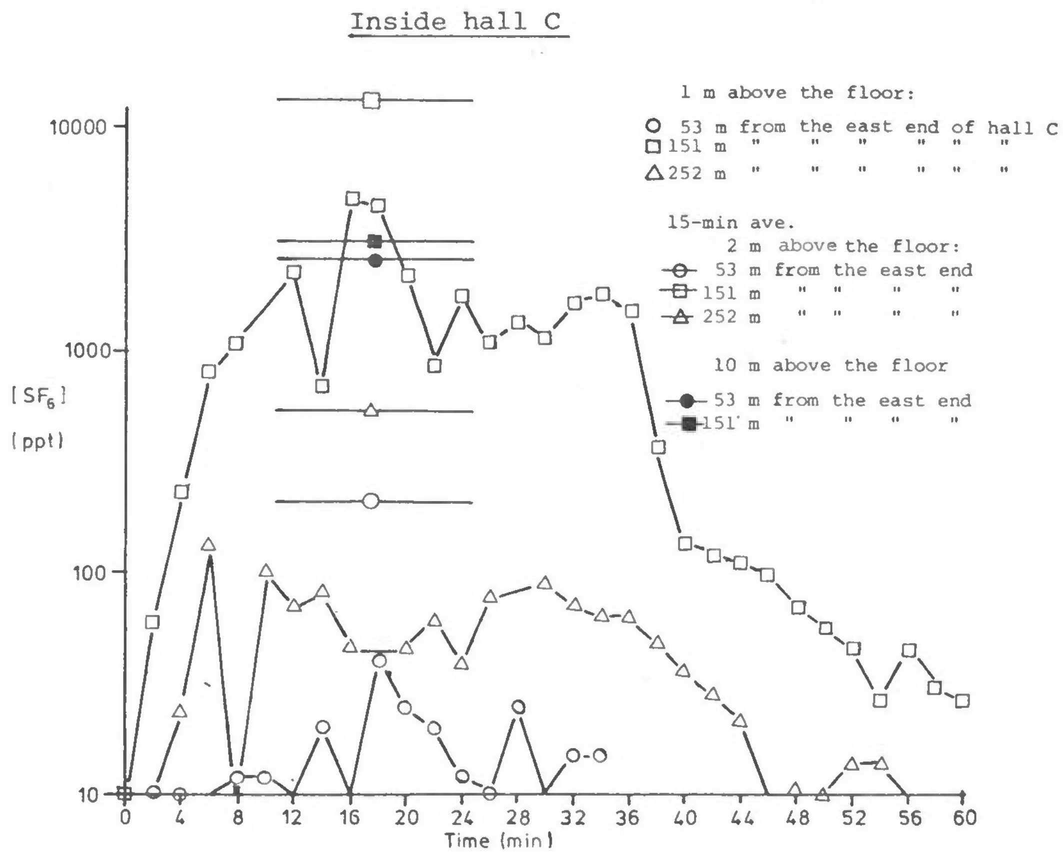


Figure 16: Release point (★)
Instantaneous (●) and
15-minute average (■)
sampling points for
test 9.





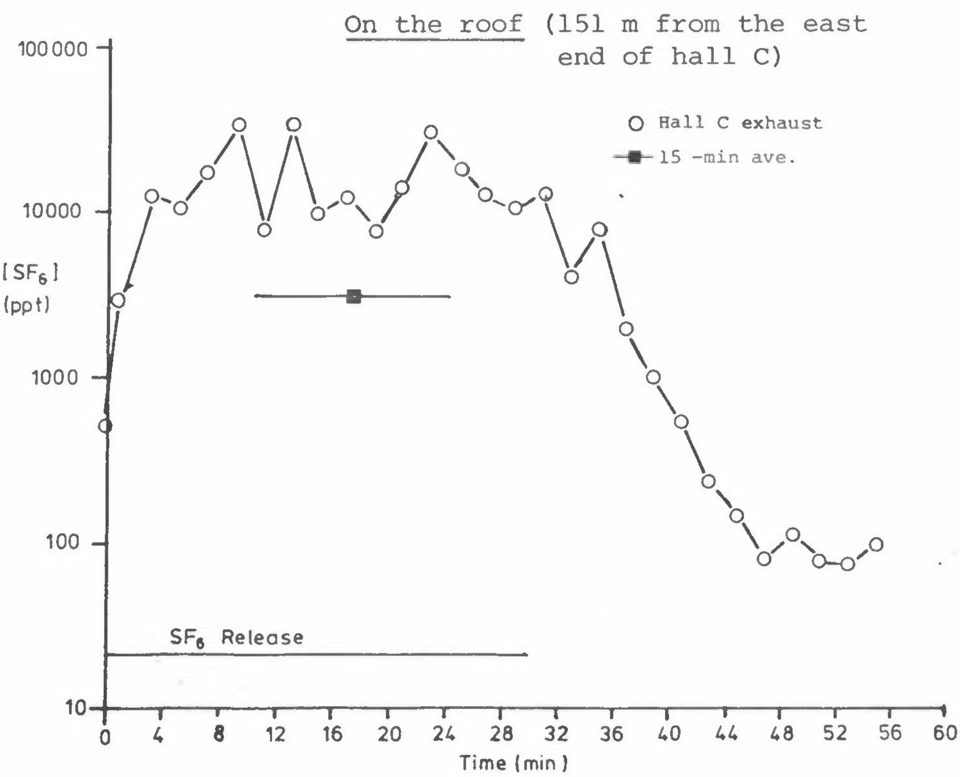


Figure 17: SF_6 instantaneous concentrations and 15-min. average concentrations observed during test 9.

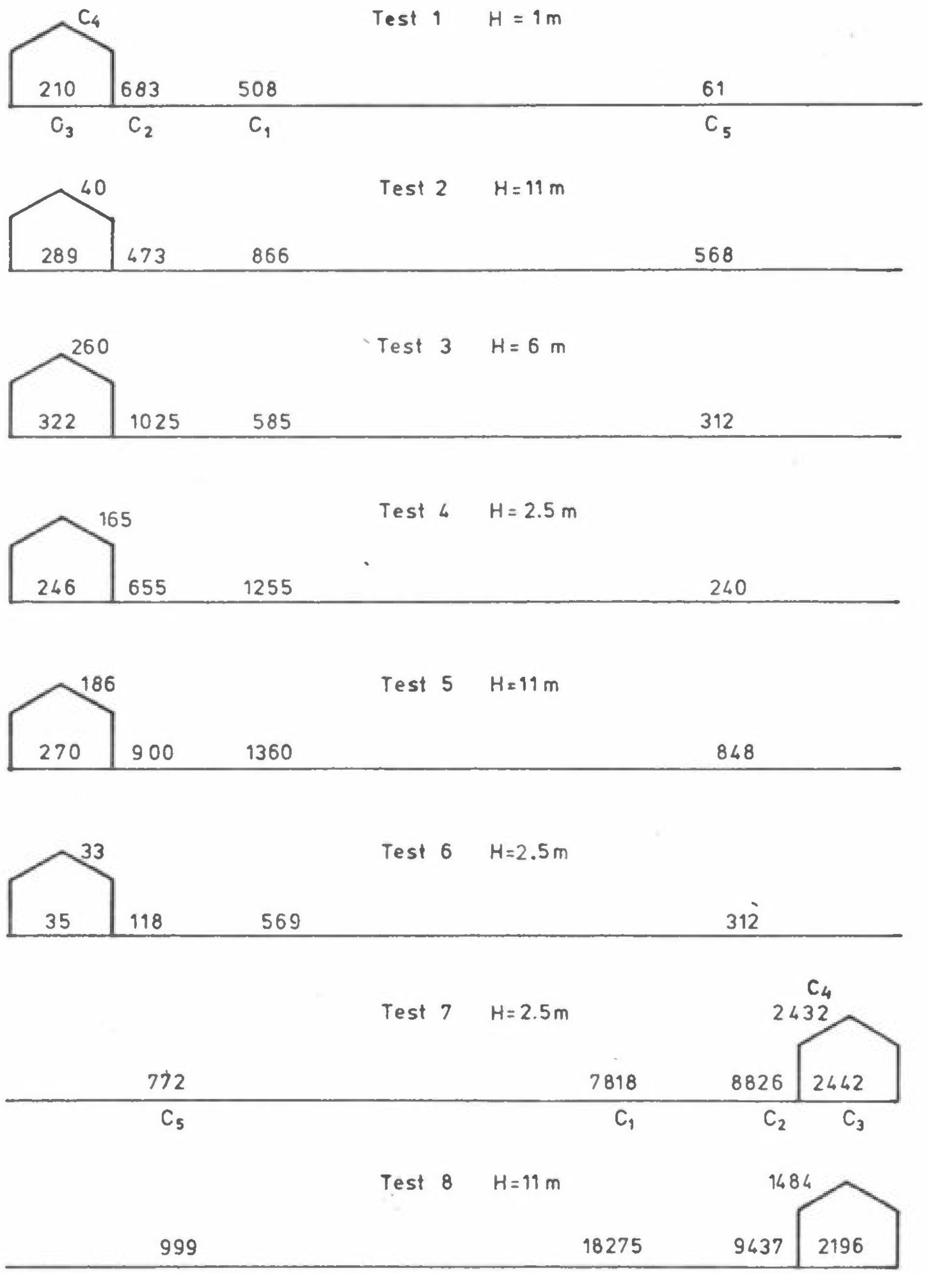


Figure 18: Average maximum instantaneous SF_6 concentrations observed at each sampling location.

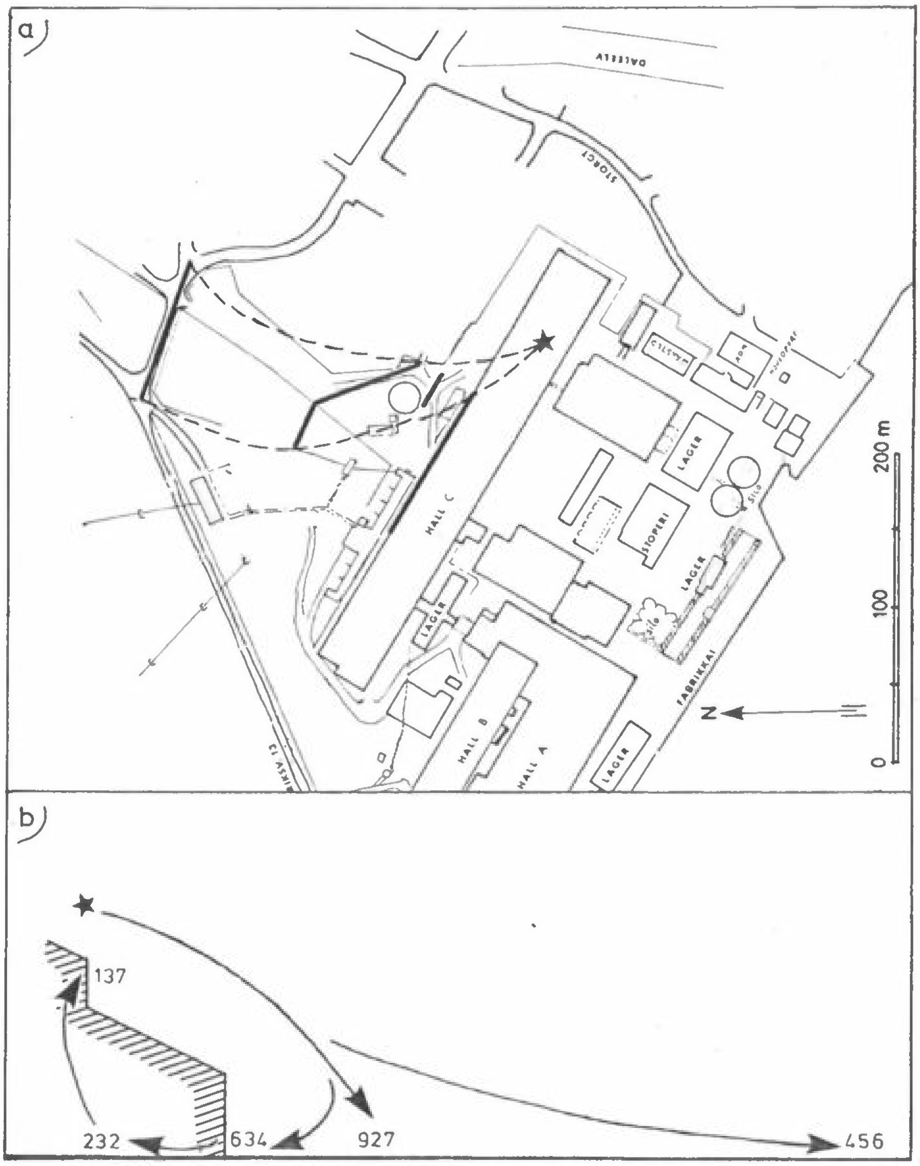


Figure 19 a) Map shows locations of observed maximum SF_6 concentrations from tests 1-6.
b) Cross-section shows probable air steamlines and the average maximum instantaneous SF_6 concentration at each sampling location from tests 2-6.

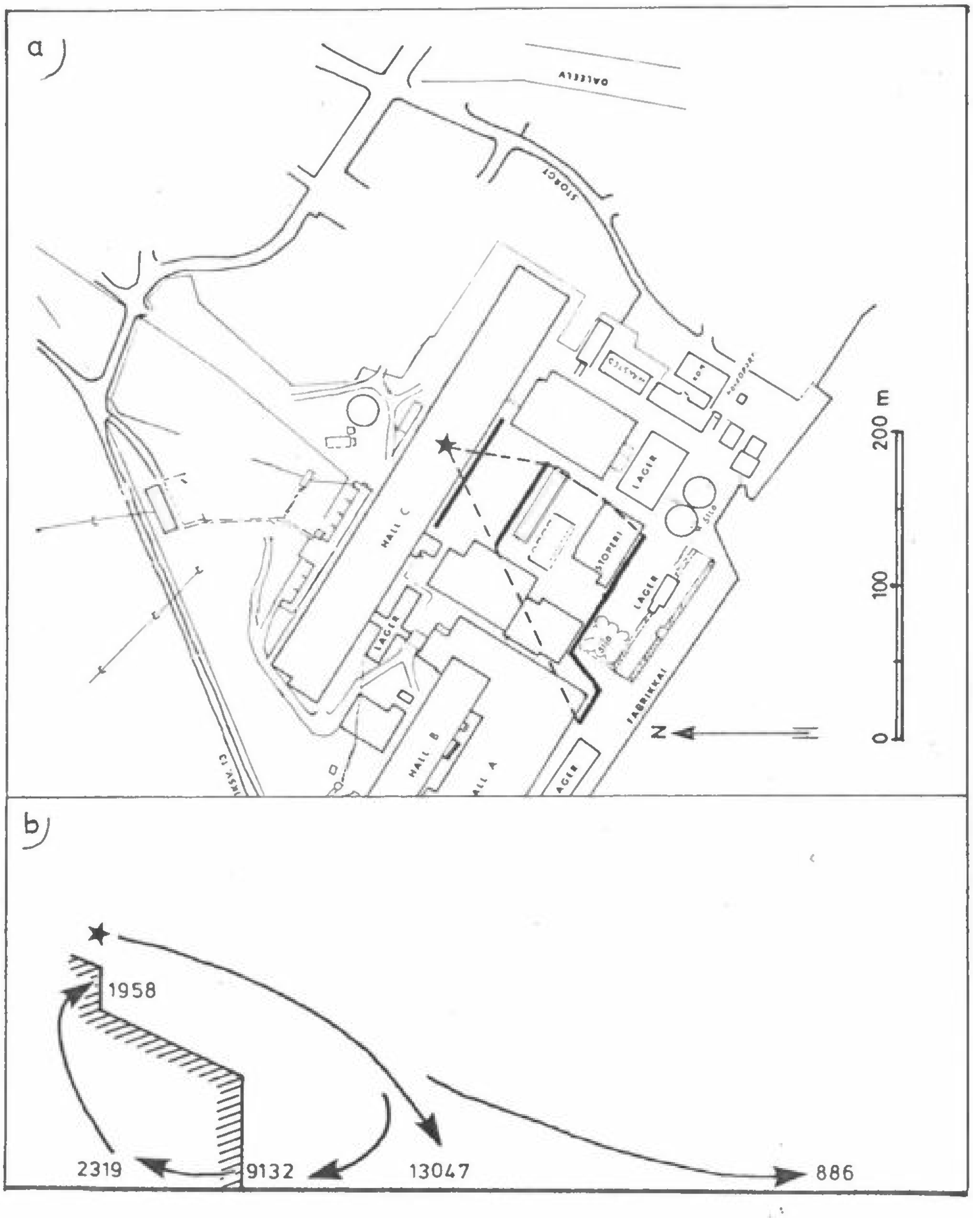


Figure 20 a) Map shows locations of observed maximum SF_6 concentrations from tests 7 and 8.
b) Cross-section shows probable air streamlines and the average maximum instantaneous SF_6 concentration at each sampling location from tests 7 and 8.

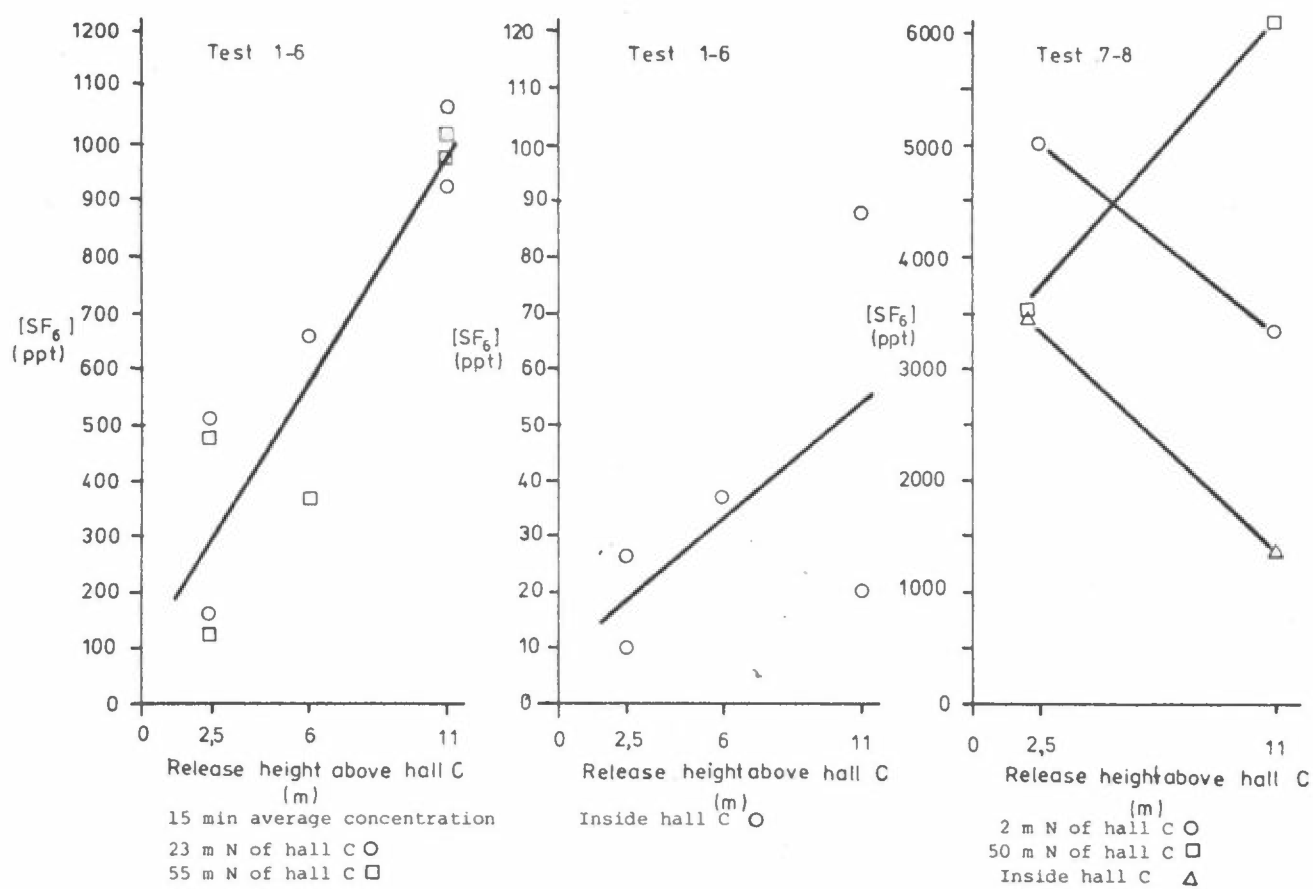


Figure 21: Maximum 15-minute average SF_6 concentrations are given as a function of the tracer release height.

NILU

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RAPPORTTYPE Oppdragsrapport	RAPPORTNR. 26/78	ISBN--82-7247-031-4
DATO May 1978	ANSV.SIGN. Odd F. Skogvold	ANT.SIDER OG BILAG 49
TITTEL A tracer investigation of the wake downwind of an aluminium smelter hall		PROSJEKTLEDER B.K. Lamb NILU PROSJEKT NR 22178
FORFATTER(E) B. K. Lamb O. F. Skogvold		TILGJENGELIGHET ** A OPPDRAGSGIVERS REF.
OPPDRAGSGIVER Årdal og Sunndal verk A/S		
3 STIKKORD (å maks.20 anslag) SF_6-tracer	Smelter	Wake

REFERAT (maks. 300 anslag, 5-10 linjer)

Ni forsøk med sporstoffet SF_6 ble utført for Årdal og Sunndal verk A/S, Høyanger, i tiden 10-14 april 1978. Sporstoffet ble sluppet fra forskjellige høyder, varierende fra 1 m til 11 m over toppen av taket på hall C.

I samtlige forsøk ble det funnet SF_6 i det turbulente området i le av bygningen. Likeledes ble 1 % til 11 % av SF_6-utslippet ført tilbake inn i bygningen igjen via friskluftinntakene.

TITTEL

ABSTRACT (max. 300 characters, 5-10 lines)

Nine SF_6 tracer experiments were conducted at the ÅSV Høyanger Aluminium Smelter during April, 1978. Tracer emitted at heights ranging from 1 m to 11 m above the roof of the smelter hall become entrained within the wake and subsequently reentered the hall through the fresh air supply vents. Approximately 1% of the SF_6 released above the roof during southerly winds infiltrated the hall, while as much as 11% of the SF_6 released above the roof during northerly winds infiltrated the hall.

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