NILU OR:39/90

NILU OR : 39/90
REFERENCE : O-8873
DATE : AUGUST 1990
ISBN : 82-425-0145-9

A TRACER INVESTIGATION OF TRAFFIC EMISSIONS FROM THE VÅLERENGA TUNNEL AT ETTERSTAD

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SUMMARY

Eighteen tracer experiments were conducted in Oslo to investigate dispersion of traffic emissions in the vicinity of the Vålerenga tunnel amid stable, wintertime conditions. Two tracer gases, sulfur hexafluoride (SF_6) and bromotrifluoromethane ($CBrF_3$), were used to characterize the emissions. One of these tracers was released at a constant rate from a fixed location in the south end of the north bound tunnel tube, while the other tracer was released from vehicles travelling with the traffic. Time-averaged air samples were collected within the tunnel and within 400 m of the tunnel portal, and in three tests, series of instantaneous grab samples were collected near the tunnel exit. Each test was fifteen minutes in duration and all samples were analyzed using gas chromatography. Data from twelve of the tests were used to test the dispersion model applied during the planning of the tunnel.

The experiments show that:

- The model predicted concentrations in the jet phase and plume phase regions which compared well with the measured concentrations. In 61.2 percent of the data, the model over-predicted the observed concentrations, and the highest ratio of the predicted to observed concentration was 2.2. In 94.7 of the cases in which the model underpredicted, the ratio was greater than 0.5. The average ratio of predicted to observed concentration was 1.12.

- The tracer gas was well mixed across the tunnel outlet.

- From 60 to 150 m out from the tunnel outlet, the measured concentrations where below 10% of the initial concentration in the outlet.

- The initial jet out of the tunnel probably extended up to 40 m out from the tunnel.

As estimated from average concentrations of the stationary source gas, the flowrate of air through the tunnel ranged from 155.9 to 403.8 m^3/s. The highest flowrate was observed during the afternoon rush hour, while the lowest flowrate occurred during an evening test. The estimated time for air to be transported through the north bound tube ranged from 129 to 336 s.

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A TRACER INVESTIGATION OF TRAFFIC EMISSIONS FROM THE VÅLERENGA TUNNEL AT ETTERSTAD

1 INTRODUCTION

Figure 1 shows the residential area surrounding the north portal of the Vålerenga traffic tunnel in Oslo, Norway. Two important sources of local pollutants in this area are: 1) traffic emissions from the tunnel, and 2) emissions from road traffic. Located within 100-200 m of the tunnel exit are several multiple-story buildings, including a nursing home (four stories), two schools (4-7 stories), a grocery store, and large apartment buildings. As shown on the map, many single-dwelling houses and smaller buildings are also in the vicinity.

It is difficult to predict the impact of locally-emitted pollutants in such areas where the airflow patterns are strongly affected by the presence and orientation of large buildings. Thus, in 1989 and 1990, a series of tracer experiments were conducted by the Norwegian Institute for Air Research (NILU) to investigate the nature of traffic emissions through the northern portal of the north bound tube, in the Etterstad area. The work was done under a contract with Vegdirektoratet (the Directorate of the Public Roads Administration) and Oslo Kommune (the City of Oslo Road Department). The remainder of this document contains a description of the experimental procedure used in these tests (Section 2), in addition to the results (Section 3) and conclusions (Section 4).

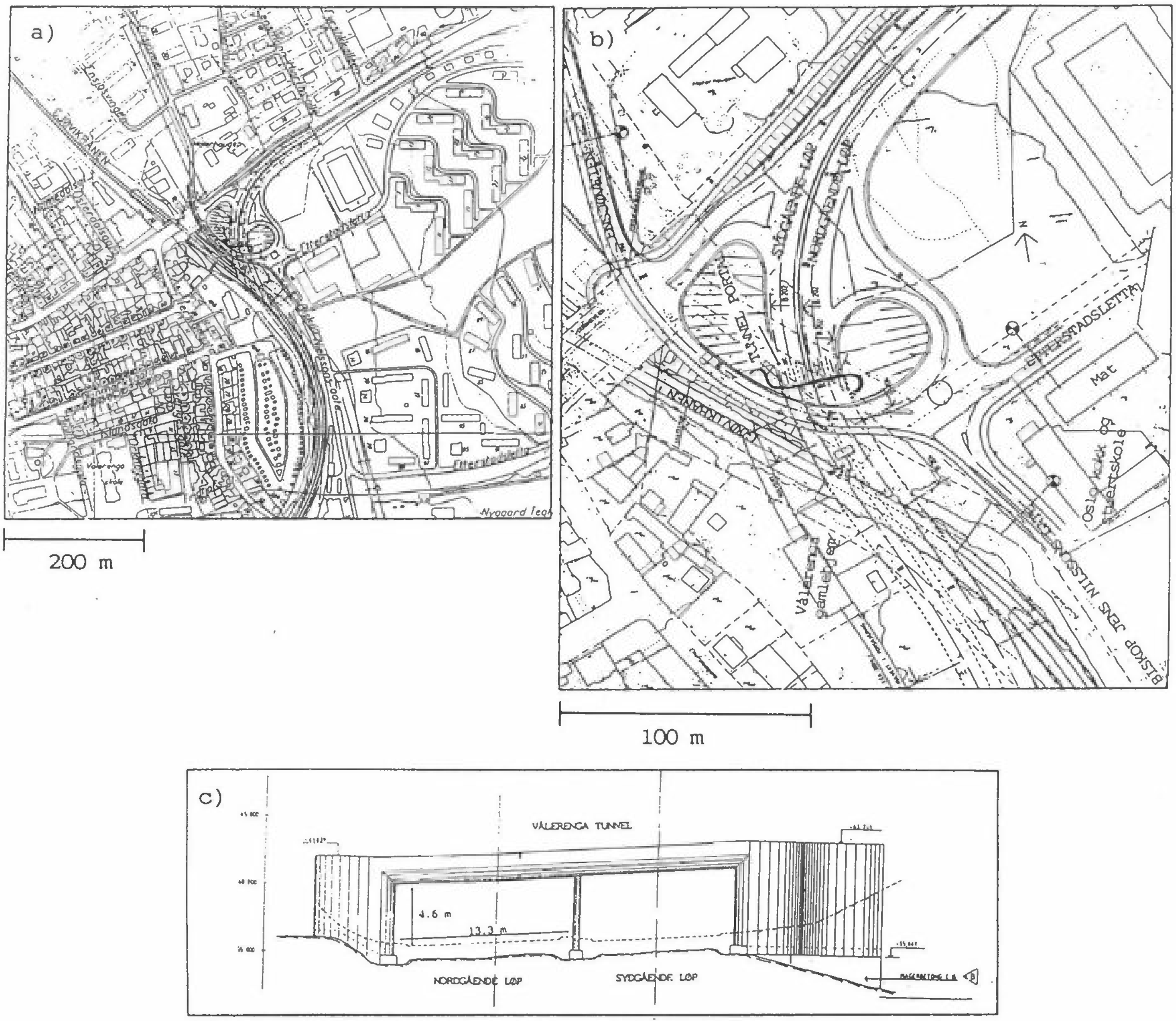


Figure 1: Diagrams showing a) the residential area surrounding the northern outlet of the Vålerenga tunnel, b) an expanded view of the area close to the tunnel portal, and c) a front view of the portal.

2 EXPERIMENTAL PROCEDURE

The length of the Vålerenga tunnel is approximately 840 m. North bound and south bound traffic are separated by a solid concrete divider. Three lanes of traffic flow through the tunnel in the north bound tube, while the south bound tube contains two lanes of traffic. According to a study by Larssen and Hoem (1989), the flow of traffic through the tunnel is approximately 14,100 vehicles/day and 10,900 vehicles/day, for north bound and south bound traffic, respectively. During rush hours, the hourly rates are 1,400 vehicles/hour and 1,100 vehicles/ hour, for respective north bound and south bound traffic, and the average speed of the cars traveling through the tunnel is approximately 60-70 km/hour.

Table 1 contains the meteorological and release conditions for eighteen tracer tests conducted in the Vålerenga area during 1989 and 1990. These experiments were performed during morning, afternoon, and evening hours, and conditions were cold and stable with light winds.

During each test, two tracer gases were used: sulfur hexafluoride (SF_6) and bromotrifluoromethane ($CBrF_3$). One of the gases, referred to as the 'stationary source', was released from a fixed point located at the south end of the north bound tunnel (approximately 10 m inside the tunnel entrance for north bound traffic), while the other gas, referred to as the 'mobile source', was released from cars traveling with the traffic.

In Tests 1A through 3B, SF_6 was used as the stationary tracer, and $CBrF_3$ was released from a single vehicle which travelled through the tunnel. During Tests 4A through 98B, $CBrF_3$ was used as the stationary source, while SF_6 was released along the routes shown in Figures 2 and 3.

Table 1: Vålerenga tunnel - release conditions.

TEST	DATE	TIME	WD	WS (m/s)	Q_s (g/min)	Q_m (g/min) Car_1	Car_2	Car_3	Avg.
1A	17-01-89	1515-1530	SW	3.0	0.884^1	2.331	-	-	-
1B	17-01-89	1530-1545	SW	3.0	0.884^1	2.331	-	-	-
2A	17-01-89	1720-1735	SW	2.7	0.632^1	2.344	-	-	-
2B	17-01-89	1735-1750	SW	2.7	0.632^1	2.344	-	-	-
3A	17-01-89	1955-2010	SW	2.4	0.853^1	0.731	-	-	-
3B	17-01-89	2010-2025	SW	2.4	0.853^1	0.731	-	-	-
4A	14-03-89	1440-1455	SW	2.0	0.562^2	0.303	0.314	0.336	0.318
4B	14-03-89	1455-1510	SW	2.0	0.562^2	0.303	0.314	0.336	0.318
5A	14-03-89	1710-1725	SW	3.0	0.506^2	0.329	0.294	0.357	0.327
5B	14-03-89	1725-1740	SW	3.0	0.506^2	0.329	0.294	0.357	0.327
6A	14-03-89	1850-1905	SW	1.5	0.537^2	0.337	0.278	0.334	0.316
6B	14-03-89	1905-1920	SW	1.5	0.537^2	0.337	0.278	0.334	0.316
7A	27-11-89	1630-1645	NW	4.5	1.387^2	0.526	0.684	0.625	0.612
7B	27-11-89	1645-1700	NW	4.5	1.387^2	0.526	0.684	0.625	0.612
97A	02-03-90	0940-0955	NNW	1.1	1.419^2	0.519	0.682	0.765	0.655
97B	02-03-90	0955-1010	NNW	1.1	1.419^2	0.519	0.682	0.765	0.655
98A	02-03-90	1150-1205	NNW	1.8	1.544^2	0.400	0.692	0.769	0.620
98B	02-03-90	1205-1220	NNW	1.8	1.544^2	0.400	0.692	0.769	0.620

where:
- WD = Mean wind direction
- WS = Mean wind speed
- Q_s = Release rate of the stationary tracer
- Q_m = Release rate of the mobile tracer
- 1 = Stationary release gas was SF_6, and mobile release gas was $CBrF_3$
- 2 = Stationary release gas was $CBrF_3$, and mobile release gas was SF_6.

During the experiments, an array of 24-40 portable automatic samplers collected air samples in the vicinity, typically within 200 or 400 m of the tunnel outlet. The air samples were collected in 20-ml polyethylene syringes, each with a 15-min averaging period, and two tests were generally conducted in sequence. In addition, during Tests 1-3, sequential grab samples were collected at two locations inside the tunnel. All samples were capped and analyzed for SF_6 and $CBrF_3$ concentrations using gas chromotagraphy. For additional information concerning sampling and analysis techniques, see Heggen and Sivertsen (1983).

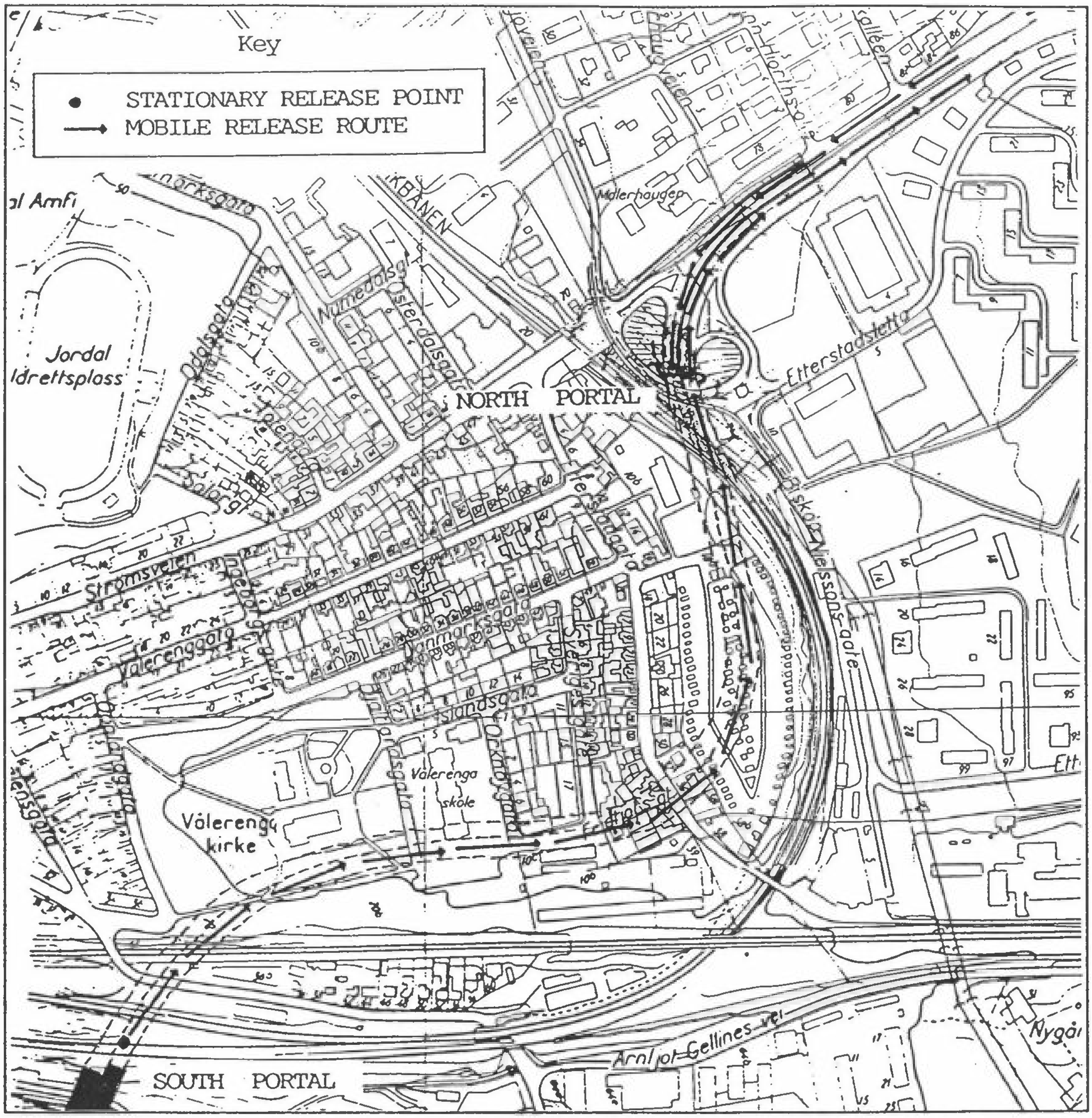


Figure 2: A site map showing the Vålerenga area. The dashed lines represent the underground tunnel, while the arrows indicate the route of the release vehicles during Tests 4A-7B. Also shown is the location of the stationary release (near the south portal).

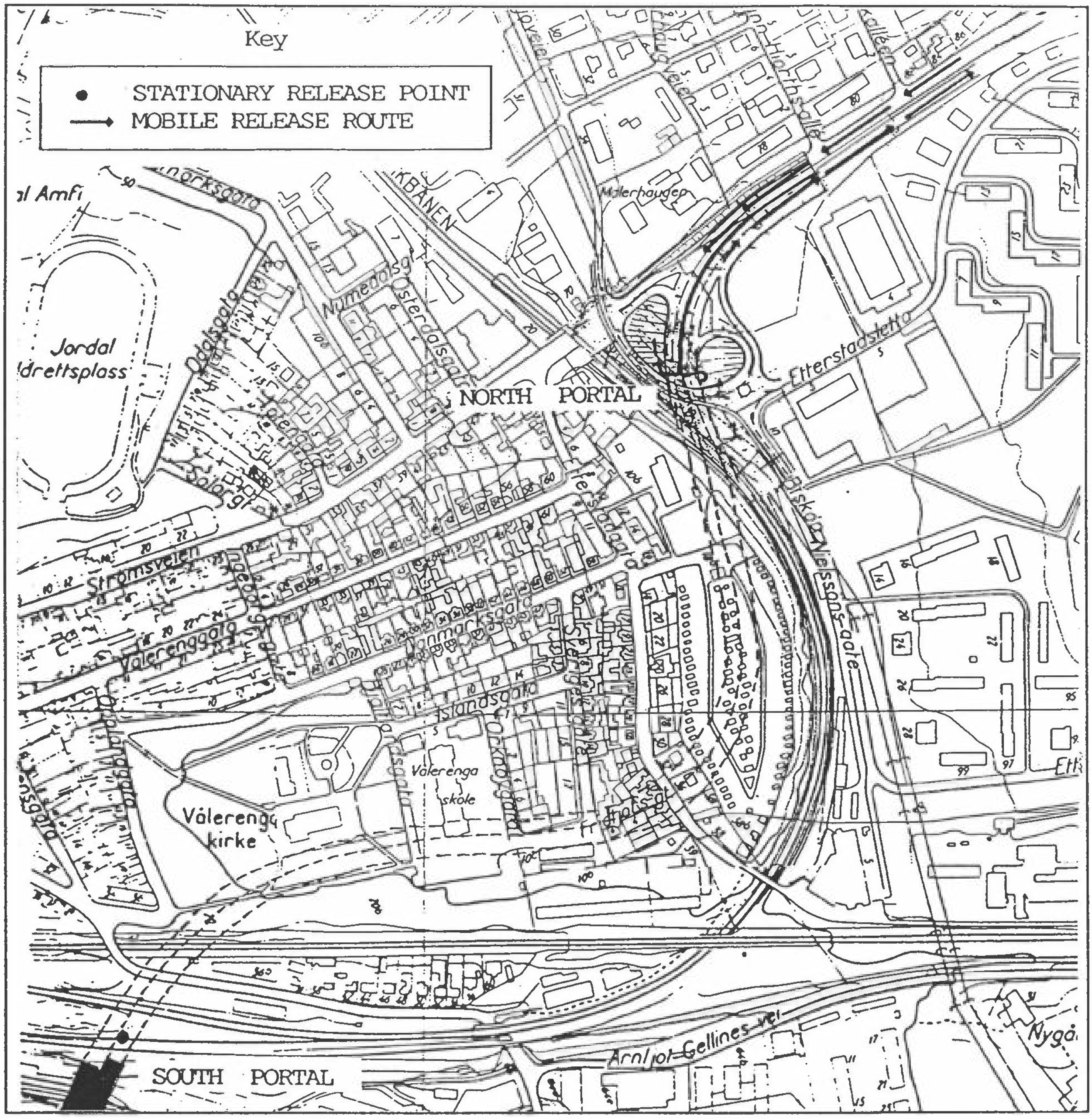


Figure 3: A site map showing the Vålerenga area. The dashed lines represent the underground tunnel, while the arrows indicate the route of the release vehicles during Tests 97A-98B. Also shown is the location of the stationary release (near the south portal).

3 RESULTS AND DISCUSSION

3.1 TESTS 1A-6B: TUNNEL CHARACTERISTICS

During Tests 1A-6B, sulfur hexafluoride was released in the southern portion of the tunnel, 10 m from the tunnel entrance for north-bound traffic. In the north end of the tunnel, four samplers were located in the positions shown in Figure 4. The two lower samplers were located near the side walls of the tunnel (5 m from the tunnel exit, and at ground level), while the two upper samplers were approximately 4 m above the road surface in lanes 1 and 3. (Note: in Tests 4A-6B, only one sampler was used, and it was located in the lower west position).

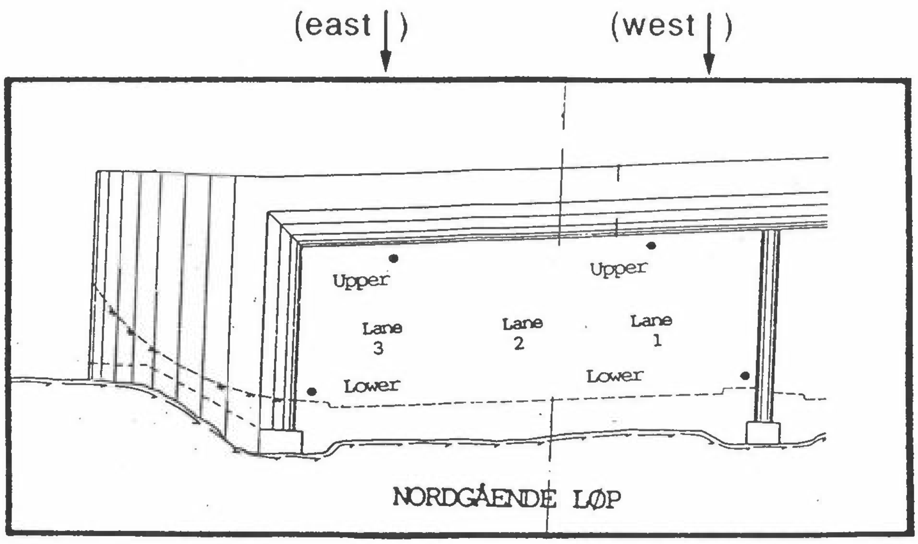


Figure 4: Sampler locations near the outlet of the Vålerenga tunnel.

The mean SF_6 concentrations from each of these four samplers were used to describe the ventilation conditions in terms of air flowrate, air velocity, and transport time through the tunnel, and the results in Tables 2 and 3 were calculated using the following equations:

$$C_{norm} = C/Q_s \tag{1}$$

$$Q_{air} = Q_s/C \tag{2}$$

$$V_{air} = Q_{air}/A \tag{3}$$

$$T = L/V_{air} \tag{4}$$

where C is the mean SF_6 concentration, Q_s is the SF_6 release rate, C_{norm} is the normalized concentration, Q_{air} is the estimated flowrate of the air through the tunnel, V_{air} is the estimated velocity of the air through the tunnel, A is the cross-sectional area of the tunnel portal (approximately 61 m^2), T is the estimated travel time, and L is the length of the tunnel (approximately 840 m). Table 2 contains the results for Tests 1A-3B, while Table 3 contains the results for Tests 4A-6B.

The magnitudes of the tracer concentrations are important because they are a measure of the ability of the tunnel system to dilute pollutants, and the distribution of the concentrations reflect the flow characteristics within the tunnel. According to the results shown in Tables 2 and 3, there were considerable variations among the twelve tests: variations which are likely caused by differences in the density and speed of the traffic going the tunnel. For example, allthough Tests 1-3 were conducted within a period of a few hours, the normalized concentrations during Test 2 and 3 were generally factors of 2 and 1.5, respectively, greater than the normalized concentrations during Test 1. The normalization step accounts for the variation in release rates; thus, conditions in the tunnel during Test 1 were more favorable for dilution of pollutants than during Test 2 and Test 3. In fact, the estimated air flowrate for Test 1 is approximately a factor of 2 greater than the estimated air flowrate for Test 2, and approximately a factor of 1.5 greater than the flowrate for Test 3.

Table 2: Vålerenga tunnel - tunnel conditions.

	TEST					
	V1A	V1B	V2A	V2B	V3A	V3B
C (ppt)						
lower west	5000	5500	8700	9000	-	-
lower east	5000	5000	8400	9000	9280	8900
upper east	6000	6500	8200	8100	9152	7900
upper west	7400	14000	8200	8264	9168	9200
C_n ($\mu g\ m^{-3}/g\ min^{-1}$)						
lower west	36.85	43.53	89.68	92.77	-	-
lower east	36.85	36.85	86.59	92.77	70.87	67.97
upper east	44.22	47.90	84.53	83.49	69.90	60.34
upper west	54.53	103.17	84.53	85.19	70.02	70.26
Average C_n	43.11	41.76*	86.33	88.55	70.26	66.19
Standard deviation	8.37	5.63	2.43	4.92	0.53	5.19
Q_{air} (m^3/s)						
lower west	452.3	411.2	185.8	179.7	-	-
lower east	452.3	452.3	192.5	179.7	235.2	245.2
upper east	376.9	347.9	197.2	199.6	238.4	276.2
upper west	305.6	161.5	197.2	195.7	238.0	237.2
Average C_{air}	396.8	403.8*	193.2	188.7	237.2	252.9
Standard deviation	70.4	52.6	5.4	10.5	1.7	20.6
V_{air} (m/s)						
lower west	7.4	6.7	3.0	2.9	-	-
lower east	7.4	7.4	3.2	2.9	3.9	4.0
upper east	6.2	5.7	3.2	3.3	3.9	4.5
upper west	5.0	2.6	3.2	3.2	3.9	3.9
Average V_{air}	6.5	6.5*	3.2	3.1	3.9	4.1
Standard deviation	1.1	0.7	0.1	0.2	0.0	0.3
T (s)						
lower west	114	125	280	290	-	-
lower east	114	114	263	290	215	210
upper east	135	147	263	255	215	187
upper west	168	323	263	263	215	215
Average T	133	129*	267	275	215	204
Standard deviation	26	17	9	18	0	15

where:

C = Mean SF_6 concentration
C_n = Normalized concentration
Q_{air} = Estimated air flowrate
V_{air} = Estimated air velocity
T = Estimated transport time
* = These averages do not include value from sampler at location upper.

Table 3: Vålerenga tunnel - tunnel conditions.

	TEST					
	V4A	V4B	V5A	V5B	V6A	V6B
C (ppt) lower west	5890	6399	6230	6721	7610	8642
C_n ($\mu g\ m^{-3}/g\ min^{-1}$) lower west	69.64	75.66	81.81	88.26	94.16	106.93
Q_{air} (m^3/s) lower west	239.3	220.3	203.7	188.8	177.0	155.9
V_{air} (m/s) lower west	3.9	3.6	3.3	3.1	2.9	2.5
T (s) lower west	215	233	255	271	290	336

where:
- C = Mean SF_6 concentration
- C_n = Normalized concentration
- Q_{air} = Estimated air flowrate
- V_{air} = Estimated air velocity
- T = Estimated transport time

In terms of the horizontal distribution of the tracer across the tunnel, concentrations on the west side of the tunnel were either greater than or equal to concentrations on the east side of the tunnel, and the largest difference between west and east samplers was observed in Test 1. The SF_6 source was located on the west side of the tunnel, thus these results probably reflect the spatial distribution of the traffic in addition to the air flowrate. For example, if the traffic is evenly distributed among the three lanes, the tracer should be evenly distributed from one side of the tunnel to the other. However, in the Vålerenga tunnel, it is possible for traffic to be more highly concentrated in Lanes 1 and 2 because Lane 3 is a turning lane. Thus tracer will take longer time to to be mixed and transported to the east side of the tunnel. The flow-rates in Test 1 were higher than in the other tests, and thus there was less time for the tracer to become well-mixed across the tunnel.

Several factors influence the flowrate of air through the Vålerenga tunnel, including the number of vehicles traveling through the tunnel, the size of the vehicles, the speed of the vehicles, and the temporal and spatial distributions of the traffic. According to Larssen (1990), the largest number of north-bound cars travel through the tunnel during an afternoon rush hour, the period 1530-1630, and the hourly average vehicle speeds vary little about an average of 60 km/h. Thus, the mean air flowrate is expected to be greatest during this period, and as a direct effect of the moving vehicles, the flowrate is expected to be greatest near the ground.

Tests 1A and 1B were conducted during the rush hour, between 1515 and 1545, whereas Tests 2A, 2B, 3A, and 3B were conducted later in the evening (i.e., between 1720 and 1750, and between 1955 and 2025). As expected, the estimated air velocity was higher during Tests 1A and 1B (average V_{air}=6.5 m/s) than during Tests 2A and 2B (average V_{air}=3.1 m/s) and Tests 3A and 3B (average V_{air}=4.0 m/s), and during Tests 1A and 1B, the average air velocity near the ground was 1.8-2.9 m/s higher than the average air velocity near the roof of the tunnel. During Tests 2 and 3, however, the average velocity in the upper level was higher than the average velocity in the lower level, but the difference of <0.4 m/s is probably insignificant with respect to the uncertainty of the velocity estimate. The apparent 'lack of a velocity gradient' is probably a combined effect of time averaging and intermittent traffic.

During Tests 4-6, the tunnel velocity decreased gradually from 3.9 m/s in Test 4A to 2.5 m/s in Test 6B. This decrease reflects the expected trend for traffic rates to decline from a maximum in late afternoon hours to a minimum during nighttime hours.

Based upon the estimated velocities, the transport time for air flowing through the tunnel was approximately 130 s during Test 1, 270 s during Test 2, and 210 s during Test 3. Likewise, the transport time for Tests 4A through 6B increased from 215 s to 336 s. These results illustrate the importance of being able to correctly predict tunnel flowrate as a function of traffic conditions. Whereas the total emissions may increase as the number of cars driving through the tunnel increases, the flowrate of the tunnel air also increases and, thus, the residence time within the tunnel decreases. The following section illustrates this concept in greater detail.

3.2 TESTS 1B, 2B, AND 3A: INSTANTANEOUS CONDITIONS

Whereas the 15-min average concentrations were used to estimate mean tunnel conditions, the time series of instantaneous concentrations were used to investigate the characteristics of the wake and the impact of emissions from a single car travelling in the center lane. Grab samples were collected at two locations inside the tunnel (one location on each side, and approximately 5 m from the exit). The sampling period of approximately 260 s consists of near-instantaneous samples collected at intervals of 5-10 s. Time t=0 corresponds to the time when the release car drove past the sampling points. Table 4 contains the $CBrF_3$ concentrations collected during Tests 1-3, and the data are presented as time series in Figures 5-7. Table 5 contains concentration statistics for these data. In figures 5-7 the notation "right" and "left" is related to the direction of the traffic.

On the east side of the tunnel, concentrations peaked within 20-25 s after the release vehicle passed, and concentrations decreased to less than 1% of the peak after approximately 190 s during Test 1, 260 s during Test 2, and slightly more than 260 s during Test 3. On the west side of the tunnel, maximum concentrations were observed between 45 and 60 s after the release vehicle passed, and concentrations decreased to less than 1% of the peak within 200 s during Test 1, and slightly longer than 260 s during Tests 2 and 3. During the three tests, the maximum concentration on the east side was a factor of approximately 2 greater than the maximum concentration on the west side, but upon reaching near-steady state conditions, the west series from the east side and the time series from the west side appear to collapse to a single curve.

Table 4: Vålerenga tunnel - instantaneous concentrations.

	$CBRF_3$ concentrations (ppt)					
	TEST: V1B		V2B		V3A	
Time (s)	East	West	East	West	East	West
0	0	0	0	0	0	0
5	0	0	0	0	0	0
10	2211	1380	6690	315	1971	1405
15	9500	3203	6184	314	2098	273
20	13351	1172	7915	335	4451	872
25	11336	2223	8612	292	2757	2225
30	8949	2966	6272	702	2952	1522
35	5567	5848	3813	1177	2111	1012
40	5570	6980	3708	2724	1179	1223
45	6440	7038	3640	4124	1492	1033
50	6858	6836	3462	4911	1062	1355
55	6865	6537	3534	5197	1389	1769
60	6680	6433	3658	4043	1409	2254
65	6698	6232	3634	4196	1539	2000
70	6650	6206	3621	3839	1579	2129
75	6284	6345	3885	3903	1249	2035
80	5840	5988	4025	3858	1517	1982
85	-	5756	-	3867	1481	1702
90	5552	5680	4137	3981	1447	-
100	4920	5126	3982	4198	1602	1621
110	3801	4082	-	4123	1552	1738
120	3426	3420	-	3720	1452	1715
130	2516	2672	-	3886	1688	1650
140	2039	2184	3805	3796	-	1638
150	1349	1696	3759	3694	1953	1754
160	979	1139	3679	3846	-	1724
170	659	718	3328	3610	2001	1926
180	291	234	3381	3417	1865	1833
190	0	90	-	3167	1788	1858
200	0	0	3367	2780	-	1779
210	0	0	2618	2513	2045	1847
220	0	0	2249	2245	2066	1790
230	0	0	1232	1851	1989	1781
240	0	0	380	990	1770	1696
250	0	0	300	401	1457	1541
260	0	0	0	90	897	617

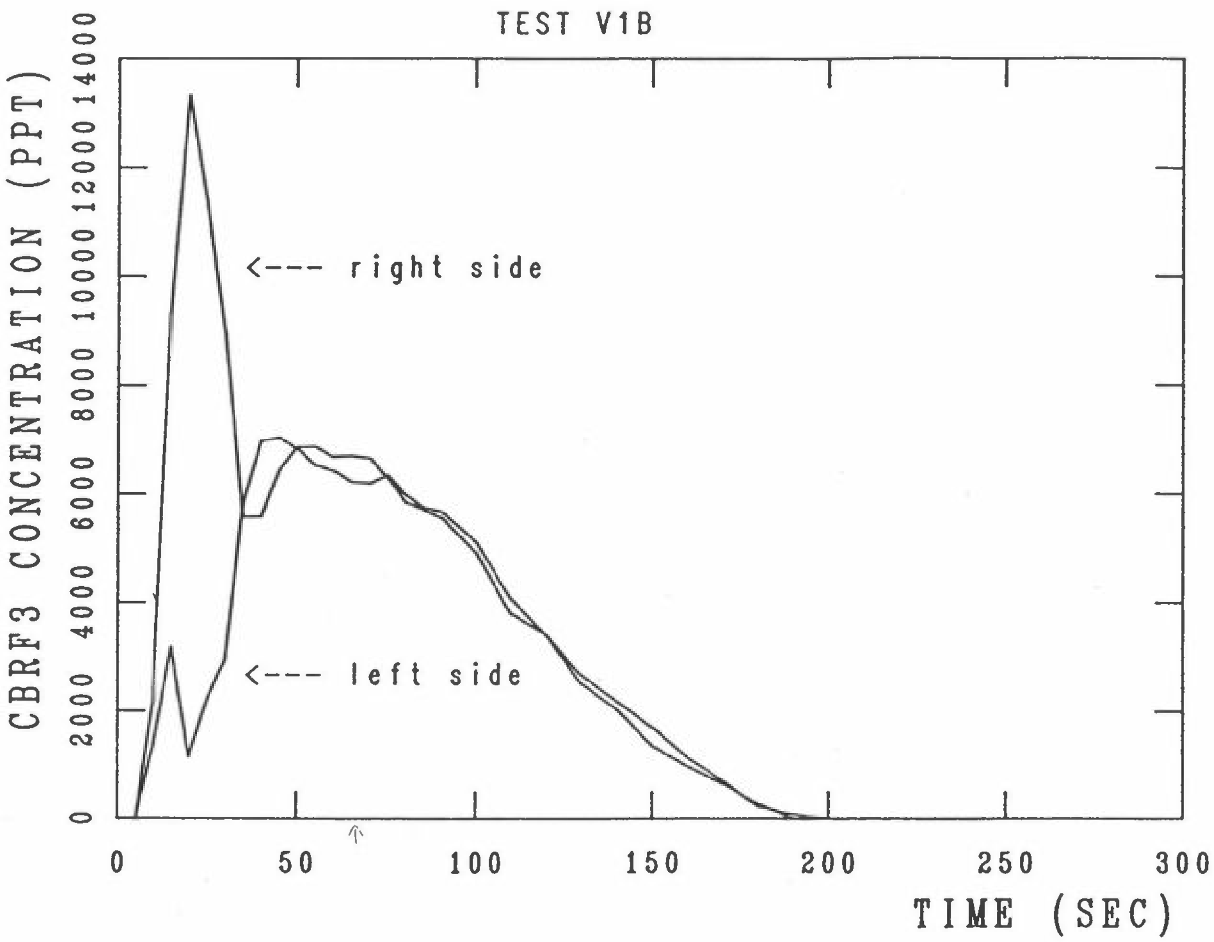


Figure 5: Concentration time series for the right and left sides of the tunnel during Test 1B.

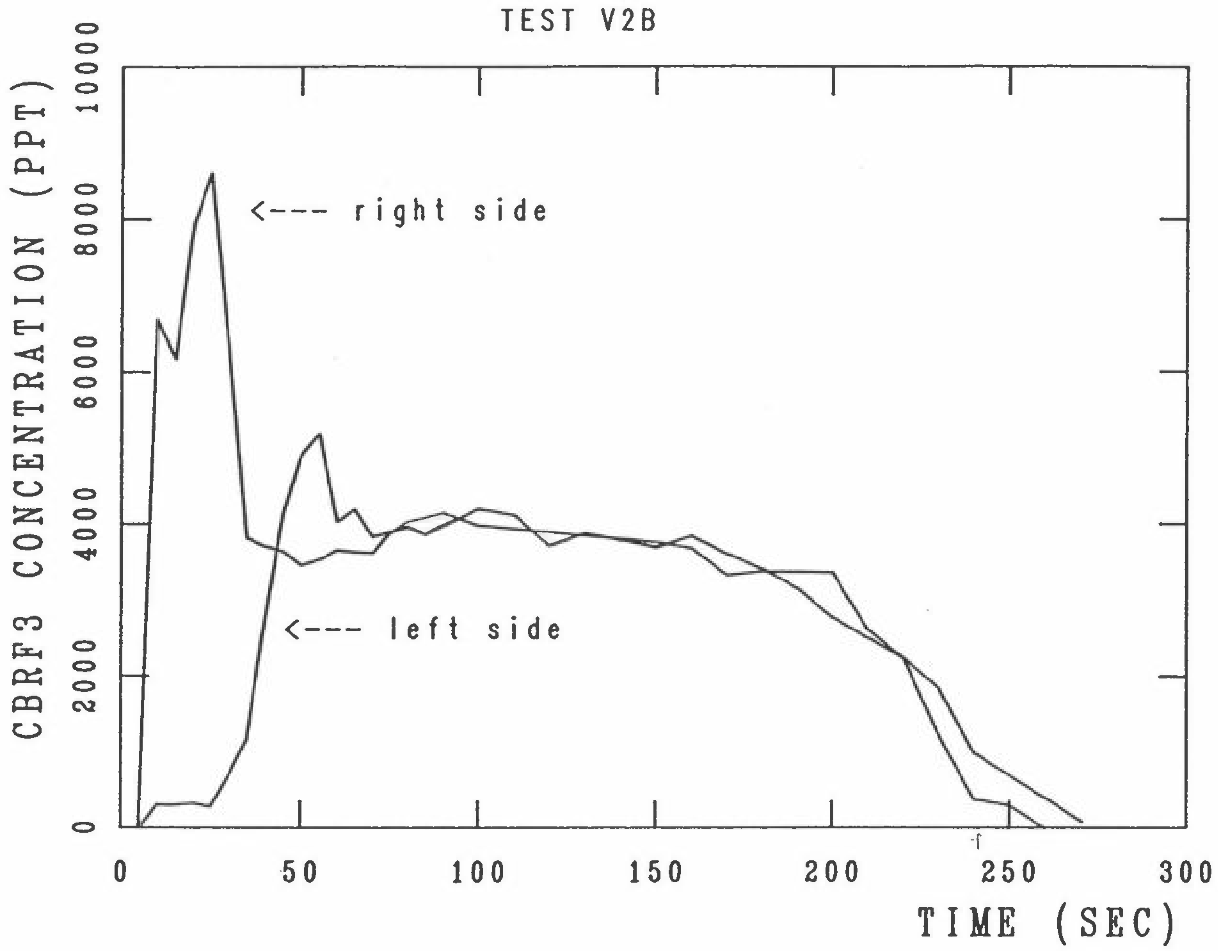


Figure 6: Concentration time series for the right and left sides of the tunnel during Test 2B.

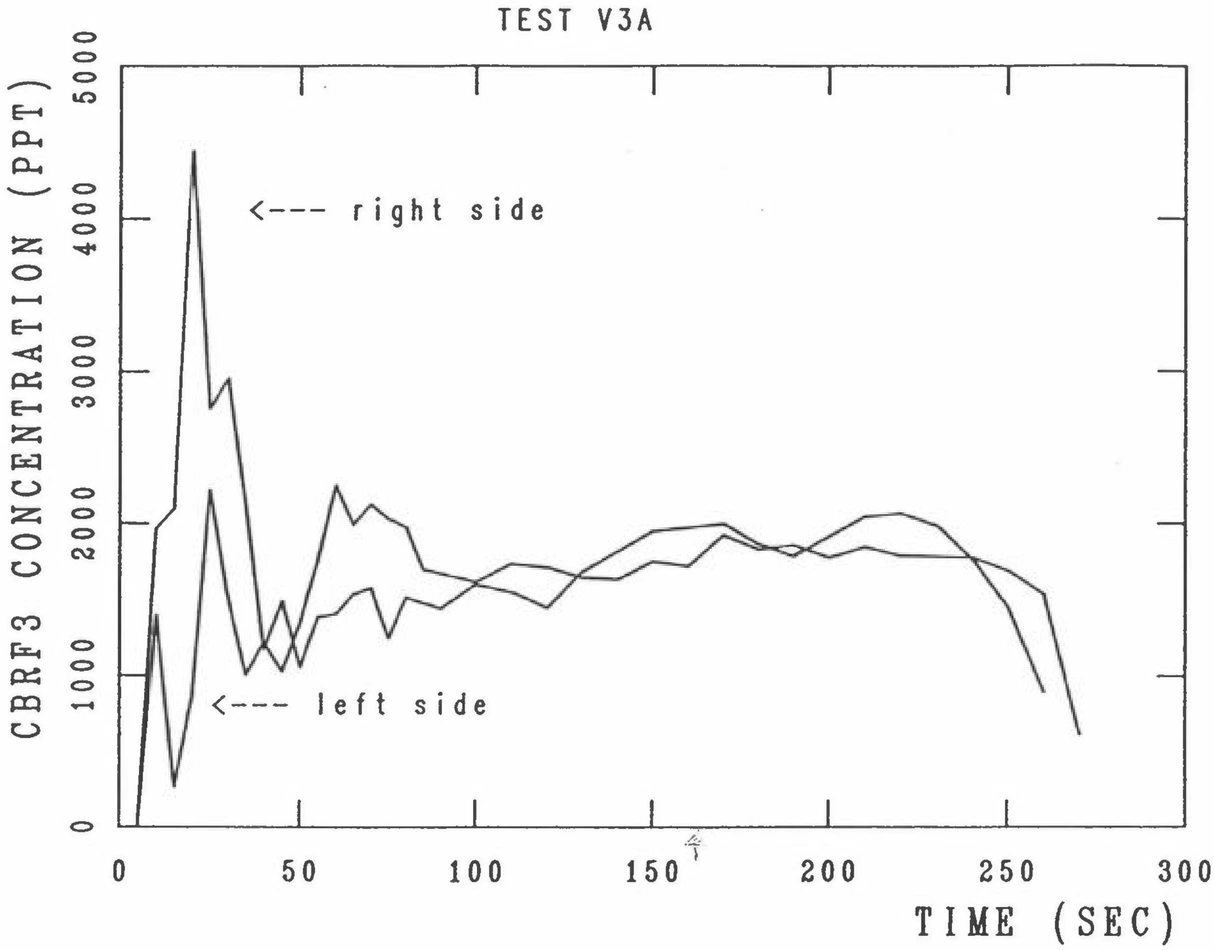


Figure 7: Concentration time series for the right and left sides of the tunnel during Test 3A.

Table 5: Vålerenga tunnel - instantaneous concentration statistics.

	V1B		V2B		V3A	
Concentration Statistic	Right	Left	Right	Left	Right	Left
N	35	36	31	36	33	35
C_{avg} [ug m^{-3} / g min^{-1}]	10.94	8.57	9.96	7.57	15.37	13.84
σ_c	10.56	7.70	6.05	4.69	7.02	5.22
C_{max}	38.06	20.06	24.41	14.73	40.46	20.22
σ_c/C_{avg}	1.0	0.9	0.6	0.6	0.5	0.4
C_{max}/C_{avg}	3.5	2.3	2.5	1.9	2.6	1.5
C_{avg}(right)/C_{avg}(left)	1.3	-	1.3	-	1.1	-
C_{max}(right)/C_{max}(left)	1.9	-	1.7	-	2.0	-

Where:

N = Number of grab samples for 260-sec period

C_{avg} = The mean concentration, normalized by release rate, and based on 'N' samples

σ_c = The standard deviation from the averaging procedure

C_{max} = The maximum normalized concentration

σ_c/C_{avg} = The ratio of the standard deviation to the mean

C_{max}/C_{avg} = The ratio of the maximum to the mean

C_{avg}(right)/C_{avg}(left) = The ratio of the mean at the right side of the tunnel to the mean at the left side

C_{max}(right)/C_{max}(left) = The ratio of maximum at the right side of the tunnel to the maximum at the left

The nature of these curves may be qualitatively explained in terms of the theory described earlier for horizontal mixing. The concentration is initially zero at both sides of the tunnel because the release vehicle traveled in the center lane, and thus the tracer released in the center lane must be transported to the walls before it is detected. The reason that $CBrF_3$ maximum is observed at the right side before the left is probably due to the fact that the tracer gas was released at the right side of the car so that the cross tunnel distance to the sampling point was shorter. Once the tracer is well-mixed across the tunnel, the concentrations maintain a steady-state level until dropping off at the end. Secondary peaks in the curves are probably caused by intermittent traffic, or during the passage of individual vehicles, whereas linear trends in the steady-state concentrations (i.e., as in Test 3A) may be caused by non-steady airflow in the tunnel, or by a non-steady velocity of the release vehicle.

The time required for the concentration to fall from a steady-state level to zero is also a function of the rate of traffic because of re-entrainment. With a high rate of traffic and when the traffic speed is greater than the speed of the tunnel air, each vehicle induces additional turbulence and mixing as it travels through the tunnel, and thus effectively elongating the trailing edge of the tracer distribution (i.e., as in Test 1B). On the other hand, under conditions in which few vehicles drive through, the tracer is expected to be transported through the tunnel as a single 'plug' with little spreading at the trailing edge (i.e., as in Test 3A).

Rough estimates of the transport time through the tunnel from the $CBrF_3$ time series data are approximately 125 s in Test 1B, 250s in Test 2B, and 275 s in Test 3A. These values were calculated by adding 50 s (the approximate time for the release vehicle to travel through the tunnel) to the time in the time series where the steady-state concentrations begin to fall off at the end. The corresponding transport times as estimated from the mean SF_6 concentrations (in Table 2) were 129 s in Test 1B, 275 s in Test 2B, and 215 s in Test 3A. Considering that the instantaneous data represents a 260-s sampling period, whereas the SF_6 data represents a 15-min period, these results compare fairly well. It probably is not significant that the transport time from the instantaneous data was lower than the transport time from the average data in Test 2B, and higher in Test 3A. Because traffic patterns are not homogeneous throughout any period (in particular during low traffic periods), the instantaneous data may either over- or under-estimate the mean conditions.

3.3 TESTS 1A-98B: MEAN DISPERSION

The tables in Appendix A and Appendix B contain the the 15-min average concentration data (normalized by the release rate) as a function of the sampling co-ordinates for all Vålerenga tracer tests. The data in Appendix A correspond to the tracer gas which was released as a stationary source, while the data in Appendix B correspond to the tracer gas which was released from the moving vehicles. Figures 8-16 contain concentration isopleths during each test for the stationary source; Figures 17-22 contain concentration isopleths during each test for the mobile source; and these results are discussed as follows.

3.3.1 Stationary Source: TESTS 1A-98B

During Tests 1-6, the mean winds blew from the southwest, and the average wind speed ranged 1.5-3 m/s during these periods. As seen in Figures 8-13, the winds transported tunnel emissions in a northeasterly direction in all twelve cases. The profile of the mean plume appears to be described by an initial jet region which extended, at most, 40 m from the tunnel portal, after which the plume dispersed (in a Gaussian fashion) in the direction of the mean wind. As expected, the highest concentrations were measured at the samplers located inside the tunnel, whereas the highest concentrations outside of the tunnel were measured on the traffic island at a sampler located 35-38 m in front of the tunnel mouth. The mean concentration within the tunnel was 2-4 times greater than the mean concentration on the island, and within 60-150 m, the concentration on the centerline of the mean plume fell to approximately 10 percent of the concentration observed within the tunnel.

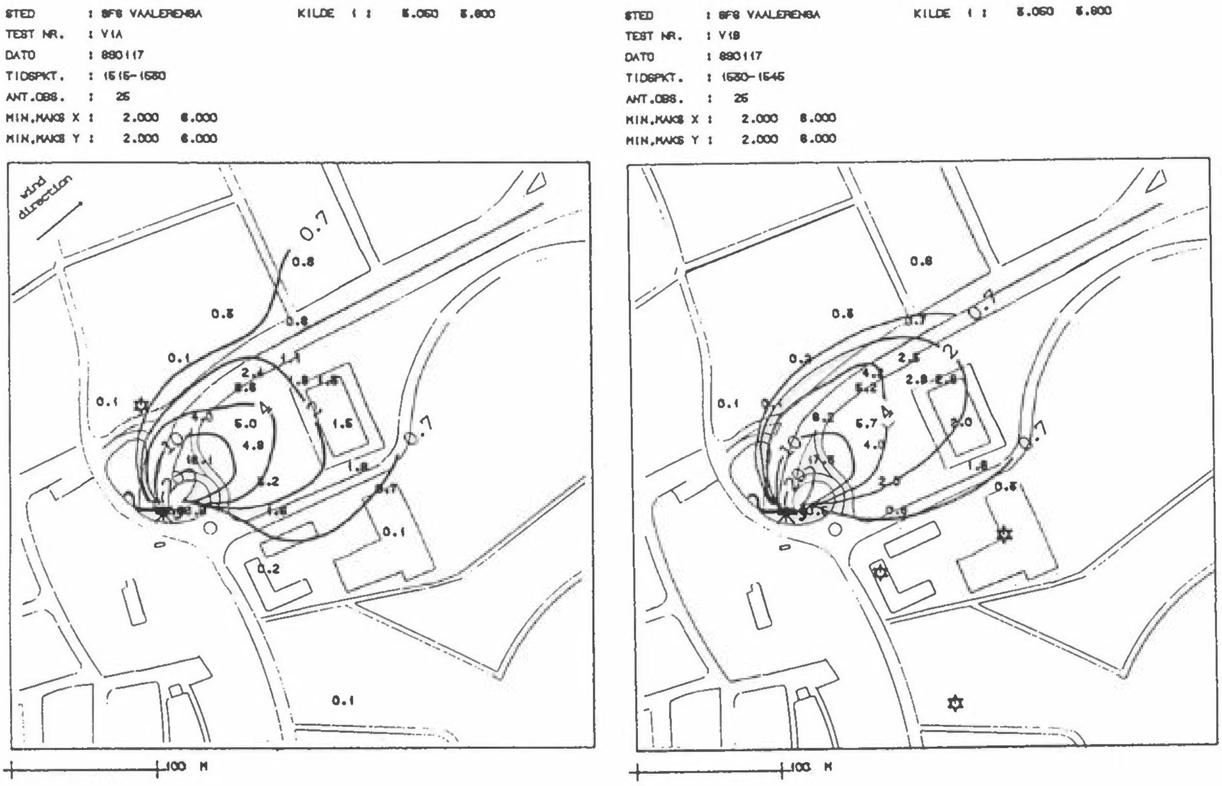


Figure 8: SF_6 isopleths for a) Test 1A, and b) Test 1B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

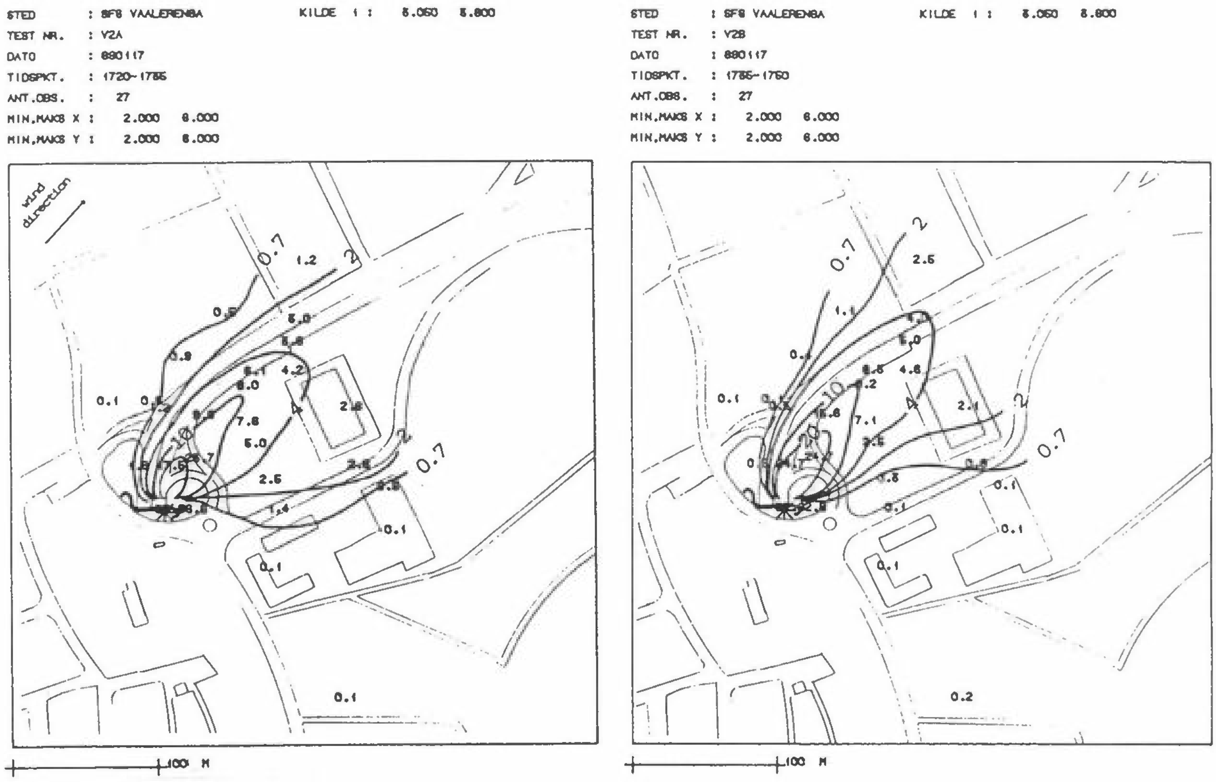


Figure 9: SF_6 isopleths for a) Test 2A, and b) Test 2B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

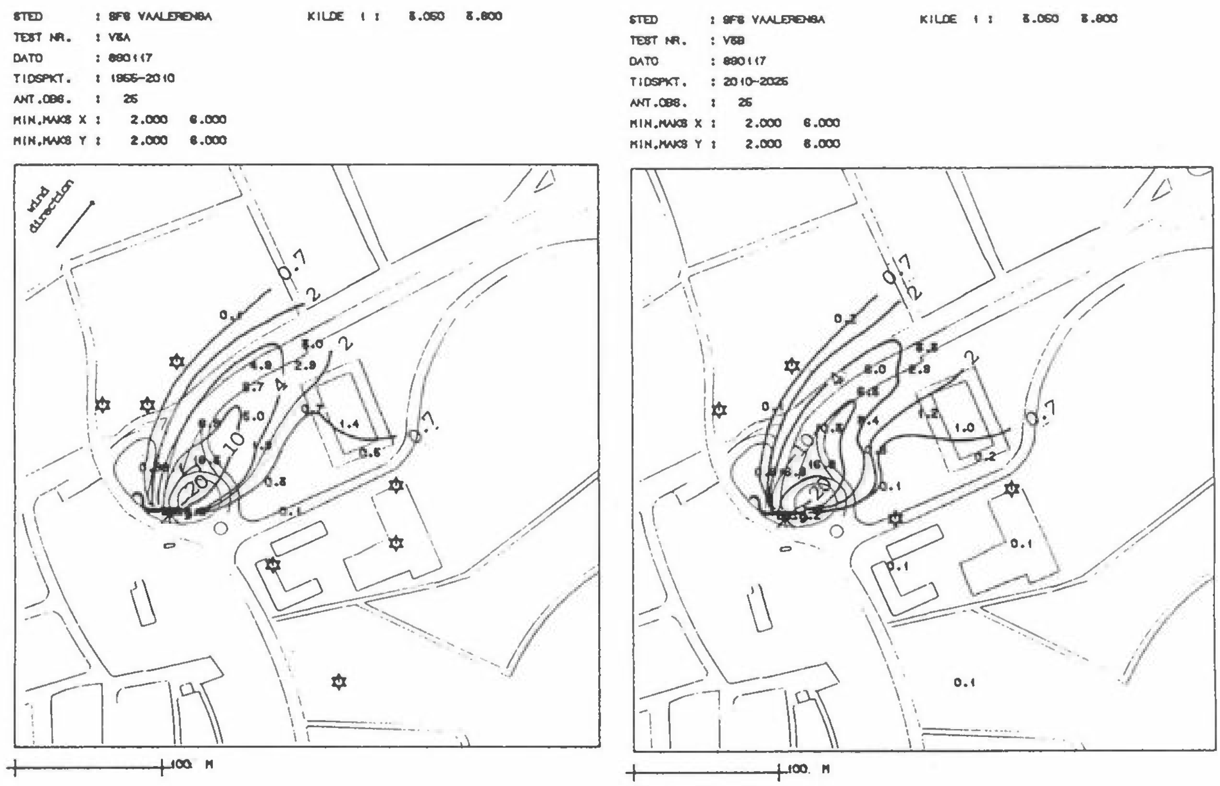


Figure 10: SF_6 isopleths for a) Test 3A, and b) Test 3B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

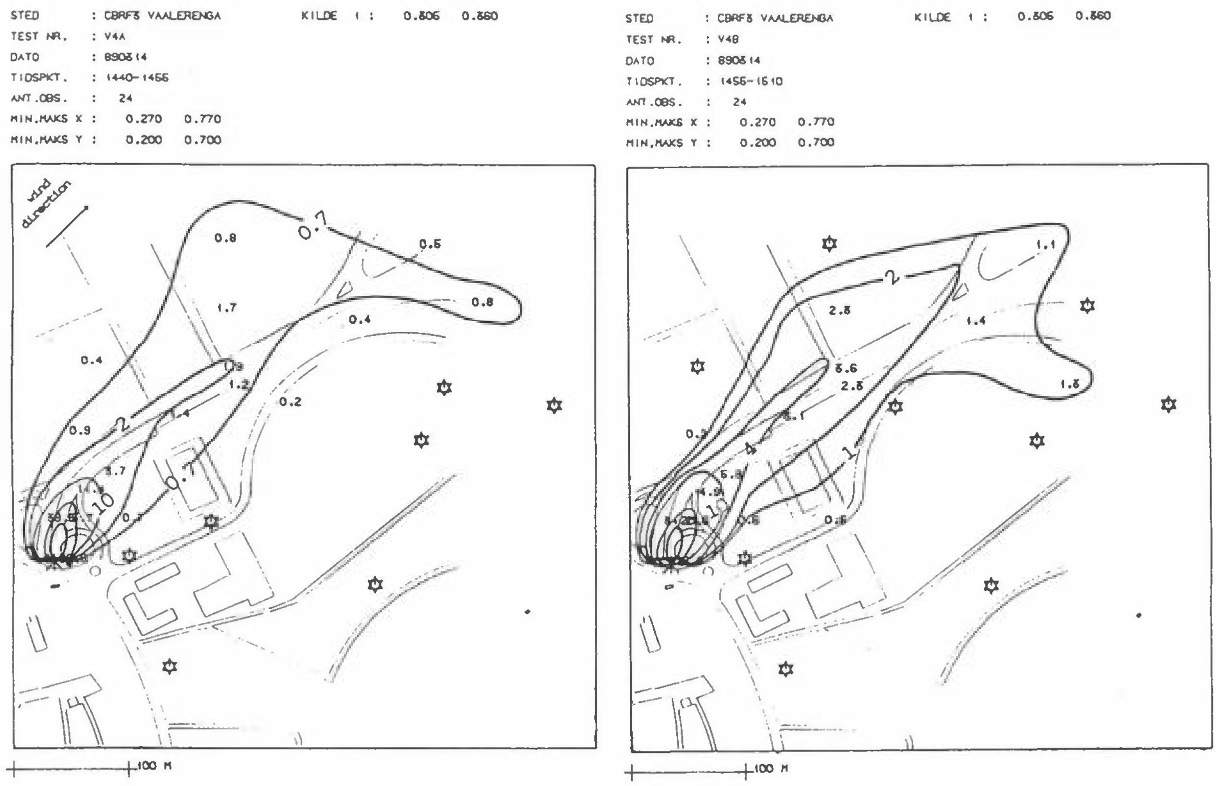


Figure 11: $CBrF_3$ isopleths for a) Test 4A, and b) Test 4B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

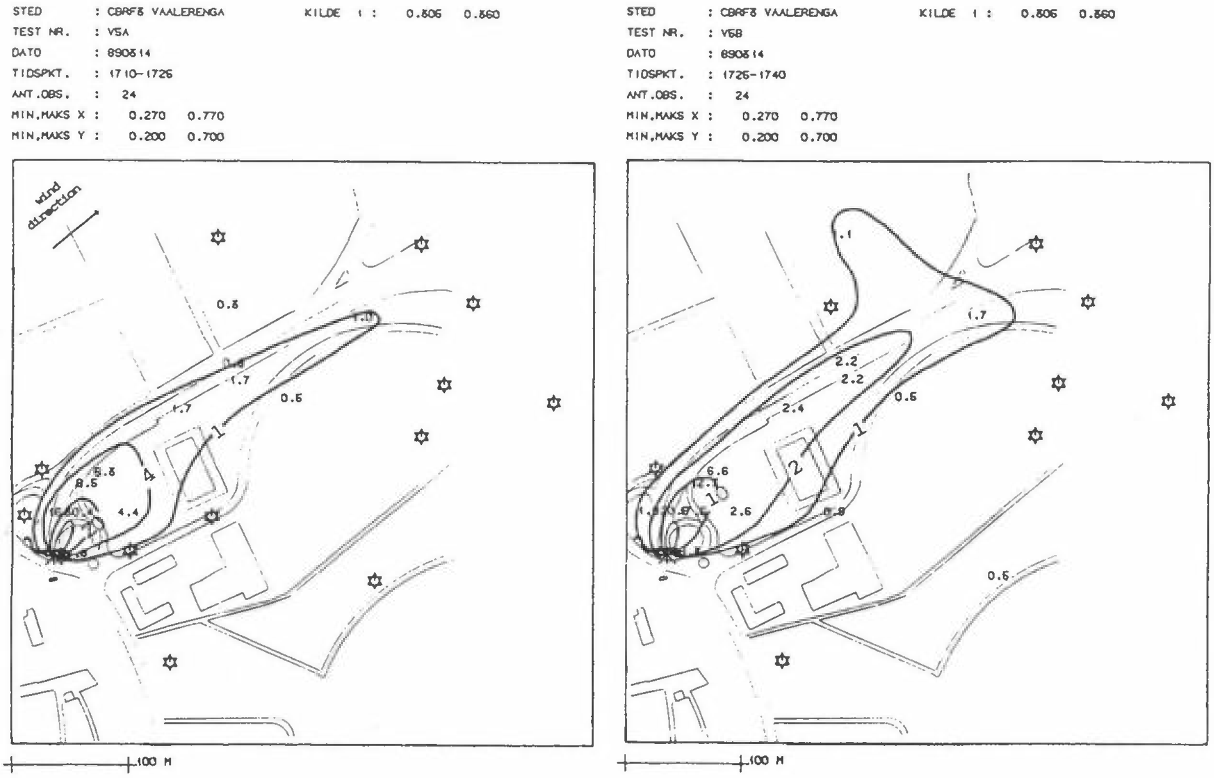


Figure 12: $CBrF_3$ isopleths for a) Test 5A, and b) Test 5B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

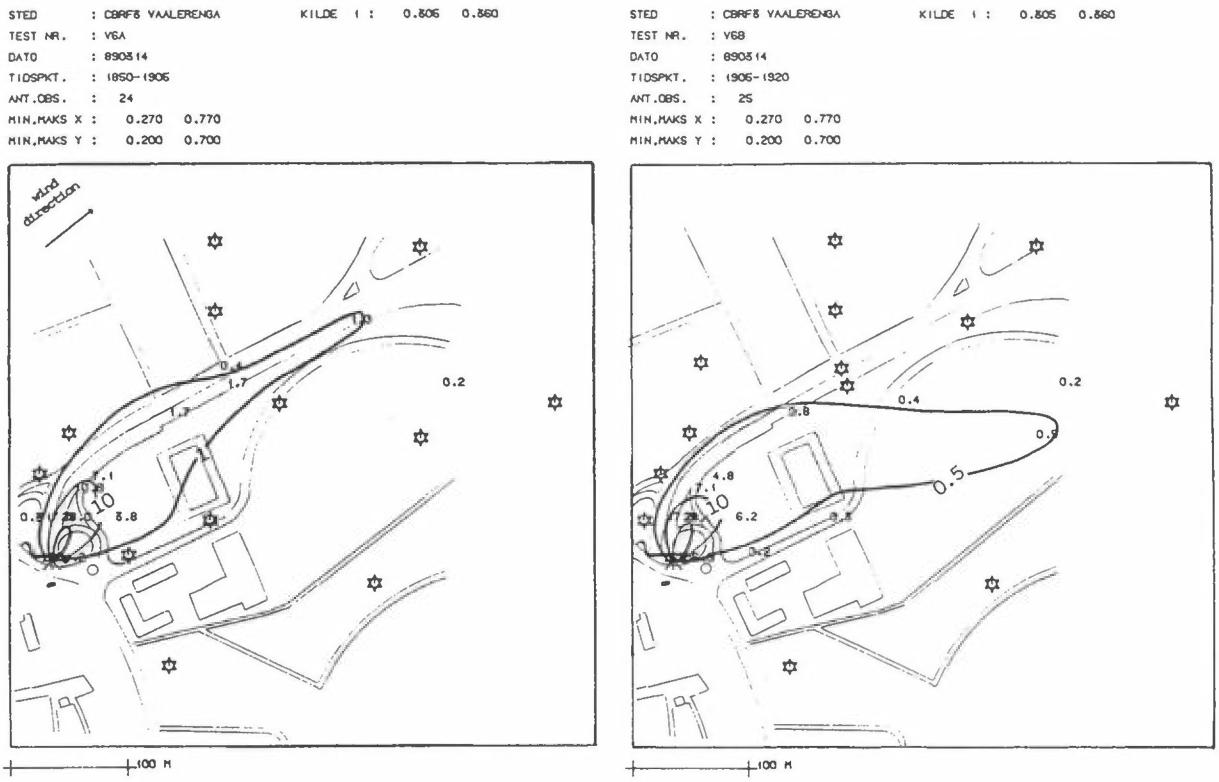
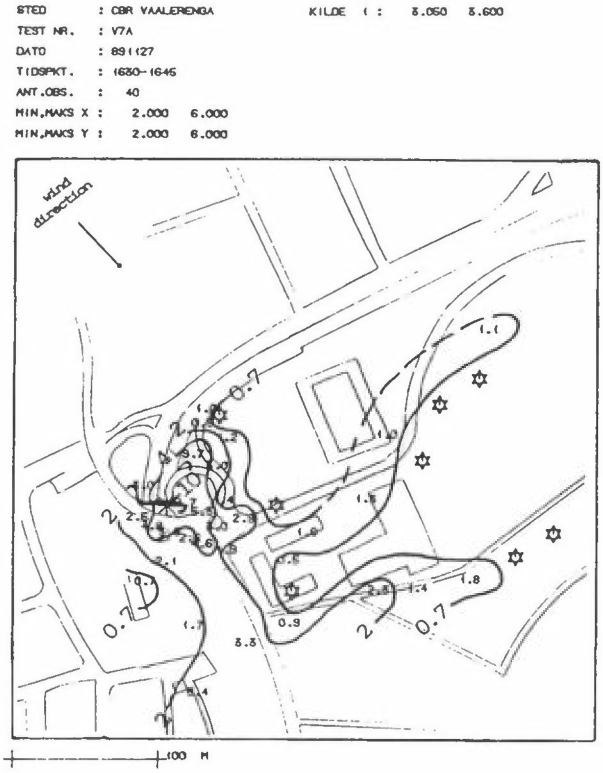


Figure 13: $CBrF_3$ isopleths for a) Test 6A, and b) Test 6B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

During Tests 7-98, the winds were from the north and northwest sectors, and the concentration isopleths are shown in Figures 14-16. No samples were collected inside the tunnel, but in Test 7 the impact of the jet is shown by the isoline of magnitude 10, approximately a factor of 2 or 3 less than observed in Tests 1-6. (The sampling array did not inlcude the region of the jet in Tests 97-98). The dispersion patterns under conditions of north to northwest winds are much more complicated than the dispersion patterns under conditions of southwest winds. The dispersion of the mean plume appears to be dominated by the local topography and building influences, and thus, the main feature describing the transport of the tunnel emissions is channelling along the roadways and around buildings. In particular, most of the emissions during Tests 7A, 7B, 97B, and 98A were channelled parallel to Biskop Nielssons Gate, and the concentrations were diluted very little in this region (i.e., in Test 7, the concentrations along the road had decreased from a magnitude of 4.0 to 3.5 over distances of 100 m). During Tests 97B and 98A, emissions were also transported along Biskop Nielssons Gate, while during Test 97A, the plume bifurcated with a portion of the emissions directed to the south, southwest. In Test 98, wind conditions shifted such that the sampling array did not capture the mean plume, and the concentrations measured within 50 m of the tunnel portal were at least a factor of 2 or 3 less than the concentrations measured during Test 97.



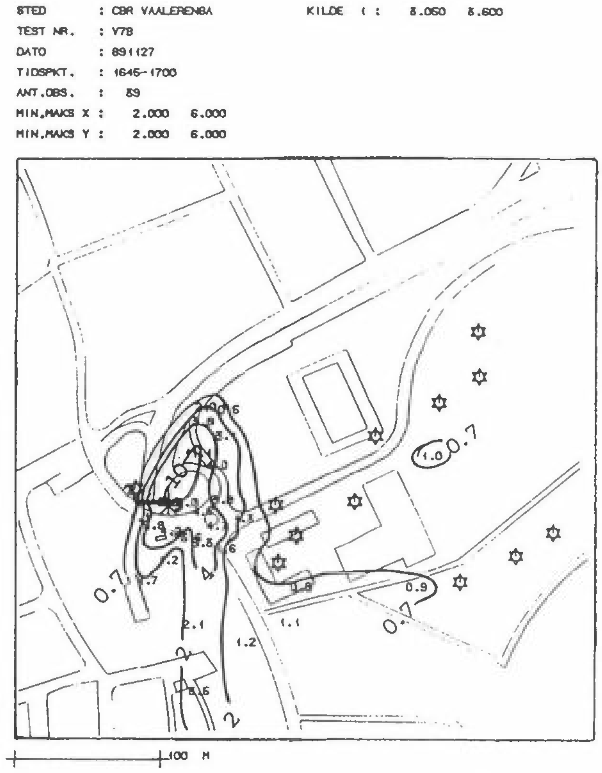


Figure 14: $CBrF_3$ isopleths for a) Test 7A, and b) Test 7B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

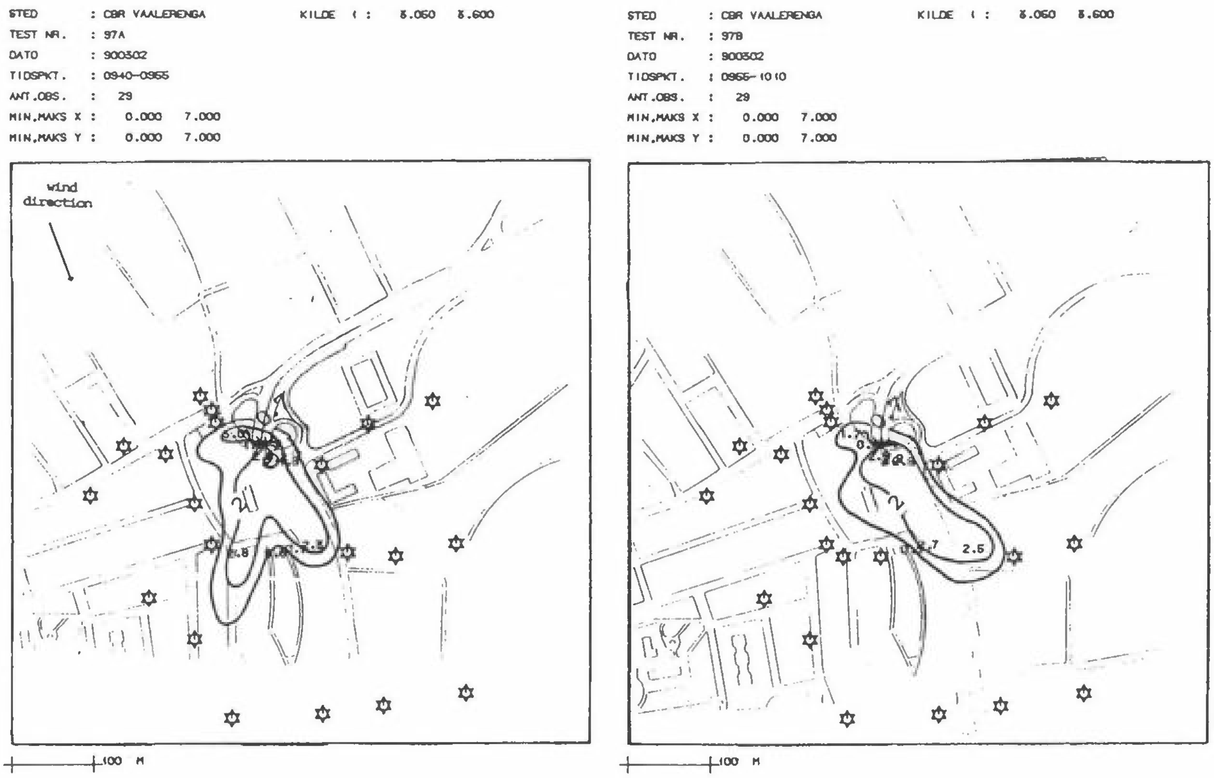
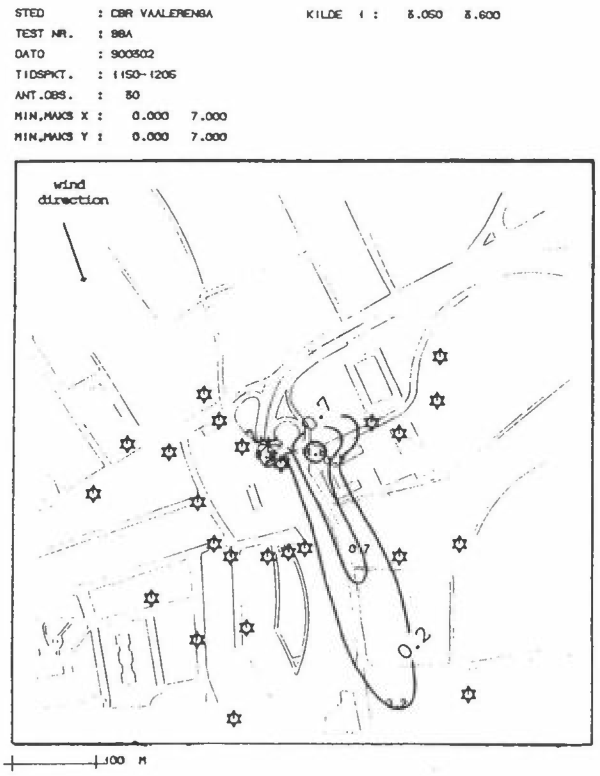


Figure 15: $CBrF_3$ isopleths for a) Test 97A, and b) Test 97B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.



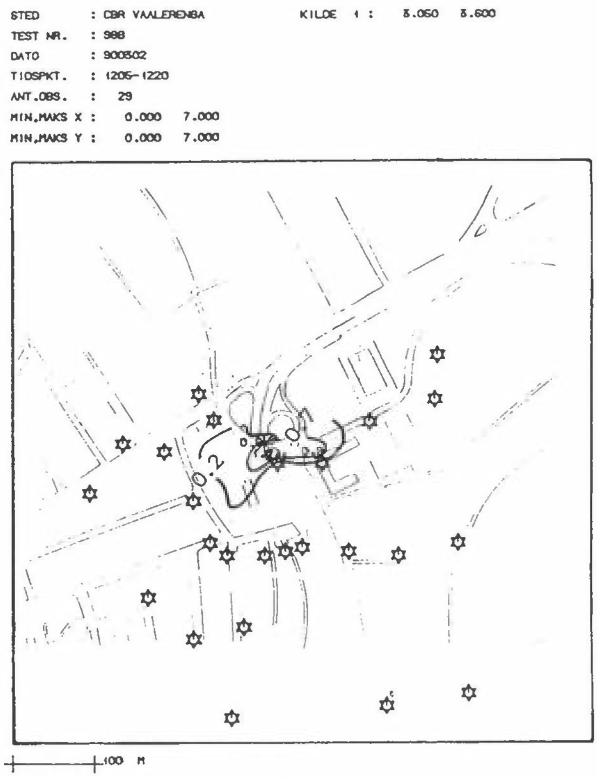


Figure 16: $CBrF_3$ isopleths for a) Test 98A, and b) Test 98B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

3.3.2 Mobile Source: TESTS 4A-98B

In Tests 4-98, SF_6 was released from three moving vehicles (equidistantly spaced) as they traveled at approximately 60 km/hr along the paths shown in Figures 2-3. In Tests 4-7, the cars released tracer as they drove through the tunnel, whereas in Tests 97-98, the release was only along the road (northeast of the tunnel portal). The concentration isopleths are shown in Figures 17-22.

While the winds were from the southwest during Tests 4-6, SF_6 was transported along the road. In all cases, the highest observed concentrations (C/Q) along the road were of order 1 or 2, and within a crosswind distance of 40-60 m, the concentrations parallel to the road were approximately 10 % of the highest concentrations.

During Test 7, the effect of the tunnel jet is apparent. The winds in this case blew from the northwest, and maximum concentrations were observed within 30-40 m of the tunnel, whereafter the emissions were transported and diffused along the direction of the wind, in particular along Biskop Nielssons Gate (very similar to the dispersion pattern from the stationary tracer source). The SF_6 released along the road was also transported and dispersed in the direction of the wind, and in general, the road emissions were diluted by a factor of 10 in approximately 100-200 m. The isolines were nearly parallel to the direction of the road, except in the vicinity of large buildings.

During Tests 97 and 98, SF_6 was released only along a 250-m section of roadway located to the northeast of the tunnel portal, and thus the concentration isopleths are not dominated by the high concentrations in the jet region. The highest concentrations were observed near the tunnel portal. These high concentrations were likely the result of the sampling points

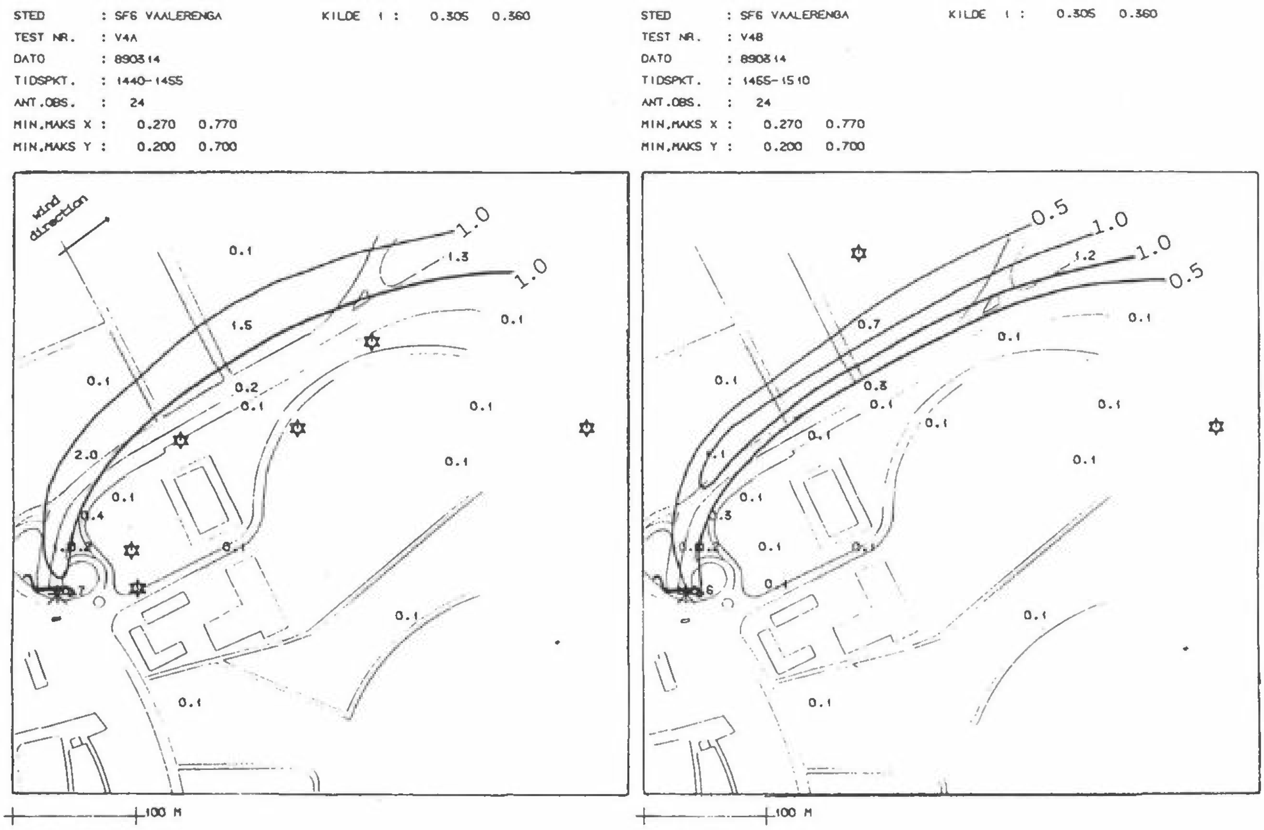


Figure 17: SF_6 isopleths for a) Test 4A, and b) Test 4B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

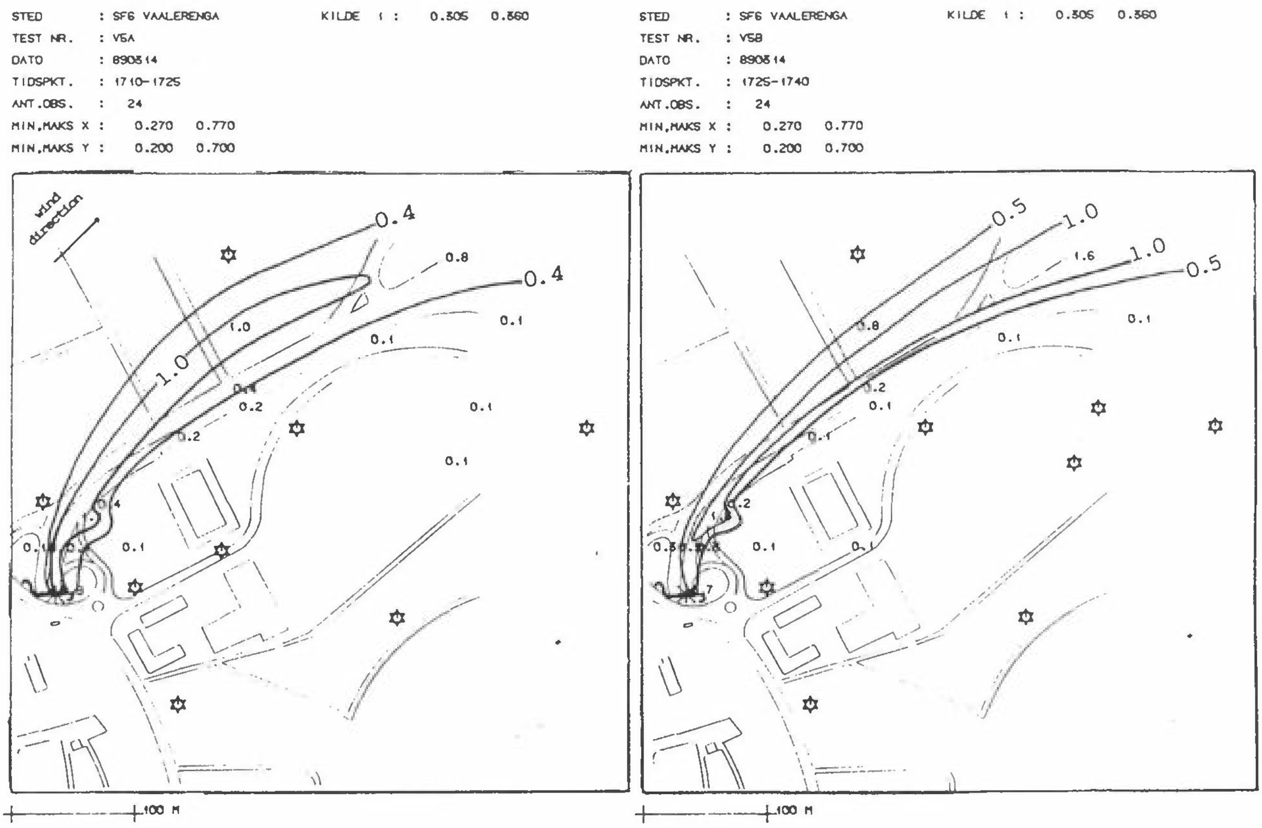


Figure 18: SF_6 isopleths for a) Test 5A, and b) Test 5B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

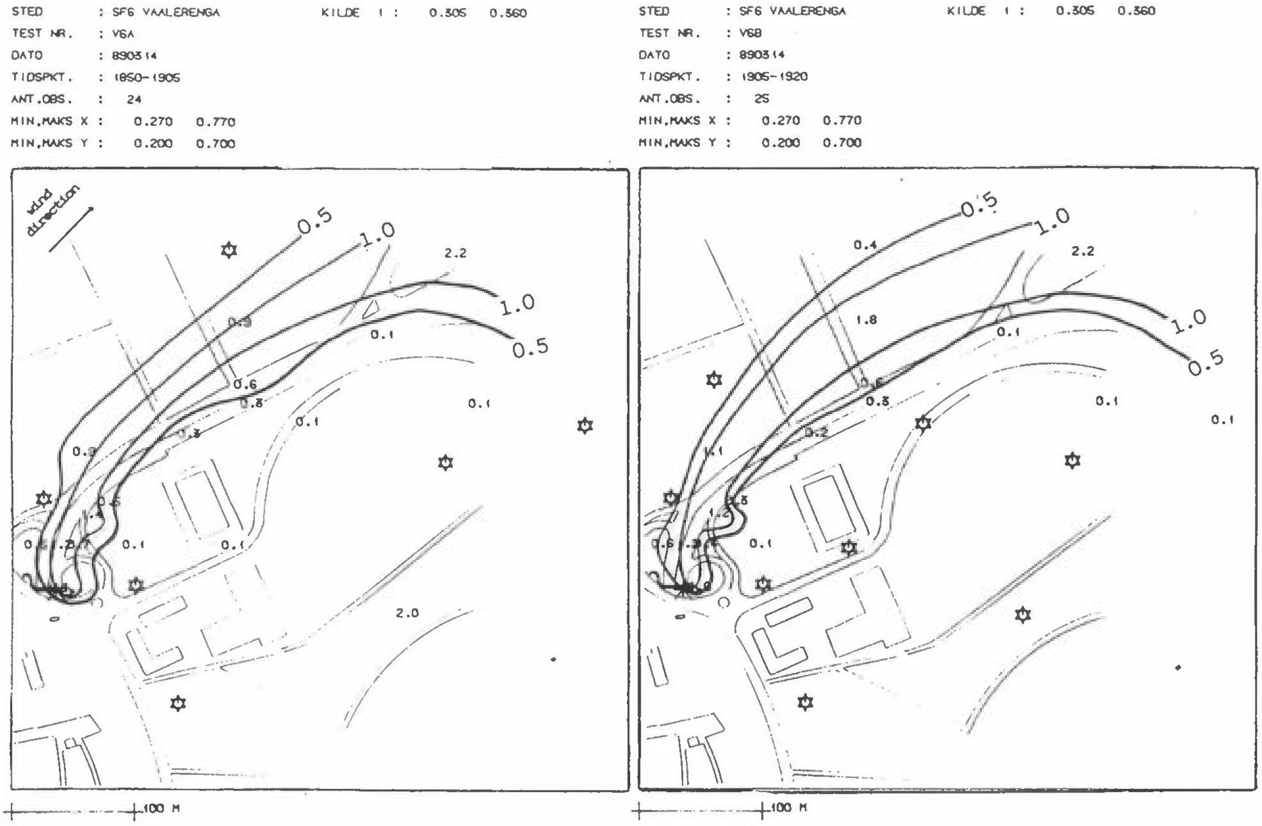


Figure 19: SF_6 isopleths for a) Test 6A, and b) Test 6B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

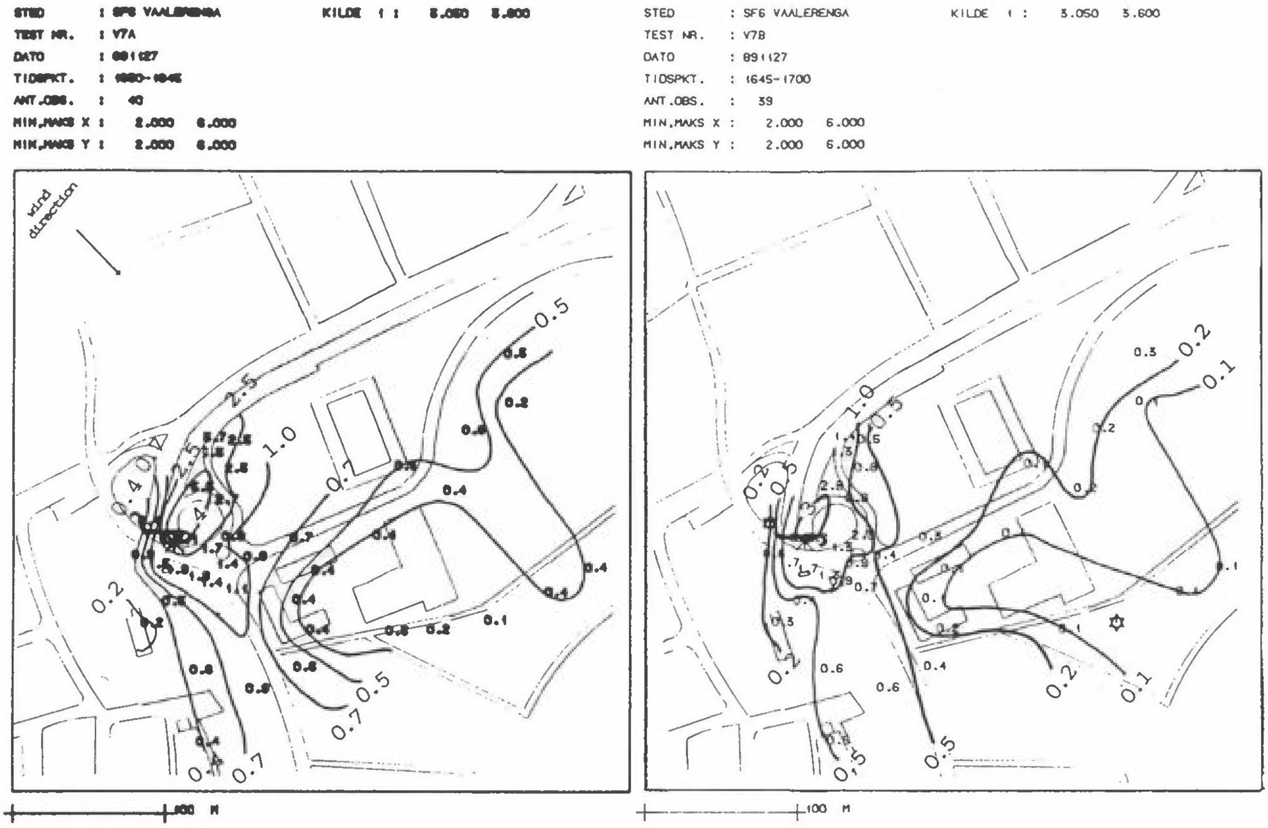


Figure 20: SF_6 isopleths for a) Test 7A, and b) Test 7B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

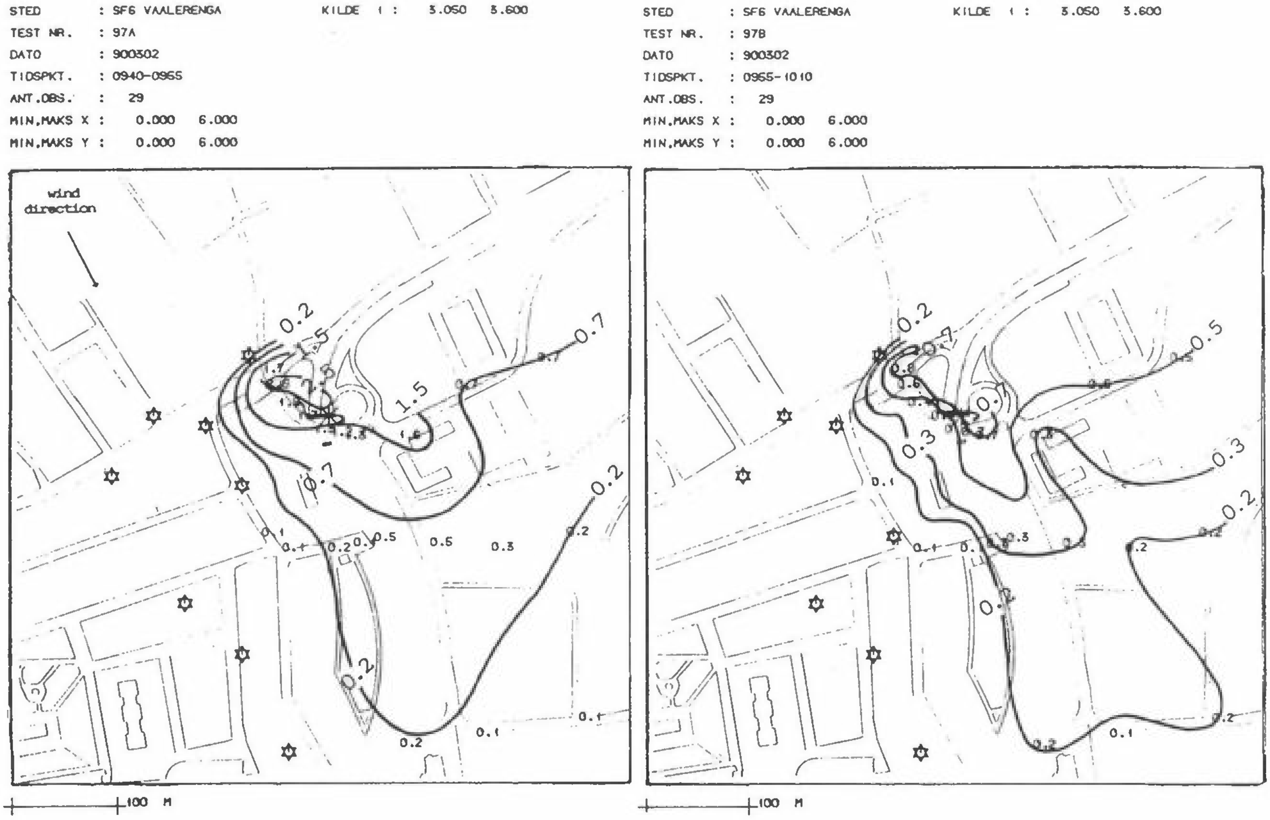


Figure 21: SF_6 isopleths for a) Test 97A, and b) Test 97B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

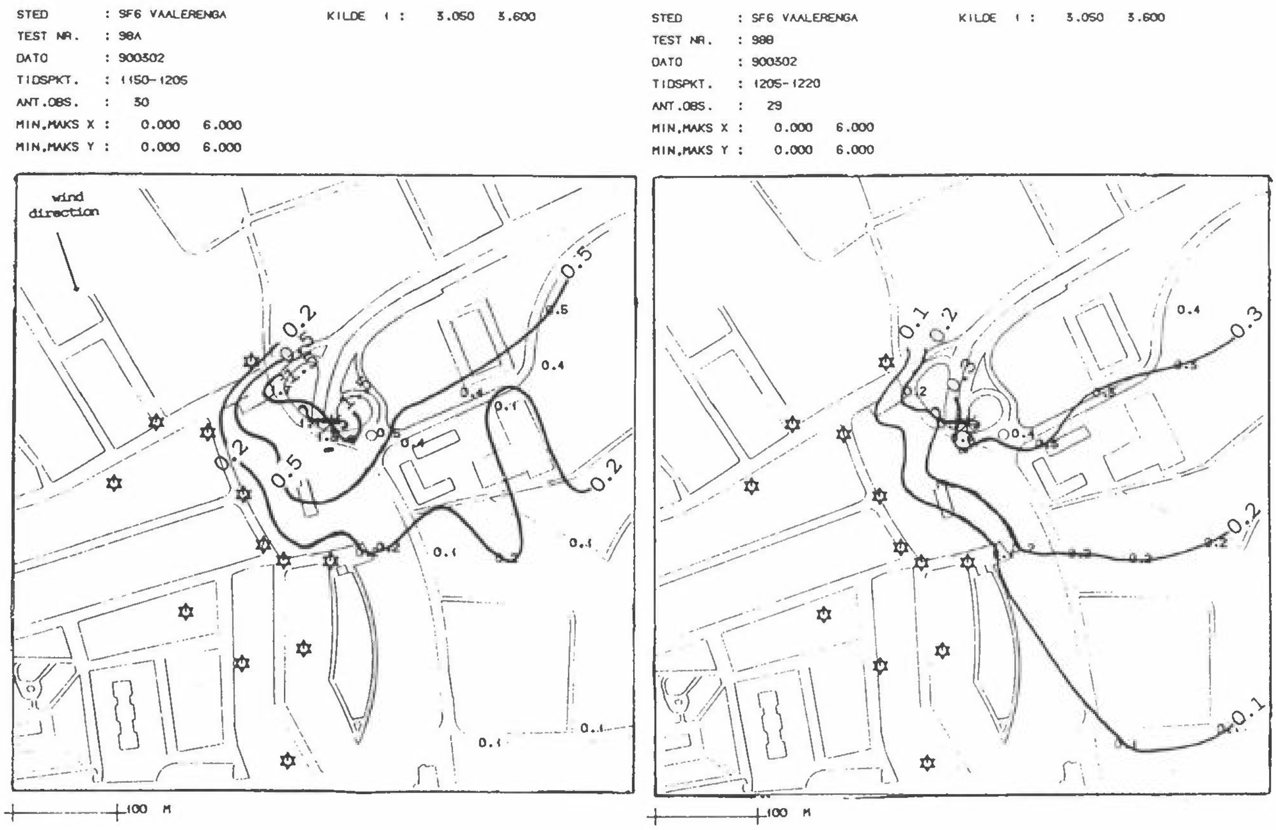


Figure 22: SF_6 isopleths for a) Test 98A, and b) Test 98B. The units are [ug m^{-3}/g min^{-1}], and the location of the tunnel portal is denoted by the symbol *.

patterns indicate drainage along Biskop Nielssons Gate during Test 97, although the isolines appear to be perpendicular to the mean wind direction within approximately 100 m of the road. In Test 98, wind direction shifted such that drainage was not observed along Biskop Nielssons Gate, but the sampling array was not large enough to capture a significant cross section of the emissions from the line source.

3.4 MODEL EVALUATION FOR TUNNEL EMISSIONS

The data from the Vålerenga tracer experiments were also used to test the dispersion model by Iversen (1982). This model computes the dispersion of traffic emissions in the vicinity of road tunnels. The dispersion process is separated into two phases: 1) the jet phase which is modeled according to the method of Ukeguchi et al. (1977), and 2) the plume phase which is modeled using the standard Gaussian formulas. Input to the model include the tunnel air speed, the mean wind speed, the cross-sectional area of the tunnel, the height of the tunnel, and the concentration of the pollutant (or tracer gas in this case) in the tunnel opening.

The model predicts the concentration for the centerline of the plume as a function of downwind distance (where X=0 corresponds to the outlet of the tunnel). The output from the model for the Vålerenga experiments are given in Appendix C. The distance to the end of the jet ranged from 11 m in Test 6B to 41 m in Test 1A.

In Figures 23-28, the concentrations observed along the centerline of the mean tracer plume at Vålerenga are shown in addition to the model predictions, and the results are given in Tables 6 and 7. (Only data from Tests 1A-6B were used to test the model because the concentration in the tunnel opening was not available for Tests 7A-98B). Although some scatter is apparent in the figures, the model performance is very good in terms of predicting the observed concentrations. As seen in the figures, both the jet phase and the plume phase are represented well. In 61.2 percent of the data, the model over-predicted the observed concentrations. The highest ratio of predicted to observed concentration was 2.2, and in 73.3 percent of the over-predicted cases, the ratio was less than 1.5. For the 38.8 percent of the data in which the model under-predicted the observed concentrations, the lowest ratio of predicted to observed concentration was 0.38, while in 94.7 percent of the under-predicted cases, the ratio was greater than 0.5. The overall average ratio was 1.12.

Several factors may contribute to the differences between the model predictions and the observed tracer data. First, the model assumes steady state conditions, and because the data are collected during a fixed, 15-minute period, it is possibile for traffic conditions and/or meteorological conditions to change during the sampling interval. Second, the model predicts concentrations on the centerline of the plume as a function of downwind distance, but the resolution of the centerline of the real plume is a function of the spacing and orientation of the sampling array. Furthermore, tracer emission and analysis errors limit the accuracy of the observed normalized concentrations, but if the emission and analysis errors are within 10 %, the ratio of the observed normalized concentration to the actual normalized concentration should range bewteen 0.82 and 1.22.

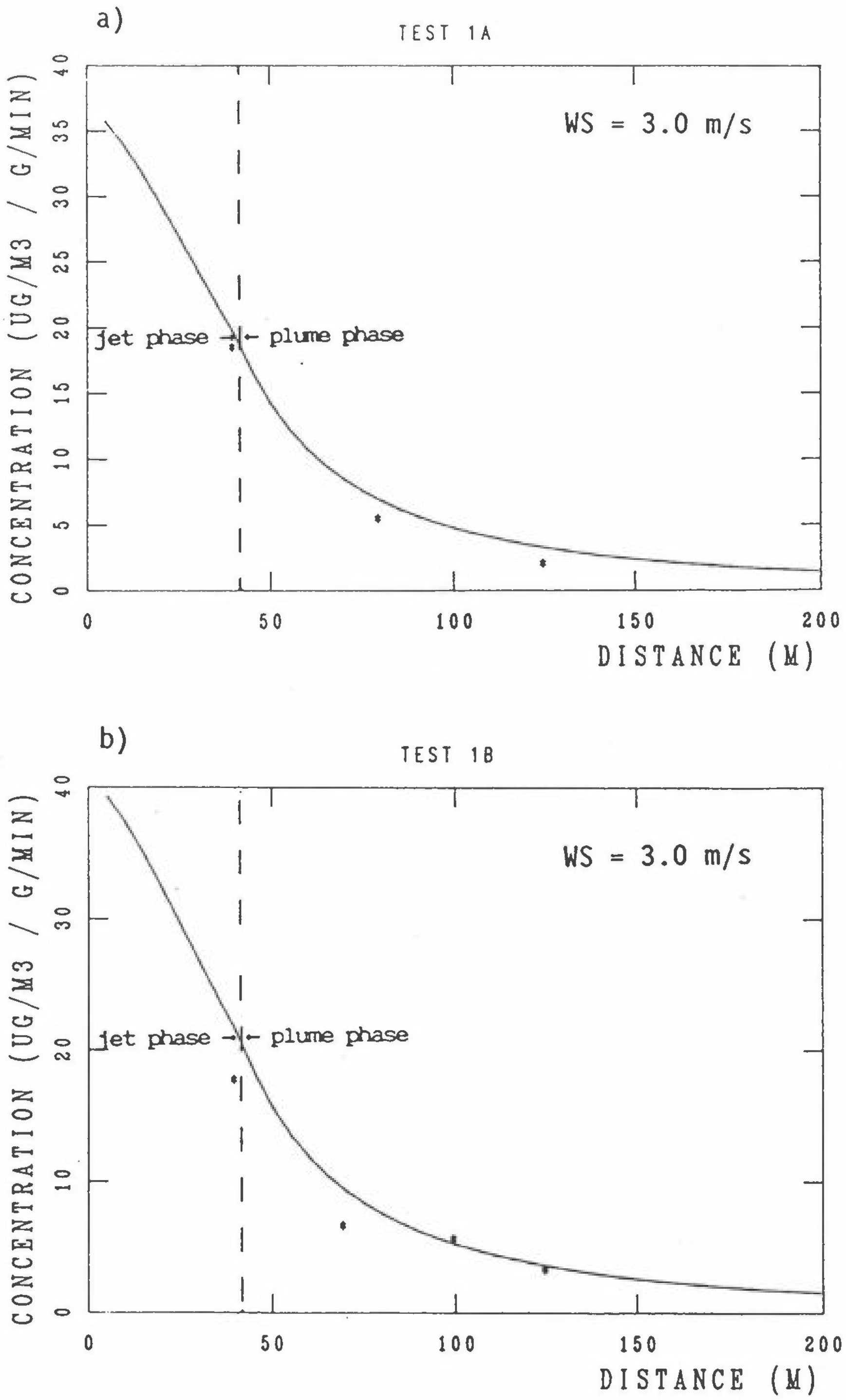
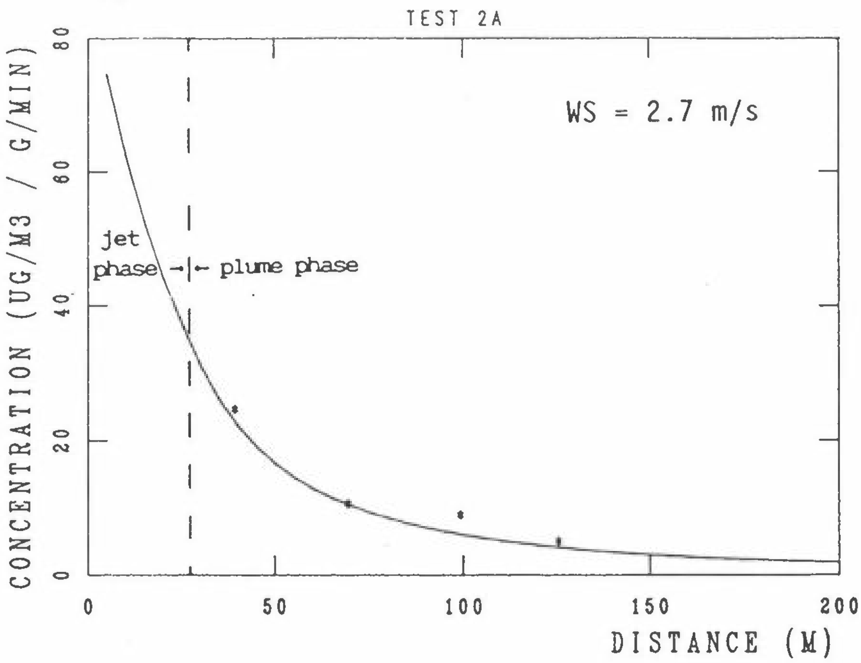


Figure 23: Concentration as a function of distance from the tunnel for a) Test 1A, and b) Test 1B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

a)



b)

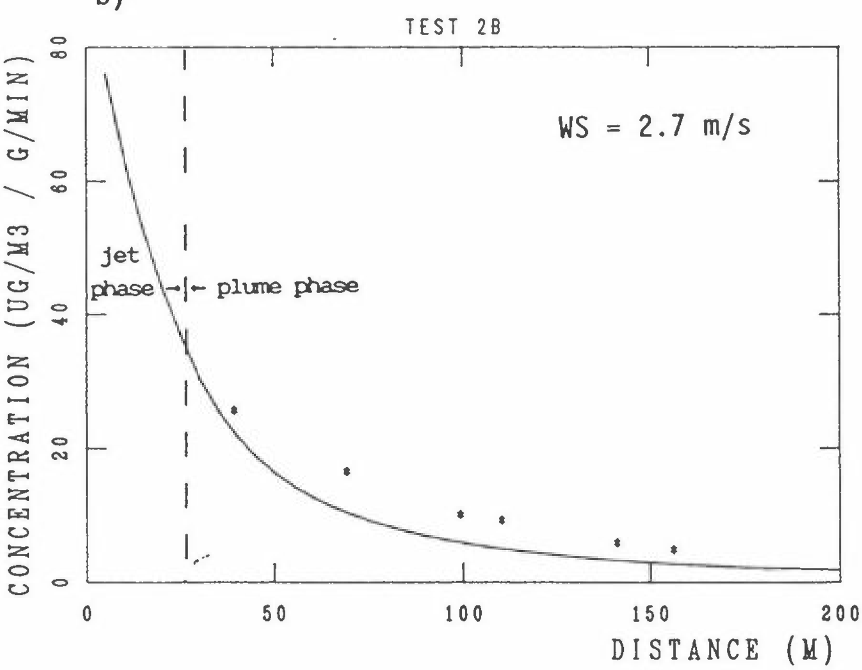


Figure 24: Concentration as a function of distance from the tunnel for a) Test 2A, and b) Test 2B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

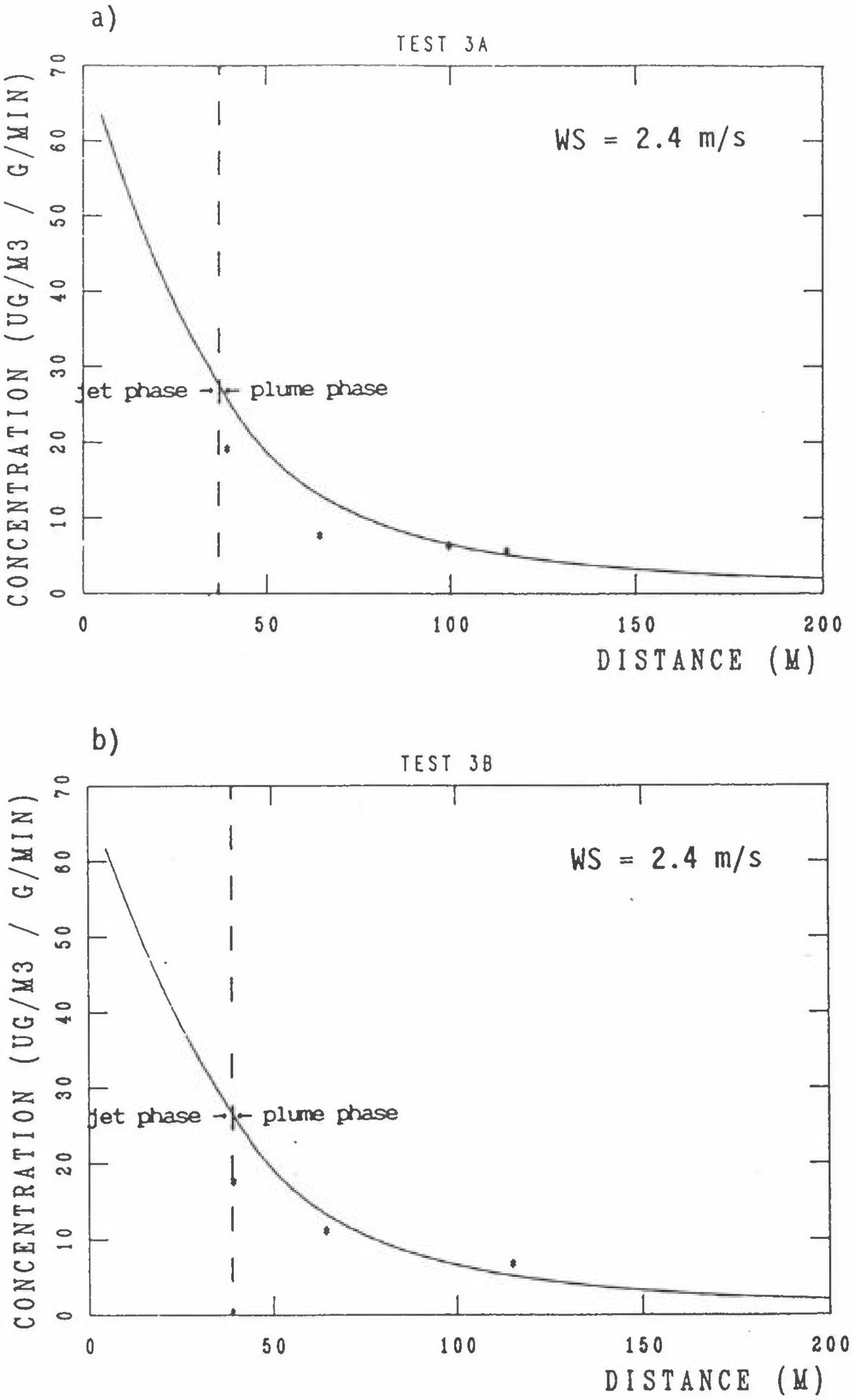


Figure 25: Concentration as a function of distance from the tunnel for a) Test 3A, and b) Test 3B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

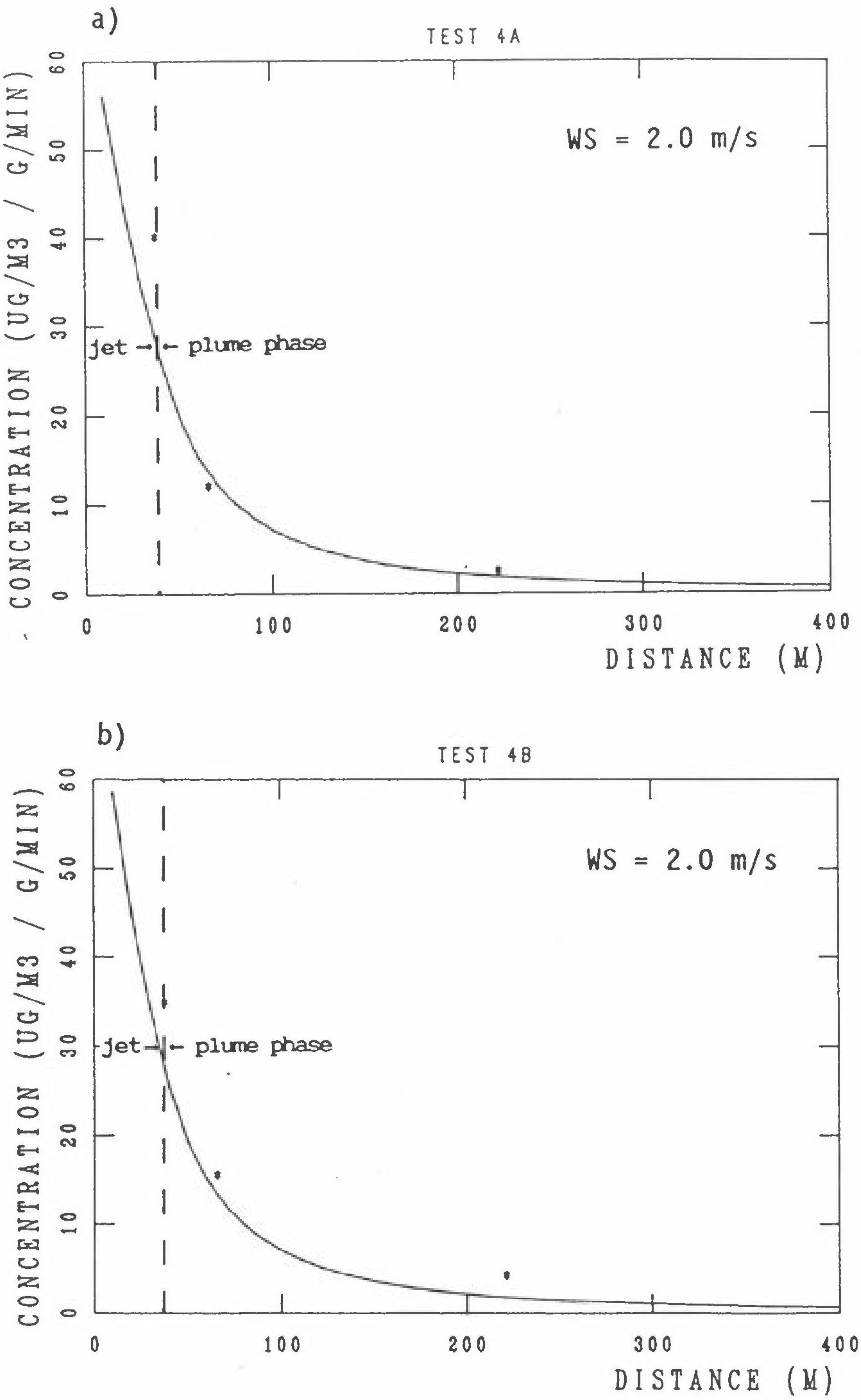


Figure 26: Concentration as a function of distance from the tunnel for a) Test 4A, and b) Test 4B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

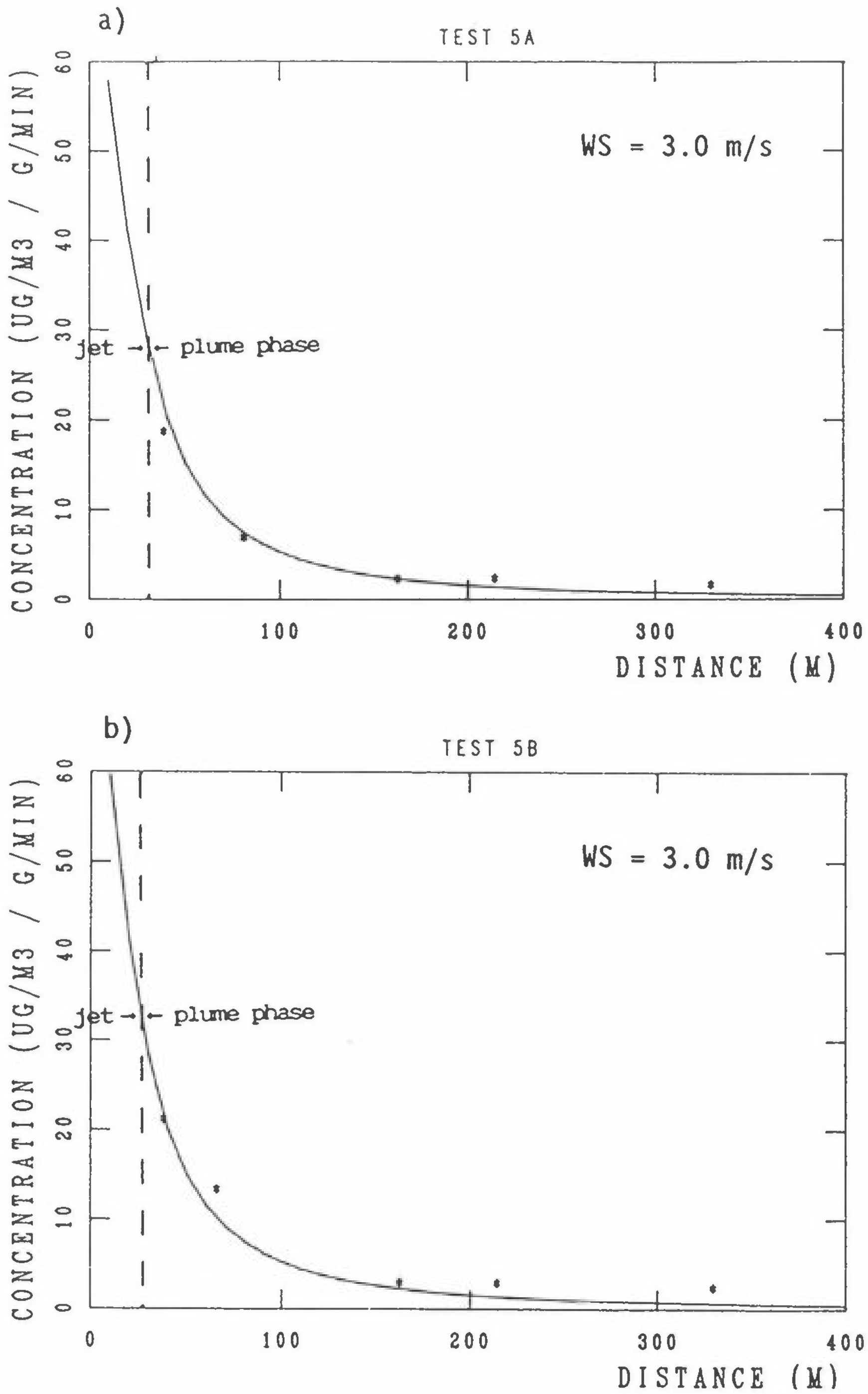


Figure 27: Concentration as a function of distance from the tunnel for a) Test 5A, and b) Test 5B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

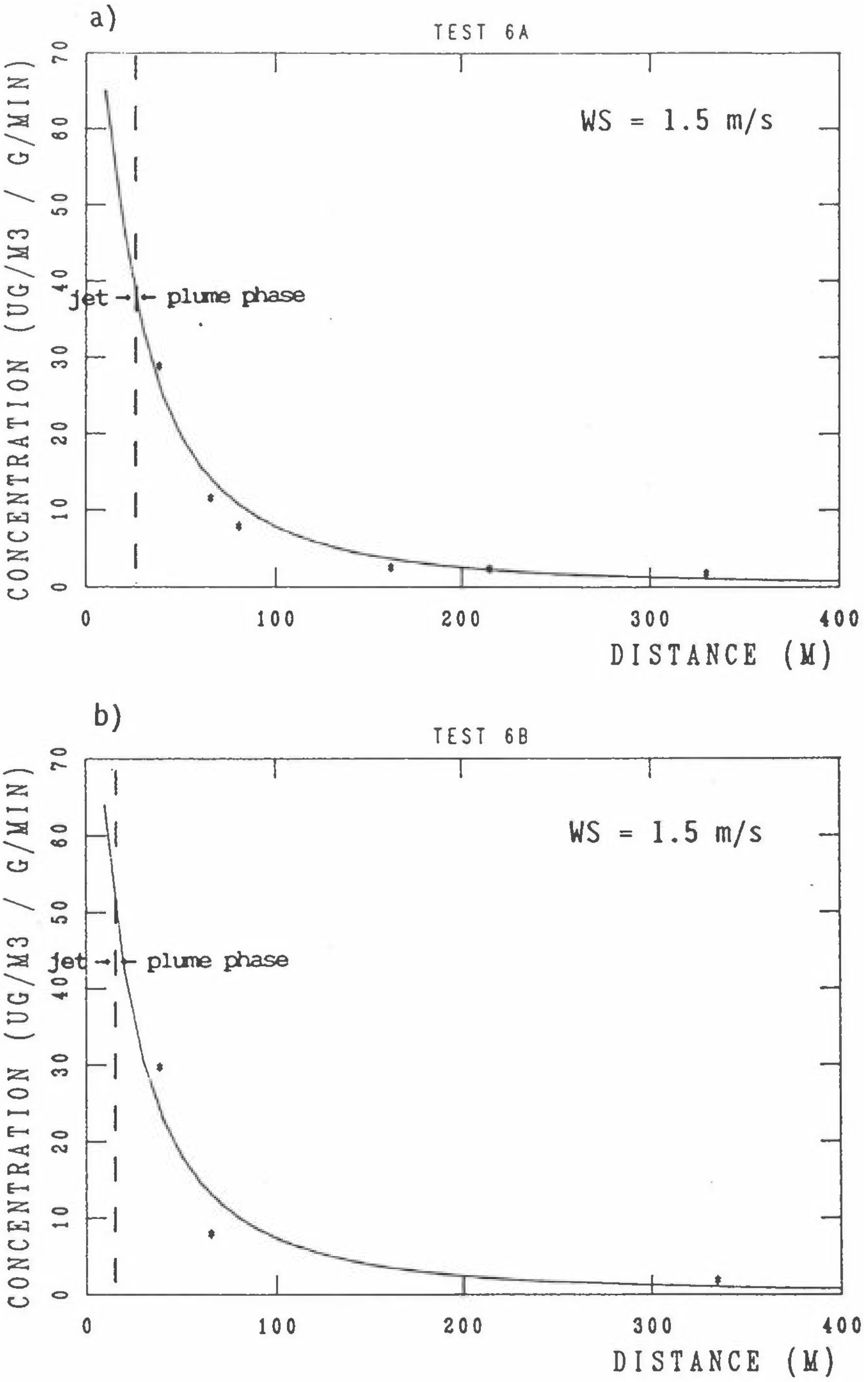


Figure 28: Concentration as a function of distance from the tunnel for a) Test 6A, and b) Test 6B. The curve represents the model of Iversen (1982), while the observed tracer data are denoted by the symbol *.

Table 6: Observed and model results.

Test	C_{obs}	X	C_{pre}	X	Ratio	Avg.
V1A	18.06	38	19.56	40	1.08	
	5.05	78	6.92	80	1.37	
	1.61	123	3.30	125	2.05	1.50 (0.50)
V1B	17.32	38	21.52	40	1.24	
	6.20	68	9.41	70	1.52	
	5.21	98	5.28	100	1.01	
	2.90	123	3.63	125	1.25	1.26 (0.21)
V2A	23.71	38	22.35	40	1.24	
	9.76	68	10.41	70	1.07	
	8.00	98	6.01	100	0.75	
	4.15	124	4.18	125	1.01	1.02 (0.20)
V2B	24.74	38	21.97	40	0.89	
	15.60	68	10.30	70	0.66	
	9.16	98	5.96	100	0.65	
	8.33	109	5.12	110	0.61	
	5.00	140	3.44	140	0.69	
	3.99	155	2.89	155	0.72	0.70 (0.10)
V3A	18.33	38	25.22	40	1.38	
	6.86	63	12.84	65	1.87	
	5.67	98	6.57	100	1.16	
	4.90	114	5.23	115	1.07	1.37 (0.36)
V3B	16.80	38	26.02	40	1.55	
	10.31	63	13.14	65	1.27	
	5.96	114	5.32	115	0.89	1.24 (0.33)

where:

C_{obs} = Normalized concentration observed on the center-line of the mean plume

C_{pre} = Normalized concentration predicted by the model

X = Downwind distance from tunnel exit

Ratio = Ratio of C_{pre} to C_{obs}

Avg. = Average (and standard deviation) of the Ratios.

Table 7: Observed and model results.

Test	C_{obs}	X	C_{pre}	X	Ratio	Avg.
V4A	39.45	35	29.86	36	0.76	
	11.44	63	14.26	64	1.25	
	1.88	219	1.92	220	1.02	1.01 (0.25)
V4B	34.22	35	28.27	36	0.83	
	14.86	63	13.73	64	0.92	
	3.58	219	2.06	210	0.58	0.78 (0.18)
V5A	30.41	36	23.60	36	0.78	
	6.33	78	7.93	78	1.25	
	1.72	160	2.42	160	1.41	
	1.67	212	1.50	210	0.90	
	0.96	327	0.66	330	0.69	1.01 (0.31)
V5B	20.59	35	23.60	36	1.15	
	12.69	63	10.71	64	0.84	
	2.38	160	2.42	160	1.02	
	2.23	212	1.50	219	0.67	
	1.75	327	0.66	330	0.38	0.81 (0.30)
V6A	28.05	36	28.35	36	1.01	
	10.78	63	14.60	64	1.35	
	7.09	78	11.23	178	1.58	
	1.74	160	3.82	160	2.20	
	1.66	212	2.43	210	1.46	
	0.98	327	1.11	330	1.13	1.46 (0.42)
V6B	28.95	36	25.93	36	0.90	
	7.14	63	13.55	64	1.90	
	0.54	332	1.07	330	1.98	1.59 (0.60)
						Overall avg.
						1.12 (0.41)

where:
C_{obs} = Normalized concentration observed on the center-line of the mean plume
C_{pre} = Normalized concentration predicted by the model
X = Downwind distance from tunnel exit
Ratio = Ratio of C_{pre} to C_{obs}
Avg. = Average (and standard deviation) of the Ratios.

4 CONCLUSIONS

Eighteen tracer tests were recently conducted in Oslo to investigate dispersion of traffic emissions in the vicinity of the Vålerenga tunnel. A dual tracer system was used in which two tracer gases, sulfur hexafluoride (SF_6) and bromotrifluoromethane ($CBrF_3$), were used to simulate traffic emissions. One of the tracers was released (at a constant rate) from a fixed location in the south end of the north bound tunnel tube, while the other tracer gas was released from vehicles travelling with the traffic. The objectives of using a stationary tracer source were: 1) to provide information about the airflow through the tunnel, and 2) to characterize the dispersion of tunnel gases in the residential area. The objectives of using a mobile tracer source were: 1) to investigate the spatial and temporal characteristics of emissions from a single car traveling with traffic, and 2) to characterize dispersion of gases released along the roadway. Time-averaged air samples were collected within the tunnel tube and within 400 m of the tunnel portal using an array of automatic, portable syringe samplers. In addition, during three tests, series of instantaneous grab samples were collected at two locations near the tunnel exit. Each test was 15 minutes in duration, and all samples were analyzed using gas chromatography.

Tests were conducted under stable, wintertime conditions during morning, afternoon, and evening hours. As estimated from the 15-min average concentrations of the stationary source gas, the average air flowrate (through the tunnel) ranged from 155.9 to 403.8 m^3/s. The highest flowrate was observed during the afternoon rush hour, while the lowest flowrate occurred during an evening test. The time for the air to be transported through the north bound tunnel was between 129 and 336 s, and mean concentrations on the right side of the tunnel were always greater than or equal to the mean concentrations on the left side of the tunnel.

The tracer data from the instantaneous samples also revealed higher concentrations (of the mobile source gas) on the right side of the tunnel than on the left side. On the right side, concentrations peaked within 20-25 s after the release vehicle passed, whereas on the left, concentrations peaked within 40-60 s. The magnitude of the maximum observed concentration was

1.7-2.0 times greater at the sampling point located on the right side of the tunnel than at the sampling point located on the left. However, after the concentration peaked at the left sampling location, the concentration time series from the two locations appeared to collapse to a single curve. As estimated from the time series data, the time for air to be transported through the north bound tunnel was 125 s during Test 1B, 250 s during Test 2B, and 275 s during Test 3A.

Under conditions of southwesterly winds, the mean plume of tunnel emissions consisted of two dispersion regimes: 1) an initial jet region in which high concentrations were measured within 35-38 m of the tunnel exit; and 2) a plume phase in which concentrations decay according to Gaussian theory. The mean concentration within the tunnel was 2-4 times greater than the mean concentration on a traffic island located <50 m from the tunnel exit, and within 60-150 m, the concentration on the centerline of the mean plume fell to approximately 10 % of the concentration observed within the tunnel. Amid northerly and northwesterly winds, jet and dispersion regimes were apparent, but the impact of the jet was a factor of 2 or 3 less than observed amid southwesterly winds, and the dispersion of the mean plume was dominated by channelling flows along Biskop Nielssons Gate.

Tracer emitted from moving vehicles was transported along the road during periods with southwesterly winds, and within a crosswind distance of 40-60 m, the concentrations fell to approximately 10 % the concentrations along the roadway. While the winds blew from the northwest, and during the tests when the release vehicles drove through the tunnel, the concentration patterns of the jet and dispersion regimes were similar to the concentration patterns from the stationary source. In general, tracer emitted along the roadway was transported and diffused along the direction of the mean winds, but in the case of light, northerly winds, a fraction of the mass was entrained by south bound traffic, or by fluctuating winds, into the portal area.

The tracer data from the Vålerenga experiments were used to test the dispersion model of Iversen (1982). The model predicted jet phase and plume phase concentrations which compared well to the observed data. The highest and lowest ratio of the predicted to observed concentration was 2.2 and 0.38, respectively, while the average ratio was 1.12.

ACKNOWLEDGEMENTS

The following NILU personnel are gratefully acknowledged for their planning, expertise, and help during the Vålerenga tunnel experiments: Trond Bøhler, Ivar Haugsbakk, Reidar Heggen, Alf Holen, Mona Johnsrud, Steinar Larssen, Dag Tønnesen, and Sverre Skrolsvik. Trond Iversen is also acknowledged as the author of the dispersion model. The work was conducted under a contract with Oslo Kommune and Vegdirektoratet, and the author of this document (HP) was sponsored by a postdoctoral fellowship from the Norwegian Council for Science and Industrial Research (NTNF).

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APPENDIX A

Tracer data for stationary source

STED : SF6 VAALERENGA
TEST NR. : V1A
DATO : 89-01-17
TIDSPKT. : 1515-1530
ANT.OBS. : 25
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	SF6/Q UG/M3 G/MIN
3.700	3.200	.16
3.750	3.600	1.56
3.700	3.800	3.23
3.600	4.050	4.75
3.550	4.200	5.05
3.550	4.450	3.58
3.600	4.550	2.35
3.250	4.250	3.99
3.200	3.950	18.06
3.150	3.600	36.85
3.000	3.600	36.85
4.200	2.300	.14
4.550	3.450	.15
4.500	3.750	.71
4.300	3.900	1.81
4.200	4.200	1.53
4.100	4.500	1.34
3.900	4.500	1.61
3.850	4.650	1.11
3.900	4.900	.77
2.600	4.350	.07
3.100	4.650	.09
3.400	4.950	.29
3.950	5.300	.85
2.900	4.350	.02

STED : SF6 VAALERENGA
TEST NR. : V1B
DATO : 89-01-17
TIDSPKT. : 1530-1545
ANT.OBS. : 25
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	SF6/Q UG/M3 G/MIN
3.700	3.200	.03
3.750	3.600	.77
3.700	3.800	2.02
3.600	4.050	4.04
3.550	4.200	5.70
3.550	4.450	5.21
3.600	4.550	4.19
3.250	4.250	6.20
3.200	3.950	17.32
3.150	3.600	40.53
3.000	3.600	36.85
4.200	2.300	.04
4.550	3.450	.03
4.500	3.750	.27
4.300	3.900	1.82
4.200	4.200	2.00
4.100	4.500	2.59
3.900	4.500	2.90
3.850	4.650	2.54
3.900	4.900	.69
2.600	4.350	.05
3.100	4.650	.23
3.400	4.950	.33
3.950	5.300	.62
2.900	4.350	.05

STED : SF6 VAALERENGA
TEST NR. : V2A
DATO : 89-01-17
TIDSPKT. : 1720-1735
ANT.OBS. : 27
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	KOORDINATER Y	SF6/Q UG/M3 / G/MIN
3.700	3.200	.09
3.750	3.600	1.39
3.700	3.800	2.46
3.600	4.050	5.04
3.550	4.200	7.57
3.550	4.450	8.00
3.600	4.550	6.11
3.250	4.250	9.76
3.200	3.950	23.71
3.150	3.600	86.59
3.000	3.600	89.68
3.000	3.900	17.52
2.800	3.900	1.89
2.950	4.300	1.23
4.200	2.300	.09
4.550	3.450	.13
4.500	3.750	.65
4.300	3.900	2.59
4.250	4.300	2.65
3.850	4.550	4.15
3.850	4.750	3.65
3.900	4.900	2.96
2.600	4.350	.07
3.100	4.650	.87
3.400	4.950	.53
3.950	5.300	1.19
2.900	4.350	.48

STED : SF6 VAALERENGA
TEST NR. : V2B
DATO : 89-01-17
TIDSPKT. : 1735-1750
ANT.OBS. : 27
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	KOORDINATER Y	SF6/Q UG/M3 / G/MIN
3.700	3.200	.09
3.750	3.600	.09
3.700	3.800	.28
3.600	4.050	2.47
3.550	4.200	7.14
3.550	4.450	9.16
3.600	4.550	8.33
3.250	4.250	15.60
3.200	3.950	24.74
3.150	3.600	92.77
3.000	3.600	92.77
3.000	3.900	24.74
2.800	3.900	.52
2.950	4.300	.55
4.200	2.300	.15
4.550	3.450	.13
4.500	3.750	.09
4.300	3.900	.87
4.250	4.300	2.07
3.850	4.550	4.63
3.850	4.750	5.00
3.900	4.900	3.99
2.600	4.350	.07
3.100	4.650	.36
3.400	4.950	1.09
3.950	5.300	2.45
2.900	4.350	.10

STED : SF6 VAALERENGA
TEST NR. : V3A
DATO : 89-01-17
TIDSPKT. : 1955-2010
ANT.OBS. : 25
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	SF6/Q $\frac{UG/M^3}{G/MIN}$
3.750	3.250	.02
3.800	3.600	.10
3.700	3.800	.30
3.600	4.050	1.87
3.550	4.250	4.99
3.550	4.450	5.67
3.600	4.600	4.90
3.250	4.200	6.86
3.200	3.950	18.33
3.150	3.600	8.25
3.000	3.600	70.87
3.000	3.900	8.12
2.850	3.900	.79
4.200	2.450	.04
4.600	3.400	.02
4.600	3.800	.04
4.350	4.000	.47
4.200	4.200	1.37
3.900	4.600	2.93
3.950	4.750	2.96
2.600	4.350	.03
3.100	4.650	.04
3.400	4.950	.11
3.950	4.300	.69
2.900	4.350	.04

STED : SF6 VAALERENGA
TEST NR. : V3B
DATO : 89-01-17
TIDSPKT. : 2010-2025
ANT.OBS. : 25
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	SF6/Q $\frac{UG/M^3}{G/MIN}$
3.750	3.250	.05
3.800	3.600	.04
3.700	3.800	.09
3.600	4.050	.57
3.550	4.250	3.36
3.550	4.450	6.29
3.600	4.600	5.96
3.250	4.200	10.31
3.200	3.950	16.80
3.150	3.600	8.21
3.000	3.600	67.97
3.000	3.900	16.80
2.850	3.900	.89
4.200	2.450	.14
4.600	3.400	.05
4.600	3.800	.05
4.350	4.000	.21
4.200	4.200	1.01
3.900	4.600	2.93
3.950	4.750	3.26
2.600	4.350	.02
3.100	4.650	.03
3.400	4.950	.22
3.950	4.300	1.18
2.900	4.350	.08

STED : CBRF3 VAALERENGA
TEST NR. : V4A
DATO : 89-03-14
TIDSPKT. : 1440-1455
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	CBRF3/Q UG/M3 G/MIN
.310	.360	69.64
.315	.395	15.72
.300	.395	39.45
.325	.420	11.44
.320	.470	.89
.330	.530	.40
.445	.575	1.75
.445	.635	.76
.405	.270	.00
.370	.365	.00
.365	.395	.70
.350	.435	3.71
.405	.485	1.40
.450	.525	1.88
.455	.510	1.24
.440	.395	.00
.500	.495	.20
.560	.565	.39
.620	.630	.48
.620	.465	.00
.640	.510	.00
.665	.580	.84
.580	.340	.00
.735	.495	.00

STED : CBRF3 VAALERENGA
TEST NR. : V4B
DATO : 89-03-14
TIDSPKT. : 1455-1510
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	CBRF3/Q UG/M3 G/MIN
.310	.360	75.66
.315	.395	20.57
.300	.395	34.22
.325	.420	14.86
.320	.470	.25
.330	.530	.00
.445	.575	2.31
.445	.635	.00
.405	.270	.00
.370	.365	.00
.365	.395	.57
.350	.435	5.82
.405	.485	3.10
.450	.525	3.58
.455	.510	2.26
.440	.395	.64
.500	.495	.00
.560	.565	1.38
.620	.630	1.14
.620	.465	.00
.640	.510	1.28
.665	.580	.00
.580	.340	.00
.735	.495	.00

STED : CBRF3 VAALERENGA
TEST NR. : V5A
DATO : 89-03-14
TIDSPKT. : 1710-1725
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	CBRF3/Q UG/M^3 / G/MIN
.310	.360	81.81
.315	.395	30.41
.300	.395	16.13
.280	.395	.00
.325	.420	8.55
.295	.435	.00
.445	.575	.28
.445	.635	.00
.405	.270	.00
.370	.365	.00
.360	.395	4.36
.340	.430	6.33
.405	.485	1.72
.450	.525	.77
.455	.510	1.67
.440	.395	.00
.500	.495	.54
.560	.565	.96
.620	.630	.00
.620	.465	.00
.640	.510	.00
.665	.580	.00
.580	.340	.00
.735	.495	.00

STED : CBRF3 VAALERENGA
TEST NR. : V5B
DATO : 89-03-14
TIDSPKT. : 1725-1740
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	CBRF3/Q UG/M^3 / G/MIN
.310	.360	88.26
.315	.395	17.53
.300	.395	20.59
.280	.395	1.88
.325	.420	12.69
.295	.435	.00
.445	.575	.00
.445	.635	1.14
.405	.270	.00
.370	.365	.00
.360	.395	2.63
.340	.430	6.61
.405	.485	2.38
.450	.525	2.21
.455	.510	2.23
.440	.395	.95
.500	.495	.54
.560	.565	1.75
.620	.630	.00
.620	.465	.00
.640	.510	.00
.665	.580	.00
.580	.340	.54
.735	.495	.00

STED : CBRF3 VAALERENGA
TEST NR. : V6A
DATO : 89-03-14
TIDSPKT. : 1850-1905
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	KOORDINATER Y	CBRF3/Q UG/M3 G/MIN
.310	.360	94.16
.315	.395	28.05
.300	.395	17.03
.280	.395	.28
.325	.420	10.78
.295	.435	.00
.320	.470	.00
.445	.575	.00
.445	.635	.00
.405	.270	.00
.370	.365	.00
.360	.395	3.80
.340	.430	7.09
.405	.485	1.74
.450	.525	.45
.455	.510	1.66
.440	.395	.00
.500	.495	.00
.560	.565	.98
.620	.630	.00
.620	.465	.00
.640	.510	.24
.580	.340	.00
.735	.495	.00

STED : CBRF3 VAALERENGA
TEST NR. : V6B
DATO : 89-03-14
TIDSPKT. : 1905-1920
ANT.OBS. : 25
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	KOORDINATER Y	CBRF3/Q UG/M3 G/MIN
.310	.360	106.93
.315	.395	28.95
.300	.395	17.80
.280	.395	.00
.325	.420	7.14
.295	.435	.00
.320	.470	.00
.330	.530	.00
.445	.575	.00
.445	.635	.00
.405	.270	.00
.370	.365	.21
.360	.395	6.24
.340	.430	4.80
.405	.485	.83
.450	.525	.00
.455	.510	.00
.440	.395	.30
.500	.495	.43
.560	.565	.00
.620	.630	.00
.620	.465	.54
.640	.510	.19
.580	.340	.00
.735	.495	.00

STED : CBR VAALERENGA
TEST NR. : V7A
DATO : 89-11-27
TIDSPKT. : 1630-1645
ANT.OBS. : 40
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	cbrf3/Q UG/M3 G/MIN
3.820	2.780	.87
4.420	3.010	2.33
4.690	3.020	1.40
5.060	3.080	1.80
5.450	3.260	.00
5.710	3.420	.00
5.180	4.810	1.07
5.190	4.490	.00
4.790	3.920	.00
4.910	4.310	.00
4.470	4.080	.96
4.330	3.630	1.35
3.930	3.400	1.57
3.790	3.610	.00
3.500	3.490	2.93
3.810	3.210	.52
3.900	3.020	.00
2.840	3.060	.68
2.980	3.200	2.08
3.160	2.760	1.68
3.520	2.640	3.27
3.200	2.300	3.37
3.320	3.440	3.02
3.400	4.240	.00
3.240	4.260	.98
3.220	4.160	.95
3.380	4.060	1.17
3.160	3.940	9.75
3.320	3.860	2.99
3.360	3.620	1.40
3.220	3.540	5.33
3.060	3.600	12.74
2.960	3.600	10.00
2.820	3.720	3.02
2.780	3.500	2.50
2.880	3.440	4.83
3.000	3.400	3.92
3.140	3.360	2.62
3.220	3.320	4.63
3.380	3.280	1.91

STED : CBR VAALERENGA
TEST NR. : V7B
DATO : 89-11-27
TIDSPKT. : 1645-1700
ANT.OBS. : 39
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	cbrf3/Q UG/M3 G/MIN
3.820	2.780	1.11
4.690	3.020	.93
5.060	3.080	.00
5.450	3.260	.00
5.710	3.420	.00
5.180	4.810	.00
5.190	4.490	.00
4.790	3.920	.96
4.910	4.310	.00
4.470	4.080	.00
4.330	3.630	.00
3.930	3.400	.00
3.790	3.610	.00
3.500	3.490	1.30
3.810	3.210	.00
3.900	3.020	.86
2.840	3.060	1.73
2.980	3.200	1.19
3.160	2.760	2.08
3.520	2.640	1.22
3.200	2.300	3.52
3.320	3.440	4.68
3.400	4.240	.47
3.240	4.260	1.96
3.220	4.160	3.79
3.380	4.060	3.07
3.160	3.940	11.10
3.320	3.860	4.00
3.360	3.620	3.76
3.220	3.540	4.57
3.060	3.600	14.02
2.960	3.600	10.95
2.820	3.720	.00
2.780	3.500	1.07
2.880	3.440	5.90
3.000	3.400	4.20
3.140	3.360	3.59
3.220	3.320	5.30
3.380	3.280	1.61

STED : CBR VAALERENGA
TEST NR. : 97A
DATO : 90-03-02
TIDSPKT. : 0940-0955
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	cbrf3/Q UG/M3 / G/MIN
2.267	4.200	.00
2.400	4.033	.00
2.450	3.883	.00
2.550	3.700	3.01
2.773	3.567	1.50
2.900	3.433	2.83
3.067	3.400	4.29
3.200	3.367	1.85
3.733	3.367	.00
4.300	3.867	.00
5.100	4.133	.00
5.380	2.400	.00
4.650	2.250	.00
4.050	2.300	.00
3.500	2.350	2.29
3.300	2.300	.75
3.050	2.250	.61
2.600	2.250	2.81
2.400	2.400	.00
2.200	2.900	.00
1.850	3.500	.00
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
3.750	.350	.00
4.500	.450	.00
5.500	.600	.00

STED : CBR VAALERENGA
TEST NR. : 97B
DATO : 90-03-02
TIDSPKT. : 0955-1010
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	cbrf3/Q UG/M3 / G/MIN
2.267	4.200	.00
2.400	4.033	.00
2.450	3.883	.00
2.550	3.700	1.69
2.773	3.567	.78
2.900	3.433	2.88
3.067	3.400	2.95
3.200	3.367	2.53
3.733	3.367	.00
4.300	3.867	.00
5.100	4.133	.00
5.380	2.400	.00
4.650	2.250	.00
4.050	2.300	2.53
3.500	2.350	2.72
3.300	2.300	.52
3.050	2.250	.00
2.600	2.250	.00
2.400	2.400	.00
2.200	2.900	.00
1.850	3.500	.00
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
3.750	.350	.00
4.500	.450	.00
5.500	.600	.00

STED : CBR VAALERENGA
TEST NR. : 98A
DATO : 90-03-02
TIDSPKT. : 1150-1205
ANT.OBS. : 30
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	cbrf3/Q $\frac{UG/M^3}{G/MIN}$
2.267	4.200	.00
2.450	3.883	.00
2.733	3.567	.00
2.900	3.433	.24
3.067	3.400	.49
3.200	3.367	.00
3.500	3.467	1.81
3.733	3.367	.18
4.300	3.867	.00
4.638	3.733	.00
5.100	4.133	.00
5.133	4.667	.00
5.380	2.400	.00
4.650	2.250	.00
4.050	2.300	.71
3.500	2.350	.00
3.300	2.300	.00
3.050	2.250	.00
2.600	2.250	.00
2.400	2.400	.00
2.200	2.900	.00
1.850	3.500	.00
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
2.800	1.400	.00
4.500	.450	.20
5.500	.600	.00

STED : CBR VAALERENGA
TEST NR. : 98B
DATO : 90-03-02
TIDSPKT. : 1205-1220
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	cbrf3/Q $\frac{UG/M^3}{G/MIN}$
2.267	4.200	.00
2.450	3.883	.00
2.773	3.567	.54
2.900	3.433	1.02
3.067	3.400	2.06
3.200	3.367	.00
3.500	3.467	.90
3.733	3.367	.00
4.300	3.867	.00
5.100	4.133	.00
5.133	4.667	.00
5.380	2.400	.00
4.650	2.250	.00
4.050	2.300	.00
3.500	2.350	.00
3.300	2.300	.00
3.050	2.250	.00
2.600	2.250	.00
2.400	2.400	.00
2.200	2.900	.00
1.850	3.500	.00
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
2.800	1.400	.00
4.500	.450	.00
5.500	.600	.00

APPENDIX B

Tracer data for mobile source

STED : SF6 VAALERENGA
TEST NR. : V4A
DATO : 89-03-14
TIDSPKT. : 1440-1455
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 / G/MIN
.310	.360	.72
.315	.395	.23
.300	.395	1.17
.325	.420	.37
.320	.470	2.03
.330	.530	.12
.445	.575	1.54
.445	.635	.06
.405	.270	.06
.370	.365	.04
.365	.395	.04
.350	.435	.12
.405	.485	.04
.450	.525	.16
.455	.510	.08
.440	.395	.06
.500	.495	.02
.560	.565	.04
.620	.630	1.31
.620	.465	.08
.640	.510	.06
.665	.580	.08
.580	.340	.06
.735	.495	.02

STED : SF6 VAALERENGA
TEST NR. : V4B
DATO : 89-03-14
TIDSPKT. : 1455-1510
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 / G/MIN
.310	.360	.57
.315	.395	.25
.300	.395	.55
.325	.420	.29
.320	.470	1.15
.330	.530	.06
.445	.575	.68
.445	.635	.04
.405	.270	.06
.370	.365	.06
.365	.395	.06
.350	.435	.12
.405	.485	.10
.450	.525	.27
.455	.510	.08
.440	.395	.06
.500	.495	.08
.560	.565	.08
.620	.630	1.17
.620	.465	.06
.640	.510	.06
.665	.580	.08
.580	.340	.08
.735	.495	.04

STED : SF6 VAALERENGA
TEST NR. : V5A
DATO : 89-03-14
TIDSPKT. : 1710-1725
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 / G/MIN
.310	.360	.90
.315	.395	.44
.300	.395	.74
.280	.395	.06
.325	.420	1.12
.295	.435	.00
.445	.575	.96
.445	.635	.00
.405	.270	.04
.370	.365	.04
.360	.395	.10
.340	.430	.40
.405	.485	.22
.450	.525	.38
.455	.510	.18
.440	.395	.04
.500	.495	.04
.560	.565	.10
.620	.630	.82
.620	.465	.10
.640	.510	.06
.665	.580	.10
.580	.340	.04
.735	.495	.04

STED : SF6 VAALERENGA
TEST NR. : V5B
DATO : 89-03-14
TIDSPKT. : 1725-1740
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 / G/MIN
.310	.360	.74
.315	.395	.30
.300	.395	.90
.280	.395	.26
.325	.420	1.63
.295	.435	.04
.445	.575	.84
.445	.635	.04
.405	.270	.02
.370	.365	.04
.360	.395	.08
.340	.430	.20
.405	.485	.12
.450	.525	.22
.455	.510	.06
.440	.395	.08
.500	.495	.02
.560	.565	.08
.620	.630	1.55
.620	.465	.02
.640	.510	.00
.665	.580	.08
.580	.340	.04
.735	.495	.02

STED : SF6 VAALERENGA
TEST NR. : V6A
DATO : 89-03-14
TIDSPKT. : 1850-1905
ANT.OBS. : 24
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 G/MIN
.310	.360	1.11
.315	.395	.66
.300	.395	1.18
.280	.395	.49
.325	.420	1.40
.295	.435	.00
.320	.470	.87
.445	.575	.91
.445	.635	.00
.405	.270	.00
.370	.365	.00
.360	.395	.08
.340	.430	.49
.405	.485	.27
.450	.525	.64
.455	.510	.27
.440	.395	.06
.500	.495	.08
.560	.565	.08
.620	.630	2.23
.620	.465	.04
.640	.510	.06
.580	.340	1.98
.735	.495	.04

STED : SF6 VAALERENGA
TEST NR. : V6B
DATO : 89-03-14
TIDSPKT. : 1905-1920
ANT.OBS. : 25
MIN,MAKS X : .270 .770
MIN,MAKS Y : .200 .700

KOORDINATER X	Y	SF6/Q UG/M3 G/MIN
.310	.360	1.01
.315	.395	.41
.300	.395	1.18
.280	.395	.62
.325	.420	1.22
.295	.435	.02
.320	.470	1.13
.330	.530	.00
.445	.575	1.77
.445	.635	.43
.405	.270	.00
.370	.365	.04
.360	.395	.14
.340	.430	.31
.405	.485	.25
.450	.525	.64
.455	.510	.29
.440	.395	.04
.500	.495	.04
.560	.565	.14
.620	.630	2.21
.620	.465	.04
.640	.510	.08
.580	.340	.02
.735	.495	.06

STED : SF6 VAALERENGA
TEST NR. : V7A
DATO : 89-11-27
TIDSPKT. : 1630-1645
ANT.OBS. : 40
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	sf6/Q UG/M3 / G/MIN
3.820	2.780	.64
4.420	3.010	.26
4.690	3.020	.21
5.060	3.080	.13
5.450	3.260	.39
5.710	3.420	.36
5.180	4.810	.52
5.190	4.490	.23
4.790	3.920	.35
4.910	4.310	.65
4.470	4.080	.49
4.330	3.630	.35
3.930	3.400	.36
3.790	3.610	.68
3.500	3.490	.83
3.810	3.210	.36
3.900	3.020	.42
2.840	3.060	.23
2.980	3.200	.52
3.160	2.760	.63
3.520	2.640	.88
3.200	2.300	.43
3.320	3.440	1.43
3.400	4.240	2.46
3.240	4.260	3.73
3.220	4.160	3.31
3.380	4.060	2.29
3.160	3.940	5.55
3.320	3.860	2.73
3.360	3.620	.89
3.220	3.540	1.69
3.060	3.600	4.12
2.960	3.600	3.99
2.820	3.720	.43
2.780	3.500	.88
2.880	3.440	1.49
3.000	3.400	1.88
3.140	3.360	1.77
3.220	3.320	1.38
3.380	3.280	1.10

STED : SF6 VAALERENGA
TEST NR. : V7B
DATO : 89-11-27
TIDSPKT. : 1645-1700
ANT.OBS. : 39
MIN,MAKS X : 2.000 6.000
MIN,MAKS Y : 2.000 6.000

KOORDINATER X	Y	sf6/Q UG/M3 / G/MIN
3.820	2.780	.35
4.690	3.020	.14
5.060	3.080	.02
5.450	3.260	.12
5.710	3.420	.06
5.180	4.810	.30
5.190	4.490	.13
4.790	3.920	.18
4.910	4.310	.20
4.470	4.080	.05
4.330	3.630	.05
3.930	3.400	.15
3.790	3.610	.32
3.500	3.490	.43
3.810	3.210	.15
3.900	3.020	.20
2.840	3.060	.29
2.980	3.200	.39
3.160	2.760	.65
3.520	2.640	.56
3.200	2.300	.47
3.320	3.440	.85
3.400	4.240	.48
3.240	4.260	1.41
3.220	4.160	1.32
3.380	4.060	.77
3.160	3.940	2.79
3.320	3.860	.77
3.360	3.620	2.33
3.220	3.540	1.31
3.060	3.600	3.69
2.960	3.600	3.70
2.820	3.720	.03
2.780	3.500	.61
2.880	3.440	1.70
3.000	3.400	1.68
3.140	3.360	1.27
3.220	3.320	.90
3.380	3.280	.68

STED : SF6 VAALERENGA
TEST NR. : 97A
DATO : 90-03-02
TIDSPKT. : 0940-0955
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	sf6/Q $\underline{UG/M^3}$ G/MIN
2.267	4.200	.05
2.400	4.033	1.66
2.450	3.883	2.65
2.550	3.700	1.86
2.733	3.567	1.69
2.900	3.433	1.27
3.067	3.400	1.21
3.200	3.367	1.32
3.733	3.367	1.62
4.300	3.867	.74
5.100	4.133	.72
5.380	2.400	.20
4.650	2.250	.27
4.050	2.300	.47
3.500	2.350	.55
3.300	2.300	.45
3.050	2.250	.17
2.600	2.250	.06
2.400	2.400	.08
2.200	2.900	.04
1.850	3.500	.03
1.350	3.600	.00
.950	3.000	.02
1.650	1.750	.02
2.200	1.250	.05
2.650	.300	.04
3.750	.350	.18
4.500	.450	.15
5.500	.600	.12

STED : SF6 VAALERENGA
TEST NR. : 97B
DATO : 90-03-02
TIDSPKT. : 0955-1010
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	sf6/Q $\underline{UG/M^3}$ G/MIN
2.267	4.200	.04
2.400	4.033	.77
2.450	3.883	.63
2.550	3.700	.44
2.773	3.567	.51
2.900	3.433	.52
3.067	3.400	.67
3.200	3.367	.68
3.733	3.367	.31
4.300	3.867	.52
5.100	4.133	.46
5.380	2.400	.21
4.650	2.250	.23
4.050	2.300	.35
3.500	2.350	.30
3.300	2.300	.26
3.050	2.250	.09
2.600	2.250	.06
2.400	2.400	.00
2.200	2.900	.06
1.850	3.500	.04
1.350	3.600	.00
.950	3.000	.01
1.650	1.750	.03
2.200	1.250	.03
2.650	.300	.03
3.750	.350	.17
4.500	.450	.14
5.500	.600	.18

STED : SF6 VAALERENGA
TEST NR. : 98A
DATO : 90-03-02
TIDSPKT. : 1150-1205
ANT.OBS. : 30
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	sf6/Q UG/M3 / G/MIN
2.267	4.200	.00
2.450	3.883	1.73
2.733	3.567	1.12
2.900	3.433	1.32
3.067	3.400	1.65
3.200	3.367	.00
3.500	3.467	.51
3.733	3.367	.37
4.300	3.867	.39
4.638	3.733	.12
5.100	4.133	.38
5.133	4.667	.47
5.380	2.400	.08
4.650	2.250	.18
4.050	2.300	.15
3.500	2.350	.23
3.300	2.300	.16
3.050	2.250	.00
2.600	2.250	.00
2.400	2.400	.00
2.200	2.900	.00
1.850	3.500	.02
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
2.800	1.400	.00
4.500	.450	.08
5.500	.600	.06

STED : SF6 VAALERENGA
TEST NR. : 98B
DATO : 90-03-02
TIDSPKT. : 1205-1220
ANT.OBS. : 29
MIN,MAKS X : .000 6.000
MIN,MAKS Y : .000 6.000

KOORDINATER X	Y	sf6/Q UG/M3 / G/MIN
2.267	4.200	.00
2.450	3.883	.24
2.773	3.567	.19
2.900	3.433	.30
3.067	3.400	.40
3.200	3.367	.00
3.500	3.467	.42
3.733	3.367	.32
4.300	3.867	.28
5.100	4.133	.26
5.133	4.667	.41
5.380	2.400	.22
4.650	2.250	.19
4.050	2.300	.17
3.500	2.350	.19
3.300	2.300	.12
3.050	2.250	.03
2.600	2.250	.00
2.400	2.400	.03
2.200	2.900	.00
1.850	3.500	.00
1.350	3.600	.00
.950	3.000	.00
1.650	1.750	.00
2.200	1.250	.00
2.650	.300	.00
2.800	1.400	.00
4.500	.450	.07
5.500	.600	.12

APPENDIX C

Output from dispersion model of Iversen (1982)

PROGRAM TUNNEL

TEST 1A

WIND SPEED	(M/S) :	3.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	6.50
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	36.85
DISTANCE TO END OF JET	:	41.23

Distance (m)	Concentration
5.0	35.75
10.0	33.90
15.0	31.69
20.0	29.28
25.0	26.80
30.0	24.31
35.0	21.89
40.0	19.56
45.0	16.75
50.0	14.34
55.0	12.43
60.0	10.88
65.0	9.61
70.0	8.56
75.0	7.67
80.0	6.92
85.0	6.27
90.0	5.71
95.0	5.23
100.0	4.80
105.0	4.43
110.0	4.10
115.0	3.80
120.0	3.53
125.0	3.30
130.0	3.08
135.0	2.89
140.0	2.71
145.0	2.55
150.0	2.41
155.0	2.27
160.0	2.15
165.0	2.04
170.0	1.93
175.0	1.84
180.0	1.75
185.0	1.66
190.0	1.59
195.0	1.52
200.0	1.45

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST 1B

WIND SPEED	(M/S) :	3.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	6.50
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	40.53
DISTANCE TO END OF JET	:	41.23

Distance (m)	Concentration
5.0	39.32
10.0	37.29
15.0	34.85
20.0	32.21
25.0	29.47
30.0	26.74
35.0	24.07
40.0	21.52
45.0	18.42
50.0	15.77
55.0	13.67
60.0	11.97
65.0	10.57
70.0	9.41
75.0	8.44
80.0	7.61
85.0	6.90
90.0	6.28
95.0	5.75
100.0	5.28
105.0	4.87
110.0	4.50
115.0	4.18
120.0	3.89
125.0	3.63
130.0	3.39
135.0	3.18
140.0	2.98
145.0	2.81
150.0	2.65
155.0	2.50
160.0	2.37
165.0	2.24
170.0	2.13
175.0	2.02
180.0	1.92
185.0	1.83
190.0	1.75
195.0	1.67
200.0	1.59

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST2A

WIND SPEED	(M/S) :	2.70
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.20
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	89.68
DISTANCE TO END OF JET	:	27.48

Distance (m)	Concentration
5.0	74.63
10.0	62.62
15.0	52.71
20.0	44.45
25.0	37.53
30.0	31.38
35.0	26.29
40.0	22.35
45.0	19.24
50.0	16.74
55.0	14.70
60.0	13.01
65.0	11.60
70.0	10.41
75.0	9.39
80.0	8.52
85.0	7.76
90.0	7.10
95.0	6.52
100.0	6.01
105.0	5.56
110.0	5.15
115.0	4.79
120.0	4.47
125.0	4.18
130.0	3.91
135.0	3.67
140.0	3.46
145.0	3.26
150.0	3.07
155.0	2.91
160.0	2.75
165.0	2.61
170.0	2.48
175.0	2.36
180.0	2.25
185.0	2.14
190.0	2.04
195.0	1.95
200.0	1.87

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST 2B

WIND SPEED	(M/S) :	2.70
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.10
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	92.77
DISTANCE TO END OF JET	:	25.74

Distance (m)	Concentration
5.0	76.09
10.0	63.22
15.0	52.77
20.0	44.18
25.0	37.06
30.0	30.71
35.0	25.79
40.0	21.97
45.0	18.94
50.0	16.50
55.0	14.50
60.0	12.85
65.0	11.47
70.0	10.30
75.0	9.30
80.0	8.44
85.0	7.69
90.0	7.04
95.0	6.47
100.0	5.96
105.0	5.52
110.0	5.12
115.0	4.76
120.0	4.44
125.0	4.15
130.0	3.89
135.0	3.65
140.0	3.44
145.0	3.24
150.0	3.06
155.0	2.89
160.0	2.74
165.0	2.60
170.0	2.47
175.0	2.35
180.0	2.24
185.0	2.13
190.0	2.04
195.0	1.95
200.0	1.86

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST 3A

WIND SPEED	(M/S) :	2.40
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.90
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	70.87
DISTANCE TO END OF JET	:	36.67

Distance (m)	Concentration
5.0	63.55
10.0	56.36
15.0	49.75
20.0	43.78
25.0	38.43
30.0	33.68
35.0	29.46
40.0	25.22
45.0	21.60
50.0	18.71
55.0	16.37
60.0	14.44
65.0	12.84
70.0	11.49
75.0	10.35
80.0	9.37
85.0	8.52
90.0	7.79
95.0	7.14
100.0	6.57
105.0	6.07
110.0	5.63
115.0	5.23
120.0	4.87
125.0	4.55
130.0	4.26
135.0	3.99
140.0	3.75
145.0	3.54
150.0	3.34
155.0	3.15
160.0	2.98
165.0	2.83
170.0	2.69
175.0	2.55
180.0	2.43
185.0	2.32
190.0	2.21
195.0	2.11
200.0	2.02

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST 3B

```
WIND SPEED         (M/S) :      2.40
WIND SPEED CORR.   (M/S) :       .38
TUNNEL JET SPEED   (M/S) :      4.10
GAUSS PLUME AREA   (M2)  :     61.18
CONC. AT TUNNEL          :     67.97
DISTANCE TO END OF JET   :     38.39
```

Distance (m)	Concentration
5.0	61.75
10.0	55.32
15.0	49.26
20.0	43.69
25.0	38.63
30.0	34.06
35.0	29.97
40.0	26.02
45.0	22.24
50.0	19.23
55.0	16.79
60.0	14.80
65.0	13.14
70.0	11.75
75.0	10.57
80.0	9.56
85.0	8.69
90.0	7.94
95.0	7.28
100.0	6.69
105.0	6.18
110.0	5.72
115.0	5.32
120.0	4.95
125.0	4.62
130.0	4.33
135.0	4.06
140.0	3.81
145.0	3.59
150.0	3.39
155.0	3.20
160.0	3.03
165.0	2.87
170.0	2.72
175.0	2.59
180.0	2.46
185.0	2.35
190.0	2.24
195.0	2.14
200.0	2.04

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V4A

WIND SPEED	(M/S) :	2.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.90
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	69.64
DISTANCE TO END OF JET	:	38.52

Distance (m)	Concentration
10.0	56.19
20.0	44.36
30.0	34.70
40.0	26.75
50.0	20.08
60.0	15.64
70.0	12.53
80.0	10.27
90.0	8.57
100.0	7.26
110.0	6.24
120.0	5.41
130.0	4.74
140.0	4.19
150.0	3.73
160.0	3.34
170.0	3.01
180.0	2.73
190.0	2.48
200.0	2.27
210.0	2.08
220.0	1.92
230.0	1.77
240.0	1.64
250.0	1.53
260.0	1.42
270.0	1.33
280.0	1.24
290.0	1.17
300.0	1.10
310.0	1.03
320.0	.97
330.0	.92
340.0	.87
350.0	.83
360.0	.79
370.0	.75
380.0	.71
390.0	.68
400.0	.65

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V4B

WIND SPEED	(M/S) :	2.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.60
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	75.66
DISTANCE TO END OF JET	:	35.09

Distance (m)	Concentration
10.0	58.59
20.0	44.94
30.0	34.33
40.0	25.65
50.0	19.39
60.0	15.18
70.0	12.21
80.0	10.03
90.0	8.39
100.0	7.13
110.0	6.13
120.0	5.33
130.0	4.67
140.0	4.13
150.0	3.68
160.0	3.30
170.0	2.98
180.0	2.70
190.0	2.46
200.0	2.25
210.0	2.06
220.0	1.90
230.0	1.76
240.0	1.63
250.0	1.52
260.0	1.41
270.0	1.32
280.0	1.24
290.0	1.16
300.0	1.09
310.0	1.03
320.0	.97
330.0	.92
340.0	.87
350.0	.82
360.0	.78
370.0	.74
380.0	.71
390.0	.67
400.0	.64

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V5A

WIND SPEED	(M/S) :	3.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.30
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	81.81
DISTANCE TO END OF JET	:	29.06

Distance (m)	Concentration
10.0	57.92
20.0	41.36
30.0	29.45
40.0	20.65
50.0	15.29
60.0	11.79
70.0	9.37
80.0	7.63
90.0	6.33
100.0	5.34
110.0	4.57
120.0	3.95
130.0	3.45
140.0	3.04
150.0	2.70
160.0	2.42
170.0	2.17
180.0	1.97
190.0	1.79
200.0	1.63
210.0	1.50
220.0	1.38
230.0	1.27
240.0	1.18
250.0	1.09
260.0	1.02
270.0	.95
280.0	.89
290.0	.83
300.0	.78
310.0	.74
320.0	.69
330.0	.66
340.0	.62
350.0	.59
360.0	.56
370.0	.53
380.0	.50
390.0	.48
400.0	.46

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V5B

WIND SPEED	(M/S) :	3.00
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	3.10
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	88.26
DISTANCE TO END OF JET	:	26.24

Distance (m)	Concentration
10.0	59.60
20.0	41.30
30.0	28.47
40.0	20.14
50.0	15.00
60.0	11.62
70.0	9.26
80.0	7.56
90.0	6.29
100.0	5.32
110.0	4.55
120.0	3.94
130.0	3.45
140.0	3.04
150.0	2.71
160.0	2.42
170.0	2.18
180.0	1.97
190.0	1.79
200.0	1.64
210.0	1.50
220.0	1.38
230.0	1.28
240.0	1.18
250.0	1.10
260.0	1.02
270.0	.95
280.0	.89
290.0	.84
300.0	.79
310.0	.74
320.0	.70
330.0	.66
340.0	.63
350.0	.59
360.0	.56
370.0	.53
380.0	.51
390.0	.48
400.0	.46

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V6A

WIND SPEED	(M/S) :	1.50
WIND SPEED CORR.	(M/S) :	.38
TUNNEL JET SPEED	(M/S) :	2.90
GAUSS PLUME AREA	(M2) :	61.18
CONC. AT TUNNEL	:	94.16
DISTANCE TO END OF JET	:	24.75

Distance (m)	Concentration
10.0	65.06
20.0	46.74
30.0	33.87
40.0	25.42
50.0	19.79
60.0	15.86
70.0	13.00
80.0	10.85
90.0	9.20
100.0	7.89
110.0	6.85
120.0	6.01
130.0	5.31
140.0	4.72
150.0	4.23
160.0	3.82
170.0	3.46
180.0	3.15
190.0	2.88
200.0	2.64
210.0	2.43
220.0	2.25
230.0	2.08
240.0	1.94
250.0	1.80
260.0	1.69
270.0	1.58
280.0	1.48
290.0	1.39
300.0	1.31
310.0	1.24
320.0	1.17
330.0	1.11
340.0	1.05
350.0	1.00
360.0	.95
370.0	.90
380.0	.86
390.0	.82
400.0	.78

SLUTT PROGRAM TUN-ALL

PROGRAM TUNNEL

TEST V6B

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WIND SPEED         (M/S) :      1.50
WIND SPEED CORR.   (M/S) :       .38
TUNNEL JET SPEED   (M/S) :      2.50
GAUSS PLUME AREA   (M2)  :     61.18
CONC. AT TUNNEL          :    106.93
DISTANCE TO END OF JET   :     11.11
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Distance (m)	Concentration
10.0	63.98
20.0	42.86
30.0	30.83
40.0	23.29
50.0	18.24
60.0	14.69
70.0	12.09
80.0	10.13
90.0	8.61
100.0	7.41
110.0	6.45
120.0	5.67
130.0	5.02
140.0	4.47
150.0	4.02
160.0	3.62
170.0	3.29
180.0	3.00
190.0	2.74
200.0	2.52
210.0	2.32
220.0	2.15
230.0	1.99
240.0	1.85
250.0	1.73
260.0	1.62
270.0	1.51
280.0	1.42
290.0	1.34
300.0	1.26
310.0	1.19
320.0	1.13
330.0	1.07
340.0	1.01
350.0	.96
360.0	.91
370.0	.87
380.0	.83
390.0	.79
400.0	.76

SLUTT PROGRAM TUN-ALL

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POSTBOKS 64, N-2001 LILLESTRØM

RAPPORTTYPE OPPDRAGSRAPPORT	RAPPORTNR. OR 39/90	ISBN-82-425-0145-9	
DATO AUGUST 1990	ANSV. SIGN.	ANT. SIDER 88	PRIS NOK 135,-
TITTEL A tracer investigation of traffic emissions from the Vålerenga tunnel at Etterstad		PROSJEKTLEDER D. Tønnesen	
		NILU PROSJEKT NR. O-8873	
FORFATTER(E) H.G. Peterson and D. Tønnesen		TILGJENGELIGHET * A	
		OPPDRAGSGIVERS REF. Sidsel Kålås, Vegdir.	

OPPDRAGSGIVER (NAVN OG ADRESSE)
Statens vegvesen v/Veisjefen i Oslo,
Vegdirektoratet, Planavdelingen/Driftsavdelingen, Etterstad, Oslo

3 STIKKORD (a maks. 20 anslag)

Spredningsforsøk	Tunnel	Trafikkforurensning

REFERAT (maks. 300 anslag, 7 linjer)

TITLE

ABSTRACT (max. 300 characters, 7 lines)
Eighteen tracer experiments were conducted in and near the northbound tube of the Vålerenga tunnel. The tracer tests confirm previous modelling results concerning air pollution impact from the tunnel. The tracer gas concentration 60 to 150 m from the tunnel was below 10% of the concentration in the tunnel outlet. For wind along Strømsveien, tracer gas concentrations 40-60 meters from the road was 10% of the roadside concentrations.

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