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# A TRACER INVESTIGATION OF POLLUTANT DISPERSION IN AN URBAN STREET CANYON

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TABLE OF CONTENTS

## SAMMENDRAG

Et sporstoff-eksperiment med svovel heksafluor ($SF_6$) og "electron capture gas chromatography" ble utført i en situasjon med svak vind og vinterforhold i en typisk norsk bygate. Hensikten med undersøkelsen var å utforske spredning av forurensning fra biler i en bygate, og å demonstrere anvendeligheten av sporstoffteknikk til en slik oppgave. Sporgassen ble sluppet ut kontinuerlig fra en bil i fart. Øyeblikksprøver av luft ble tatt ved fem stasjoner langs gaten. Resultatene viste at konsentrasjonen avtok eksponensielt. Den tiden det tar for konsentrasjonen å avta med 1/e i middel ved de fem prøvestasjonene var 48 sekunder.

## SUMMARY

A tracer experiment involving sulfur hexafluoride and electron capture chromatography was conducted during low wind, winter conditions in a typical Norwegian urban street. The purpose of the study was to investigate the dispersion of vehicular pollutants emitted in an urban street and to demonstrate the applicability of tracer techniques to this problem. The tracer gas was released continuously from a moving vehicle; instantaneous air samples were collected at five stations along the street. The results indicated that the concentrations decreased in an irregular exponential manner. The average time for the concentration to decrease by 1/e at the five sampling points equaled 48 seconds.

# A TRACER INVESTIGATION OF POLLUTANT DISPERSION IN AN URBAN STREET CANYON

## 1 INTRODUCTION

The complex turbulence patterns created in the confines of an urban street preclude a simple analysis of the dispersion of pollutants which are emitted in such areas. Descriptions of the relationships which exist among vehicular emission rates, traffic density, urban topography, meteorology, and ambient pollutant concentrations generally must be drawn from experimental observations. A unique means of establishing the relationship between emission characteristics and resulting pollutant concentrations is through the application of atmospheric tracer techniques. This experimental method involves inert, nontoxic gases, such as sulfur hexafluoride, and electron capture gas chromatography. The purpose of this work was to demonstrate the usefulness of tracer techniques for studying dispersion in an urban street canyon.

## 2 EXPERIMENTAL PROCEDURE

### 2.1 Time and location

A single experiment was performed between 1057 and 1106 on 29 December, 1977, in Lillestrøm on one block of Voldgata. This street lies in the business section of Lillestrøm; one and two story buildings line both sides of the street. A map of the area is shown in Figure 1.

### 2.2 Emission of $SF_6$

Sulfur hexafluoride was released manually from a syringe held at the tailgate of a Vauxhall station wagon; 50 $cm^3$ of gas were released during 23 seconds as the car traveled along Voldgata at approximately 18 km/hr. This corresponds to an emission rate of 2.8 g $SF_6$/km.

### 2.3 Sampling procedure

Instantaneous air samples were collected manually in 20 $cm^3$ plastic syringes at the 5 stations shown in Figure 1. Samples were collected every 15 seconds for 3 minutes and, then, each minute for the next six minutes. The first sample was taken as the release vehicle entered the block. A total of 96 samples were collected.

### 2.4 Analytical procedure

All samples were analyzed within 24 hours of the test using two electron capture gas chromatographs. Details of the operation of the instruments are available elsewhere (Lamb, 1978). The chromatographs were calibrated twice before the test using an exponential dilution method. The results of these calibrations agreed within 5%. The calibration curve for one of the chromatographs is shown in Figure 2. The calibration results indicate

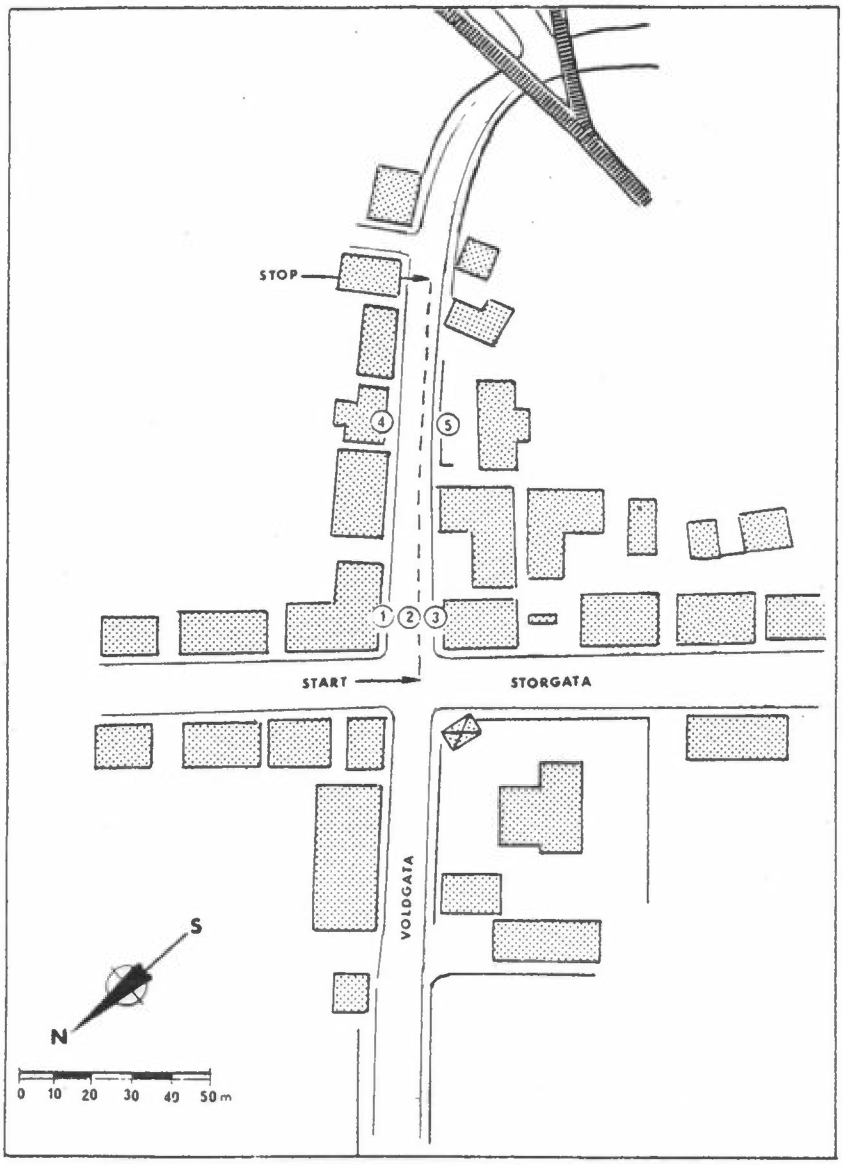


*Figure 1: Voldgata Tracer Test 29.12.77*

*Voldgata test area, Lillestrøm, ①-⑤ sampling stations, ( - - - -) release path.*

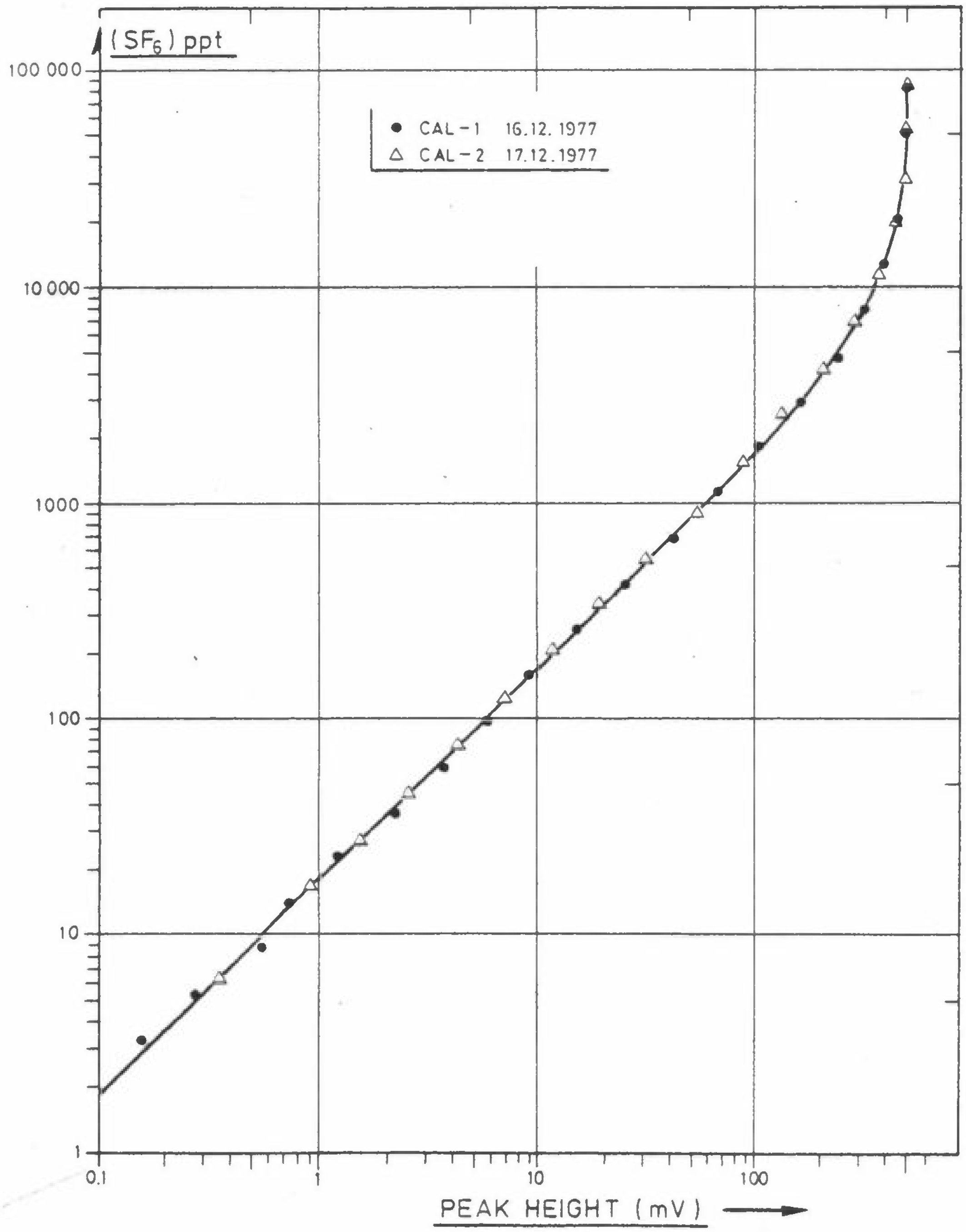


*Figure 2: Calibration curve for chromatograph A2.*

that $SF_6$ can be detected over 5 orders of magnitude with a lower limit of detection of approximately $10^{-12}$ parts $SF_6$ per part air (1 part per trillion, ppt).

## 2.5 Meteorological conditions

Meteorological conditions during the morning were calm and cloudy. A warm front approaching from the west produced a light snowfall and southerly winds aloft. A balloon released in Lillestrøm at 1050 showed calm in the first 50 m and light winds from south-southeast aloft. The temperature in Lillestrøm at 1120 was -9.7°C, the temperature in Rælingen, 50 m above Lillestrøm, at 1130 was -8.5°C. These data indicate that a slight temperature inversion existed during the test.

# 3 PRESENTATION AND DISCUSSION OF RESULTS

## 3.1 $SF_6$ concentration data

The $SF_6$ concentration data are tabulated in Table 1. No $SF_6$ was detected in the background samples. Ambient levels of $SF_6$ in Oslo have been measured to be less than $3 \cdot 10^{-13}$ p $SF_6$/p air (De Bortoli and Peechio, 1976). The $SF_6$ data are plotted as a function of time by station in Figures 3-7. The data are plotted as a function of the time since the release vehicle passed each station. For stations 4 and 5 this time is approximately 0.25 min less than the times listed in Table 1. As might be expected from the amount of traffic along Voldgata (no actual traffic counts were taken), a large degree of scatter appears within the overall pattern of concentrations decreasing with time. The concentrations peaked within 15 to 30 seconds after the release vehicle passed; concentrations decreased to less than 1 ppt in approximately 6 to 7 minutes. For stations 1, and 3, it appears that there was a increase in the rate at which concentrations decreased after approximately 3 to 4 minutes. This may have been caused by a change in meteorological conditions or a change in traffic density.

*Table 1: Voldgata tracer test, Lillestrøm 29.12.77*
*$SF_6$ tracer concentrations.*

| Time * (min) | PPT | | | | |
|---|---|---|---|---|---|
| | STATION 1 | STATION 2 | STATION 3 | STATION 4 | STATION 5 |
| Background | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | - | 0 | 0 | 0 |
| .25 | 10800 | ∿100 000 | 2764 | - | 0 |
| .50 | 1266 | 6600 | 4400 | 2263 | 198 |
| .75 | 5780 | 5800 | 5850 | 5850 | 1005 |
| 1.00 | 1688 | 4420 | 7700 | 4200 | 1243 |
| 1.25 | 111 | 2891 | 3070 | 3303 | 629 |
| 1.50 | 506 | 2033 | 2338 | 235 | 856 |
| 1.75 | 785 | 879 | 934 | 744 | 398 |
| 2.00 | 1195 | 608 | 333 | 784 | 5 |
| 2.25 | 808 | 590 | 380 | 420 | 2 |
| 2.50 | 104 | 518 | 365 | 136 | 3 |
| 2.75 | 991 | 319 | 481 | 92 | 0 |
| 3.00 | 380 | 803 | 3 | 47 | 0 |
| 4.00 | 113 | 8 | 0 | 25 | 15 |
| 5.00 | 12 | 0 | 0 | 29 | 8 |
| 6.00 | 0 | 0 | 0 | 8 | 2 |
| 7.00 | 0 | 0 | 0 | 2 | 0 |
| 8.00 | 0 | 0 | 0 | 1 | 0 |
| 9.00 | 0 | 0 | - | 0 | - |

* Time measured from when the release vehicle entered the intersection of Voldgata and Storgata.

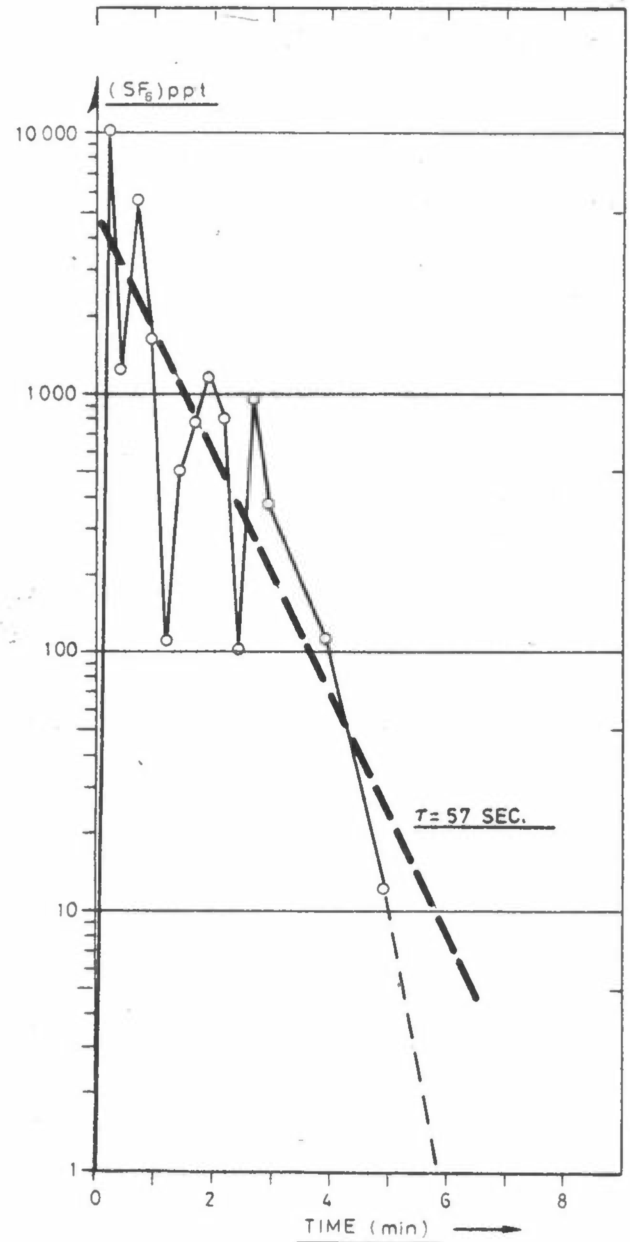


*Figure 3: Voldgata tracer test 29-12-77. $SF_6$ concentrations observed at station 1 as a function of time.*

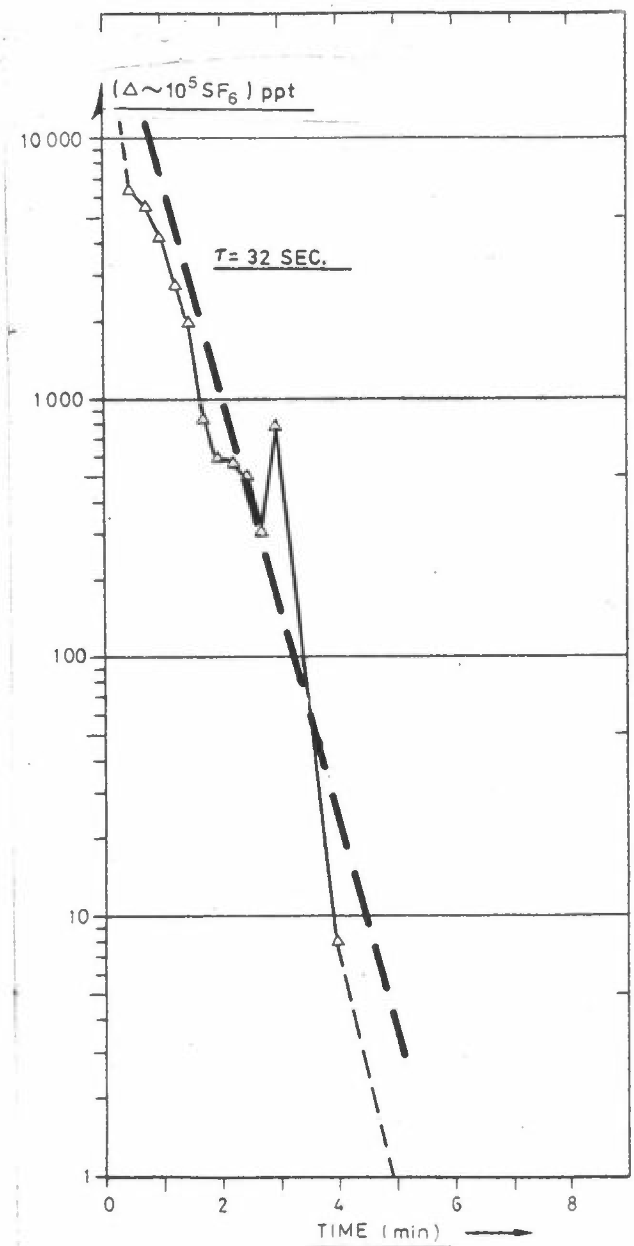


*Figure 4: Voldgata tracer test 29-12-77. $SF_6$ concentrations observed at station 2 as a function of time.*

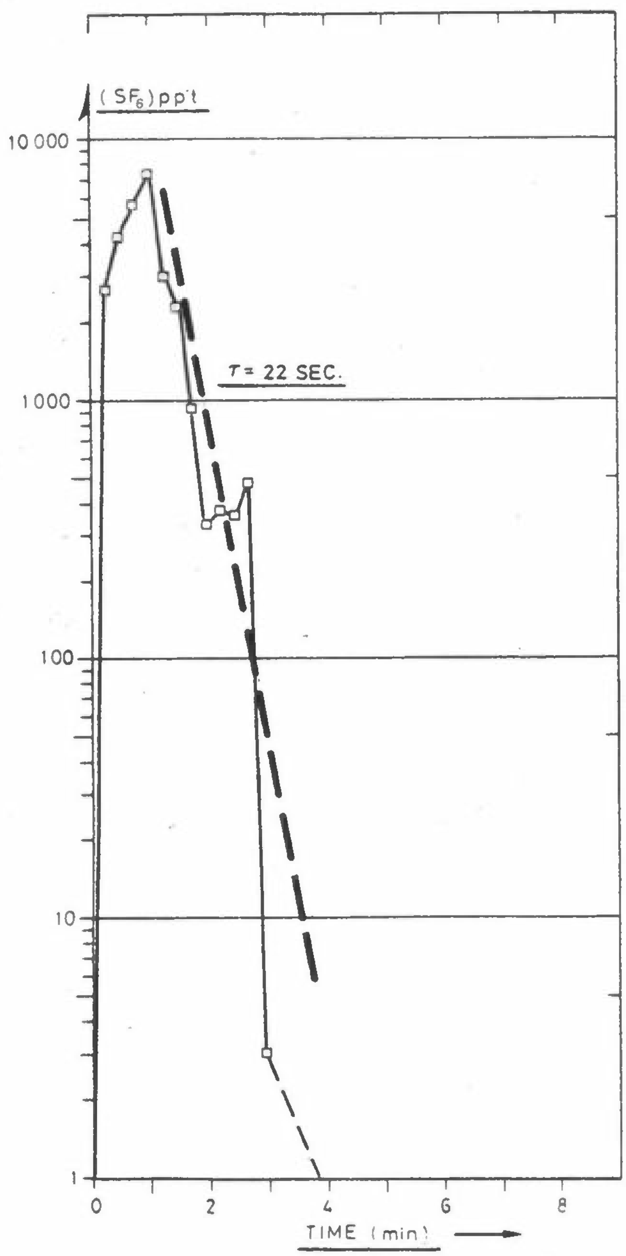


*Figure 5:* *Voldgata tracer test 29-12-77. $SF_6$ concentrations observed at station 3 as a function of time.*

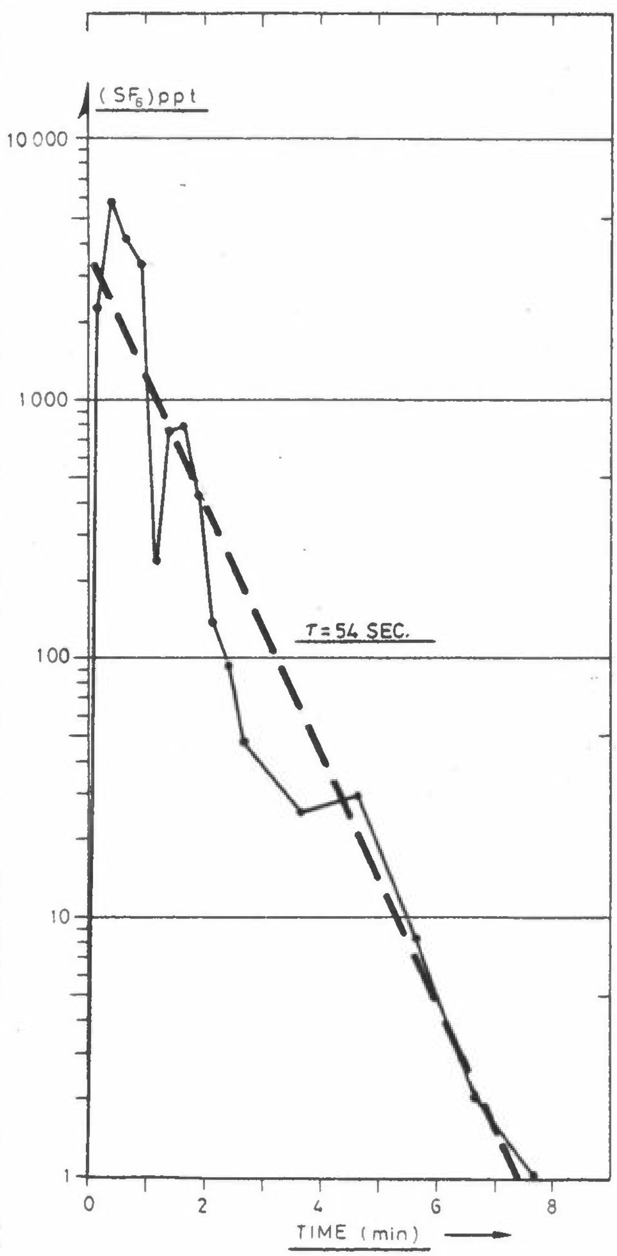


*Figure 6:* *Voldgata tracer test 29-12-77. $SF_6$ concentrations observed at station 4 as a function of time (measured from when the release vehicle passed the station, approximately 0.25 min after the test started).*

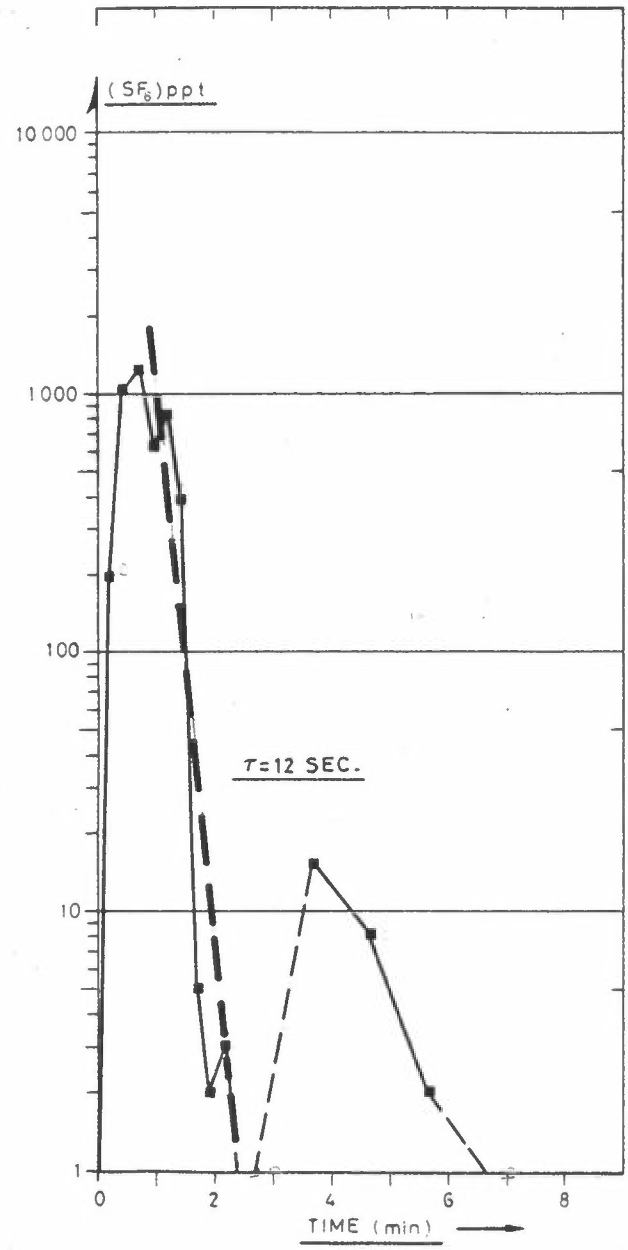


*Figure 7: Voldgata tracer test 29-12-77. $SF_6$ concentrations observed at station 5 as a function of time (measured from when the release vehicle passed the station).*

Although there was no wind at street level, stations 1 and 4 were downwind of the release with respect to the winds aloft. Similarly, stations 3 and 5 were upwind of the release. Furthermore, the two downwind stations were located in front of buildings. The downwind side of the street forms a continuous wall of the street canyon. The upwind side of the street is broken in two places by open lots. Station 3 was located in front of a building, station 5 was in front of an open lot.

Peak values at the two downwind stations, 1 and 4, agree within a factor of 2 and the rates of decrease in concentration appear to be approximately equal. A characteristic time, $\tau$, can be defined as the time required for the concentration to decrease by 1/e. Least-squares best-fits of the data for station 1 and 4 give values of $\tau$ equal to 57 and 54 seconds, respectively, as indicated in Figures 3 and 6.

The maximum concentration observed during the test, equal to $\sim 10^5$ ppt, occurred at station 2 in the middle of the street immediately after the release vehicle had passed. The concentrations at station 2 decreased more rapidly than those on the downwind side of the street. The best-fit value of $\tau$ for station 2 equals 32 seconds.

The curves for stations 3 and 5 do not show the degree of similarity found between stations 1 and 4. The maximum value observed at station 3 is 6 times greater than that found at station 5. The low concentrations observed at station 5 are probably caused by the presence of the open lot behind the station. For stations 3 and 5, the best-fit values of $\tau$ are 22 and 12 seconds, respectively.

The value of $\tau$ for station 5 does not take into account the reappearence of $SF_6$ at this station between 4 and 7 minutes.

A least squares best-fit line through all of the data is shown in Figure 8. The slope of this line gives a characteristic decay time equal to 48 seconds. It is interesting to note that characteristic times calculated from carbon monoxide data collected on two different days in a street in Drammen, Norway, were equal to 41 and 42 seconds, respectively (Grønskei, 1978).

## 3.2 Mass balance analysis

A mass balance of the tracer can be performed by considering the concentrations observed at a particular time at each station to be representative of the concentration throughout the volume of the street canyon. For example, at t= 0.75 minutes concentration levels in the street appear to be relatively uniform. The average concentration over the 5 stations at 0.75 minutes was 4857 ppt. The Voldgata street canyon measures approximately 110 m long x 10 m wide x 10 m high. The total volume of tracer in this volume at 0.75 minutes was

$$4.857\ 10^{-9} \frac{\mathrm{cm^3\,SF_6}}{\mathrm{cm^3\,air}} \cdot 1.10\ 10^{+10}\,\mathrm{cm^3} = 53\ \mathrm{cm^3\ SF_6}$$

Thus, all of the tracer which was released is accounted for in the mass balance.

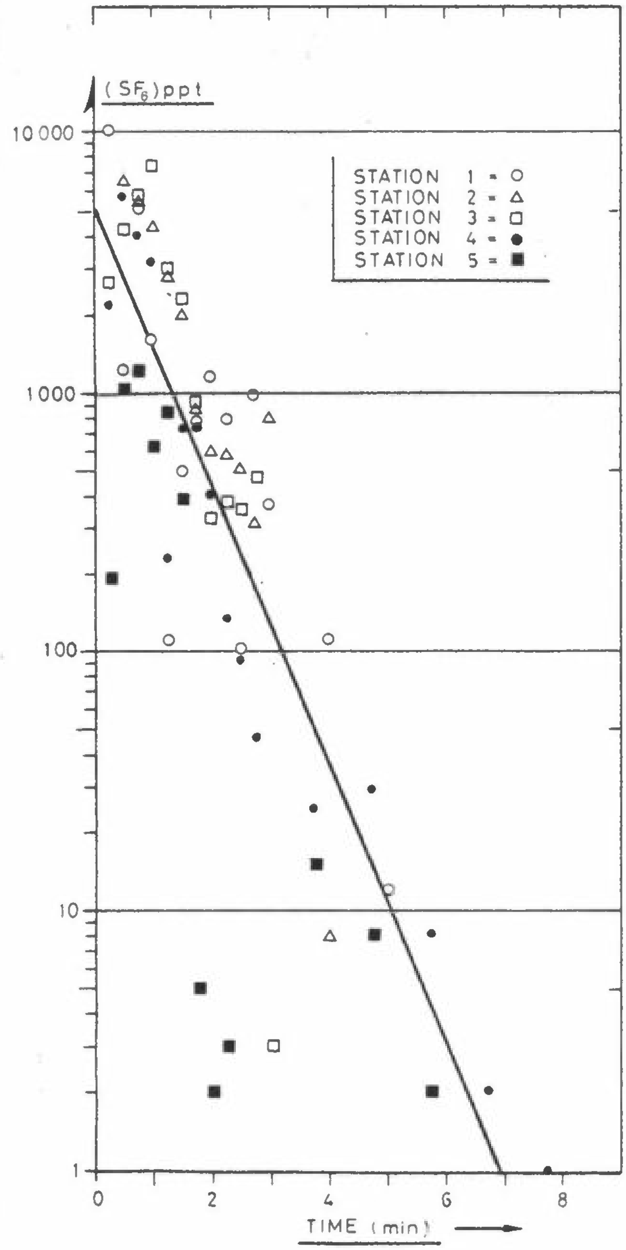


*Figure 8: Voldgata tracer test 29-12-77.*
*$SF_6$ concentration as function of time (measured from when the release vehicle passed each station).*

*The least squares best-fit line through the data gives $\tau = 48$ sec.*

## 4 ESTIMATES OF EMISSION/CONCENTRATION RELATIONSHIPS

Although no carbon monoxide or traffic density data were collected during this preliminary experiment, the calculation of CO vehicular emission rates from tracer data can be outlined. Under the conditions found in an urban street canyon, carbon monoxide can be considered as an unreactive gas. Since the tracer was released very near the exhaust, it can be assumed that the tracer was mixed rapidly with the hot exhaust gases. Thus, we can assume that CO and $SF_6$ behaved similarly after being emitted from the release vehicle.

The tracer data suggest that the concentration pattern produced by a single vehicle can be described by:

$$C(t) = C_{max} e^{-t/\tau} \qquad (1)$$

where $C_{max}$ is the maximum concentration observed, $t$ is the time elapsed since $C_{max}$ occurred, and $\tau$ is the characteristic decay time. Under steady state conditions, the total concentration produced by a number of vehicles (traffic density constant) will be:

$$C_T(t) = C_{max} \sum_{i=1}^{N} \exp\left[-(t+\lambda)(i-1)/\tau\right] \qquad (2)$$

where $\lambda$ is the time interval between vehicles, $t$ in this case has the range $o \leq t \leq \lambda$, and $N$ is the number of cars which contribute to $C_T(t)$. For $N$ sufficiently large, the series approaches the limit:

$$C_T(t) = C_{max} \left[\frac{1}{1-e^{-(t+\lambda)/\tau}}\right] . \qquad (3)$$

The values of $C_{max}$ and $\tau$ for a given set of conditions can be obtained from the tracer data; the value of $\lambda$ must be estimated from traffic counts. If the average maximum CO concentration, $C_T(CO)$, is known, the average CO emission rate can be calculated:

$$Q_{co} = Q_{SF_6} \cdot \frac{C_{T_{co}}}{C_{T_{SF_6}}} \qquad (4)$$

where $Q_{SF_6}$ is the measured $SF_6$ release rate used in the tracer experiments.

These calculations are typical of the empirical relationships which can be developed from the tracer data. However, it is anticipated that, in addition to supplying empirical data for specific streets, the tracer data will provide the basis for developing a general model for describing dispersion of pollutants emitted in urban street canyons. As the results of the Voldgata tracer test demonstrate, the tracer technique offers a relatively inexpensive, straightforward method for obtaining detailed dispersion data. In closing, it is worthwhile to note that the release, sampling and analysis in this tracer study required approximately 13 person-hours; the sampling syringes and the $SF_6$ cost less than 150 Norwegian crowns.

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