

Air Quality in a Subarctic Community Fairbanks, Alaska

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ABSTRACT. Expanding population centred around Fairbanks has brought concern that air pollution in the area may become intolerable. The atmosphere of the lower Chena River Valley is extremely stable during much of the year. Temperature inversions are believed to be among the steepest in the world. Inversions at -35°C . or below are characterized by a dense layer of "ice fog." This study found that pollution levels doubled or tripled during periods of extreme cold inversions. Some pollutants approached national urban averages, while total suspended matter and carbon monoxide averages exceeded ambient standards. Since air contaminants as well as ice fog increase with human habitation, the possibility of pollution reaching hazardous proportions in this subarctic community should be viewed with urgency.

RÉSUMÉ: *Qualité de l'air dans une agglomération subarctique: Fairbanks, Alaska.* L'expansion de la population concentrée autour de Fairbanks amène à craindre que la pollution atmosphérique dans ce secteur ne devienne intolérable. Dans cette basse vallée de la Chena, l'atmosphère est extrêmement stable durant la plus grande partie de l'année. On considère ces inversions de température comme les plus fortes au monde. Les inversions à -35°C ou moins se caractérisent par une dense couche de brouillard glacé. La présente étude a révélé qu'au cours de périodes d'inversion extrêmement froides, les niveaux de pollution atmosphérique doublent ou triplent. Pour certains polluants on approche des moyennes urbaines nationales, tandis que le total de solides en suspension et les moyennes pour le monoxyde de carbone dépassent les normes d'ambiance.

Comme les contaminants de l'air et le brouillard glacé augmentent avec l'habitat humain, il faudrait de toute urgence envisager la possibilité que la pollution atteigne des proportions dangereuses dans cette agglomération subarctique.

РЕЗЮМЕ. *Качество воздуха в субарктических поселениях Аляски в районе Фербенкс.* Рост населения в окрестностях Фербенкса вызывает опасения, что загрязнение воздуха в этом районе может принять угрожающие размеры. Атмосфера в нижней части реки Чена исключительно стабильна в течение большей части года. Температурные инверсии здесь считаются одними из наиболее резких в мире. Инверсии при температуре -35°C или ниже характеризуются образованием плотного слоя «ледяного тумана». Проведенные исследования показывают, что уровень загрязнения воздуха удваивается или утраивается в течение периодов особенно сильных инверсий холода. Содержание некоторых загрязняющих веществ приближается к среднероссийскому национальному уровню, в то время как общий уровень взвесей и окиси углерода превышает этот уровень. Загрязнения воздуха и ледяной туман увеличиваются с ростом населения и могут достигнуть опасной степени, что делает насущным безотлагательное рассмотрение данного вопроса.

INTRODUCTION

A steady growth in the population in and around Fairbanks, Alaska, has brought with it major concern about the deterioration of the area's air quality. Migrants from larger communities find the situation ironic.

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The population of the city of Fairbanks is 18,000 and the total, including the area 20 miles around the city, is about 40,000. The greater Fairbanks population occupies a basin surrounded on three sides by hills 500 to 600 metres above its floor. This topography retards ventilation, and atmospheric stratification in the lower Chena Valley creates a pollution potential as significant as that of a much larger metropolis. It has been estimated that during stratification mixed-air volume per capita can approximate that of Los Angeles.

This stratification is evident during much of the year, but is most apparent in the winter when continental polar air shrouds interior Alaska. Radiative cooling of the earth's surface generates a layer of cold air which covers the Chena basin. The resulting temperature inversions may be among the steepest known (Benson 1970). It is not unusual, for example, for surface temperatures to reach -30°C . or below, while the temperature at the highest point of the inversion, perhaps a hundred metres above the surface, is -15°C . or above. During such a condition, a fog of microscopic ice crystals results from the condensation of water from



FIG. 1. Photographs taken across Airport Road, Fairbanks, Alaska, at two sub-zero temperatures (-17°C . and -44°C .).



combustion and evaporation. The effect on visibility is evident in Fig. 1. In this illustration, visibility is reduced to about 30 metres. This blanket of ice fog is not only a detriment to visibility, but it reflects the tendency of the air to stratify and to contain contamination. Once formed, it affects local circulation patterns in such a way as to sustain itself. This is due to radiative cooling from the surface of the ice fog layer which causes the phenomenon to continue to grow.

Several works have been published on the characteristics of ice fog in Fairbanks. These include some analytical work on lead and halogen levels during ice fog conditions (Winchester *et al.* 1967) and on low background levels (Benson 1970). Benson mapped the relative intensities of contamination by logging conductance measurements of melted snow samples taken throughout the area, and was supported by a photographic record of the ice fog. Work has also been done on describing the mechanism of ice fog crystal nucleation and formation (Ohtake 1970). A good summary of these works was recently published by Weller (1969).

AIR CONTAMINANTS SELECTED FOR STUDY

In 1967 the Environmental Sciences Branch of the Arctic Health Research Center initiated a study to determine the extent of air pollution in Fairbanks. The studies previously mentioned provided the background information for making the desired quantitative measurements. The isolation of Fairbanks from other settlements facilitated the determination of pollution levels and the assessment of such parameters as fuel consumption, sources of evaporation, air volume and air flow.

The contaminants expected to be of greatest significance to air quality in this isolated, non-industrial community were those common to domestic sources, such as the combustion products from fossil heating fuels and combustion-engine emissions. The particulate load of the atmosphere was also expected to be high because of the number of gravelled roads, the nature of the top soil, and proximity of the town to large glacial river bars. In summer, a considerable amount of dust is suspended in the air. In winter, the dust is suppressed by snow cover but the practice of spreading cinders aggravates dust levels in areas of heavy traffic. The aerosol concentrations that occur in winter in the form of tiny ice fog particles have already been mentioned.

Gases

Gaseous pollutants surveyed included nitrogen dioxide, nitric oxide, sulfur dioxide, and the aliphatic aldehydes measured as formaldehyde. The oxides of nitrogen originate from internal combustion engines and other high temperature combustion processes. The nitric oxide produced from these sources oxidizes in the atmosphere to nitrogen dioxide. Both nitric oxide and nitrogen dioxide are absorbed through the respiratory system and complex blood hemoglobin which can cause methemoglobinemia. The oxides of nitrogen are more injurious than carbon monoxide in equivalent concentrations (Magill 1956). Sulfur dioxide was sampled as an indicator of the extent of industrial pollution, although such pollution was expected to be minimal and insufficient to constitute a public health hazard. In lesser concentrations it might, however, be sufficient to destroy

vegetation and corrode metal surfaces when dissolved in water aerosols. Aliphatic aldehydes are associated with incomplete combustion, usually as a product of blowby in internal combustion engines (Magill 1956). They may irritate the eyes of sensitive persons in concentrations as low as 0.25 ppm by volume ($203 \mu\text{g}/\text{m}^3$).

Particulates

Particulate pollutants surveyed were sulfate ($\text{SO}_4^{=}$), chloride (Cl^-), nitrate (NO_3^-), lead (Pb), ammonia (as NH_4^+), and total particulates. These were measured to obtain information on the sources of contamination. In the case of Fairbanks, $\text{SO}_4^{=}$ and Cl^- particulates were expected to be minimal in the absence of industry and sulfur-contaminated fuels (0.2 to 0.3 per cent sulfur coal is used in the area). Nitrate, formed by oxidation, should be proportional to the length of time the oxides of nitrogen reside in local air. Lead in the atmosphere generally results from the combustion of leaded fuels, and reflects traffic density. All particulates may irritate the respiratory tract, whatever their biochemical effects.

Sampling

Three types of measurements were made of gaseous and particulate air contaminants. 1) Composite samples were collected at random times at various locations from 1967 to 1971 to arrive at a 24-hour average concentration of air contaminants. During the first year of the survey National Air Sampling Network (NASN) samples were taken at random days throughout the year for a total of 24 samples. Composite samples were also taken from 4 perimeter locations. Together they provided the basis for estimating the extent of pollution in the area. 2) Grab samples were taken within the same period to arrive at concentrations at particular times for special study. In addition, 76 grab samples were taken for NO_2 and CO determinations at 4 specified locations during the winter of 1969-70. 3) Carbon monoxide was monitored continuously in downtown Fairbanks for approximately 1 month in the winter of 1969-70, and for 8 months during the winter of 1970-71, to determine its persistence and buildup.

From the data obtained in Benson's studies and in our first winter of sampling, maximum deterioration was expected to occur in the core of the City of Fairbanks. Sampling during the winter of 1968-69 was therefore concentrated in the core area with periodic sampling in perimeter areas for purposes of comparison. The Post Office (Federal Building) and the building housing the local newspaper and a commercial printing shop were used as sampling sites in the core area. The following were perimeter sampling sites: GSA Motor Pool, two retail establishments, State Police compound, and three elementary schools (Fig. 2). Continued NASN sampling provided quality control on our analyses.

Aerosols which settled from the atmosphere were collected on a 0.25 m^2 platform over a period of 24 hours to determine the quantity of gas and particulates per unit area dissolved in, entrapped by, or absorbed on ice fog particles. The settling out of ice fog particles is one mechanism by which air is cleansed or contamination lessened.

Nitrogen dioxide and carbon monoxide were monitored on a daily basis during the winter of 1969-70. The nitrogen dioxide was collected in a sampling train for

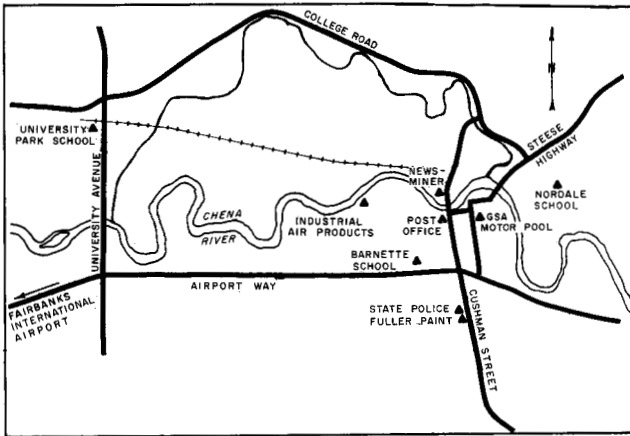


FIG. 2. Fairbanks air quality sampling sites.

a 24-hour period. CO was monitored continuously at the Federal Building in the core area using a non-dispersive infrared analyser. Grab samples were collected once a day at perimeter school sites and analysed in the same manner. Local meteorological data were obtained from the National Weather Service at the Fairbanks International Airport in the hope of establishing air quality dependence on atmospheric parameters. The station makes two daily soundings to determine air temperature at various elevations. From the pseudo-adiabatic charts made of each sounding, the temperature lapse rate and inversion height, if any, could be estimated. The average and resultant wind velocity were obtained from monthly local climatological data sheets. From these data we hoped to arrive at an index for predicting pollution levels in a manner similar to making a weather forecast.

ANALYTICAL PROCEDURES

Gases were trapped from air in a series of sampling trains, using specific absorbing solutions. The sampling trains (Fig. 3) are designed to bubble the air stream through the specific reagents for 24 hours before analysis (U.S. Public Health Service 1965). Excellent collection efficiency was attained by passing each stream through a coarse glass impinger into 20 ml. of absorbing reagents on 25 x 200 mm. test tubes. Air was filtered before entering the trains and the flow regulated by means of a calibrated restricted orifice downstream from the train.

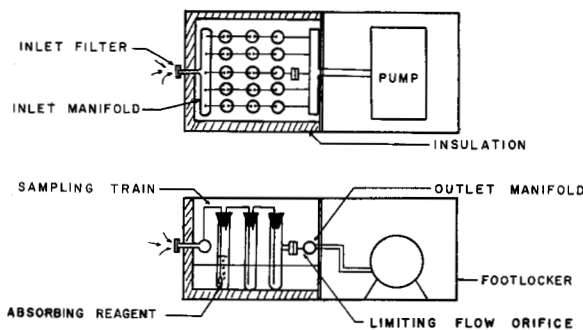


FIG. 3. Gas contaminant sampler.

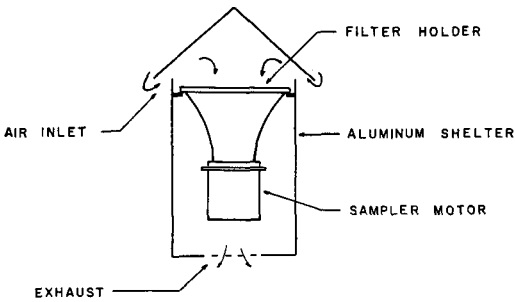


FIG. 4. High-volume particulate sampler.

The flow in all cases was from 0.185 to 0.225 litre/min. ± 0.005 litre/min. at standard pressure. The temperature of the sampling train was maintained at 25°C.

Collection and detection of total and specific particulate contamination followed NASN procedures (Morgan *et al.* 1966); Table 1 gives methods of analysis. Particulate samples were collected with a high-volume air sampler illustrated in Fig. 4. The air was passed through a tared 8 inch x 10 inch (21 cm. x 25 cm.) fiberglass filter for 24 hours at the rate of approximately 50 m.³ per minute. The average flow was computed from a flowmeter read before and after each sampling period. The filter was then divided in half for quantitative analyses; one portion for acid soluble lead particulates, the other for water solubles, NO_3^- , SO_4^- , Cl^- , and NH_4^+ .

Samples of precipitated aerosol were collected concurrently with the high volume particulate samples (Fig. 5). The precipitated material was weighed and extracted in the same manner as for the high volume particulates. The chemical analyses of the extracts provided data on the relative precipitation rates of contaminants per unit area. Samples were collected during periods of ice fog and during clear weather. An inability to determine the suspended load of ice in the air eliminated the possibility of comparing the total suspended particulate matter with that settling from the air. However, the precipitation per unit area for each contaminant was compared with the average concentration of the same

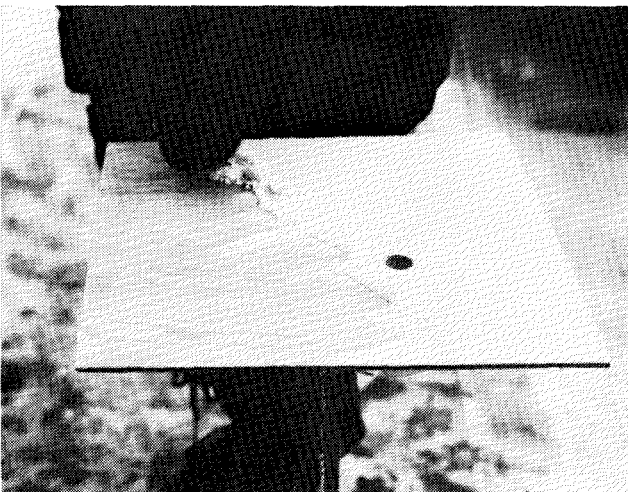


FIG. 5. A 24-hour ice fog sample taken at the News-Miner site.

contaminant suspended in the air over the same period of time. A ratio of these values reduces to a settling velocity having a dimensional value of metres per day, providing an indication of the relative rate at which each contaminant precipitated from the atmosphere. Without a measurement of suspended ice in the air, these rates could not be related to the settling of ice during ice fog. Instead, they were compared one with the other.

The air contaminants were measured using the methods of the NASN (Table 1).

TABLE 1. Methods of Analysis

Pollutant	Category	Method	Type
NO ₂	Gas	Saltzman	Colorimetric
NO + NO ₂	Gas	Saltzman	Colorimetric
SO ₂	Gas	West and Gaeke	Colorimetric
Aldehydes	Gas	MBTH	Colorimetric
Ammonia	Part.	Nesslerization	Colorimetric
Sulfates	Part.	Barium Sulfate	Turbidimetric
Nitrates	Part.	Hydrazine Reduction	Colorimetric
Chlorides	Part.	Ferric Thiocyanate	Colorimetric
Lead	Part.	Acid Extraction	Atomic Absorption

RESULTS AND DISCUSSION

Atmospheric Stratification

The Fairbanks-Chena basin experiences a stratification of air much more often than is indicated by ice fog. Although uncommon during the summer months, the air above the Fairbanks area is stratified a significant part of the year. A common inversion is shown in Fig. 6. In this example, the surface temperature

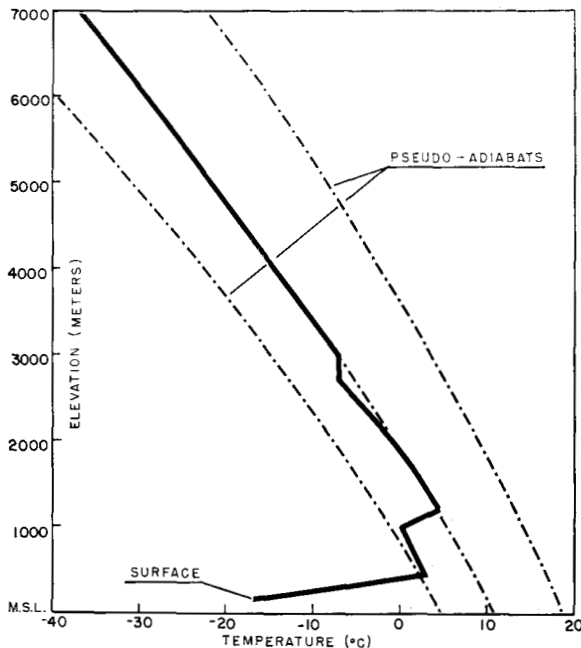


FIG. 6. Pseudo-Adiabatic Chart — temperature vs. elevation at Fairbanks International Airport — December 17, 1969, 2:00 p.m.

was not low enough to form ice fog, but the temperature lapse rate was very steep from the surface. Extrapolating along pseudo-adiabatic lines from upper levels, one finds theoretical surface temperatures that would be expected if the air were mixed. Inversions such as this may be on an average 3 times as steep as a typical Los Angeles inversion. Equally significant, Fairbanks' inversions usually begin at ground level, minimizing the air available for mixing. The development of an ice fog may raise the inversion off the surface slightly due to radiative cooling from the top of the fog layer. In contrast, the Los Angeles' basin has 400 to 500 m. of mixed air beneath its infamous inversion which merely acts as a lid on the air shed (Benson 1970). These factors lead to a close approximation of the mixed air volume per capita in the two cities.

TABLE 2. Comparison of Pollution Levels at News Miner Building in Fairbanks, Alaska

	<i>Non-Ice Fog</i> $\mu\text{g}/\text{m}^3$	<i>Ice Fog</i> $\mu\text{g}/\text{m}^3$	<i>National Urban</i> <i>Average*</i> $\mu\text{g}/\text{m}^3$ 1966	<i>NASN-Fairbanks</i> <i>Post Office 1968,</i> $\mu\text{g}/\text{m}^3$
NO ₂	37	85.2	141	107 _a
NO + NO ₂	66	198.2	na	na
SO ₂	0.6	33.8	na	8 _a
CH ₂ O	7.3	10.3	na	10 [†]
Total Particulates	492	—	102	207 _a
NO ₃ ⁻ + NO ₂ ⁻ (N)	0.16	0.3	65	na
SO ₄ ⁼	3.6	5.8	10.7	na
Cl ⁻	2.1	4.3	na	na
Pb	0.6	1.8	0.6-0.8 [†]	na
NH ₄ ⁺	trace	1.6	na	na

* Air Quality Data Summaries — 1966 Edition.

† Average of published data.

na: Not available.

a: 1969 Arithmetic mean.

TABLE 3. Mean Relative Settling Velocities — m./day

	<i>Post Office</i>	<i>News Miner</i>
Lead	201	230
Sulfate	1117	1044
Nitrate + Nitrite Nitrogen	1103	871
Ammonium	221	290
Chloride	402	544

Average Concentrations

The results of the study are summarized in Tables 1 to 3. Table 2 compares the national urban averages for various pollutants with the arithmetic averages obtained at one of the sites in downtown Fairbanks, and with values obtained for the NASN at the second site in the downtown area. During periods of ice fog the averages at the News-Miner Building ranged from 2 to 3 times higher than during periods of no ice fog (samples were not taken during ice fog at the Post Office site), but were below the national urban averages with two exceptions. Particulate lead was found to be 3 times the national urban average, as computed by the National Air Pollution Control Administration (Environmental

Protection Agency (EPA) 1966). The averages obtained for both sites in downtown Fairbanks exceeded the Environmental Protection Agency's (EPA 1971) primary standard for particulates, which allows $75 \mu\text{g}/\text{m}^3$ annual geometric mean and $260 \mu\text{g}/\text{m}^3$ maximum 24-hour concentration not to be exceeded more than once a year.

Aerosol Precipitation

The values obtained for settled and suspended particulate sampling afforded an interesting insight into the behaviour of particulates in the atmosphere. The average settling velocity of each suspended contaminant (Table 3) is based on a comparison of its average concentration in the air over a 24-hour period with the amount precipitated onto a specific area in the same period. During ice fog, lead apparently resides as or with an aerosol relative to its suspended concentration longer than do other contaminants under the same conditions. The sulfate and nitrate appeared to precipitate at 5 times the rate of lead aerosols during ice fog. During periods when no ice fog was present, the difference in rates was not as marked, sulfate and nitrate precipitating at relatively much slower rates. This observation alone implies the seeding of ice fog by anions of sulfur and nitrogen, and merits further investigation. It is possible that the difference in settling velocities results from the relative difference in the elevation of emission from the ground. The primary sources of sulfate are the high stacks of coal-fired power plants, and significant amounts of nitrate and nitrite nitrogen can be expected from the same source. Lead, on the other hand, is considered a surface emission from automotive fuels. The work of Winchester *et al.* (1967) discounts any significant background lead concentration. Such an assumption would mean that aerosols from higher above the ground may have more time to grow, and perhaps warmer conditions in which to develop. The resulting larger crystals would be expected to settle at a faster rate.

Graphic Correlation

Graphic correlation was used to determine if a relationship existed between atmospheric stratification and the concentration of pollutants. Plots were made of the weekly averages of pollutant concentrations, wind velocity, and temperature at the Federal Building sampling site. These showed that pollutant concentrations were independent of temperature. Although fuel consumption increases at lower temperatures, pollution at street level did not appear to be influenced proportionally. The average concentrations seemed more dependent upon the velocity of the air than on net directional velocity of the air. The data for the winter of 1969-70 indicated that there was a 3-month pattern of fairly stable conditions, with brisk winds occurring a month apart.

Statistical Correlation

Daily NO_2 concentrations and CO grab samples collected during the winter of 1969-70 were related statistically to meteorological parameters measured by the National Weather Service at the Fairbanks International Airport. The parameters were temperature, height of mixed air, and average wind velocity. Both linear and logarithmic relationships were investigated. No significant relation-

ship between meteorological conditions and NO_2 or CO contamination could be demonstrated, thus it was not possible to develop a satisfactory pollution index. The Weather Service data were unfortunately too distant to be representative of any of the sampling sites.

Pollutants monitored during the winter of 1969-70 resulted primarily from automotive exhaust. The data collected for the month of February indicated that CO was a direct function of traffic and that it dissipated rapidly as traffic subsided (Fig. 7). After the 6:00 p.m. rush hour the averages declined rapidly and rose again with the 7:30 a.m. rush hour. For the 24-hour period, maximum 8-hour levels for CO exceeded the Environmental Protection Agency's primary standard of 10 mg./l. (9 ppm) which is not to be exceeded for 8 hours more than once a year (EPA 1971). Windy conditions, however, maintained CO levels at a minimum even during rush hour periods. The sharp contrast between the hourly average CO and the average hourly maximums (Fig. 7) over the same sampling period clearly demonstrates that averaging can mask short-term conditions which may have significant health effects.

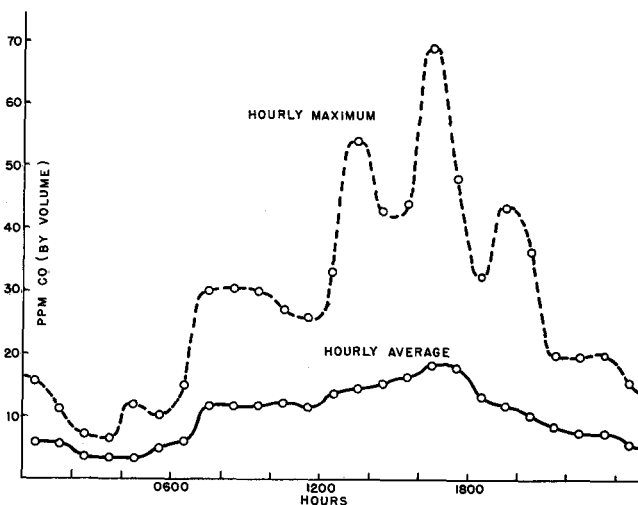


FIG. 7. Hourly carbon monoxide concentrations at Fairbanks Post Office, February 1970.

The peripheral sites, evaluated by grab sample, were not monitored and were therefore evaluated by averaging the results obtained. The concentrations obtained in samples from these sites were consistently lower than for the core area. The average daily concentration of NO_2 at these sites provided longer-term pattern of residence in the air and was a good indicator of the extent of contamination over a large area.

CONCLUSION

Fairbanks, the only sizeable community in the North American Subarctic, is in an area where the atmosphere is often stratified to the extent that air pollution is visible as a dense layer of fog which persists when temperatures drop below -30°C . The average concentrations for pollutants during ice fog were approximately half the national urban averages except for particulate lead, which were

about triple the available urban averages. This is interpreted as stratification influence on concentration, compared to random samples taken with no meteorological consideration in mind. Average particulate and CO levels exceeded the Environmental Protection Agency's primary National Air Quality Standards (EPA 1971). Total suspended particulates averaged 5 times the national urban levels (EPA 1966). The area studied is relatively dry in the absence of snow cover, so that glacial dust and silt exposed during the summer are readily picked up by wind. Gravel roads and emissions from inefficient combustion also contribute to the high level of suspended particulates. Lead aerosols appeared to have significant residence times in extremely cold air. This probably has significant dependence on the rapid cooling of the exhaust, the availability of lead-containing nuclei, and the ultimate size of crystal formed.

This study demonstrated that Fairbanks has the potential for an air pollution problem. Atmospheric conditions are often calm and stagnant in the Fairbanks area. The sources of more serious contamination are associated primarily with the use of automotive transportation. These factors, together with the presumption that the population of the Fairbanks area will continue to expand as a result of arctic mineral exploitation, make air quality control in the area of paramount importance.

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