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APPENDIX 5 TO MAIN REPORT

STUDY OF APPLE HILL ENERGY EFFICIENT HOMES

TASK F - AIR QUALITY TESTS

PREPARED FOR:

THE TECHNICAL RESEARCH DIVISON

OF

CANADA MORTGAGE AND HOUSING CORPORATION

BY

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Executive Summary

In response to increasing energy costs, the demand for energy efficient homes has increased. Government subsidized programs are emphasizing tighter, more insulated homes. One major area of emphasis has been in the field of controlling air infiltration. In attempts to reduce the heating costs associated with uncontrolled infiltration, many builders are constructing houses with infiltration rates in the order of 0.1 to 0.2 ACPH. An appreciation that insufficient fresh air is being supplied to the occupant has resulted in the inclusion of mechanical ventilation systems in some of these houses. However, there appears to be no guarantee that the systems provide adequate air supply or that they are fail safe in operation.

The Apple Hill Project allowed an opportunity to monitor several potentially dangerous pollutants which a typical homeowner may be exposed to in an airtight house. Pollutants, such as carbon monoxide, carbon dioxide and oxides of nitrogen were measured over three distinct seasons. These gases were measured using a Draeger Multi Gas Detector System, which allows for quick on site evaluation of pollutants levels. The system proved to be a quick and cost effective tool for assessing pollutant levels. Both CO and NO were well below recommended dangerous levels. The geometric mean of carbon dioxide levels in the three test periods range from approximately 500 to 600 ppm. This substance is largely produced by

the human metabolism an indicates, in most cases, the presence of a number of people in the immediate vicinity. High CO2 levels are indicative of poor ventilation or circulation in a home and thus suggests that possible improvements in the air circulation of the homes could be made. These levels of carbon dioxide are significantly below the levels recommended by ASHRAE, however, they border on levels commonly found to cause complaints of poor air quality in office buildings(MOL,1983).

Radon and Radon Daughter levels were independently monitored by the Radiation Protection Bureau of the Federal Department of Health and Welfare using both grab sampling and time average techniques. The Apple Hill subdivision, located in March Township has been characterized by high radon levels. These homes represented an excellent opportunity to assess the degree of the radon concentration associated with tighter homes in the area, as well as, supply a substantial test data base for the Bureau. This data base was used to cross-check the montoring equipment. The results revealed stratification of the radon throughout the house. Basement levels were generally higher than those of the upper floors. It is suggested that these higher levels are attributed to radon being carried by soil gas and ground water which generally migrate through foundation and basement slab. The Apple Hill testing showed annual geometric means of radon gas levels in the basement of the houses to be in the order of 2.5pCi/L. Testing also showed the annual WL data for the homes to have a geometric mean of the order of 0.01 WL. This would imply that over 50% of the homes could be classified in th investigative level as defined by the

AECB (1977). Furthermore, 15% of the homes exceed the annual average primary criterion of 0.02 WL. These high levels suggest remedial action, on th Apple Hill houses, and consideration of the hazard for future housing and in particular, energy efficient housing located in the proximity of known naturally occurring uraniferous materials.

In a similiar manner to pollutants and radon build-up in tighter homes, due to insufficient fresh air, the build up of moisture in the air is also a serious concern. Unlike other pollutants high relative humidity is much more visible in the home. Significant moisture accumulation on windows, peeling paint, and mold deposits were frequently observed in many Apple Hill homes. These problems were most prevalent during early fall and winter. Many houses had Relative Humidity levels well above recommended levels. It has been suggested that moisture stored within the house structure is released during the fall and winter as outside relative humidities drop with the cooler temperatures. One other major source suggested is the basement slab. It is recommended that in a similiar manner to pollutants, the sources and levels of this moisture be further evaluated such that proper remedial action can be implemented.

The monitoring and evaluation of air quality in tighter homes is a fundamental concern before proper cost-effective remedial action can be implemented. The results of such monitoring could represent not only guidelines for regulatory committees but also an important

source of information to enhance the knowledge of the occupants in airtight houses. Furthermore, this information will allow them to more fully understand their own environment and give them more control over the remedial action available to them. It is recommended that standard indoor air quality test procedures be developed so that all tests undertaken in the residential environment will be done on the same basis.

1.0 INTRODUCTION

Increasing energy awareness has increased the emphasis on airtightness in new house construction. This emphasis is in response to the need to reduce heat loss due to excessive infiltration of cold air and exfiltration of warm air in houses. It has resulted in lower natural infiltration rates and raises many questions about "air quality" in energy efficient homes.

The term "air quality" addresses a number a issues. Particularly:

1) Is there an adequate supply of oxygen to safely sustain the lives of the occupants.

2) Is the air supply to the occupants reasonably free of health hazardous pollutants such as carbon monoxide (CO), Nitric Oxide (NO), Nitrogen dioxide (NO2), sulfur dioxide (SO2), formaldehyde, radon and others.

3. Is the moisture content in the air low enough to ensure the structural integrity of the house and still maintain the minimum comfort level required by the occupants.

A separate issue which overlaps with the air quality issue is the need for an adequate air supply to combustion devices. This is

more of an air quantity problem than an air quality problem. However, if there is an inadeqate supply of air for combustion the situation can quickly become an air quality problem.

Almost all of the standards for air quality and air supply are currently under review with respect to their application in new and existing airtight houses. One of the tasks of the Apple Hill study was to monitor some of the potentially dangerous pollutants that the homeowners may be exposed to. This monitoring was in the form of grab samples taken during each phase of testing. Some additional time averaged monitoring for radon and formaldehyde were conducted in the late stages of the study. This report presents the methodology, results, conclusions and recommendation based on this air quality monitoring.

2.0 OBJECTIVES

The purpose of this task was to identify and monitor some of the potentially dangerous pollutants that a homeowner is most likely to be exposed to in an airtight residential environment.

These pollutants are outlined below:

1. Carbon monoxide (CO), and oxides of nitrogen (itric oxide NO, and nitrogen dioxide NO2). These gases are commonly associated with combustion processes in and around the house such as cigarette smoking, car exhausts and gas furnace emmissions.

2. Radon and Radon Daughter levels. Apple Hill is located in March Township which is characterized as having high radon levels.

3. Formaldehyde levels, a pollutant more commonly associated with urea formaldehyde foam insulation (UFFI) but also present in resins and glues used in many construction materials and in many fabrics and carpeting materials.

4. Relative Humidity Levels.

Although not generally considered a pollutant, the RH level does reflect the quantity of moisture in the air. High levels of moisture are generally responsible for mold growth in the home and can lead to high levels of condensation on window panes hich can result in rapid deteoration of paint and window frames.

3.0 METHODOLOGY

After some investigation, the most suitable technique for measuring these gases was found to be the use of a Draeger Multi Gas Dectector, which consists of a pump and a direct reading Draeger tube. It is relatively simple, low cost system which provides reliable results within a range of 15%. The lower levels of detection for each gas are:

CO	0.5 ppm
CO2	100.0 ppm
NO+NO2	12.5 ppm

Detailed procedures for testing using the Draeger detector are presented in Appendix A.

The department of Heath and Welfare Canada Enviromental Radiation Hazard Section conducted grab samples of Radon and Radon daughters in Apple Hill using the Lucas Chamber method and the Kusnetz field method respectively. (This is also described in Appendix A.) Concentrations of radon gas were measured on each level of the house to provide data concerning stratification.

In addition to the grab samples, the department is also performing time averaged tests of Radon and Radon Daughters to substantiate the grab samples. Originally Passive Environmental Radon Monitors (PERMS) were placed in several homes through the first three phases

of testing. In the winter of 1982 a new time integrated technique of measuring radon was adopted. This method developed by Terradex, in California is called the "Track Etch" detector. These were installed in all the Apple Hill houses and the study is continuing through 1983.

The growing concern of formaldehyde emmissions from resins and glues used in construction materials prompted the use of passive formaldehyde Dosimeters developed by Dupont. The study was performed in the spring of 1983.

4.0 RESULTS

A detailed summary of air quality measurements for CO, CO2, NO, radon, formaldehyde and humidity are presented in Appendix B. Data sheets are presented in Appendix C. The results for each of the pollutants monitored are discussed in the following sections.

4.1 Carbon Monoxide (CO)

Typical CO readings of 0.5 ppm or less were frequently observed with a maximum observed reading of 3.0 ppm in Apple Hill and 3.5 ppm for the whole project. Attempts at correlating any elevated levels with air change rates proved to be inconclusive. Seasonal variations indicate increased levels in winter. Occupant lifestyles such as smoking resulted in slightly elevated CO levels in some instances. These are suggested findings based on the available results, however, no definite conclusions can be made.

4.2 Nitric Oxide and Nitrogen Dioxide (NO+NO2)

NO+NO2 levels were almost invariably less than 12.5 ppb. The Short Term Exposure Limit (STEL) for Nitric Oxides as recommended by the American Conference of Governmental Industrial Hygenists is 35ppm. Limits for time weighted average concentration of NO2 are set at 5ppm. The maximum reading for (NO+NO2) was 38ppm for Apple Hill and 50 ppm for the whole project. Again connections to lifestyles and air change rate were observed. A note of caution with

reference to Apple Hill houses is necessary. As all gas heated homes in Apple Hill are enclosed in furnace rooms, the resulting NOX levels may not be indicative of levels that may be experienced in a tight home with conventional gas furnance.

4.3 Carbon dioxide (CO2)

The geometric mean of carbon dioxide levels in the three test periods range from approximately 500 to 600 ppm. This substance is largely produced by the human metabolism an indicates, in most cases, the presence of a number of people in the immediate vicinity. High CO2 levels are indicative of poor ventilation or circulation in a home and thus suggests that possible improvements in the air circulation of the homes could be made. These levels of carbon dioxide are significantly below the levels recommended by ASHRAE, however, they border on levels commonly found to cause complaints of poor air quality in office buildings(MOL,1983).

4.4 Radon and Radon Daughter Testing

The air quality measurements of radon were performed by the Radiation Protection Branch of Health and Welfare Canada. Three separate testing methods were used. Grab samples were taken at all levels in each house during each phase of testing. These samples were used to determine both radon and radon daughter concentrations. Track Etch radon detecters were left in each house from January to March, 1983. Health and Welfare also installed

PERM'S, long term radon monitors, in the basements of 14 houses. There was general agreement in the results of grab samples and Track Ektch detectors. The PERM'S showed consistently, higher results. This discrepency is being investigated by the Radiation Protection Branch.

The Kanata area has shown much higher levels of radon than most other parts of Canada. The results from the Apple Hill tests bear this out. As radon is carried by soil gas and ground wasters, its point of entry into the house is generally the basement. Thus basement readings are generally higher than those from upper floors. The Apple Hill geometric mean for basement readings is 2.7 PCi/L the January - March, 1983 period (see table 4.1). This area falls within the medium radon concentration (0.5 - 4.0 PCi/L) as designated by the Environmental Protection Agency (EPA) in the United States. At least 5 houses show frequent basement readings of over 6.0 PCi/L, the EPA standard maximum.

All home owners have had regular reports on their test results, including radon testing. Homeowners with concerns about high radon levels have had ready access to Radiation Protection Branch Staff. Possible remedial actions include basement floor and wall sealing, increased ventilation, and the installation of electronic air cleaners to reduce radon daughters concentration.

4.5 Formaldehyde (CH2O)

Time average measurements of formaldehyde concentration were made over the period of February 28, 1983 to May 31, 1983. These levels were measured using Du Pont Pro-Tek TM air monitoring badges for formaldehyde (CH2O). The badges were mounted in the living room of seven houses in the sample. They were left there for periods up to two weeks at which time they were replaced with new badges. The exposed badges were analysed using gas / liquid chromatography. The results of the formaldehyde monitoring are presented in Table 4.2. The results appear to be fairly consistent. Some of the results were voided because the samplers were left in the house too long. The exposure period oof two weeks is probably too long and in general the formaldehyde values recorded here could be low compared to the actual values in the home.

Table 4.1
Statistics of Radon Measurements in Apple Hill, Kanata
Period January March, 1983

Location	Track Etch					Grab Sample				
	n	x	s	vg	Sg	n	x	s	vg	Sg
Basement	34	3.2	2.0	2.7	2.0	36	2.8	2.3	2.4	2.1
Upstairs	17	2.2	1.5	1.8	1.8	36	2.0	1.7	1.4	2.2
Ratio Upstairs/ Basement		0.69		0.67			0.71		0.58	

* detector placement period: January 13 - March 17, 1983

\+ sampling period: January 17 - 25, 1983

n - no. of homes

x - normal mean, pCi/L

s - normal standard deviation, pCi/L

vg - gemometric mean, pCi/L

Sg - geometric standard deviation, pCi/L

TABLE 4.2

SUMMARY OF FORMALDEHYDE PERIOD (PPM)

HOUSE NUMBER	CONSENIRATION PER MONITORING PERIOD (PPM)						
	1 FEB 15 TO FEB 28	2 FEB 28 TO MAR 15	3 MAR 15 TO MAR 30	4 APR 19 TO APR 29	5 APR 29 TO MAY 17	6 MAY 17 TO MAY 31
8		.069	.061	.072	.063	.083
10		.09	.108	.12		.118
20				.068	.088	.091
28		.049	.051	.085		
32		.061	.063	.067		
34		.124	.078	.087	.091	.1
39				.141	.084	.063

4.6 Humidity

Relative humidity measurements were performed during air change/air quality testing using a portable psychrometer. The method proved very reliable and easy. Periodic checks with wall hygrometers in some homes provided a good opportunity to verify the results. The checks indicated good correlation.

Unlike pollutant levels whose effects are subtle and invisible, elevated levels of relative humidity can be very graphic in the form of condensation or frost on the inner surface of windows. A survey of the results obtained in the Apple Hill project indicate high relative humidities during the summer months. Although these high humidities can be discomforting during these periods, these levels do not cause any obvious problems since outdoor temperatures will not induce condensation. However, it has been suggested that these high levels are associated with high degrees of moisture storage in the structure itself. Thus with the advent of the heating season and lower outdoor relative humidities, this moisture is released back into the home. The combination of closing up the house, lower air change rate, release of stored moisture combined with natural moisture generation leads to higher than recommended levels of relative humidity.

These high levels of humidity create concerns about condensation, mold, and deteoriation of paint on and around window sills. Results obtained during the heating season indicate at least 65% of

the homes were operating above the recommended relative humidity levels outlined in Table 4.3 . In this category two homes had relative humidity levels in the order of 75% higher than the recommended levels.

Another potentially serious problem with greater ramifications than widow condensation is the possibility of exfiltration/condensation in the second floor walls and ceiling of these houses. Pressure measurements consistently show the neutral pressure plane (N.P.P.) to be at the floor level of the second story. It drops about one meter lower during furnace fan operation because of the enclosed furnance room and fresh air duct. As a result the envelop area above the N.P.P. is continually subjected to a positive pressure differential, relative to outside, throughout the heating season. This causes warm moist air to exfiltrate through cracks and openings in the air vapour barrier.

As this air passes through the wall cavity, which is filled with about 30cm of insulation, it is cooled. It is most likely that it is cooled below its dew point where moisture will condense inside the cavity. This creates two problems. In the short term the condensed moisture is absorbed by the fiber glass insulation reducing its R-value and increasing the heat loss. This can progress to the point where ice forms inside the walls, effectively eliminating all of the insulating properties. The second longer term problem is the possibility of damage to wooden structural components exposed to prolonged levels of high moisture inside the wall cavity. This can result if the cavity is unable to adequately

ventilate itself during the summer months.

These two problems were not investigated as part of the study and the possibility of their existence is speculative. However the conditions for exfiltration/condensation exist and the possible consequences should be considered.

TABLE 4.3

RECOMMENDED INDOOR HUMIDITY LEVELS FOR
A HOME WITH DOUBLE-GLAZED WINDOWS

OUTSIDE TEMPERATURE		RECOMMENDED INDOOR RELATIVE HUMIDITY AT 20C (68F)
CELSIUS	FAHRENHEIT	
0 OR ABOVE	32 OR ABOVE	45% - 50%
0 TO -6	32 TO 21	40%
-6 TO -12	20 TO 10	35%
-12 TO -18	10 TO 0	30%
-18 TO -24	0 TO -11	25%
-24 TO -30	-11 TO -22	20%
-30 OR BELOW	-22 OR BELOW	15%

5.0 EVALUATION OF TEST PROCEDURES

5.1 Draeger Multi-Gas Detector System

The Draeger Multi Gas Detector Method of measuring CO, CO2, and NO+NO2 was found to be useful in determining the order of magnitude to which these gases existed in the homes. The CO2 levels observed in Apple Hill proved to be consistent with observations made by others. In the case of CO and NO, NO2, the levels did not warrant further analysis with more sophisticated equipment. In the case of CO2 discerable levels as indicated by the Drager tube were useful in establishing a baseline level characterized by a relatively tighter home.

6.0 CONCLUSIONS

6.1 Measured concentrations of carbon monoxide (CO), carbon dioxide (CO2) and oxides of nitrogen are below the current recommended levels for these pollutants. Carbon dioxide (CO2) was the only pollutant found, in a small number of houses, to be relatively high indicating poor air circulation in the house. The major sources of these pollutants, namely the furnace and water heater are isolated in well vented, enclosed rooms. This could be the main reason why they are not detected in the living space. Due to some operational problems with the furnace rooms, in these houses, there is a possibility that the furnance rooms will be effectively dismantled in the near future. If so, this will put these combustion devices in direct competition with the occupants for air supply. It will also increase the risk of combustion products leaking into the living space. This could potentially create an air quality problem which does not exist now.

6.2 In general, levels of radon measured in the Apple Hill houses was greater than would be expected. In some cases levels are high enough to warrant some form of remedial measures. {this is currently being investigated further and recommendations will be made in the near future.

6.3

Formaldehyde levels were found, in some cases, to be as high as the recommended maximum level set for houses insulated with Urea Formaldehyde Foam Insulated (UFFI) in spite of the fact that UFFI was not used in these houses. The apparent sources are building materials and furniture. The low air change rates in these houses appear to compound the problem by not allowing for adequate venting or removal of this pollutant. Other researchers have noted a positive correlation between formaldehyde levels in homes and the relative humidity in the homes. It could also be that low air change rates lead to higher than normal humidity and therefore higher than anticipated formaldehyde levels.

6.4

The potential for exfiltration/condensation and its associated problems exists in the upper half of the exterior envelopes of these houses.

7.0 RECOMMENDATION

The results obtained from the Apple Hill Air Quality Study present several areas of potential concern. Since the Apple Hill Project, programs such as the Ministry of Enery Housing Demonstration Program and the R-2000 Program have set airtightness specifications as much as twice as tight as those observed in Apple Hill. Although mechanical ventilation devices are becoming commonplace in these tight homes, a full appreciation of the potential risks due to pollutant build-up and radon exposure have received only passing concern. This is primarily due to the tremendous reliance on these mechanical ventilation devices which at present do not guarantee a healthy environment.

Thus, there is a fundamental need to continually evaluate and monitor residential air quality such that cost-effective control measures can be adequately defined. Secondly, an awareness by both builders and homeowners about air quality is required, so that, unhealthy indoor air quality conditions are not imposed upon individuals without their knowledge or consent.

7.1

Carbon dioxide results for Apple Hill indicate that a potential exists for high spot levels of the pollutant in some houses. These levels are not anticipated to be detrimental to the residents, however, they are indicative of poor air circulation. As such they

would indicate an increased possibility that other cominant levels could be high. The results currently indicate an average value for the house and it is appropriate that further testing be done in Apple Hill to establish the level of CO2 in various areas of the home. Should levels exceed 1000 ppm balancing the air distribution system to provide more air to the isolated parts of the house will quickly overcome any potential problems.

At present the recommended CO2 levels are based upon experience in office buildings and it is not known whether they are strictly applicable for residential buildings. Further work should be done to ascertain normal levels in residential homes and coordinate this data with the habits of occupants. This work could use short term Draeger tubes as a first approximation to isolate those houses with significantly elevated levels. Long term (4 hour) tubes would be more appropriate for gathering a data base suitable for making recommendations. At present, it is not anticipated that more sophisticated instrumentation is required to provide deetails of the CO2 cause/effect relationships.

As discussed, Apple Hill homes have enclosed furance rooms, thus, possibly isolating a major source of nitrous fumes. It is recommended that tests on conventional tight gas heated houses be performed before the insignificant levels observed in Apple Hill houses can be substantiated. This would be essential before making any recommendations of disposing of the Furnace rooms.

7.2 RADON

Although much of the work concerning radon was carried out by the Radiation Protection Branch, the results reflect a genuine concern of the possiblity of elevated levels of radon in tighter homes. Whether these levels are dangerous is still being discussed within the Branch, however, any further work in energy efficient housing research should analyze this area of air quality. Thus homeowners can be made aware of possible risks and available remedial action.

7.3 HUMIDITY

The high relative humidity levels and the large degrees of condensation, frost and even frozen windows reflect the demand on homeowners to become aware of the potential problems associated with tighter houses and preventative measures available. Because of the graphic nature of high relative humidities and its potential destructive nature on ones investment, it is recommended that emphasis be placed on isolating these moisture storage areas and their contribution to high humidity during the heating season.

APPENDIX A

TEST PROCEDURES.

AIR QUALITY PROCEDURES

EQUIPMENT

Measurement of CO_2, CO, and NO + NO_2 was performed using the Drager Gas Detector which consists of a Drager Tube + Drager pump. The Drager pump is a hand operated bellows pump which supplies 100cm3 of air per stroke.

PROCEDURE

1. Evacuate the pump two to three times to ensure a clean bellow and proper functioning of the bellow.
2. Before each series of measurements, check the pump for leaks with an unopened tube.
3. Break of the tips of the tube.
4. Insert the tube tightly in the pump Lend (arrow points toward pump)
5. Suck the air sample through the tube by fully compressing the bellows, then releasing. The end of the suction process is reached when the limit chain is taunt. Repeat this procedure as required.
6. At the completion of the test record the concentration referring to the appropriate scale outlined in the instruction sheet and container.
7. Before packing pump away evacute the bellows two to three times.

Caution: The Drager Pump has a special break off plate to facilitate breaking the Drager tube tips. Make sure to place a large piece of paper, 2 to 3 strips of tape or a paper bag beneath this plate in order to collect the broken glass. Keep eyes and face away from the breaking area.

Air Quality Testing - Special Notes Based on Apple Hill Testing.

An extension of the range of measurement for both CO and NO + NO2 was required in order to obtain adequate measurements. The relationships are indicated below as extracted from the Drager Detector Handbook (4th Edition - August 1979)

$$\text{ppm CO} = \frac{10 \times \text{numerical value (10-stroke scale)}}{\text{number of strokes (n)}}$$

where n=100

$$\text{ppm(NO+NO2)} = \frac{\text{scale value read-off} \times 5}{\text{number of strokes (n)}}$$

where n=200

Radon

Health and Welfare Canada,s Environmental Radiation Hazard Section is conducting grab samples of radon and radon daughter concentrations using the Procedures outlined in the "Proceedings of the Specialist Meeting on Personal Dosimetry and Area Monitoring Suitable for Radon and Daughter Products" which is included in this section.

"Proceedings..."

"Proceedings of the Specialist Meeting on Personal Dosimetry and Area Monitoring Suitable for Radon and Daughter Products."
Elliot Lake, Canada, 4 - 8 October 1976.
Nuclear Energy Agency, OECD.

PRESENT PRACTICES OF THE DEPARTMENT OF NATIONAL HEALTH AND WELFARE FOR THE AREA MONITORING OF RADON AND DAUGHTER PRODUCTS

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Introduction

This communication outlines the present practices of the Department of National Health and Welfare for the area monitoring of radon and daughter products. The measurements have been largely directed towards specific studies pertaining to occupational and environmental health and not to any extent for the routine monitoring of uranium mines.

This Department first became involved with the measurement of radon and daughter products in mine atmospheres in 1958. At that time, A.J. de Villiers and J.P. Windish[1] expanded an on-going study of lung dust diseases among miners in Newfoundland to include radiation exposure in the fluorospar mines of St. Lawrence. An average radon daughters concentration in the range 2.5 to 10 Working Levels was found, even though the uranium content of the ore was less than 0.005% U_3O_8. It was concluded that radon was not being emanated directly from the exposed rock walls, but, that it was being released from mine waters into which radon had dissolved at more distant locations.

In subsequent years, measurements of radon and daughter products have been carried out in other non-uranium mines, including a columbium ore mine and a tin ore mine. In these mines, also, elevated radon daughter levels were found to be associated with high levels of radon dissolved in mine waters. Moreover, the ventilation systems were not specifically designed to cope with radon daughters because the presence of radon was not anticipated.

At the two active uranium-producing mines at Elliot Lake, Ontario, intercomparison measurements have been carried out with the operators directly in the mines and mills[2]. These field studies were undertaken to evaluate the quality of the monitoring data being generated by the mines for the calculation of cumulative occupational exposures to radon daughters.

Recently, the same techniques have been applied to measure radon and daughter products in the homes and buildings of a community located near a major uranium ore-body. In this study, it was found that below ore-grade levels of uranium in crushed development rock used as fill and in driveways generated sufficient radon to accumulate in the homes. In addition, small,

natural local occurrences of radioactive material appeared to contribute in some locations.

The procedures used in the foregoing examples are briefly described in the following sections.

Present Practices

A. Radon Gas

Radon gas concentrations are determined by the Lucas chamber method[3]. In the original design, a 5 cm diameter by 6 cm long metal cylinder with a hemi-spherical top and a quartz window on the bottom served as a chamber for radon. The active volume was about 100 ml. The inside of the metal portion was coated with zinc sulphide (silver-activated) scintillator. A stopcock capable of maintaining a vacuum was sealed to the top for emptying and filling the cell.

At the desired sampling location, the stopcock of a pre-evacuated cell is opened to admit air through a filter until atmospheric pressure is reached. After the radon daughters have fully grown in, the scintillation rate is measured with a multiplier phototube and scaler-timer.

During field studies, a 2.5 cm diameter phototube in a portable, self-contained battery-operated detector is used. In the laboratory, a 5 cm phototube is used in a system having a printing scaler and timer. Any desirable counting period up to 999.9 minutes may be selected. At the end of the pre-selected time, the total counts accumulated are printed out, the scaler is reset automatically and the counting cycle is repeated until stopped by the operator. The total elapsed time is also registered to measure the in-growth period for the radon daughters.

The radon cells are calibrated by de-emanating known amounts of radon from standard solutions of radium-226 obtained from the U.S. National Bureau of Standards. The average efficiency observed was 5 cpm per pCi of radon-222 after equilibrium with daughters has been reached. When new, the background of the cells averaged less than 0.1 cpm.

B. Short-lived Radon Daughters

Short-lived radon daughters concentrations are determined by the Kusnetz field method[4], modified by using a scaler-timer in place of a ratemeter to measure the alpha count rate. In this well-known procedure, the air to be sampled is drawn through a filter at a known flow rate for a known time. After allowing the collected radon daughters to decay for a period of 40 to 90 minutes, the alpha count rate is determined with a zinc sulphide alpha scintillation detector. The pulsed output from a multiplier phototube viewing the scintillations is amplified and recorded on a scaler-timer. The detector is calibrated using a source prepared from a standardized solution of americium-241.

The collection system presently in use consists of a rotary-vane vacuum pump driven by a 6 V D.C. motor. Two rechargeable lead batteries in parallel allow at least twenty 5-minute duration samples to be collected. A rotameter-type flowmeter, calibrated against a wet-test meter, is used to measure the flow rate. A flow rate of 10 liters per minute is usually chosen to give a large volume for better counting statistics, especially for samples from homes and buildings. For these studies, the need for minimum size and weight is not as pressing as it is for use in mines.

The filter used is a 25 mm diameter membrane type having a pore size of 0.8 μm. The filter holder itself is readily detachable, permitting a number of them to be pre-loaded for rapid use in the field.

The possible sources of errors in this method have been reviewed by Loysen[5]. In his review of available instrumentation, Budnitz[6] quotes

studies which confirm that with appropriate attention to the factors, the method is intrinsically accurate and sensitive.

C. Other Natural Radionuclides

The low-level environmental radioactivity laboratory of the Radiation Protection Bureau in Ottawa is well equipped to carry out radioanalytical procedures for the long-lived precursors of radon and for the long-lived daughter products from the decay of radium-C. Specifically, these include uranium, thorium-230, radium-226, lead-210, bismuth-210 and polonium-210. The instruments on hand include low-background alpha and beta counters, NaI(Tl) scintillation gamma spectrometers, high resolution Ge(Li) gamma spectrometers, an alpha spectrometer, a fluorometer and a liquid scintillation counter. A vacuum system for concentrating radon from air, water and exhaled breath for subsequent measurement in Lucas cells is available. These laboratory procedures have provided useful analytical data to support studies of environmental levels of radon and daughter products which are of interest to public health.

Recent Studies

Recent studies of radon and daughter products in non-uranium mines have shown that surprisingly high levels can accumulate. In a columbium mine, the concentration of daughter products ranged from 3.4 WL at an ore ramp to 19 WL at a new face and 29 WL at the end of a cross-cut. These levels were greatly improved by the judicious use of ventilation.

In a tin mine, which is presently in a stand-by state with only a sump pump operating pending further development, Working Levels started at 1.1 WL half-way into the entrance incline and progressively increased to 5 WL, 11 WL, 47 WL and 63 WL at the farthest point from the entrance.

Radon gas samples were also taken at the same time and locations. This allowed the calculation of the ratio of (100 x WL) to radon concentration in pCi/l. This fraction of theoretical equilibrium ranged from 0.3 in the entrance incline to 0.98 in the interior. This confirmed the lack of any air movement and clearly pointed to the need for substantial ventilation.

As a contrast to the situation in these non-uranium mines, some findings from a systematic survey of a uranium mining community are summarized. Approximately 20% of the 500 homes and buildings were found to have radon daughter Working Levels over an arbitrary value of 0.03 WL. At least 11 were over 1 WL, with the highest over 2 WL. The source of the radon was attributed to the use of below-grade mine development rock which was crushed and used as fill for driveways, sidewalks and other construction purposes. Contribution from small natural occurrences of uranium-containing outcroppings were also not precluded.

It was of interest to measure the fraction of equilibrium values of Working Levels which were reached in these homes. This fraction ranged from 0.3 to 0.5 in the basement of the majority of those homes which contained measurable amounts of radon. These ratios imply a reasonable circulation of air, partly due to the air intake for oil burners of furnaces which were in operation during the measurement period.

Summary

The present practices of the Radiation Protection Bureau for the measurement of radon and daughter products have been briefly described. For radon gas, the Lucas chamber method is in use. Short-lived radon daughter products are determined by the modified Kusnetz method. These field methods are supported by radioanalytical procedures carried out at the environmental radioactivity laboratory.

Some recent studies using these methods have been briefly summarized. Concentrations of daughter products up to 29 WL were found in a columbium mine and 63 WL in a tin mine under development. The level of radon daughters in

some homes in a uranium mining community ranged up to 2 WL.

References

1. de Villiers, A.J. and Windish, J.P., British J. Indust. Med. 21, 94 (1964).

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3. Lucas, H.F., Rev. Sci. Inst. 28, 680 (1957).

4. Kusnetz, H.L., Am. Ind. Hyg. Quarterly 17, 85 (1956).

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Discussion

A question was raised on whether the mines mentioned in this presentation were normally wet or dry. Both the columbium mine and the tin mine were very wet, with mine water coursing through most drifts. Water from a drift face in the columbium mine had 220 nanocuries of radon-222 per litre. In the tin mine, 60 nanocuries per litre was measured. Concentrations of 4.2 and 12.8 nanocuries per litre have been reported for the fluorospar mine in St. Lawrence, Newfoundland.

It was also noted that dry mines can also accumulate high levels of radon and daughter products, as found in the United Kingdom.

APPENDIX B

SUMMARY OF DATA

APPLE HILL AIR QUALITY RESULTS

HOUSE NO	PHASE 2					PHASE 3					PHASE 4				
	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	UPSTRS	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	UPSTRS	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	UPSTRS
1	BDL	500.00	BDL	14.90	0.50	BDL	500.00	BDL	25.50	1.30	0.80	600.00	BDL	10.00	7.30
2	0.50	700.00	BDL	3.50	0.30	BDL	600.00	BDL	17.90	2.40	BDL	400.00	BDL	6.30	4.00
3	0.50	500.00	BDL	15.90	0.50	BDL	400.00	BDL	12.30	1.40	BDL	600.00	BDL	15.10	9.80
4	1.00	900.00	BDL	27.40	5.60	BDL	600.00	BDL	4.50	2.30	BDL	600.00	BDL	5.70	2.30
5	0.50	800.00	BDL	5.00	0.50	0.50	800.00	12.50	3.50	1.10	0.50	400.00	17.50	7.50	4.20
6	----	800.00	BDL	10.40	0.80	BDL	600.00	25.00	17.00	2.70	0.50	400.00	25.00	4.60	2.20
7	0.50	900.00	20.00	2.10	0.50	0.50	400.00	BDL	3.30	1.70	0.70	500.00	BDL	4.60	3.90
8	----	----	----	----	----	0.50	400.00	12.50	71.40	12.10	0.50	600.00	42.50	10.80	7.30
10	BDL	600.00	15.00		4.90	0.80	800.00	BDL	49.20	46.40	0.50	600.00	BDL	43.20	33.00
11	0.50	400.00	12.50	11.60	1.20	BDL	400.00	BDL	16.50	4.40	BDL	600.00	BDL	7.50	1.70
12	0.60	600.00	12.50	17.10	7.00	BDL	400.00	BDL	12.50	10.20	0.70	400.00	BDL	6.60	3.40
13	0.70	400.00	12.50	13.90	0.40	BDL	600.00	BDL	14.10	1.50	0.50	400.00	BDL	7.60	2.10
14	0.50	900.00	12.50	13.90	0.40	BDL	600.00	BDL	49.00	6.40	0.60	500.00	BDL	20.00	15.10
E15	0.50	800.00	12.50	25.50	7.30	0.50	400.00	BDL	1.70	1.60	0.50	500.00	BDL	10.80	7.40
16	1.00	500.00	0.50	12.90	0.70	----	----	----	----	----	BDL	400.00	BDL	4.10	1.80
E17	0.50	400.00	12.50	15.00	1.20	BDL	400.00	BDL	20.20	2.70	0.70	400.00	BDL	12.30	7.90
18	0.60	1000.00	12.50	1.70	1.30	BDL	600.00	BDL	9.30	8.00	1.00	600.00	BDL	10.70	2.30
20	BDL	900.00	BDL	28.00	9.70	----	----	----	16.80	3.40	0.50	500.00	12.50	20.20	12.80
21	0.70	400.00	BDL	0.70	0.20	1.00	600.00	BDL	3.00	0.60	0.80	600.00	BDL	10.70	5.50
22	3.00	600.00	BDL	3.40	1.60	BDL	600.00	BDL	6.30	2.20	0.90	400.00	BDL	8.20	2.00
E23	0.70	1000.00	BDL	7.70	6.90	BDL	400.00	BDL	5.30	7.90	0.70	400.00	BDL	4.40	3.50
24	BDL	600.00	BDL	20.50	1.70	0.50	600.00	BDL	25.50	2.20	0.50	500.00	BDL	26.50	14.90
25	0.50	400.00	BDL	10.90	4.10	BDL	600.00	BDL	12.40	2.20	BDL	500.00	12.50	3.20	2.40
27	0.70	500.00	BDL	2.90	0.50	0.80	400.00	BDL	3.50	1.40	0.90	400.00	BDL	6.20	5.70
28	0.50	400.00	BDL	12.20	5.10	1.00	400.00	BDL	13.30	3.20	0.50	400.00	BDL	1.80	1.40
29	1.00	400.00	BDL	6.80	2.70	0.50	800.00	BDL	10.40	3.70	2.00	400.00	30.00	12.10	3.80
30	BDL	600.00	BDL	10.30	1.80	0.50	600.00	BDL	10.10	1.80	0.50	400.00	BDL	5.00	2.50
E31	0.50	400.00	----	12.10	1.00	1.00	400.00	----	1.40	0.30	1.00	400.00	12.50	3.10	5.90
32	0.90	1000.00	12.50	0.90	0.50	0.50	400.00	BDL	10.00	2.80	1.00	500.00	25.00	5.30	4.40
34	0.50	1000.00	BDL	11.80	0.30	BDL	600.00	BDL	24.00	4.80	0.50	500.00	BDL	12.30	7.60
35	BDL	500.00	BDL	1.00	0.50	0.50	400.00	12.50	5.90	4.70	0.60	600.00	BDL	2.20	1.60
37	0.80	1000.00	BDL	30.00	1.00	BDL	600.00	BDL	27.40	7.10	0.50	700.00	BDL	15.50	11.00
39	0.50	300.00	BDL	14.40	1.90	BDL	200.00	BDL	12.30	0.90	0.50	500.00	20.00	13.20	4.90
50						2.80	1800.00	25.00	5.60	3.90	3.50	800.00	50.00	20.10	23.90
51						1.00	600.00	BDL			0.50	500.00	BDL	2.90	0.40

BDL= BELOW DETECTION LIMIT

TABLE 9.2
APPLE HILL RELATIVE HUMIDITY AND TEMPERATURE SUMMARY

HOUSE NO	PHASE 1				PHASE 2				PHASE 3				PHASE 4			
	RH(IN) %	RH(OUT) %	T(IN) C	T(OUT) C	RH(IN) %	RH(OUT) %	T(IN) C	T(OUT) C	RH(IN) %	RH(OUT) %	T(IN) C	T(OUT) C	RH(IN) %	RH(OUT) %	T(IN) C	T(OUT) C
1	46.00	84.00	20.90	3.30	62.00	41.00	23.00	24.00	60.00	78.00	24.00	29.00	42.00	93.00	18.50	3.20
2	41.00	64.00	20.40	5.00	66.00	53.00	24.00	22.00	70.00	65.00	24.90	25.00	27.00	46.00	22.00	-14.00
3	38.00	36.00	20.90	6.00	57.00		23.30	19.00	55.00	59.00	21.00	14.00	36.00	40.00	20.50	-16.00
4	42.00	81.00	20.10	5.00	69.00	78.00	23.50	20.00	70.00	59.00	20.00	16.00	40.00	40.00	20.00	-11.00
5		61.00		8.60	58.00	63.00	19.00	14.00	65.00	93.00	20.00	7.00	35.00	85.00	16.40	-13.00
6	34.00	36.00	19.00	6.00	59.00	59.00	23.90	18.00	60.00	59.00	22.00	17.00	30.00	67.00	18.00	-10.00
7	45.00	36.00	15.90	4.60	57.00	58.00	21.00	20.50	56.00	67.00	18.40	12.00	32.00	62.00	17.00	-9.00
8									70.00	82.00	21.00	16.00	41.00	93.00	20.30	4.00
MEAN	41.00	56.86	19.53	4.36	61.14	57.33	22.53	19.64	63.25	70.25	21.41	15.00	35.38	65.75	19.09	-8.23
10					64.00		20.00	20.00	62.00	55.00	22.00	16.00	35.00	46.00	22.90	-15.00
11	46.00	76.00	17.90	8.50	62.00	38.00	22.20	24.00	50.00	50.00	20.40	2.00	60.00	69.00	18.00	2.00
12	44.00	56.00	20.60	2.60	64.00	45.00	23.00	17.10	60.00	81.00	18.00	7.50	35.00	66.00	19.00	-14.00
13	43.00	56.00	22.40	5.30	74.00	70.00	23.00	22.40	67.00	66.00	21.30	11.00	55.00	93.00	20.00	0.00
14	40.00	36.00	19.10	-0.60	61.00	60.00	22.70	20.00	65.00	82.00	21.00	10.00	34.00	65.00	18.90	-19.00
E15	38.00	60.00	21.50	-4.00	65.00	59.00	20.50	30.00	60.00	94.00	20.00	10.90	42.00	55.00	19.00	-17.00
16	38.00	61.00	20.00	0.30	64.00	52.00	21.00	19.00	70.00	71.00	18.00	11.00	33.00	70.00	17.40	-19.00
E17	60.00	84.00	18.60	6.30	57.00	30.00	21.00	24.60					46.00	60.00	17.00	6.00
18	32.00	52.00	20.00	10.00	66.00	59.00	27.70	29.60	60.00	80.00	20.00	11.00	42.00	80.00	19.50	1.00
MEAN	34.71	48.14	17.26	3.55	65.00	48.57	22.91	23.06	62.00	70.43	20.10	9.93	42.00	69.86	19.39	-8.33
20	43.00	60.00	22.60	2.60	60.00	76.00	20.00	14.00					33.00	75.00	18.20	1.00
21	46.00	55.00	19.90	2.60	60.00	36.00	20.50	20.50	50.00	66.00	19.00	11.00	53.00	86.00	19.00	1.00
22	46.00	45.00	18.50	2.60	60.00	60.00	21.00	21.40	70.00	100.00	19.00	13.00	29.00	50.00	17.20	-18.00
E23	48.00	65.00	23.00	7.40	70.00	64.00	21.00	18.00	63.00	56.00	18.10	3.00	45.00	55.00	14.00	-21.00
24	49.00	60.00	20.90	2.70	69.00	61.00	25.00	24.20	72.00	100.00	19.00	11.00	44.00	93.00	17.50	-1.00
25					75.00	59.00	18.70	18.00	75.00	60.00	20.00	19.00	52.00	66.00	17.00	-14.00
MEAN	46.00	55.00	20.40	3.50	68.00	57.00	21.53	19.35	68.75	81.50	19.25	11.40	42.20	74.00	17.94	-8.00
27	57.00	65.00	20.60	7.40	73.00	83.00	23.00	20.00	56.00	57.00	16.90	6.70	36.00	42.00	17.00	-15.00
28						64.00	19.00	17.90	70.00	88.00	20.00	14.00	37.00	51.00	18.50	-14.00
29	17.00	48.00	21.00	7.00	61.00	60.00	20.20	19.00	60.00	82.00	18.00	16.00	28.00	33.00	18.60	-22.00
30					72.00	65.00	24.00	22.70	71.00	94.00	18.00	10.50	33.00	65.00	17.60	-17.20
MEAN	37.00	56.50	21.20	7.60	68.67	68.00	21.55	19.90	64.25	80.25	18.23	11.00	33.50	52.75	17.93	-17.05
E31	51.00	56.00	19.00	7.00	60.00	29.00	21.40	23.00	58.00	49.00	19.00	6.00	51.00	86.00	20.00	-6.00
32	41.00	73.00	19.30	2.60	72.00	73.00	23.00	23.30	60.00	56.00	22.00	19.00	54.00	100.00	20.90	7.00
MEAN	41.00	73.00	19.30	ERROR	72.00	73.00	23.00	23.15	60.00	56.00	22.00	12.50	54.00	100.00	20.90	0.50
34		86.00	18.00	-4.60	63.00	63.00	21.00	16.00	70.00	80.00	20.00	15.00	40.00	42.00	17.70	-15.00
35		84.00	15.60	3.30	72.00	64.00	24.20	21.10	75.00	100.00	21.40	11.00	37.00	86.00	19.00	0.70
MEAN		85.00	17.20	-0.65	67.50	63.50	22.60	18.55	72.50	94.00	20.70	13.00	38.50	64.00	18.35	-7.15
37	43.00	56.00	21.50	5.30	64.00	69.00	22.90	22.00	65.00	80.00	22.00	122.00	46.00	86.00	19.50	-17.00
39	28.00	60.00	21.30	-4.00		60.00	17.00	15.70	60.00	82.00	18.00	13.00	44.00	93.00	19.60	-1.00
50					65.00	39.00	29.00	27.00	66.00	100.00	19.00	1.00	66.00	100.00	18.70	1.00
51									63.00	54.00	19.00	12.00	36.00	79.00	16.70	-10.00
ELECTRIC	49.25	60.25	20.73	4.30	63.00	45.50	22.90	24.10	45.25	49.75	14.40	4.90	46.00	64.00	17.50	-9.50
GAS	33.04	62.31	19.72	ERROR	58.29	63.15	21.75	19.91	64.47	77.00	20.21	26.19	41.95	75.67	19.09	-8.30

APPENDIX C

Detailed Data Sheets

Retrospectors

TEST HOUSE NO. 1

DATE June 10 /82

TECHNICIAN WS

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	4	x0.1 =	0.4 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 1

DATE SEPT. 14

TECHNICIAN ELIO PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM (0.1 m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	< 5	x0.1 =	< .5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	< 0.5	x25 =	< 12.5 ppb

Retrospectors

TEST HOUSE NO. 1

DATE FEB. 3/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	8	x0.1 =	0.8 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 2

DATE June 18/82

TECHNICIAN D.F.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.1m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.07	$x10^4$ =	700 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 2

DATE SEPT. 14\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	< 5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 2

DATE JAN 20-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	< 5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 3

DATE June 15/82

TECHNICIAN Fugler

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5 ppb

Retrospectors

TEST HOUSE NO. 3

DATE OCT. 4/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

0.1m LIVING ROOM

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 3

DATE DEC 09/82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

FIRST FLOOR - 0.1m high

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	2.5	x0.1 =	0.25 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 4

DATE June 29/82

TECHNICIAN W.S

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.09	$x10^4$ =	900 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 4

DATE OCT 5/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 4

DATE JAN. 20/83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.1 M ABOVE FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 5

DATE June 4/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 5

DATE OCT. 5/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

0.1 m, LIVING ROOM

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 5

DATE JAN 27-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.7	x25 =	17.5 ppb

Retrospect

TEST HOUSE NO. 6

DATE June 17 /82

TECHNICIAN WS

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.6 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	0	x0.1 =	0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5 ppb

Retrospectors

TEST HOUSE NO. 6

DATE SEPT. 20 82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	1.0	x25 =	25 ppb

Retrospectors

TEST HOUSE NO. 6

DATE JAN 10-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5 m high

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	1	x25 =	25 ppb

Retrospectors

TEST HOUSE NO. 7

DATE June 8

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.09	$x10^4$ =	900 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.8	x25 =	20 ppb

Retrospectors

TEST HOUSE NO. 7

DATE OCT. 20/82

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING Room , .1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 7

DATE JAN 27-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 8

DATE SEPT. 28\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 8

DATE JAN 11-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	x10^4 =	600 ppm
($NO+NO_2$) 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 10

DATE June 15/82

TECHNICIAN W. Seton

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Kitchen 1.2 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	4	x0.1 =	0.4 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.6	x25 =	15.0 ppb

Retrospectors

TEST HOUSE NO. 10

DATE OCT. 19/82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	8	x0.1 =	0.8 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<125 ppb

Retrospectors

TEST HOUSE NO. 10

DATE JAN. 26/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.5 m.

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 11

DATE June 10/82

TECHNICIAN D.F

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.2 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5 ppb

Retrospectors

TEST HOUSE NO. 11

DATE SEPT. 23/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 11

DATE Dec 07-82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

First Floor - 0.1m high

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<< 5	x0.1 =	<<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<<0.5	x25 =	<<12.5 ppb

Retrospectors

TEST HOUSE NO. 12

DATE June 2/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Dining Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	6	x0.1 =	0.6 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 12

DATE SEPT. 17/82

TECHNICIAN Pasquini

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM. (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 12

DATE JAN 21-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM- 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 13

DATE May 31/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 13

DATE SEPT. 21/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	< 5	x0.1 =	< 0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	< 0.5	x25 =	< 12.5 ppb

Retrospectors

TEST HOUSE NO. 13

DATE JAN 07-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	$<<0.5$	x25 =	$<<12.5$ ppb

Retrospectors

TEST HOUSE NO. 14

DATE 05/28/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room, 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.09	$x10^4$ =	900 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 14

DATE OCT. 7\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 14

DATE JAN. 26/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	6	x0.1 =	0.6 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 15

DATE June 16/82

TECHNICIAN W.S

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.7 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 15

DATE SEPT 16\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 15

DATE FEB 9 83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM FLOOR, 0.1m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	NIL	x25 =	— ppb

Retrospectors

TEST HOUSE NO. 16

DATE June 24/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	.2	x25 =	5.0 ppb

Retrospectors

TEST HOUSE NO. 16

DATE JAN 13-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM- 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 17

DATE June 8/82

TECHNICIAN D.F.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5 ppb

Retrospectors

TEST HOUSE NO. 17

DATE OCT. 4\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 17

DATE FEB.18/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 18

DATE July 7/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	6	x0.1 =	0.6 ppm
CO_2 0.01%/a	10	0.01-0.30	0.10	$x10^4$ =	1000 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5.0 ppb

Retrospectors

TEST HOUSE NO. 18

DATE OCT. 6\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 18

DATE JAN 31-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

BASEMENT- 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 20

DATE June 22/82

TECHNICIAN WS

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	2	x0.1 =	0.2 ppm
CO_2 0.01%/a	10	0.01-0.30	0.09	$x10^4$ =	900 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.1	x25 =	2.5 ppb

Retrospectors

TEST HOUSE NO. 20

DATE JAN 06-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
($NO+NO_2$) 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 21

DATE June 4/82

TECHNICIAN D.F

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7.	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.4	x25 =	10 ppb

Retrospectors

TEST HOUSE NO. 21

DATE OCT. 29/82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, .1 m FROM FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 21

DATE JAN. 25/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.5 m ABOVE FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	8	x0.1 =	0.8 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 22

DATE July 12/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.3 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	30	x0.1 =	3.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5.0 ppb

Retrospectors

TEST HOUSE NO. 22

DATE SEPT. 28 \82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 22

DATE FEB.11/83

TECHNICIAN SINHA.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4m ABOVE FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	9	x0.1 =	0.9 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 23

DATE June 11

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.10	$x10^4$ =	1000 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.1	x25 =	2.5 ppb

Retrospectors

TEST HOUSE NO. 23

DATE SEPT. 16 82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM. (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 23

DATE JAN. 19/83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM FLOOR, 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 24

DATE July 8/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	1	x0.1 =	0.1 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.1	x25 =	2.5 ppb

Retrospectors

TEST HOUSE NO. 24

DATE SEPT 21/82

TECHNICIAN Fugler/Pasquini

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 24

DATE JAN 07-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM- 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	< 12.5 ppb

Retrospectors

TEST HOUSE NO. 25

DATE June 18/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.4	x25 =	10 ppb

Retrospectors

TEST HOUSE NO. 25

DATE OCT. 6\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 25

DATE DEC. 10/82

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 27

DATE June 29/82

TECHNICIAN D.F

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Front Hall | Living Rm 0.2m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.7 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.4	x25 =	10 ppb

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Retrospectors

TEST HOUSE NO. 27

DATE OCT. 21/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM , .1 M

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7.5	x0.1 =	0.75 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 27

DATE FEB. 9/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	9	x0.1 =	0.9 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 28

DATE 05/25/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 28

DATE SEPT. 28\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 28

DATE JAN. 13/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM FLOOR, 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 29

DATE 05/27/82

TECHNICIAN D.F.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.25	x25 =	6.25 ppb

Retrospectors

TEST HOUSE NO. 29

DATE SEPT. 22/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 29

DATE JAN. 4/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

0.2m, LIVING ROOM CENTRE

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	20	x0.1 =	2.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	1.5	x25 =	30 ppb

Retrospectors

TEST HOUSE NO. 30

DATE July 7/82

TECHNICIAN W.S

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	2	x0.1 =	0.2 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.1	x25 =	2.5 ppb

Retrospectors

TEST HOUSE NO. 30

DATE SEPT 30/82

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<125 ppb

Retrospectors

TEST HOUSE NO. 30

DATE JAN. 17/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, .5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 31

DATE June 7/82

TECHNICIAN D.F.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0	x25 =	0 ppb

5-113

Retrospectors

TEST HOUSE NO. 31

DATE SEPT. 13\82

TECHNICIAN E. PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM (0.1 m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	—	x25 =	< 1 ppb

Retrospectors

TEST HOUSE NO. 31

DATE JAN 10-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Intermediate Steps in split level

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 32

DATE May 31/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Dining Room 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	9	x0.1 =	0.9 ppm
CO_2 0.01%/a	10	0.01-0.30	0.10	$x10^4$ =	1000 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

5-116

Retrospectors

TEST HOUSE NO. 32

DATE SEPT. 22/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM. (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.05	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 32

DATE Dec 03-82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

First Floor - 0.1m high

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1.0 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	1.0	x25 =	25.0 ppb

Retrospectors

TEST HOUSE NO. 34

DATE June 7/82

TECHNICIAN WS

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Rm 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.10	$x10^4$ =	1000 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 34

DATE OCT. 1 \ 82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING. RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 34

DATE FEB 11-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.1 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 35

DATE July 12/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	3	x0.1 =	0.3 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5.0 ppb

Retrospectors

TEST HOUSE NO. 35

DATE OCT. 8\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.04	$x10^4$ =	400 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.5	x25 =	12.5 ppb

Retrospectors

TEST HOUSE NO. 35

DATE JAN. 24/83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM., 0.1M ABOVE FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	6	x0.1 =	0.6 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 37

DATE 05/28/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Living Room - 0.5 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	8	x0.1 =	0.8 ppm
CO_2 0.01%/a	10	0.01-0.30	0.10	$x10^4$ =	10.00 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.2	x25 =	5 ppb

Retrospectors

TEST HOUSE NO. 37

DATE SEPT. 15\82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM. (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.05	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 37

DATE JAN. 24/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.5m FROM FLOOR

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.07	$x10^4$ =	700 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 39

DATE 05/25/82

TECHNICIAN W.S.

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

Dining Room 1m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.03	$x10^4$ =	300 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.3	x25 =	7.5 ppb

Retrospectors

TEST HOUSE NO. 39

DATE SEPT. 23/82

TECHNICIAN PASQUINI

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING RM. (0.1m)

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	<5	x0.1 =	<0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.02	$x10^4$ =	200 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 39

DATE JAN 06-83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM- 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	0.8	x25 =	20 ppb

Retrospectors

TEST HOUSE NO. 50

DATE OCT. 29/82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM FLOOR, 0.2 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	28	x0.1 =	2.8 ppm
CO_2 0.01%/a	10	0.01-0.30	0.18	$x10^4$ =	1800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	1.0	x25 =	25 ppb

Retrospectors

TEST HOUSE NO. 50

DATE JAN. 29/83

TECHNICIAN FUGLER

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

FIRST FLOOR, 0.4 m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	35	x0.1 =	3.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.08	$x10^4$ =	800 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	2	x25 =	50. ppb

Retrospectors

TEST HOUSE NO. 51

DATE NOV.1/82

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

DEN @0.4m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	10	x0.1 =	1 ppm
CO_2 0.01%/a	10	0.01-0.30	0.06	$x10^4$ =	600 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 51

DATE FEB 08-83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM - 0.5m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	5	x0.1 =	0.5 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

Retrospectors

TEST HOUSE NO. 52

DATE FEB 11/83

TECHNICIAN SINHA

SAMPLE LOCATION (FIRST FLOOR, HIGH USE AREA) & HEIGHT

LIVING ROOM, 0.4m

GAS & TUBE IDENTIFICATION	NO OF PUMP STROKES	USE SCALE	READING	MULTIPLIER	CONCENTRATION
CO 5/c	100	5-150	7	x0.1 =	0.07 ppm
CO_2 0.01%/a	10	0.01-0.30	0.05	$x10^4$ =	500 ppm
$(NO+NO_2)$ 0.5/a	200	0.5-10	<0.5	x25 =	<12.5 ppb

A REVIEW OF INDOOR AIR QUALITY TESTING AT APPLE HILL

A Report for

CANADA MORTGAGE AND HOUSING CORPORATION
OTTAWA, ONTARIO
File # CR176-4-31

Prepared by

A.J. Chandler, P.Eng.
Willowdale, Ontario

September 1984

INTRODUCTION

It is the intent of this discussion to present the sources, the effects and normal levels of the indoor air contaminants. Particular attention is paid to the contaminants monitored in the Apple Hill Study:

- o Carbon Monoxide,
- o Carbon Dioxide,
- o Oxides of Nitrogen (Nitric Oxide and Nitrogen Dioxide),
- o Radon, and
- o Formaldehyde.

In addition, the results of the study will be considered along with the review of some of the limitations of the study methods.

Between June 1982 and January 1983, up to 35 homes in the Apple Hill study program were tested to assess indoor air quality levels. Three sets of tests were started in June, September and January. In addition to these tests, monthly tests for radon were conducted and spot tests for formaldehyde were undertaken. The method of choice for measuring the gaseous components CO, CO_2 and NO/NO_2 were Draeger colorimetric sampling tubes. Formaldehyde was tested using commercial dosimeters and radon was monitored using both grab sample methods and Track-Etch techniques. The results of this study are presented in Appendix 5 of the Apple Hill Energy Efficient Home Study - Task F Air Quality Tests. The following review of the study was completed after discussion with one of the principal authors and a detailed review of the material presented in the study.

Common Indoor Air Contaminants

While ambient air quality standards are defined for numerous substances, as yet few, if any, jurisdictions have adopted indoor air quality standards. Some recommendations are currently available including those published by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE, 1980), the Canadian Standards for Formaldehyde in UFFI Homes (UFFI/ICC Criteria), and the criteria for radon (AECB, 1977). Even with these guidelines available, they do not cover all the potential

contaminants in a home and some of the standards have only been applied in selected areas (radon in uranium mining areas, formaldehyde in UFFI homes). This makes the problem of defining acceptable levels for residential air quality rather difficult. In order to provide the reader with some understanding of the issues involved with these various pollutants, the following quick review is presented.

Carbon Monoxide

Carbon monoxide is a stable product of incomplete combustion. It is not readily perceived by humans as it is a colourless, odourless substance. It is commonly given off by gas-fired appliances, smoking and the major contributor, automobiles.

Carbon monoxide forms carboxyhemoglobin (COHb) in the blood and thus inhibits oxygen uptake. It is not known at present whether there is a threshold for adverse effects for oxygen deprivation due to COHb. Spengler and Sexton (1983) quote a study that shows that exercising adults are sensitive to COHb concentrations as low as 1%. Community air pollution and indoor exposures to combustion by-products or side-streamed cigarette smoke can raise COHb in non-smokers to the 2 to 3% level. One symptom of CO exposure is a headache. Exposures in excess of 2 hours are needed before these effects are noted. At exposures in excess of 1000 ppm, severe headaches, dizziness, and nausea exist followed closely by death. If one survives an exposure in excess of 1000 ppm, long-term physiological problems remain (Henkin, 1974).

In a recent review of carbon monoxide effects and air quality standards (HWC, 1983) it is suggested that CO levels should be set consistent with preventing health effects due to COHb levels in the blood. The report suggests that this level is 2 1/2 to 3% for non-smoking patients sensitized by coronary atherosclerosis. This would imply two hour exposure levels of 30 to 40 ppm. The report (HWC, 1983) also notes a 24-hour level set by WHO (1979), of 10 ppm. Since home exposures tend to be long-term, the 10 ppm level may be the most appropriate for an indoor standard. The report (WHO, 1979) states that this will maintain COHb levels at 2 1/2 to 3%. The eight hour ambient air quality standard for Canada, at the most stringent level, specifies carbon monoxide levels between 0 and 5.5 ppm.

Carbon Dioxide

Sources of carbon dioxide include combustion and the metabolism of human beings. Outdoors the major source of CO_2 is the flue gases emitted from large industrial establishments. It should be noted that CO_2 can arise from any combustion process and large levels of CO_2 in homes are generally associated with unvented gas ranges, gas fired clothes dryers and gas or liquid fired space heaters. Normal ambient levels of CO_2 in the urban environment run as high as 400 ppm with higher levels being registered close to major thoroughfares or industrial sources.

Carbon dioxide is a simple asphyxiant and is a potent stimulant to the respiratory system. It is a both a stimulant and depressant to the central nervous system. High levels (30000 ppm) are required to produce CO_2 poisoning effects such as headaches, dizziness, nausea. Little, if any, information currently exists on low level, long-term exposures to CO_2. In their 1979 publication, the World Health Organization recommended that the effects of low level CO_2 exposure should be re-examined.

Standards for CO_2 in residential houses are recommended at 2500 by ASHRAE (1980). No other residential standards are currently available. The occupational exposure standards range between 8 hour, 5000 ppm levels set by ACGIH and a 24 hour average 1% limit set for US Navy Submarine Environments. Recent information published by the Ontario Ministry of Labour (MOL, 1983) recommends that levels in excess of 600 ppm be studied to see whether they can be lowered. They note that complaints about poor air quality in offices rise as the CO_2 level rises to 1000 ppm. Above this level of CO_2, complaints of poor air quality in offices are common.

Monitoring of carbon dioxide in houses is helpful in establishing air circulation patterns. CO_2 levels tend to vary with the amount of circulation in the home and high levels indicate areas where other contaminant concentrations may be high. CO_2 monitoring at numerous locations in the house provides not only an indication of the use patterns or occupancy of the various sections of the house but also of the performance of the air handling system. If one were to assess appropriate level for CO_2 level in houses, it would probably be somewhere in the range of 800 to 1000 ppm when sampled for four hours.

Oxides of Nitrogen

The classification oxides of nitrogen covers a number of compounds. The main ones of concern are indoor air contaminants are nitrogen dioxide, a red/brown gas that can influence visibility (smog) and nitric oxide, a compound which readily oxidizes to nitrogen dioxide. Small (1983) notes that NO is the major portion of naturally occurring oxides of nitrogen emissions. It is chiefly caused by bacterial action and is particularly noticeable under rainy conditions. Both NO and NO_2 are products of combustion and depending upon the type of device being used, the ratio of NO to NO_2 can change. Aside from the open flame burning of liquid and gaseous fuels, the major sources of NO_2 are automobiles and industry. In the home tobacco smoke and natural gas and other combustion operations can contribute significantly to oxides of nitrogen levels. Automobiles run in attached garages are also a significant potential source of these compounds. When nitric oxide is created in the home, it is quite likely that this highly reactive compound will readily oxidize to nitrogen dioxide.

The only standards available for nitric oxide are those applied by the ACGIH and these would suggest that the toxicity of nitric oxide is some five times lower than that of nitrogen dioxide.

The effects of nitrogen dioxide exposure are to impair lung function. The mode of action is basically inhalation into the lungs where it is converted to nitrous acid and nitric acid. These substances are irritating and corrosive to the mucous lining of the lungs. Other effects that have been noted include a reduction in sensory perception particularly with respect to the ability to distinguish odours. Although open to some discussion, some researchers have noted an increase incidence of asthma when subjects are exposed to nitrogen dioxide. This latter situation was first reported by Melia et al in 1977 but later work would suggest that there may have been other contributing conditions to the effects noted in some of the subjects he studied (Young, 1981).

Existing levels of nitric oxide inside homes are generally reported to be in the range of 30 to 300 ppb with maximum levels as high as 500 ppb (Small, 1983). Outdoor values of nitric oxide are not routinely measured, but Robinson (1970) reports a non-urban level to average 2 ppb. Nitrogen dioxide is one of the more routinely monitored ambient air quality pollutants and annual mean values at all stations in Canada in 1979 are reported

to be approximately 260 ppb. These measurements tend to be taken in areas where higher levels occur, along busy roads or in downtown areas, and 92% of the stations report 24-hour average values between 0 and 110 ppb. Indoor values as reported by the US. NRC (1981) range from 100 to 530 ppb. Other data is available that suggests that levels can go as high as 900 ppb in homes with gas ovens.

Studies generally report higher levels in homes with gas ranges than in homes with electric ranges; as one would imagine, levels are highest in the kitchen. Average values of 112 ppb NO_2 in kitchens have been reported in some studies and the same studies report an average of 18 ppb for homes with electric ranges. Furthermore, values in other locations in the houses found 30 ppb in bedrooms of homes with gas ranges and 14 ppb in bedrooms of homes with electric ranges.

The 24-hour standard for ambient levels of nitrogen dioxide is set by the federal government at 107 ppb (EPS, 1976). This value is at the lower end of the range recommended by the World Health Organization (WHO, 1977) for one hour exposure. The annual Canadian standard, based on a arithmetic mean of all values, is 0 to 32 ppb. A value of 100 ppb is probably an appropriate level to use for NO_2 when judging the results of indoor air quality studies.

Formaldehyde

Formaldehyde is an ubiquitous chemical, characterized by a pungent odour detectable at levels in excess of 80 ppb. The material is present in the resins of particle board plywood, the size used in textiles, cigarette smoke and combustion emissions of both natural gas appliances and automobiles. Furthermore, formaldehyde gas is noted to be released by urea formaldehyde foam insulation when this material degrades. While the above mentioned odour threshold for formaldehyde is recorded, Canadian work has noted that irritation of the eyes can also occur at levels somewhat below 80 ppb.

Health effects of formaldehyde are generally irritation of the eyes, ears, nose and throat and skin. Respiratory disorders include coughing, headaches and dizziness which occur in many subjects. Some reports of fatigue setting in for owners of homes with UFFI insulation have also been noted. Currently the Canadian government has set a standard of 0.1 ppm for indoor air quality levels of formaldehyde and this level corresponds with

that set in Norway, Denmark and West Germany. It is slightly above the levels set in Sweden and Czechoslovakia who mandate a 0.08 ppm (Small, 1983).

Radon

Radon is a radioactive decay product of radium 226. This substance, in turn, is a decay product in the uranium chain and is generally found in areas with granitic rock structures. Radon gas, in itself, is not a hazardous substance but the fact that it decays within a relatively short period to form solid daughter products which attach themselves to aerosols presents the problem. These aerosols in turn become embedded in the lungs and irradiation of surrounding tissue occurs when the daughter products decay. Radon can diffuse into indoor air from soil, building materials, water from weeping tile around the foundations or well water. Higher concentrations are typically measured in basements, crawl spaces and homes with low air exchange rates.

The assessment of the radiological hazard associated with a given radon concentration is complex. The subject will not be dealt with here and the reader is referred to various other documents available discussing the subject (MMAH, 1984; Small, 1983). The US EPA (1980) report for a 0.01 WL concentration and a lifetime exposure of 75% of the time, 1% of all individuals exposed will contract fatal lung cancer over an average lifetime of 70.7 years. The WL is the standard by which the radiological hazard of radon is assessed. The Ontario Government has set standards as have the AECB (1977). The AECB standard was basically written to designate primary cleanup criterion for radon daughter products. The level assessed was 0.02 WL. The document states that the health risk resulting from the continual exposure to 0.02 WL is comparable to the risk associated with radiation dose limits specified by the Atomic Energy Control Regulations for persons living in the neighbourhood of licenced nuclear facilities. These specified dose limits for members of the public are 1/10 of the limit for persons exposed to radiation in the course of their work.

AECB (1977) go on to state that three levels can be used to screen buildings intended for applications, actual or potential living space (homes) or occupied space in other buildings. They apply these levels to the average radon daughter concentration over the course of one year. It should be realized that the short term fluctuations above the quoted values are not significant as long as the yearly average meets the clean up

criteria. Three levels specified for radon daughter levels inside buildings are:

- o prompt interim action - greater than 0.15 WL,
- o primary criterion - greater than 0.02 WL,
- o investigative level - greater than 0.01 WL.

These values are probably the most appropriate to consider when reviewing indoor air quality data for radon gas concentrations.

Generally accepted background levels for radon 222 in the atmosphere range from 100 to 1000 pCi/m^3 (0.1 to 1.10 pCi/L). McGregor et al (1979) report on the measurement of radon and radon daughters carried out in 14 Canadian cities and 9,999 homes. The geometric means of the different cities varied from 0.14 to 0.88 pCi/L for radon gas and 0.3339 to 0.0036 WL for radon daughters. It was concluded from that study that the radon originated from natural radioactivity in soils surrounding the homes. Other data is available that shows radon concentrations in homes varies from 0.1 to 1140 pCi/L depending upon the location and the season (Oswald et al, 1982).

In summary it is possible to look at the results of the Apple Hill study in terms of some of the other data that is available in the literature and assess whether the levels found in those homes are within the bounds that one normally expects.

Apple Hill Results

As can be seen from the data presented in the task F report, numerous results were collected. The results have been brought together in that report and will not be reproduced in this document. Rather, a look at the distribution of the data that was produced in the Apple Hill document will be undertaken. Before looking at this distribution, however, some words of caution must be entered into the discussion. There are some limitations on the sampling methodologies used in this study and therefore some of the data should be considered only with these limitations in mind.

Procedures for sampling involved two technicians arriving at the house. At the commencement of sampling the fan on the furnace was turned on and SF_6 tracer gas injected into the system. At the same time as the fan was turned on, the other

technician proceeded to commence sampling for the various gases (CO, CO_2, NO/NO_2). This sampling was undertaken with Draeger tubes which produce a colour change as the chemical of interest is extracted from the air sampled. Unfortunately, during this particular test program short term tubes were utilized and the limitations of the detection of the CO and nitrous (NO/NO_2) fume tubes were too high to be appropriate for this test. In order to overcome this limitation, the study team chose to use the tubes with an extended number of pump cycles thereby effectively lowering the detection limit to a level they considered appropriate for this study. Limits of detection available to the study team were:

- CO - 0.5 ppm,
- CO_2 - 100 ppm,
- NO/NO_2 - 12.5 ppb.

The limitations of sampling identified for this particular sampling are as follows:

- only one location was tested in each house,
- the same location was not always tested in that two or three deviations were found on the data sheets,
- the fan was operating on the furnace during the testing thereby mixing concentrations of contaminants in the house,
- the methods for CO and NO + NO_2 required in excess of 100 strokes of the Draeger pump, a situation providing numerous potential sources of error including incomplete compression, incomplete expansion, and miscounting the numer of strokes.

Aside from these obvious limitations with the testing procedure other studies (Concord, 1984) have shown that the Draeger tubes may lie considerably outside their stated accuracy of ± 15%. Studies with CO_2 tubes found the tubes to be out as much as 30% when calibrated with known concentrations of gas. Some of these limitations may explain why in the review of the distribution of the data, certain outliers occur. Regardless of the limitations that the methodology places upon the results of this study, the values collected are helpful in providing more data to determine normally occurring levels of pollutants in residential facilities.

While one can look at the data presented in the study F report, and examine the range and arithmetic averages, it is more helpful to review the data in terms of its distribution. From a knowledge of the distribution of the data, it's possible to determine if the measurements appear to belong to the same general population and if not, to identify any outliers. It also provides information about the percentage of houses that appear to fall above regulatory guidelines. It has been noted by others (King, 1971) that results which are rate dependent tend to follow a lognormal distribution. This distribution should therefore hold for the levels of contaminants in the environment and specifically for indoor air quality concentrations. Other investigators, George et al (1982); McGregor et al (1980), have used the lognormal distributions to analyse their radon concentration measurements. The techniques to analyse lognormal distributions are described in the references of King, (1971) and Aitchison & Brown, (1957).

Once the distributions have been determined for each of the various sampling periods and contaminants, it is possible to determine whether the geometric means of the various concentrations are significantly different. If the concentration of contaminants are lognormally distributed, the logs of the concentrations will be normally distributed. Therefore, it is possible to determine if there are differences by analysing the logarithmic transformation of the concentrations using the approach developed by Welsh (1937) and cited in Meyers (1972). These procedures were used to analyse the data collected for the Apple Hill study.

ANALYSIS OF DATA

With the exception of the radon data, the data points that were above the detection limit of the sampling tube, as presented in Appendix 5 of the Apple Hill report, were plotted to arrive at the various distributions presented in this section of the discussion. For the radon data the monthly or seasonal data was averaged together for each house and the average of this value used for plotting the distribution data. In this way the radon data reflects annual averages and can be directly compared to the criteria set by AECB for radon and radon daughters in homes.

Carbon Monoxide

Carbon monoxide distribution data is presented in Figures 1 through 4. Of the 20 data points for the June survey, four of them appear to be outliers, three at the bottom end and one at the high end. The September data shows one outlier in the thirteen data points plotted and the January data shows four outliers in the 23 points plotted. All of these outliers would tend to indicate that the fit chosen for the experimental data may be slightly in error. However, given the sampling limitations mentioned above, the values were thought to be representative. The data shows that the geometric mean of the values in the various houses ranged from 0.6 ppm to 0.76 ppm over the period of the study. The data provides an indication of expected levels in 90% of the homes under normal circumstances and these range from just slightly above 1 ppm to 1.4 ppm. There appears to be little difference between the data recorded for June and January, however, the September data shows a larger disparity. This could be solely the result of fewer data points above the detection limit. Using the techniques to compare the differences between the geometric means of the data for the three sets of data chosen, t values ranging from 0.2 to 0.4 were obtained. These are well within the level that would allow one to confirm no difference between the means of the data. The data outliers, although they may tend to indicate bad data, concur with similar data found in sealed homes in two studies undertaken by this reviewer. In both those cases, highs in the houses of 3.5 ppm were recorded over a four hour sampling period.

On the basis of the 10 ppm CO standard mentioned earlier in this report, the CO data from the Apple Hill study shows little, if any, area for concern.

Carbon Dioxide

A review of the carbon dioxide distribution data is provided in Figures 5 through 8. Thirty-one data points were available for the June CO_2 study. The plot shows only one value to be borderline outside the distribution's 95% confidence limit. The mean of the data is 620 ppm and the 90 percentile value is 980 ppm. The September CO_2 data involved 33 data points of which two appear to be definite outliers and four others are borderline. The mean of the data is approximately 520 ppm, the 90 percentile being 760 ppm. The January CO_2 data involved plotting 35 data points. This particular set of data shows a confidence limit that is very narrow due to the low spread in the data that was

FIGURE I

Distribution of CO Data-June

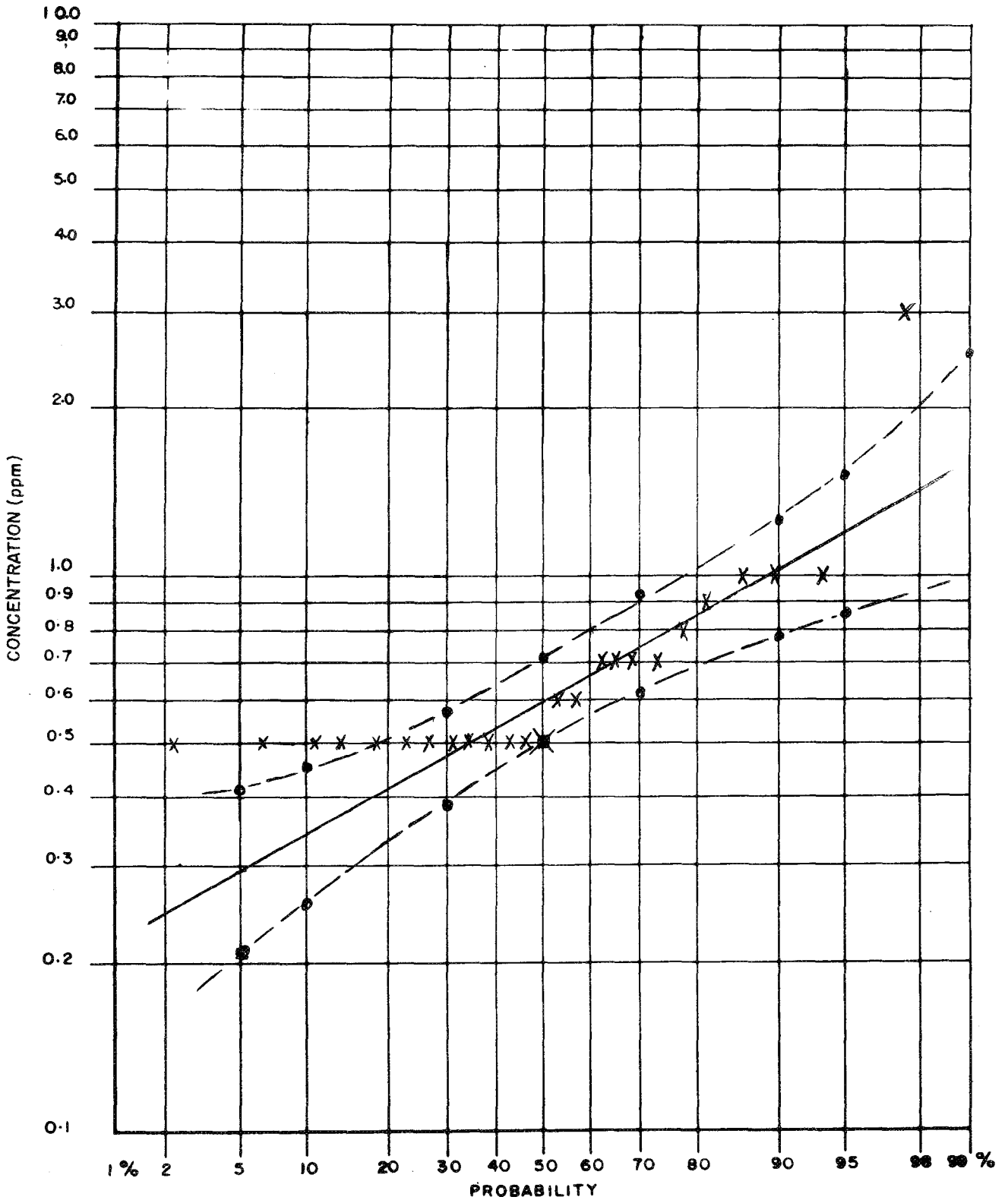


FIGURE 2

Distribution of CO Data - September

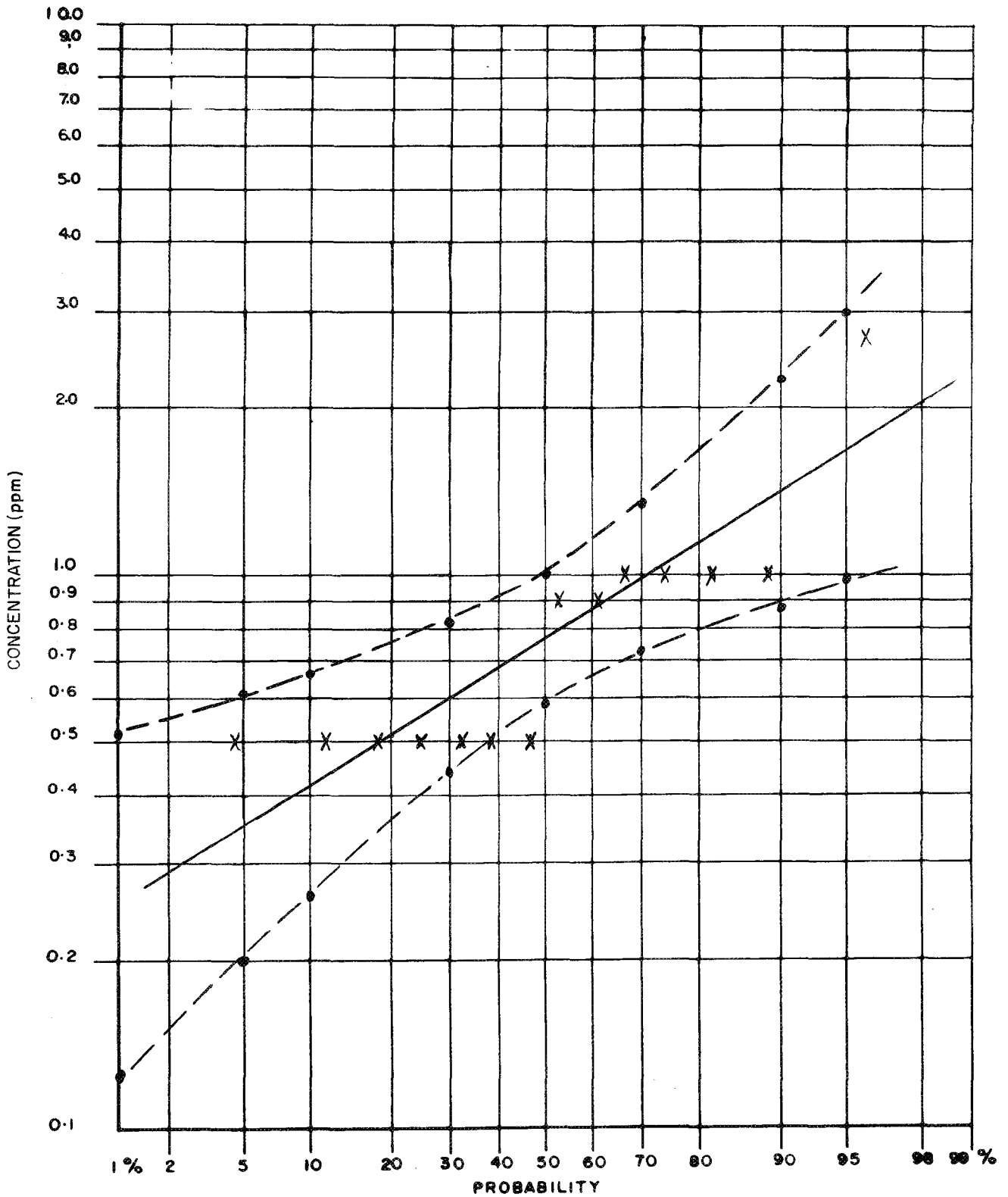


FIGURE 3

Distribution of CO Data-January

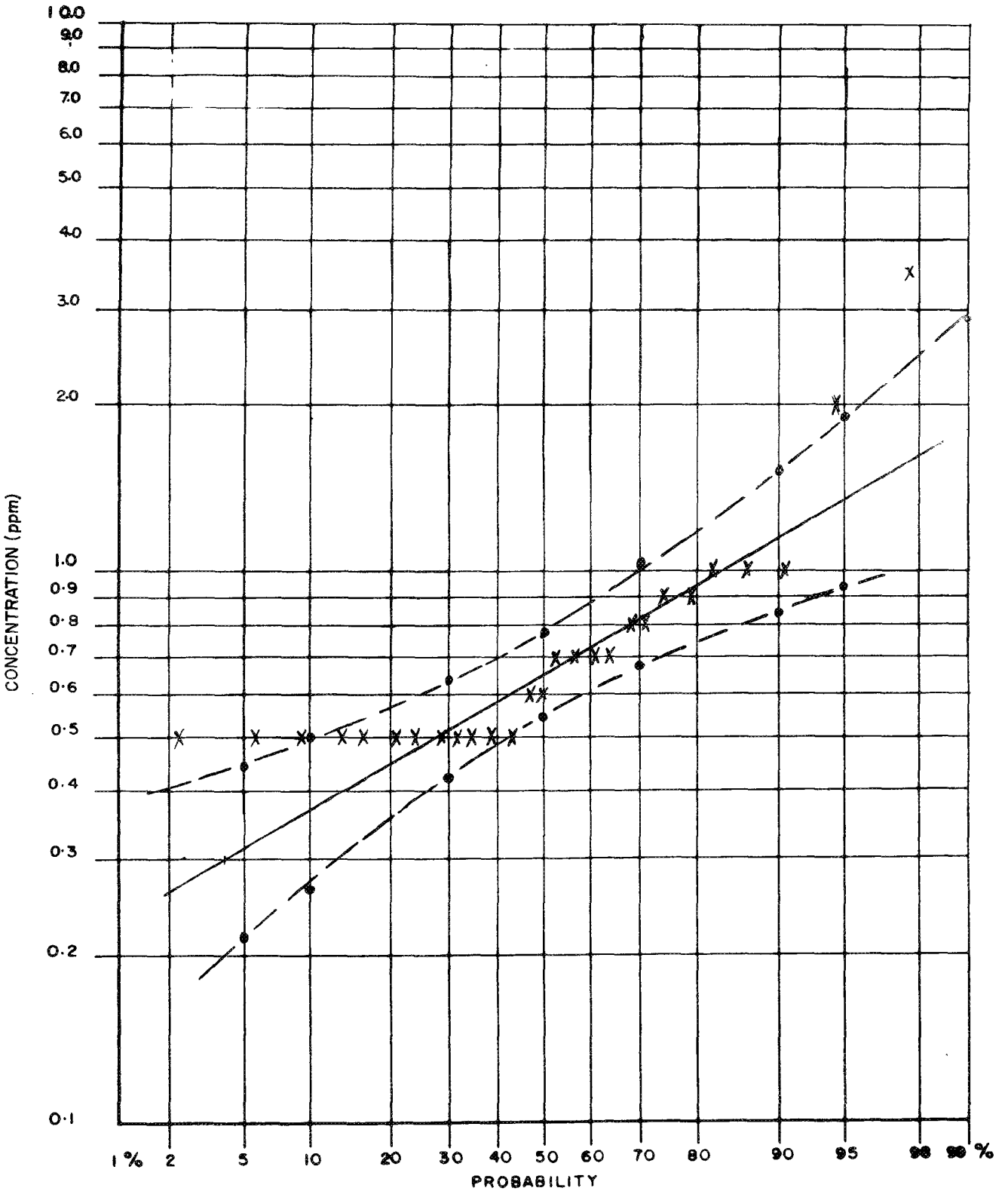


FIGURE 4

Summary of CO Distribution Data

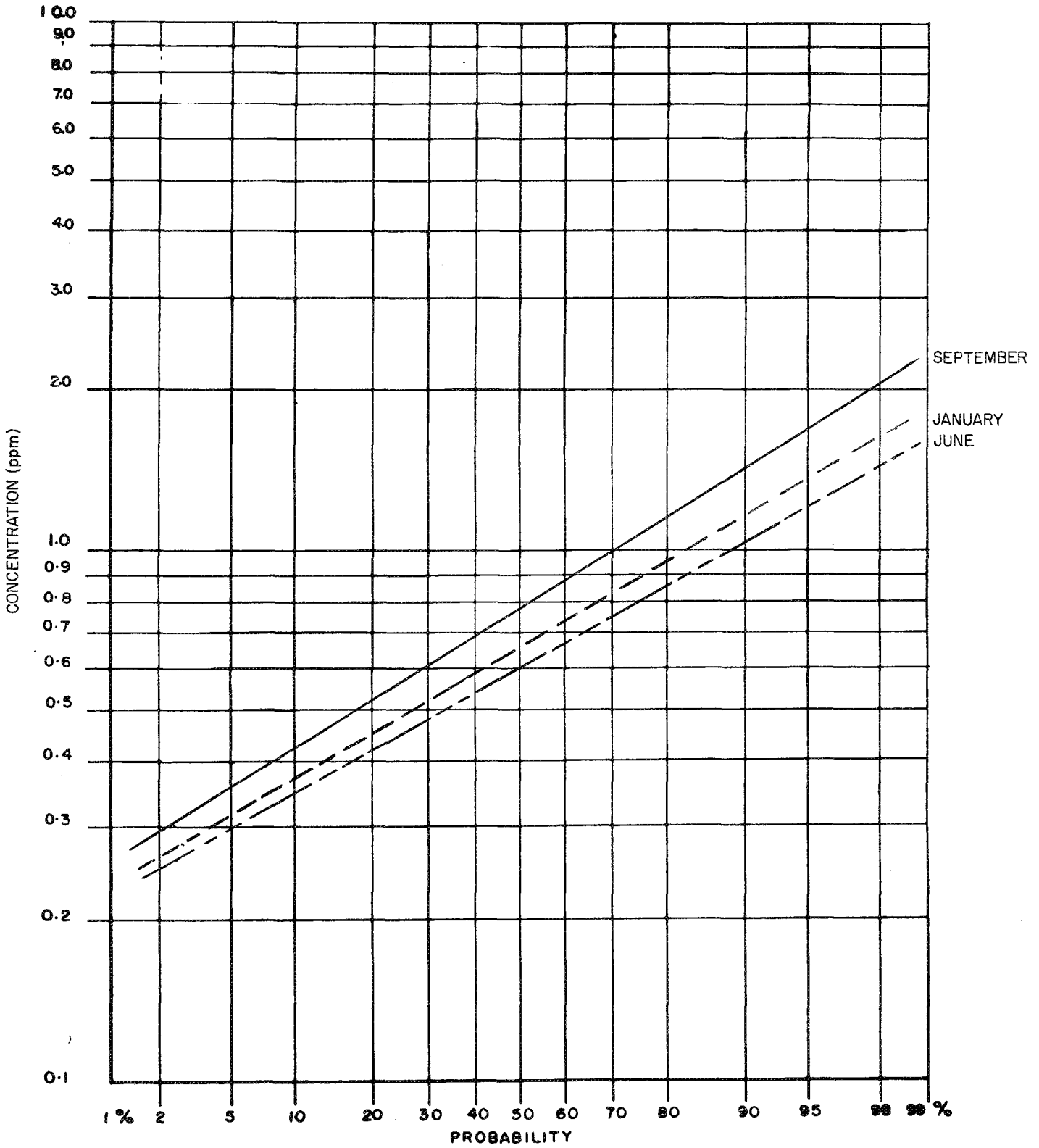


FIGURE 5

Distribution of CO_2 Data–June

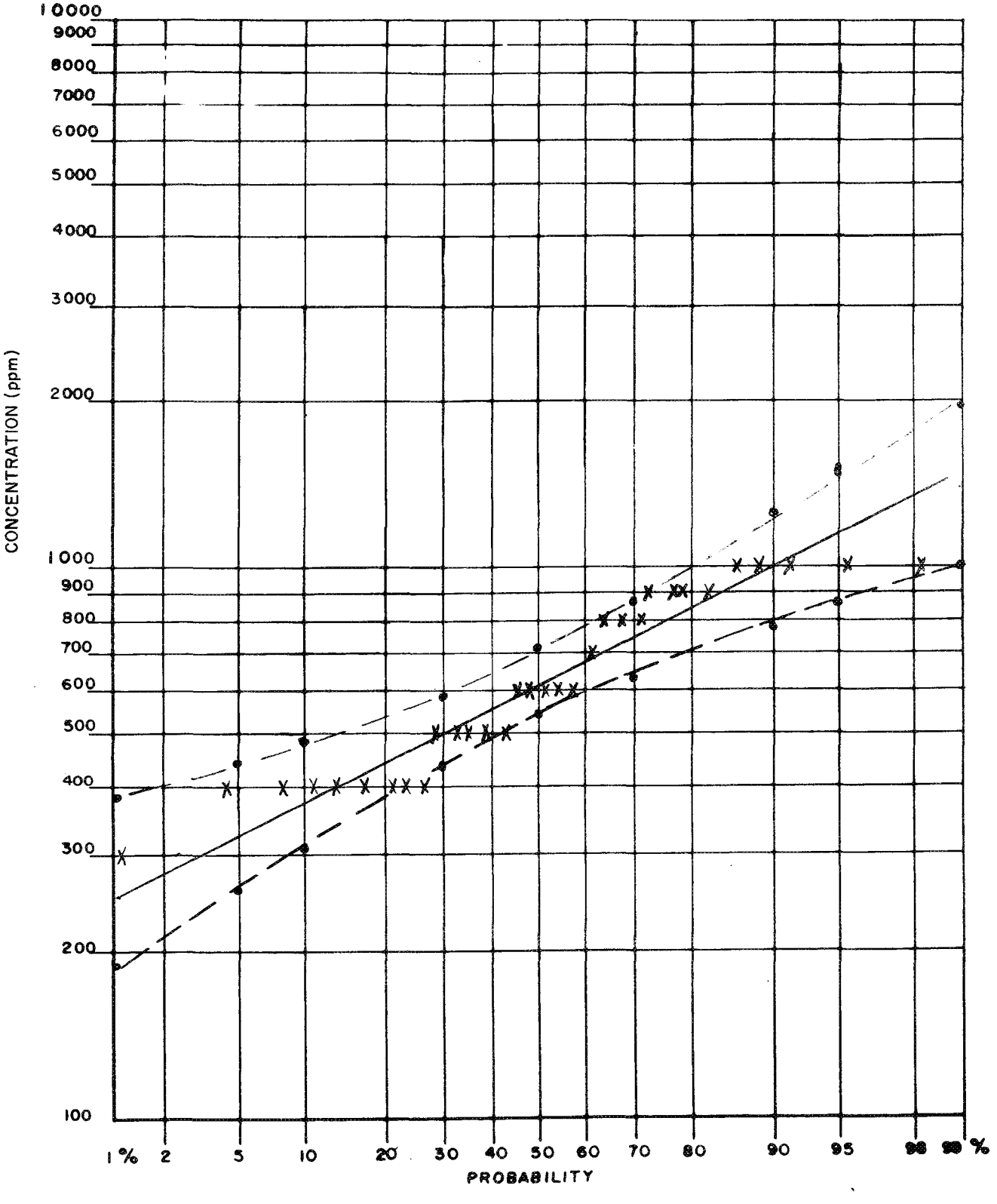


FIGURE 6

Distribution of CO_2 Data - September

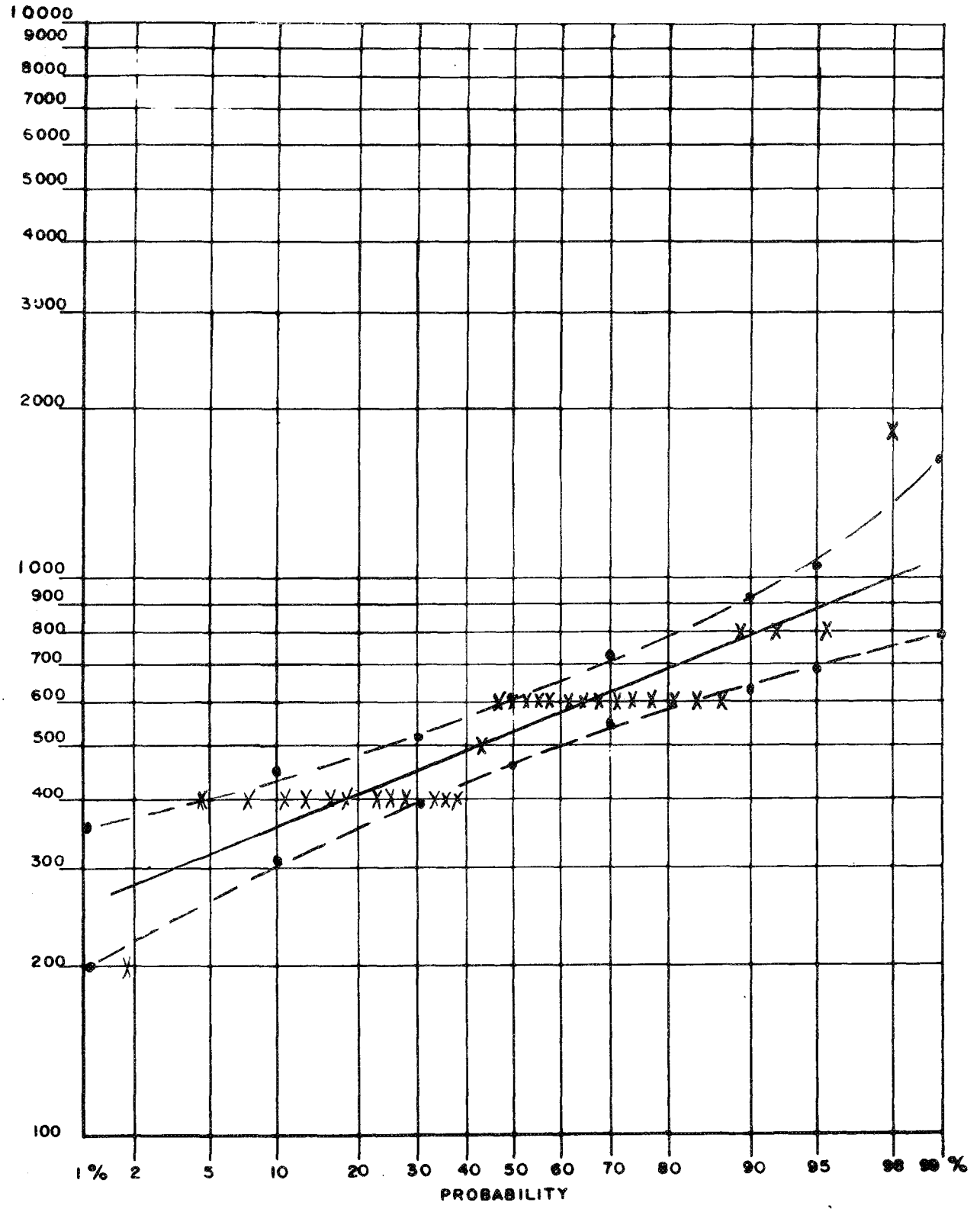


FIGURE 7

Distribution of CO Data-January

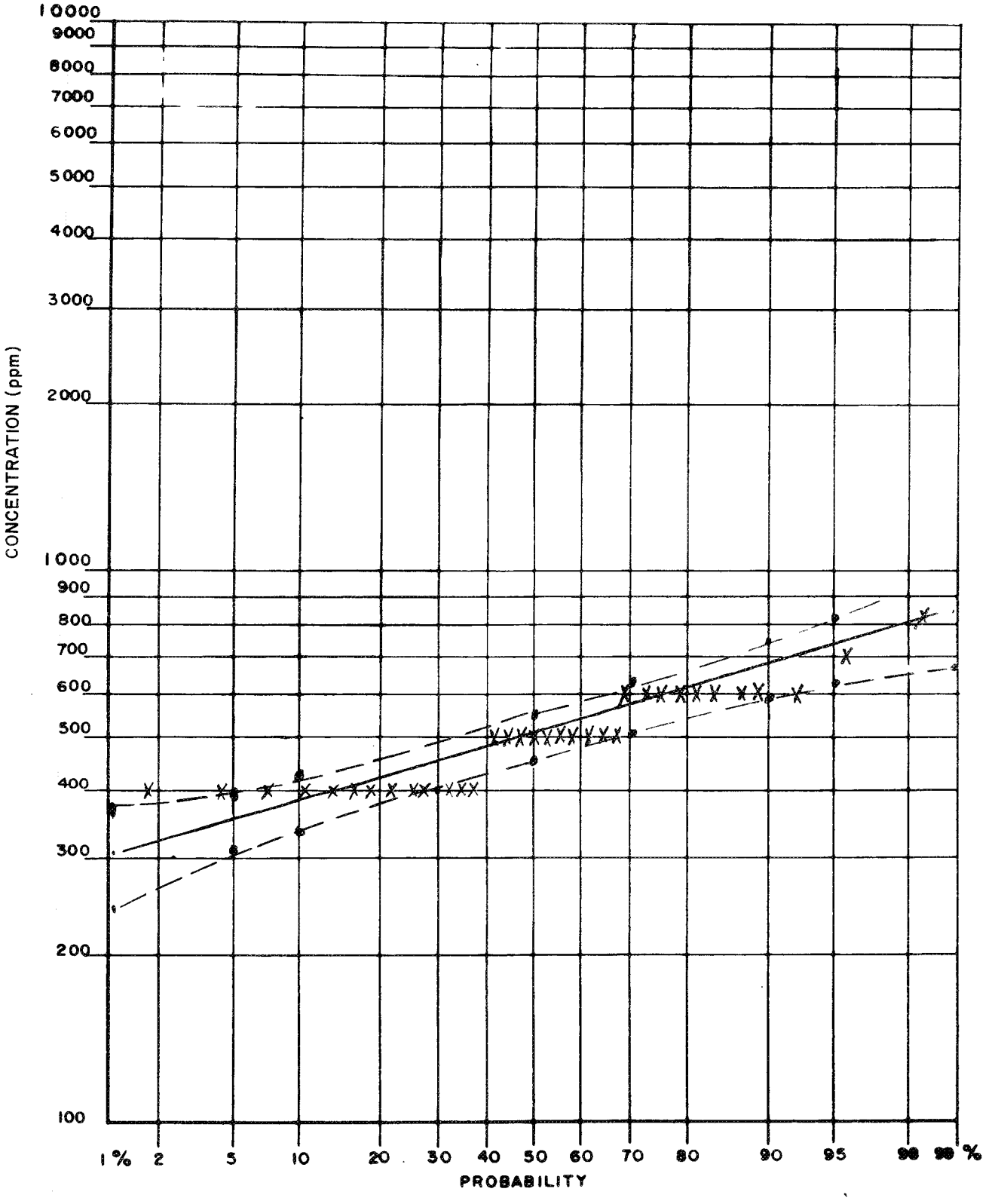
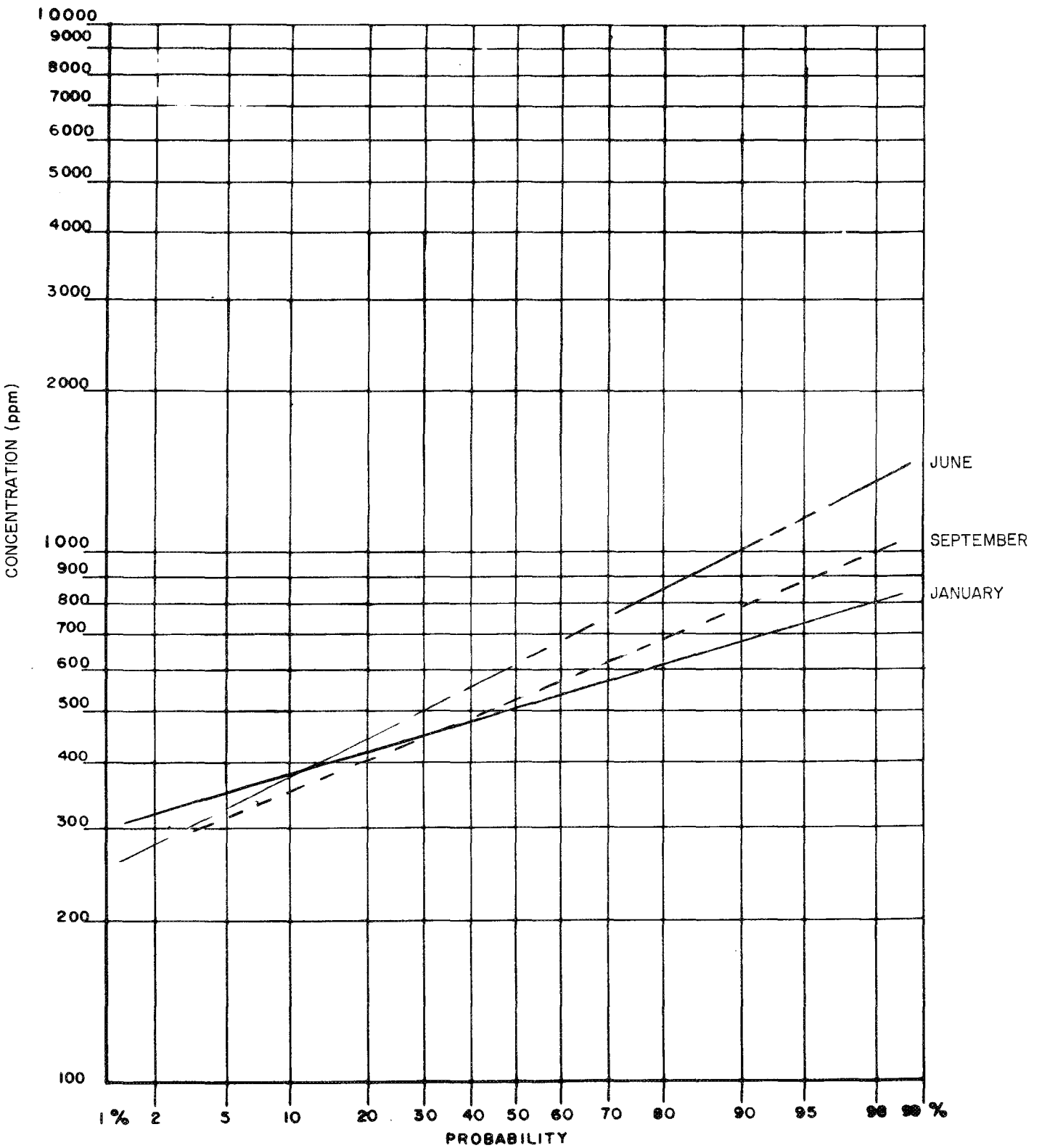


FIGURE 8

Summary of CO_2 Data



plotted. Two data points can be definitely identified as outside the 95% confidence limits at the lower end and three more are suspect. No outliers occur at the upper end. The mean of the January data is approximately 500 ppm with the 90 percentile value being 660 ppm.

Whereas Figure 4, the distribution of CO data plotted by the month, showed minor parallel shifts from the June to September to January data, a different picture is revealed in Figure 8, the summary data for the CO_2 concentration. While the CO_2 sample test mean moves from approximately 500 to just over 600 ppm the lines are no longer parallel to each other. The slope of the various lines differs somewhat and when the statistical test was run on this particular data the means were shown to be significantly different. This type of performance is not particularly surprising considering that the owners may have different habits in the warmer periods of the year compared to the colder periods. Doors and windows tend to be left open more often during the summer and fall than in the winter. Interestingly enough rather than having the winter concentrations being the highest, the initial concentration appears to be the highest. No readily available answer explains this variation.

As was discussed earlier, the CO_2 values are more an indication of incomplete circulation of air in the house than they are of any particular problems of indoor air quality. The values reported for Apple Hill are more indicative of average house conditions since the furnace fans were operating during the testing. The 90 percentile value of the study homes ranged from just under 700 ppm to approximately 1000 ppm, a value that is not uncommon for most sealed homes in the experience of this author. High end outliers of approximately 1700 ppm, recorded during the September study, are also not unusual. In a recently completed study for the Department of Energy, Mines and Resources in air sealed homes in the community of Richmond Hill just outside of Toronto, a geometric mean of 457 was found for CO_2 before the houses were air sealed and this value moved to 524 after air sealing of these houses. The 90 percentile value for the house average was 670 ppm before, 760 ppm after sealing. Seventeen houses were monitored in the after case including three control houses which had not been sealed. Even these control houses showed a minor increase in CO_2 levels. The highest four hour levels recorded were between 1500 and 2500 ppm.

Oxides of Nitrogen

A review of the oxides of nitrogen data shows the following information:

- o three values greater than the detection limit in June (12.5 to 20 ppb),
- o four values greater than the detection limit in September (12.5 to 25.0 ppb),
- o nine values greater than the detection limit in January (12.5 to 50 ppb).

With only a limited number of data points it was decided not to plot distribution data for the NO + NO_2 results. These results are all significantly below the 110 ppb level mandated for 24-hour NO_2 average concentrations. The tubes used provide an indication of oxides of nitrogen expressed as NO_2.

The highest levels for each of the three contaminants were recorded in House #50. Records show that house 50 is an electrically heated home and one would anticipate it to have a lower air change rate than the other homes in the study. No further information is available on the living habits of the occupants of this home, however, one would suspect that the occupants smoke, given the fact that the combustion contaminants all tend to be high in this house. It was in this house that the 50 ppb NO + NO_2 was recorded.

The results of the NO + NO_2 tests undertaken in these homes do not appear to be out of line with results found by this author in sealed homes. Particularly in those homes where gas ranges were used, a range of values comparable to the literature reported values of NO/NO_2 were found by this author. Considering that no gas fired ranges are among the population of the houses tested in Apple Hill, and that the furnace rooms of these houses were isolated from the rest of the house, it is not surprising to find relatively low NO/NO_2 levels in the homes.

Radon

As mentioned earlier, radon data was measured by using both grab samples in studies conducted by HWC and the Track Etch method available from Terradex. Both sets of radon gas concentrations data were plotted and the results are shown in Figures 9 and 10. In both these figures, the annual average values for the basement of each home have

FIGURE 9

Radon Distribution Data-
Annual Average of Grab Sample Results

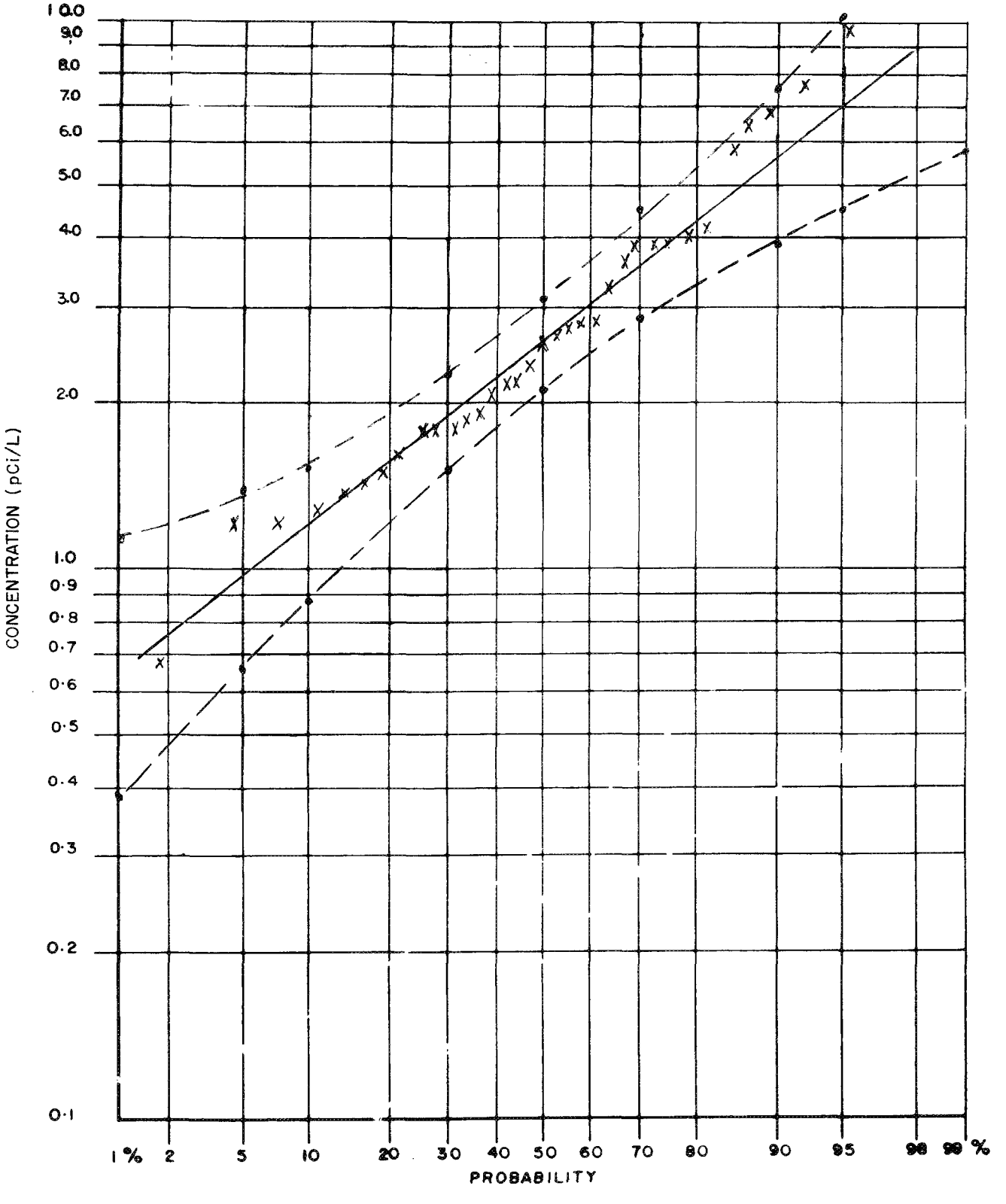
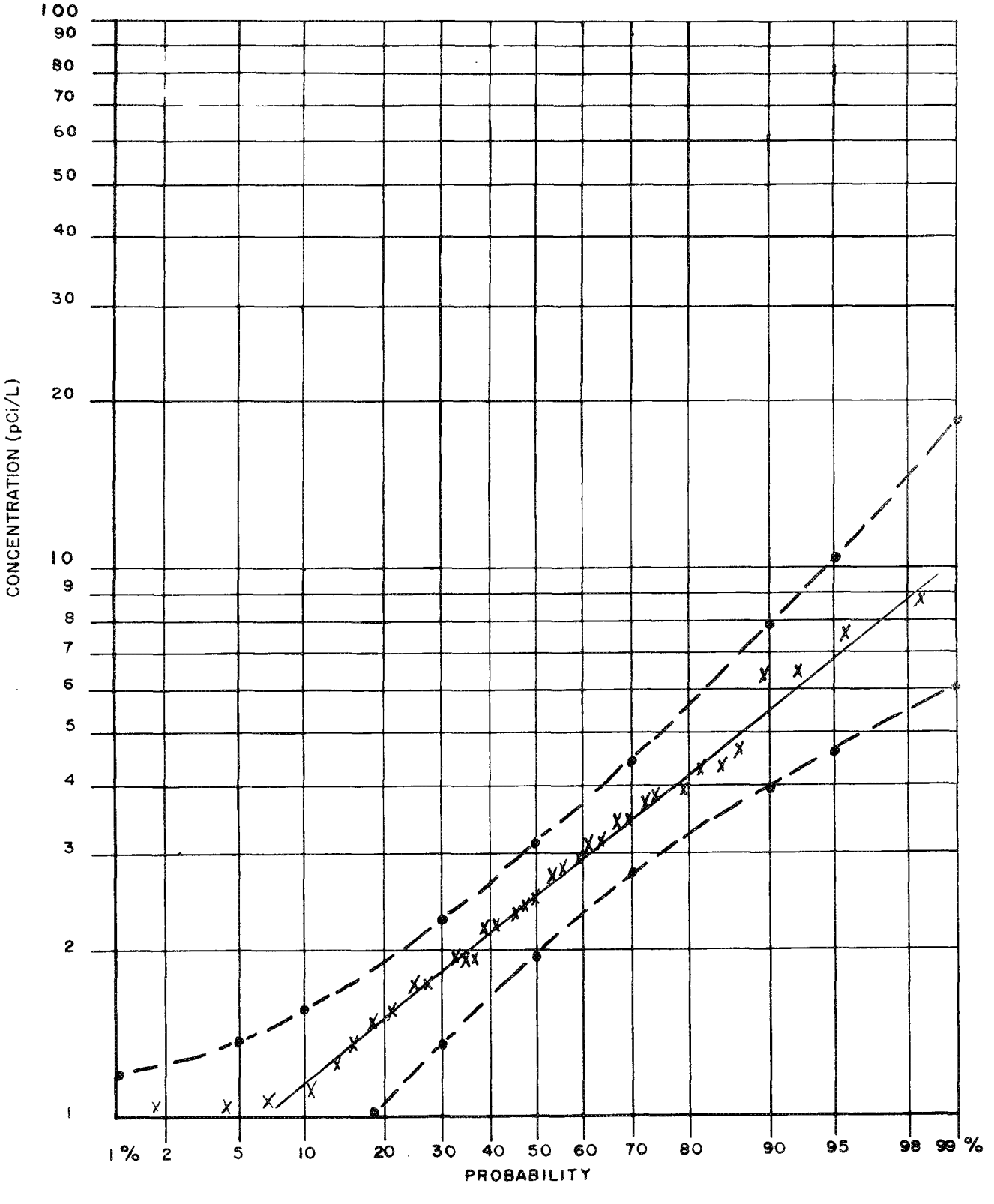


FIGURE 10

Radon Distribution Data-
Annual Average of Tracketch Results



been plotted and the results of this plot show 50 percentile values of 2.5 pCi/L using the Track Etch technique and 2.64 pCi/L using the grab sample technique. The 90 percentile values for the Track Etch technique are 5.5 pCi/L and for the grab samples an identical value was obtained. A plot of the confidence limits on both these data sets show all the data to lie within the same distribution and as one would expect, statistically there is no difference between the mean as calculated for the Track Etch data or from the grab sample data.

A slight shift in values occurs towards the top end of both sets of samples. It appears that between 15 and 20% of the data at the top end rides somewhat higher than does the bulk of the rest of the data. This result is also revealed when one considers the WL plot shown in Figure 11. This data was derived from the HWC grab sample data. This produces one marginal outlier at the 0.03 WL value. The balance of the data lies well within the 95% confidence limits. The mean value for the 35 houses tested over the period of the year was slightly higher than the AECB investigative level of 0.01 WL and the 90 percentile value was in excess of the AECB 0.02 standard being 0.023 WL. The values recorded in the top three or four homes would suggest further investigation and elimination of the source of radon gas in these homes would be appropriate.

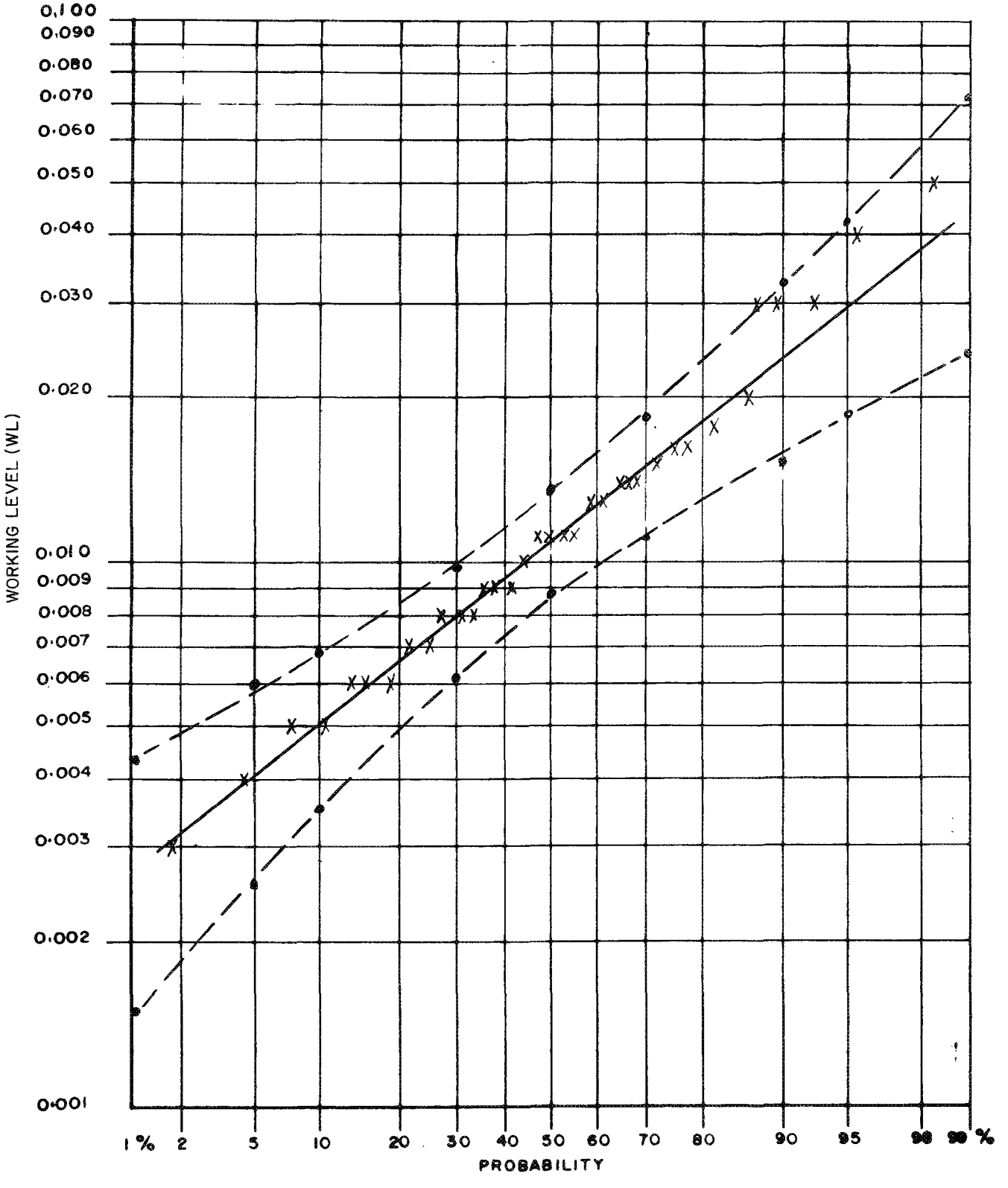
Formaldehyde

Only limited formaldehyde sampling was undertaken. The data is probably biased low by the long sampling period, however, no accurate assessment of the magnitude of this bias can be made. The results indicate levels in the range of 0.05 - 0.15 ppm. These values are higher than typical for most non-UFFI houses but not unlike those found in other "tight" homes. They are not particularly surprising given the newness of the homes and the likely presence of particle board and carpet which are known sources of formaldehyde.

These results would indicate the need for more data collection. Several dosimeters should be installed in the houses and results gathered for 4 separate weeks in each season. The dosimeters should only be exposed for seven days. If possible, recording hygrothermographs should also be run in these homes to enable better interpretation of the results.

FIGURE II

Working Level Distribution Data-
Annual Average of Grab Sample Results



Humidity

While not truely an air contaminant humidity can affect both comfort in the homes and the physical structure of the homes. High humidities can cause condensation on windows and lead to paint and wood deterioration.

The authors of the Apple Hill report note that some homes have relative humidity levels well above commonly accepted appropriate levels. The difficulty with relative humidity data though is that it is a function of air temperature. With the lower temperatures recorded in some homes, the relative humidities appear to be much higher than the 68°F (20°C) recommended standards. In actual fact, the absolute humidities in several of these homes were not appreciably above those that would be present at the 20°C temperature. Caution must therefore be utilized when reviewing indoor temperature and relative humidity if it is to be compared to standards.

CONCLUSIONS

In the judgement of this reviewer, the results of the Apple Hill study do not present many surprising results. The methods are not the best but given the restraints of the project represent a worthwhile attempt to gather more information in a cost effective manner. The size of the data set contributes to the usefulness of the study.

Further work is necessary to:

- investigate stratification of CO_2 in the homes and identify areas with potentially high contaminant levels;
- define the actual formaldehyde levels and thus exposures in the homes; and
- identify the sources of and effect reduction in the levels of radon gas and daughter products in these houses.

Moreover, the study illustrates the need for the CGSB committee on Indoor Air Quality to devise methods for monitoring based upon:

- a definition of appropriate standards for indoor air quality levels; and
- the economic benefits that would arise from remedying currently high levels in some of the houses.

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