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A CROSS-SECTIONAL SURVEY OF INDOOR RADON CONCENTRATIONS IN 966 HOUSING UNITS AT THE CANADIAN FORCES BASE IN WINNIPEG, MANITOBA

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ABSTRACT

This paper summarizes the results of a cross-sectional survey of indoor radon concentrations in a total group of 966 housing units at the Canadian Forces Base (CFB) in Winnipeg, Manitoba. The major objective of the study was to characterize the distribution of indoor radon levels in the housing group as the first step in developing a radon control strategy. Subsequent investigations on sub-groups of these houses (not reported here) were conducted to examine the building factors associated with the indoor concentrations and the efficacy of post-construction control measures.

Measurements were obtained from 670 of the 966 housing units (69% participation). The study group was composed of large numbers of nominally identical housing units of several different building styles. The two-day average measurements were taken using charcoal canisters during extremely cold weather, -28°C to -35°C. A short questionnaire administered to the occupants by the field workers who installed and removed the canisters recorded basic data on occupant activities and building factors.

For the entire group, the geometric mean concentration was 112 Bq/m^3 (3.0 pCi/L), approximately twice as high as the geometric mean obtained by an earlier summertime study of 563 Winnipeg houses. Data was subgrouped based on geographic location within the city, and the subgroup geometric mean concentrations varied between 25 and 206 Bq/m^3 (0.7 and 5.6 pCi/L). Individual house measurements ranged from <10 Bq/m^3 to >5400 Bq/m^3 (<0.3 pCi/L to >146.0 pCi/L). No building or occupant factors were initially identified as being associated with the variation in levels.

INTRODUCTION

In the fall of 1989, the Department of National Defence (DND) retained the authors to design and conduct a study to investigate the indoor radon levels in the residences occupied by DND personnel at the Canadian Forces Base (CFB) Winnipeg, MB. These residences included housing units (PMQ's) owned by DND, bulk leased (BL) housing units rented by DND, and barracks units (BU). Radon levels were also surveyed in 46 areas of the officers' and non-commissioned members' messes and other occupied areas on both north and south areas of CFB Winnipeg.

Radon has been identified as a naturally occurring pollutant that is broadly distributed throughout Canada. In 1977 to 1980, Health and Welfare Canada conducted a study to survey indoor radon levels in 14000 homes in 19 cities across Canada (1). These data are frequently referred to in discussions regarding the radon situation in Canada and are used to rank cities with respect to their radon risk potential. In this study, Winnipeg was identified as the Canadian city having the highest geometric mean indoor radon level (57 Bq/m^3) based on a sample of 563 houses. For the purposes of this paper, the conversion 37 Bq/m^3 = 1 pCi/L can be used.

Many studies of indoor radon levels have been conducted and while a more complete understanding of the factors that influence indoor levels is emerging, at present, the only reliable method of estimating the radon concentration in a specific building is to measure it (2).

The study design included three parts to be conducted consecutively:

Part 1. Cross-Sectional Survey of Indoor Radon Concentrations.

The focus of this part of the project was to provide an overview screening of the radon concentrations occurring in the homes. The data would also provide a statistical database for future studies. DND requested that all of the occupants of both the owned and leased housing units be given the opportunity to participate in the study. In an attempt to obtain the highest indoor readings, measurements were taken in the lowest levels of the houses during calm, cold weather.

Part 2. Detailed Engineering Study of a Selected Sub-group of Houses.

This work focused on identifying the building factors that influence indoor radon concentrations and provided information for the development of mitigation techniques. It included a more intensive study on a sub-group of approximately 40 houses identified in the part 1 work as having the highest and lowest indoor radon concentrations.

Part 3. Mitigation Study on a Small Group of Houses.

The focus of this work was to select five houses with high indoor radon concentrations, make building modifications and evaluate the impact of the modifications on the indoor radon concentrations.

All houses having part 1 screening levels >150 Bq/m^3 had alpha track monitors installed for the period from October 90 to March 91.

This paper deals with the results of the cross-sectional survey (part 1) of the study.

For the purposes of data presentation and discussion, the current Manitoba Government interim guidelines (3) are referred to in the report. In summary, these are:

1) If the screening measurement is about 150 Bq/m^3 or lower and was taken during cold weather with the house closed up, there is little chance that the home will have an annual average concentration greater than 150 Bq/m^3. Follow-up measurements are probably not required.

2) If the screening measurement is about 150 - 800 Bq/m^3, consider performing follow-up measurements.

3) If the screening measurement is about 800 Bq/m^3 or greater, perform long term (minimum three months) measurement as soon as possible.

OBJECTIVES

Part 1 of the study had two major objectives:

1) Measurement of indoor radon levels in all CFB Winnipeg residences (PMQ, BL and BU) and selected other buildings to give DND an accurate assessment of the current indoor radon levels. These data would be used to determine if additional measurements or mitigation work were required to ensure indoor radon levels were maintained below levels established by DND.

2) Characterization of the distribution of radon levels and analysis of the levels in conjunction with selected building and occupant factors. The analysis would identify factors that are statistically associated with the radon concentration and will be used in subsequent phases of work.

STUDY DESIGN

The initial phase of the study was a cross-sectional survey to measure the two day average concentration in (nominally) all of the 966 residential units potentially inhabited by base personnel. CFB Winnipeg engineering staff also prepared a list of 17 buildings to be monitored. A total of 46 monitors were placed in various locations in the lowest levels of these buildings.

Prior to conducting the study, the base command prepared an information package containing basic information about radon and a brief overview of the proposed study which was mailed to all occupants of homes in the study. Only homes that were occupied during the test period were monitored since gaining access to homes where the occupants were not present was not permitted. Participation in the study was at the discretion of the occupant.

The study consisted of an initial home visit to install the radon monitor and a follow-up visit 48 hours later to remove the monitor and complete (with the homeowner's assistance) a short questionnaire concerning the building construction and occupant activities. If the homeowner indicated that they would not be home when the monitor was to be removed, they were carefully instructed as to the protocol for repackaging the monitor. The homeowner would leave the monitor in the mailbox for pick-up.

Twenty-three temporary contract employees were used over a four day period to install and remove the monitors. They were all paid on an hourly basis and instructed to take as much time as necessary to complete each house visit (average 15 minutes). On the day before the monitoring began, a two hour seminar was held to train all of the personnel assisting with the study. A phone-in help line was manned at all times so that workers could phone in for assistance. Only five calls requesting minor information were received during the study.

The field work was conducted from 10-14 December, 1989. During the test period, the weather was clear and relatively calm with the outdoor air temperature varying between -28°C to -35°C.

Additional monitors and questionnaires were available at the base engineering office for persons who phoned in to say they were in the city but would not be home when the visits were being made. These people were invited to come to the engineering office to pick up the materials for self administration. These data are not included in this report.

For this survey, the sample population and the target population were identical since all residences were included in the survey. Considerations as to sample size, representativeness of sample and estimation of the distribution of indoor radon levels are eliminated in a total sampling program. This is an important point in designing radon research projects since the nature of radon concentration distributions varies widely depending upon local circumstances.

The following potential biases may affect the study, however, they are not considered significant in the analysis.

Although all of the residences occupied by base personnel were included in the survey population, some houses were not monitored. For most cases, the reason for not being included was that the occupants were not home at the time the house was initially visited (between the hours 8:00 to 21:00 Monday or Tuesday). Several attempts were made at various times of the day over the two day period.

The non-participants may bias the selection of the data group towards residences where a co-operative individual was home, however, there does not appear to be any systematic reason why this would affect the validity or interpretation of the study results. The demographic and building data obtained from the questionnaire would correctly account for these occupant differences. Of the 966 potential residences, 670 measurements were obtained.

The questionnaire contained primarily descriptive and quantitative questions concerning the building and the occupant activities during the two day monitoring period. A section for general homeowner comments was also included.

METHODOLOGY

The indoor radon concentration was measured using RADPAC TM activated charcoal canisters. The nominal exposure time suggested by the supplier was two days, however, as long as the exposure time was accurately recorded, exposures in the range of 45 to 72 hours were acceptable.

The canisters were installed approximately 0.6 m above the floor in the lowest level of the residence, centrally located away from drafts and in accordance with the manufacturer's instructions.

All of the canisters were received by the supplier for analysis within 48 hours of removal from the house.

The monitor supplier was listed as a registered participant in both the US EPA and Health and Welfare Canada quality assurance programs. In 10 locations, duplicate canisters were installed as an internal check of the measurements.

QUESTIONNAIRE DESIGN

The questionnaire was designed to be either self-administered or filled in by the survey employee with assistance from the homeowner. It consisted of 36 questions requiring;

1) a yes or no response about building characteristics.

2) basic physical information about the building such as the number of windows, main floor area or type of space heating system.

3) selection of a ranked descriptor to rate the condition of the foundation walls and floor.

4) estimation of hours spent doing specific household activities or frequency of door/window openings.

The purpose of the questionnaire was to obtain information on building and occupant factors that would influence the indoor radon concentration either directly or indirectly.

ANALYSIS

The survey yield for the entire housing group was 670 measurements from a total population of 966 (69%). Since the geographic location was considered to be an important factor associated with the indoor radon concentration, the data were sub-grouped 1 to 8 (somewhat arbitrarily) based on location.

The sub-groups used in the initial analysis were combinations of streets based on a common geographic area. For the sub-groupings used, the smallest yield was 62% of all possible houses so all of the areas were considered to be adequately sampled.

Information from the questionnaire can be used to group the houses into different categories. Most of the questionnaire information can not be directly assigned a quantitative value that could be used in a mathematical analysis, but will be useful in identifying houses that can be grouped together on the basis of some common characteristics and compared with respect to other factors.

RESULTS

The authors or project manager should be contacted for information on the detailed survey results.

A frequency distribution of all of the indoor concentration data is presented in Figure 1 and replotted with the logarithm of the concentration in Figure 1a. All logarithms are taken to the base 10. The distribution in Figure 1a follows the log-normal distribution and therefore, the geometric mean (GM) rather than the arithmetic mean is used to describe the central tendency of the data. For the entire group, the geometric mean indoor radon concentration was 111.8 Bq/m^3 (123.1 Bq/m^3 for the housing units only) which was well above the 57 Bq/m^3 geometric mean for Winnipeg given by the Cross-Canada study.

The class intervals for the histograms were selected to allow group frequencies corresponding to the Manitoba guideline values to be calculated.

A second set of frequency distributions were prepared by breaking the population into six geographic areas (somewhat arbitrarily) based on the physical proximity of groups of streets Figure 2. Also included are the separate data from the north and south base building areas. The data are presented in Table 1.

The geometric means, arithmetic means and standard deviations for the geographic sub-group of data are given in Table 1. These values show the wide variation in mean radon concentrations both within the groups and based on location. It is important to note that the grouping based on location is, in some cases, a surrogate grouping based on other building factors such as house style or ventilation system type. The sub-groups also include buildings owned and maintained by DND and bulk leased housing that is owned and maintained by the leasing company.

In future analysis (beyond the scope of this report) the data for the individual geographic locations (where applicable) may be further sub-grouped based on the general retrofit status of the detached and semi-detached houses. Over the past years, different levels of improvements have been made to the DND housing stock. The present housing stock falls into one of the following categories:

1) original construction as built in the 1940's:

2) replacement of windows and doors with more modern units:

3) replacement of windows and doors along with reinsulation and siding of the exterior walls above grade.

Other possible analysis include examination of the effect of house style, heating/ventilating system type, foundation type and foundation condition.

DISCUSSION

The initial screening survey indicated that there is a wide variation in radon levels in the buildings occupied by CFB Winnipeg personnel.

Overall, the indoor radon concentrations are much higher than the 57 Bq/m^3 geometric mean level obtained in the Cross-Canada study by Health and Welfare Canada. To a large extent, this may be related to the test conditions under which the measurements were taken. The Cross-Canada study used short term (<10 minute) measurements conducted in the summer. For this study, two day averages during sealed house conditions in very cold weather were taken. While detailed modelling is beyond the scope of this study, several building science principles support these results:

1) The cold outdoor temperatures would result in high sustained negative pressures at the lower level of the buildings. This would maximize the pressure potential driving radon into the buildings.

2) Although the high negative pressures should result in an increase in the air exchange rate for the houses, a concerted effort on the part of the homeowners to keep all windows and doors closed (as compared to summer when children are home from school and window/door opening may provide the only cooling ventilation) may have offset the pressure effect and resulted in lower overall outdoor air exchange rates. Many of the homeowners reported taking special care to keep their homes "sealed up" during the winter to minimize drafts and reduce heating costs.

The groups with the lowest geometric mean indoor radon levels (25-30 Bq/m^3) were the south and north base buildings - groups 7 & 8 and the two storey six/eight family units in group 5 located adjacent to the north base. All of these buildings had hot water heating systems and no mechanical ventilation systems.

All of the other groups were single or double family residences. While a detailed analysis is not provided, there is a general tendency for the north base areas to have higher geometric mean indoor radon levels (group 1 - 206.5 Bq/m^3, group 2 - 173.4 Bq/m^3, group 4 - 147.0 Bq/m^3) than the south base areas (group 3 - 110.2 Bq/m^3, group 6 - 156 Bq/m^3).

Table 2 lists the values for the replicate measurement tests. For the ten locations, two charcoal monitors were placed side by side and exposed for the same time period. In nine cases, the agreement was within a maximum range of 16.7% and typically much smaller. For the test at Location E, the monitor results varied by a factor of six. There are no procedural differences that would account for this anomalous result. Using a paired t-test analysis, the differences between the measured values (excluding Location E) were not significant at the 5% level of significance.

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3. "RADON - An Interim Guide for Manitoba Homeowners", Manitoba Energy and Mines Information Center, Winnipeg, MB., 1989.

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TABLE 1. INDOOR RADON CONCENTRATION DATA FOR GEOGRAPHICAL SUB-GROUPS

GROUP	NO. OF HOMES	NO. OF MEAS.	GEO. MEAN Rn (Bq/m^3)	ARITHMETIC MEAN (Bq/m^3)	NO. > 150 (Bq/m^3)	NO. > 800 (Bq/m^3)
1	214	145	206.5	319.1	88	10
2	180	111	173.4	206.3	68	1
3	243	181	108.2	183.0	47	6
4	106	65	147.0	200.8	34	1
5	105	77	25.7	29.2	0	0
6	118	91	152.1	266.7	40	4
7	-	35	27.2	47.0	2	0
8	-	11	27.8	35.0	0	0

TABLE 2. COMPARISON OF REPLICATE MEASUREMENTS

Location	RADPAC Bq/m3	% Diff.
Location A	125.8 125.8	0
Location B	88.8 88.8	0
Location C	103.6 99.9	3.6
Location D	55.5 66.6	16.7
Location E	140.6 806.6	82.6
Location F	388.5 388.5	0
Location G	299.7 299.7	0
Location H	629.0 629.0	0
Location I	510.6 503.2	1.4
Location J	92.5 88.8	4.0

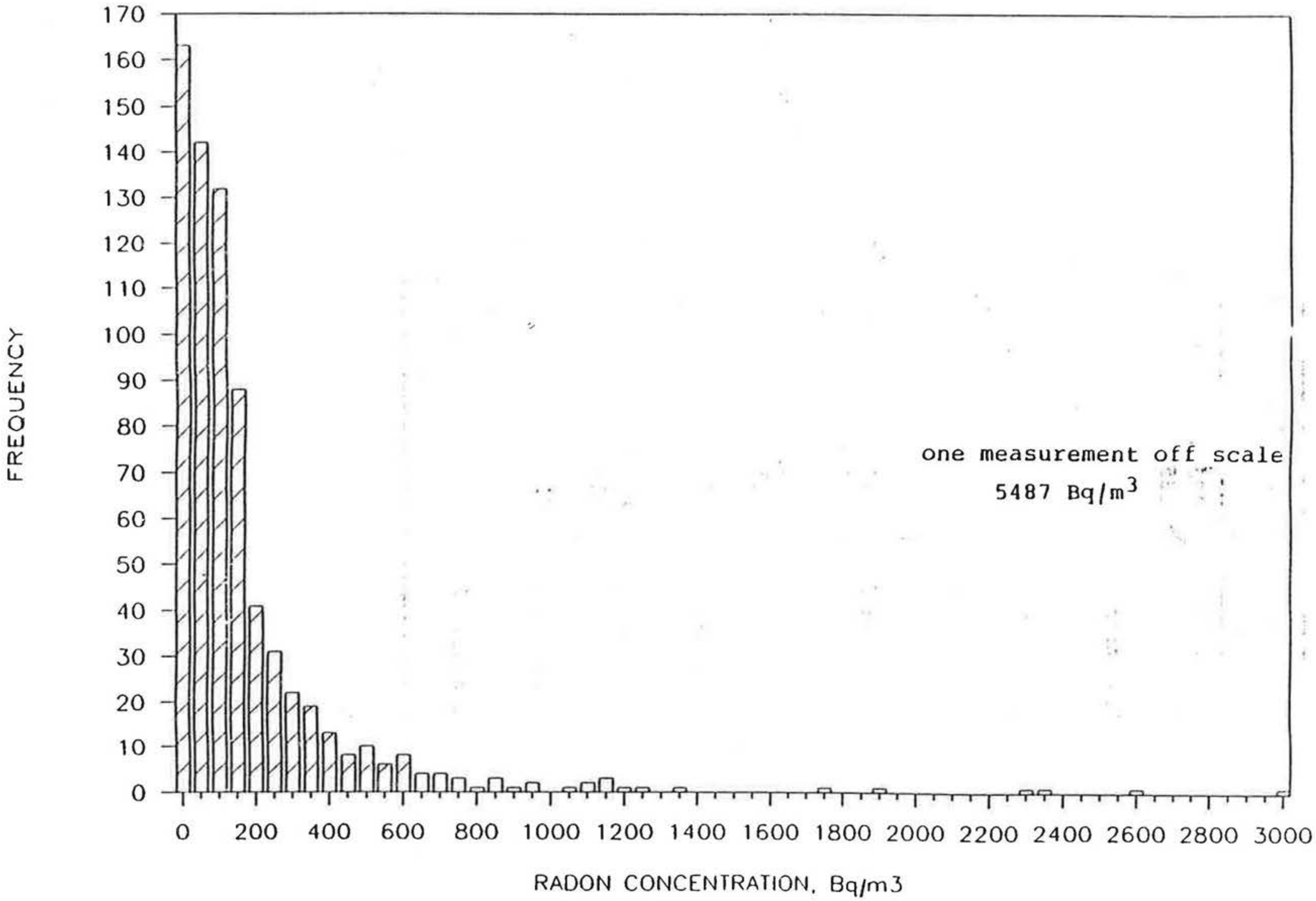

FIGURE 1. FREQUENCY DISTRIBUTION OF ALL INDOOR MEASUREMENTS

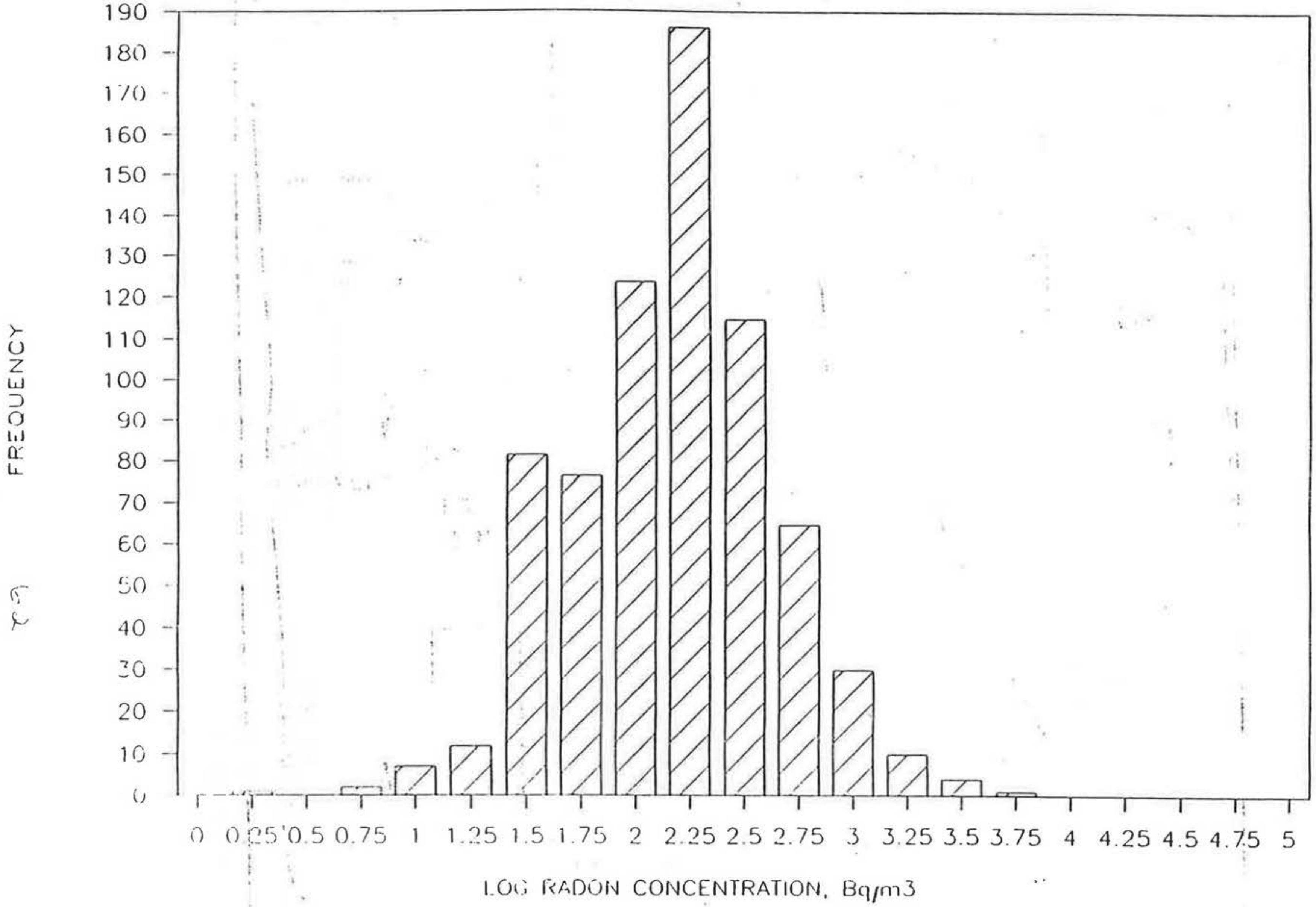

FIGURE 1A. FREQUENCY DISTRIBUTION OF ALL INDOOR MEASUREMENTS (LOGARITHM)

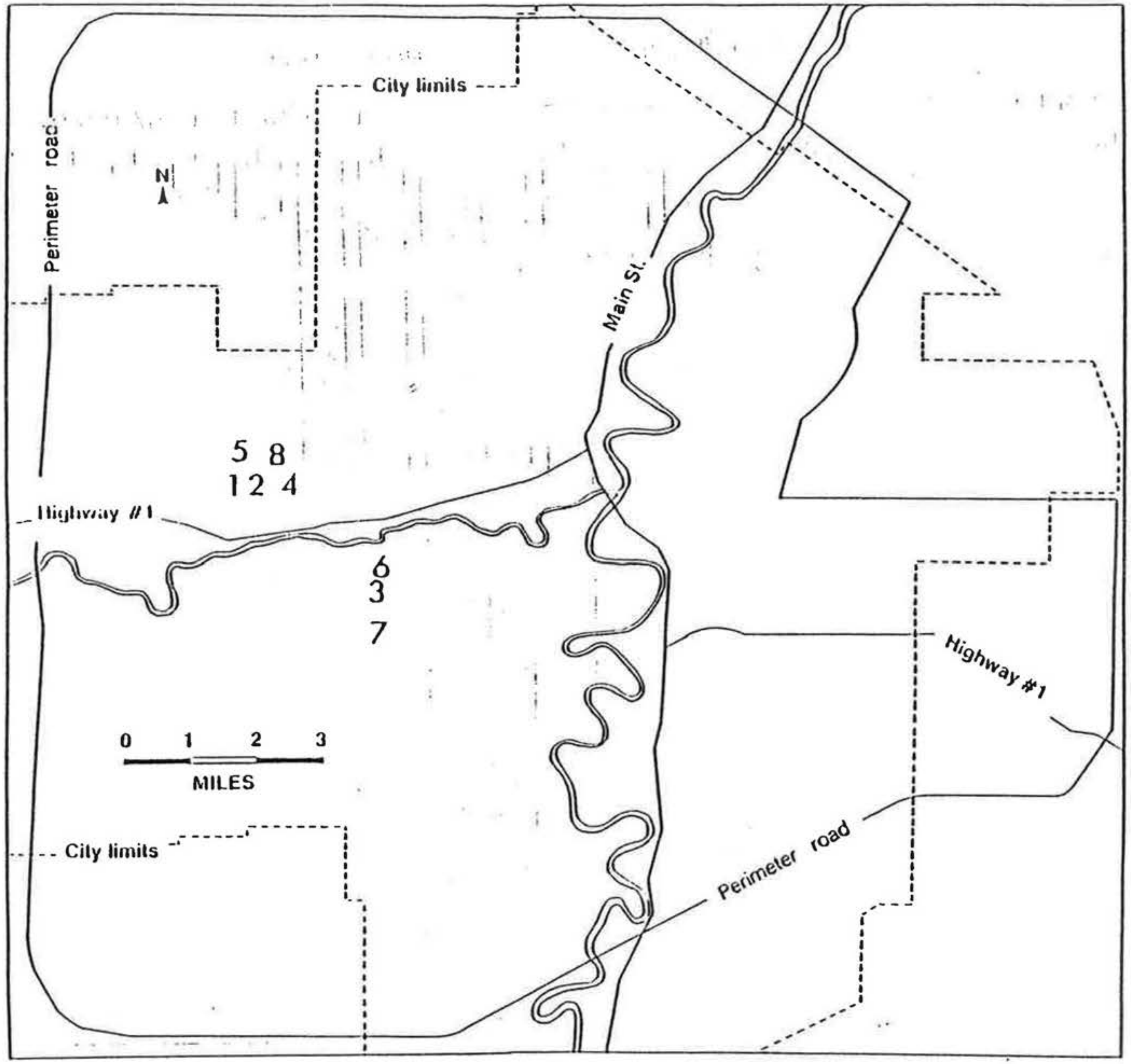

FIGURE 2. MAP OF WINNIPEG SHOWING EIGHT SAMPLING GROUP LOCATIONS