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AECB 1164-3

THIRD WORKSHOP ON RADON AND RADON DAUGHTERS IN URBAN COMMUNITIES ASSOCIATED WITH URANIUM MINING AND PROCESSING

Sponsored by the
Atomic Energy Control Board
Under the
Aegis of
The Federal Provincial Task Force on Radioactivity

Port Hope, Ontario
12-14 March, 1980

PART I

ATTENDEES - RADON WORKSHOP III

CANADA

Atomic Energy Canada Ltd.
- C. Wernli

Atomic Energy Control Board
- R. Eaton
- W. Courneya
- R. Washington
- R. Hendrickson
- G. Spence
- W. Whitehead
- D. Howchin

Bondar-Clegg & Co. Ltd.
- R. McCorkell

British Columbia, Ministry of Health
- D. Morley

Central Mortgage & Housing Corporation
- D. Anderson
- W. Harrigan

Dilworth, Secord, Meagher & Associates Ltd.
- W. O. Findlay
- A. Scott
- D. Smith
- C. Gauthier

E.D.A. Instruments Incorporated
- M. Roman-Barber
- W. Thuma

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Eldorado Nuclear Limited
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S. Frost
R. Forbes
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D. Carson

Environment Canada
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Health & Welfare Canada Ltd.
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James F. MacLaren Ltd.
E. Chart
B. Stewart
J. Beal
G. Case
R. Maruska
P. Manley

Keith Consulting Engineers
E. Kindrachuk
R. Mackie
E. Haubrich
R. Crilly

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H. Frank

Ontario Ministry of Labour
E. Baker
L. Pai
G. MacDonald

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Pylon Electronic Development Co. Ltd.
G. Vandrish

Québec, Service de protection de l'environnement
P. Carrière

R.H. Morse & Associates
R.H. Morse

Rio-Algom Ltd.
P. Pullen
A. Vivyurka

Saskatchewan, Ministry of the Environment
R. Sentis
R. Busch
E. Wagner

Town of Port Hope
A. Blackwood
R. Stewart

5215 Inc.
L. Haywood

SWEDEN

National Board of Physical Planning & Building
Wilhelm Tell

National Institute of Radiation Protection
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Scandanavian Engineering Corporation
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UNITED KINGDOM

National Radiological Protection Board
K. Cliff

UNITED STATES

Lawrence Berkeley Laboratory
W. Nazaroff

Monsanto Research Corporation
G.R. Hagee

NAHB Research Foundation
R. Johnson

U.S. Department of Energy
A.C. George

U.S. Department of Housing & Urban Renewal
G. Winzer

E.P.A. Laboratory
S. Windham

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INTRODUCTION: R.S. Eaton

Welcome to Port Hope and to our third workshop. As before, the location of our gathering has been chosen so as to allow you to view the work going on and to get you into the environment where you can appreciate the difficulty of this type of activity.

The success of our previous meetings has encouraged the attendance of larger numbers. I particularly appreciate those of you who have come from other countries. I hope that you can learn from us and I expect that we can learn from your experiences.

Our invitational letter has been published in the local newspaper. While this action was somewhat disturbing, I believe in making the meeting as open as possible, simply because nuclear energy has an aura of secrecy about it that is misplaced in the type of work that we are doing. Because we are working in the community, I do feel an obligation that individuals should be made aware of what is going on. However, there are conflicting problems. We have no right to identify particular houses or survey results as this is the privileged information of the homeowner. As a result, speakers will please avoid specific reference to properties.

As many of you know, the Task Force on Radioactivity has no responsibility for new construction in mining communities and has no responsibility for housing outside of those communities associated with the nuclear fuel cycle. However, I believe that we have generated in our program knowledge which I hope can be passed on to other agencies. I have invited representatives of these agencies to this gathering so that they can feed back into their organizations some of those ideas presented here. I am still of the opinion that this will be our last workshop and the body of knowledge that we have developed here is going to end up "in limbo" unless somebody picks it up. There is, therefore, somewhat of a challenge.

The paper to be presented by Dick McGregor of Health & Welfare Canada is an attempt to present the outside situation - outside of mining communities where Health & Welfare is involved, to show what they have done and what they are trying to do. Other papers dealing with issues of new construction and energy conservation will also be presented.

ELLIOT LAKE PROGRESS REPORT

ELLIOT LAKE PROGRESS REPORT

By W. Findlay and A.S. Scott

INTRODUCTION

The intent of the remedial program is to

1 - Identify those houses in Elliot Lake with annual average WL's in excess of the action criterion of 0.02 WL

2 - Demonstrate that the annual average WL is below 0.02 WL in those houses where remedial work was not performed

3 - Discover the route(s) of radon entry in identified houses and to close sufficient of them to reduce the annual average WL to less than the action criterion of 0.02 WL

4 - Demonstrate that the annual average WL following remedial work is less than the action criterion of 0.02 WL.

To meet these requirements, the Remedial Program is organized in two subprograms, the Survey Program and the Remedial Action Program.

SURVEY PROGRAM

By December 31, 1979, more than 17,000 survey measurements had been carried out, identifying 157 houses where remedial action was required and confirming that remedial action was not required in 413 houses. Program status is summarized in Table 1.

At the beginning of the project there were a number of houses where the average radon daughter concentration was so far in excess of the criterion that a few measurements were sufficient to identify the house as requiring remedial work. However, by early 1978 it was clear that, in many houses, a systematic survey over 12 months would be required to properly estimate the annual average radon daughter concentration. Accordingly, two surveys were started in 1978 to estimate this quantity by making measurements over a period of 12 months. These were the WL survey and the Radon survey.

WL Survey

Statistical analysis shows that the Annual Average WL in a house can be estimated with acceptable accuracy by taking at least 13 measurements at regular intervals through the year.

At the end of 1978, 124 hourses were in this survey. By December 31, 1979, the survey had been completed in 123 houses and 6 houses had been added during the year.

Of the 123 houses, 99 were identified as below the remedial action criterion and 14 were identified as above the remedial action criterion. The remaining 10 were close to the criterion, and additional measurements will be made to determine the average more closely.

Radon Survey

The Annual Average radon concentration in a house is estimated from the average radon concentration measured over a 1-week period at 6 equally spaced intervals through the year.

At the end of 1978, 278 houses were in this survey program. On December 31, 1979, the survey had been completed in 248 houses and 42 houses had been added during the year.

Of the 248 houses, 218 were identified as below the derived remedial action criterion of 5 pCi/litre average radon concentration, and 24 were identified as above the derived criterion. The remaining 6 were close to the criterion, and additional measurements will be made to determine the average more closely.

During the year, 60 AECB passive integrating radon monitors were delivered but arrived too late to replace the pump and bag units in the radon survey. They are presently undergoing both field and laboratory tests to determine the precision and accuracy achievable in practice.

Fill-In Survey

Houses with annual average WL in excess of the criterion are often found in apparent clusters separated by a few houses that were below the investigation levels on the 1976 survey. To check if these houses were genuinely below criterion, a fill-in survey was carried out in houses adjacent to those identified as exceeding the criteria.

During 1979, 125 houses adjacent to houses in excess of the criterion were assigned to the survey. By December 31, 1979, the survey had been completed in 119 houses of which 100 were identified as below the remedial action criterion, and 8 were identified as above the criterion. The remaining 11 houses were close to the criterion, and additional measurements will be made to determine their averages more closely.

The proportions observed are not very different from those in the other surveys, suggesting that the clustering of remedial action houses is not an effect of location in town, but is the result of similar construction practices.

Gamma Dose-Rate Survey

Although the program has mainly been concerned with reduction of radon daughter concentrations in houses, there have been a few cases where gamma radiation levels were high enough to require remedial action. During the Task Force Survey of 1976, gamma measurements were made in and at many houses in town, and identified a few driveways where the exposure rate was in excess of the external gamma criterion. These driveways were removed in the first year of the project.

In addition, two houses were identified where the exposure rate inside the house was in excess of the gamma criterion. Both these houses had been built by small contractors in the early days of town expansion. Most houses were built by large contractors, and a gamma survey in about 200 of these houses found none with gamma levels in excess of the criterion. It was therefore thought that internal gamma problems were limited to those 2 houses identified previously, and so the gamma survey program was given low priority.

In September, a routine gamma measurement discovered a house built by a large contractor with internal gamma fields in excess of the criterion.

The concrete used in this house had mine waste-rock as aggregate, and so it was possible that there were other houses in town where the same concrete had been used.

As a result, the gamma survey program has been given higher priority. Exposure rate measurements are being made at and in every privately owned house in town that was built before 1977. To date, 145 houses have been surveyed and one in excess of the criteria has been found. About 800 houses remain to be surveyed.

Business Survey

A survey of commercial premises was started in late 1979. Work completed includes tracing owners and obtaining permission to survey from both owners and tenants in 152 premises. Visual inspection of the larger buildings to determine suitable sites for installation of passive integrating radon monitors, plus determination of ventilation patterns is still in progress.

Additional surveys are planned for 1980. The first is a verification survey, in which 10 percent of the remaining 900 privately owned houses that were below criterion in the 1976 survey will be surveyed. If a significant number of these houses are found to be above the criterion, the use of the Task Force Survey as a guide to investigation will be reexamined. The second is an Extra Survey, in which additional measurements will be made in all those houses found to be close to the criterion by previous surveys.

REMEDIAL PROGRAM

Introduction

Elliot Lake is a town whose sole purpose is to house the labor force directly and indirectly involved in the mining of uranium. The town's growth and prosperity is directly linked to that of the uranium industry. Briefly then, construction started in 1953, peaked in the late 50's, died away in the 60's when the demand for uranium slumped, and picked up again in the 70's with major building starting in the mid 70's. House construction is essentially the mass building of standard subdivision type houses, i.e., groups of similar types of houses. As a result of similar house designs and similar construction practices, many houses have similar routes of soil gas entry. It was therefore possible to develop a number of standard remedial measures to apply to standard problems. The list is shown in Table 2.

Experience has shown that soil gas entry routes can be adequately closed using simple techniques and materials common in the building trades. However, the apparently simple solution of blocking off entry routes is complicated by two factors.

The first is that basements were not intended to be gas-tight and have been designed and built with numerous openings to facilitate common construction methods, added to by the ingenuity of the tradesmen and frequently by owners.

The second is the difficulty in persuading contractor's forces to constantly apply high standards of attention to detail and cleanliness, for it is foreign to their background of mass production and a final cleanup. As a result, continuous supervision has been found necessary. This is all the more important as the policy is not to remove the occupants from the house during construction.

Organization

The method set up last year has been continued, and the various steps are shown on the flow diagram. A 2-stage approach is used. Stage 1 consists of an investigation limited to what can be seen. The relative importance of the routes of entry found is assessed, and they are then dealt with in order of estimated importance. The majority of houses are brought to below criterion by the end of Stage 1. If the remedial measures are unsuccessful, the house is returned for detailed investigation and testing in Stage 2. During this investigation, concealed routes are sought out by testing and the removal of finish.

Investigation

The progress during the current year is shown in Table 3. In total, 88 investigations were carried out.

Remedial Work Stage 1

The status of the work as of December 31, 1979 is shown in Table 4. The remedial measures used to close the entry points found in Stage 1 can be any of the standard listing. The visual nature of the identification can be seen in the number of floor drains, wall floor joints and cracks and openings which were treated.

Remedial Work Stage 2

This phase of the remedial program covers houses where the detailed techniques of Stage 2 investigation have been employed to locate hidden entry routes. The houses investigated have failed to respond to the closing of obvious routes or they were houses where the extent of the interior finish precluded visual inspection of the walls and floor.

The remedial treatment to be employed is usually one of the standard measures. However, the work is greatly increased by the necessity of exposing the area of entry and in the subsequent rehabilitation.

The status of the work as of December 31, 1979 is shown in Table 5. At that time, 13 houses had been successfully treated. The number of each type of fix reflects the less obvious nature of the routes being closed.

Work Deferred

In the course of Stage 2 investigation and Stage 2 remedial program, work was deferred on houses because the estimate of the costs involved were considered excessive and the probability of success with current techniques was not considered high enough. At the present time this includes houses which have a high degree of finish in the basements (such as apartments), houses with basements constructed of concrete block, and houses with water seepage.

Reduction of Gamma Levels

Three houses were identified as having gamma levels exceeding the criterion. They also had high WL's. Each house required a different approach.

House No. 1 - This was a single-storey house with a concrete block basement. Approximately half of the floor was above criterion, and when it was removed it was found that the radiation came from mine waste-rock used as sub-floor fill over half the floor.

Twelve inches of fill was replaced and a new floor slab poured. Some cracks and openings in the other half of the old floor slab were repaired. The radon daughter concentrations were found to have been reduced to below criterion.

House No. 2 - This was a single-storey frame house with a concrete block basement. The structural stability of the walls of the basement was such that it was considered inadvisable to remove the floor slab. There was sufficient headroom to pour a shielding slab and this approach was adopted. Gamma levels were reduced but radon concentration remained high. The walls have been filled with grout, columns replaced and the perimeter sealed. However, chimneys in the mortar of the blocks have been found which bypass the perimeter seal. Work to seal these is now in progress.

House No. 3 - This was a wood frame slab-on-grade house. The design is common in Elliot Lake, with at least 25 similar houses in the immediate vicinity.

The occupants were moved out and all furniture and fillings were removed.

The floor slab was cut by a diamond saw along the perimeter of each room following the line of the heating duct and the concrete was broken by jackhammers and removed. The concrete was radioactive, with mine waste-rock used as aggregate, and mine waste-rock had also been used as fill beneath the slab to a depth of 12 inches.

Cracks in the balance of the foundation were drilled out horizontally and sealed. A new slab was poured and sealed to the remaining foundation walls. Electric heating was installed to replace the forced air system and subfloor distribution ducts.

Water Entry

Several houses were found to have highly variable radon daughter concentrations. One cause of these fluctuations was that the routes of soil gas entry also allowed the entry of soil water. When the cracks or fissures were filled with water, soil gas could not enter. This raised two separate difficulties, first the routes of entry could not always be positively identified, and second the presence of water, at times under pressure, prevented the use of standard remedial treatments. In order to deal with the radon problem, it was therefore necessary to first prevent the entry of water.

Various methods were used in a number of houses, ranging from excavating around the house and replacing (or installing) weeping tile, to diverting rainwater spouts away from the house.

The successful procedures were difficult and expensive. As a result, installation of a subfloor exhaust system in such houses is now being considered as a preferred remedial measure, for it would not necessarily require that water leakage be stopped to be effective.

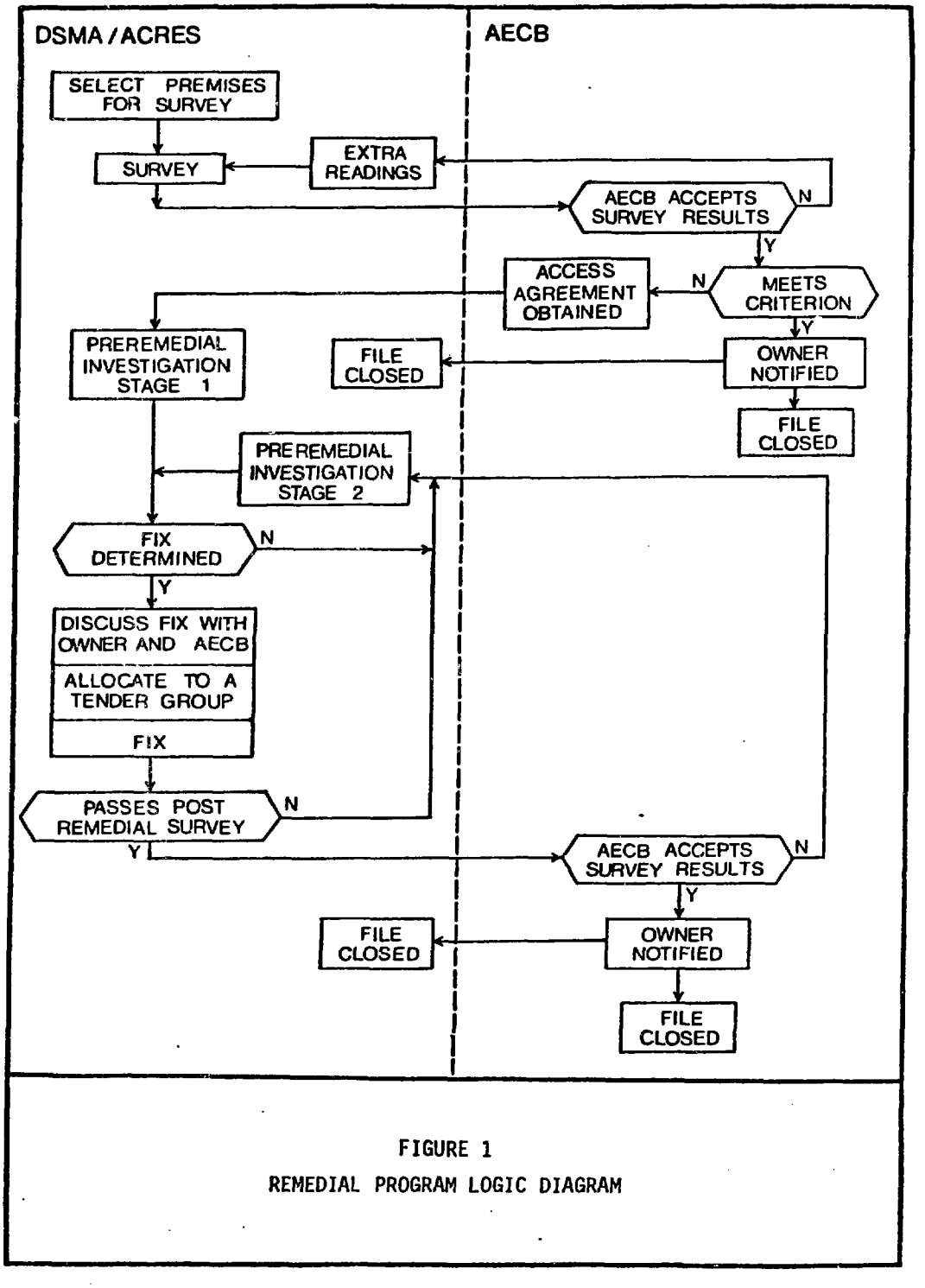


FIGURE 1

REMEDIAL PROGRAM LOGIC DIAGRAM

TABLE 1

SUMMARY OF PROGRAM STATUS ON 31 DECEMBER 1979

SURVEY

Houses under survey	105
Premises with survey planned	227
Houses with survey completed	561
Houses exceeding the criterion	155
Houses with gamma survey planned	827
Houses with gamma survey completed	145
Houses exceeding the criterion	1

INVESTIGATION

Houses under investigation	28

CONSTRUCTION

Houses receiving remedial work	7
Houses with remedial work planned	18
Houses with remedial work completed	98

MISCELLANEOUS

Survey refused	14
Remedial work refused	5

TABLE 2

STANDARD REMEDIAL ACTIONS

Fix Number	Description
1	Water-trap weeping tile connected to floor drain
2	Water-trap weeping tile connected to sump
3	Close wall-floor joint
4	Close cracks and openings through poured concrete surfaces
5	Seal exterior surface of basement walls
6	Cover exposed earth in basements
7	Cover exposed rock in basements
8	Seal interior surface of basement walls
9	Fill concrete block walls with cement grout
10	Remove radioactive concrete or fill
11	Place shielding over active concrete
12	Install fan for improved ventilation

TABLE 3

INVESTIGATION PROGRAM
TO 31 DECEMBER 1979

STAGE I	
Houses in Process	14
Investigation Completed	41
STAGE II	
Houses in Process	14
Investigation Completed	19

TABLE 4

STAGE 1 REMEDIAL PROGRAM
TO 31 DECEMBER 1979

HOUSES COMPLETED 22

FIX NUMBER	DESCRIPTION	TIMES PERFORMED
1	FLOOR DRAIN	15
2	SUMP	2
3	WALL-FLOOR JOINT	7
4	CRACKS	8
5	EXTERIOR SEAL	3
6	EXPOSED EARTH	-
7	EXPOSED ROCK	-
8	INTERIOR SEAL	-
9	GROUT WALLS	-
10	REMOVE ACTIVITY	1
11	SHIELD ACTIVITY	1
12	VENTILATION FAN	1

HOUSES IN PROCESS 19

TABLE 5

STAGE 2 REMEDIAL PROGRAM
TO 31 DECEMBER 1979

HOUSES COMPLETED 13

FIX NUMBER	DESCRIPTION	TIMES PERFORMED
1	FLOOR DRAIN	6
2	SUMP	6
3	WALL-FLOOR JOINT	8
4	CRACKS	9
5	EXTERIOR SEAL	-
6	EXPOSED EARTH	-
7	EXPOSED ROCK	3
8	INTERIOR SEAL	-
9	GROUT WALLS	4
10	REMOVE ACTIVITY	1
11	SHIELD ACTIVITY	-
12	VENTILATION FAN	-

HOUSES IN PROCESS 6

ELLIOT LAKE PROGRESS REPORT

Comments/Questions

A. George : What is the activity of the water supply in Elliot Lake?

A. Scott : 10 pico-curies per liter

E. Wagner : What does "shield activity" (Table 5) mean?

W. Findlay : Shielding consists of pouring five inches of concrete.

A SUMMARY AND HISTORICAL REVIEW OF THE RADIOACTIVE CLEAN-UP IN PORT HOPE, ONTARIO

BY

G. CASE, P. ENG.

PRESENTED TO

THIRD WORKSHOP ON RADON AND
RADON DAUGHTERS
IN URBAN COMMUNITIES ASSOCIATED
WITH URANIUM MINING AND PROCESSING

PORT HOPE, ONTARIO
MARCH 12 - 14, 1980

JAMES F. MacLAREN LTD.

A Summary and Historical Review of the
Radioactive Clean-up in Port Hope, Ontario

In the winter of 1976 the words radon gas and Port Hope, Ontario became synonomous. Reporters, camera crews and television people flocked to the area and overnight the situation became news across Canada. For several weeks the news was front page material, highlighted by the forced evacuations of several Pidgeon Hill Drive families and the entire student population of St. Mary's Separate School. The evacuations were prompted by the elevated radon gas levels detected in these structures.

Since that time, the news reports have all but dissappeared and only on infrequent occasions do you hear the standard line, "You're from Port Hope, you must glow in the dark".

For the next 25 minutes or so I would like to review the radioactive clean-up which has taken place here in Port Hope since the winter of 1976 almost four years ago. By the end of my presentation I hope you will have a better idea of the extent and nature of the situation and will have gained some insight into the problems associated with an undertaking of this magnitude.

As many of you are already aware, radon gas is a decay product of the radioactive element radium and, for long periods of exposure, has been linked with lung cancer.

Radium occurs naturally in very minute quantities and the extraction process requires many tons of ore to produce a few grams of pure radium. The extraction processes used in the thirties were generally ninety-five percent efficient and as a result produced tons of extraction residues with trace amounts of radium still entact. It is these residues which are the major source of radon gas in this area today.

Another aspect to be considered in radium extraction is the radioactive contamination of buildings and equipment as a result of direct contact with the process stream. Radium is almost totally an alpha energy emitter, and as many of you are aware, alpha contamination is a very serious problem in terms of ingestion and inhalation.

These two points, namely, the radium extraction residues and the contaminated process equipment and buildings take on more meaning with the following excerpt from the report entitled "The Preliminary Investigation of the Technical and Ecomonic Factors for the First Stage Remedial Measures at Port Hope, Ontario," which was prepared by James F. MacLaren Ltd. for the Atomic Energy Control Board in April, 1976.

' In 1932, Eldorado Gold Mine Limited commenced operation of a plant in Port Hope, Ontario, to process the ores mined at Port Radium Northwest Territories for the recovery of radium. In 1944 the company was taken over by the Canadian Government and renamed Eldorado Mining and Refining Ltd.

The first residues from the radium recovery operation were produced in 1933 and were disposed of on the plant site from 1933 to 1939. During the period 1945 to 1948 these residues were reprocessed and the waste disposed of at the Monkey Mtn. Residue Area in Port Hope.

From 1939 to 1944 residues were deposited in the Lakeshore Residue Area. This area is a short distance to the west of the plant and is adjacent to a railway embankment just south of the CNR freight shed (since demolished). In the latter part of the 1939 - 1944 period, the nature of the residue changed as the plant processes were altered from radium extraction tothe production of uranium. Approximately 4,000 to 5,000 tons of radium extraction residues were removed from the Lakeshore Residue Area in 1957 and 1958 and sold to Vitro Corporation in the United States for the recovery of other metals, the remaining residue was transferred to the Port Granby Disposal Area, ten miles west of Port Hope.

The Monkey Mountain Residue Area within the Town of Port Hope was used from 1945 to 1948 for the disposal of residue and large quantities were removed from this site and disposed of at Port Granby in 1959 and 1966. Some 800 tons of this residue were sold to Deloro Smelting and Refining Co. in 1959.

From 1948 to 1974 the Pidgeon Hill Storage Area was used for the storage of contaminated equipment and radium waste, and some incineration of combustible wastes was carried out prior to 1954 but no burial of waste was made on this site.

There were several periods during which there was an active building programme on the Eldorado property. In 1938 and 1939 a building which had contained the original radium processing plant set up in 1932 was demolished. The refining of radium ceased in 1953 and in the following two years the radium laboratories were dismantled and buried at the Welcome Residue Area. In 1954 and 1955 , the old radium circuit was removed and a new solvent extraction circuit installed; at about this time several other buildings were demolished. In 1959 the original main office building and the uranium processing building were demolished.

All of these actions produced building rubble, fill and reclaimed building material, any of which might have been contaminated and which may have been used in the Town for various purposes.'

From this brief historical background one can see the two aspects of the resulting situation; one - radon gas from the radium residues and two - radium contaminated building materials salvaged from the old plant.

In the early spring of 1976 a campaign was initiated by the Atomic Energy Control Board, Eldorado Nuclear and the Ontario Ministry of Health (new Ministry of Labour) to survey the entire town for radioactive contamination and to test the radon gas levels in all occupied structures. The surveys were carried out street by street and house by house with a total of approximately 3,500 properties being investigated. Of this total 550 homes were found to have elevated radon gas levels and/or above background levels of radiation.

Detailed surveys carried out as part of the remedial works over the past 3 1/2 years have classified approximately 150 of the initial 550 properties as no work sites. Of the remaining 400 remedial work sites approximately 150 were classed as having above criteria radon gas levels; 280 had exterior gamma levels above criteria and 220 had interior contamination of one form or another. The original 550 properties investigated are highlighted in red on the aerial map of the town.

The initial reports estimated 70,000 to 100,000 tons of low level radioactive waste would require removal and disposal as a result of the Port Hope Remedial activities. The search for a suitable disposal area for this estimated quantity of material identified a site at Chalk River Nuclear Laboratories, approximately 250 miles north and east of Port Hope.

With the acquisition of the Chalk River site a temporary storage area was required in order to stock pile material prior to its "long haulage". Eldorado Nuclear allowed the use of the old Crane plant site for this purpose. Initially the contaminated material was stored inside the old factory building to provide containment and control any runoff, The interior of the building however was quickly filled so an outside concrete pad had to be pressed into service and an asphalt berm was constructed around the pad to prevent runoff. During the winter months the pile was covered with a special polyethylene and fabrene cover.

Over the first winter approximately 2,500 cubic yards of material were stored inside the Crane building and 5,000 yards were outside covered on the concrete pad.

In the fall of 1976 the long haulage of the fill material to Chalk River commenced operation. The long distances to be travelled dictated that tractor trailer type vehicles be used - each carrying an average of 35 tons of material. Following three years of haulage, the Chalk River site had been filled to capacity with 104,225 tons of radioactive fill. The long haul operation had to be shut down in August 1979 after 2,492 trips.

The following series of slides depict the remedial work undertaken to date. The first series of slides deal with the Monkey Mtn. disposal area. Remedial work was initiated at this site in the fall of 1976, however, when it was realized that the quantity of material to be removed was much greater than originally estimated - it was decided that this effort should be redirected towards removal of contaminated material around occupied homes.

A little east of the site, remedial work was initiated on both sides of the street where surface runoff from the Monkey Mountain residue area resulted in surface contamination and elevated radon gas levels in the homes. As the slides depict excavation in many cases was to the depth of the footings and even below. However, surface runoff was not the only method of transport. A large percentage of this residue fill material was indiscriminately dumped in areas throughout the town where clean fill material was required. Low lying backyards, driveways, marshy areas, ravines, etc. all were candidates for the radioactive fill.

Such was the case of St. Mary's School, where the side of an existing ravine was extended with all types of fill material from many of the local industries including the refinery. An addition to the school was later built on this fill material.

As a result of the depth and extent of this material the remedial work involved both interior and exterior excavation. Over 8,000 tons of material were removed from around the exterior and almost 4,000 tons were removed from the interior of the school. The following series of slides depict some of the highlights of this remedial work carried out at St. Mary's School.

The next series of slides are typical examples of exterior excavations carried on throughout the town as part of the remedial works program.

The residue material in addition to its use as fill, also made an excellent subfloor drainage medium, especially when combined with waste material from the Crane sanitary casting plant. The remedial work required for most of these cases was the removal of the entire basement floor and excavation of the material beneath, sometimes to a depth of 24 - 30 inches below the existing floor slab.

One aspect of these remedial works which is overlooked most often is the removal and replacement of contaminated building materials found in some two hundred homes. The most common article to be replaced has been three- and four-inch diameter steel pipes which have been used as support columns for floor joists.

The list of things removed however, is quite varied and includes such things as wooden floor joists, wall studs, brick chimneys, concrete block foundations, steel lockers, rock wool insulation, doors, door frames, windows and window frames, steam heating pipes, stair treads, hand rails , floor coverings and wooden laminated beams. The list of contaminated personal items removed with the owner's consent and not replaced is almost as varied - with such things as ore and yellowcake samples, radium dialed war surplus compasses and aircraft instruments, tool boxes, used laboratory equipment and one interesting article; cloth flowers covered in a radium solution which would glow in the dark at parties. These flowers are shown in this slide.

In several structures the levels of interior contamination and the extent of the contamination from the basement to the attic have dictated that the only practical method of decontamination be demolition of the entire structure and disposal at Chalk River. Over 15 structures (whether in the form of houses or garages) have been demolished and shipped to Chalk River for disposal.

One example of such a demolition was a century-old home on Dorset St. W., pictured here. Another home just a block south of this Legion building currently awaits demolition, however a disposal site has not been available since the closing of the Chalk River site.

But demolition is not the only solution to these extensively contaminated buildings. One structure in particular, which had been used as a storage facility for radium salt solutions, was decontaminated using sophisticated techniques and health physics practices typical of those at Chalk River Nuclear Labs. These slides show some of the actual decontamination operation - the workmen are clad in two sets of protective clothing, rubber gauntlets and boots and are wearing full face army type respirators.

In these pictures they are bush hammering a thin layer of the surface off the poured concrete foundation walls. The contaminated air at the work face is continuously filtered using a 1,000 scfm fan coupled to pre- and absolute filters.

To date compliance files on 441 properties have been submitted to the Atomic Energy Control Board for testing. This summer approximately 20 sites will undergo some form of remedial work including two properties, only recently discovered, with contaminated block foundations. These buildings are approximately two miles outside fo the town limits and were discovered prior to their sale during a special request survey for the AECB.

Remedial work on these smaller sites has been made possible by the Town of Port Hope providing James F. MacLaren with an area in which to operate a licenced temporary storage compound which is located at the town's water pollution control centre.

However, remedial work on the larger open areas will have to be temporarily suspended until another suitable disposal area can be put into operation.

I hope my brief talk this morning has been informative and has made you a little more aware of exactly what remedial work has gone on here in Port Hope for the past 3 1/2 years.

A REPORT ON THE INVESTIGATION AND IMPLEMENTATION OF THE REMEDIAL MEASURES PROGRAM IN BANCROFT, ONTARIO AND ENVIRONS

(The observation of a higher incidence of above-criterion sites in areas with a greater potential for radioactive mineral occurences.)

BY

R. MARUSKA, B.Sc.

PRESENTED TO

THIRD WORKSHOP ON RADON AND RADON DAUGHTERS IN URBAN COMMUNITIES ASSOCIATED WITH URANIUM MINING AND PROCESSING

PORT HOPE, ONTARIO
MARCH 12 - 14, 1980

A REPORT ON THE INVESTIGATION AND IMPLEMENTATION OF THE REMEDIAL MEASURES PROGRAM IN BANCROFT, ONTARIO AND ENVIRONS

INTRODUCTION

A program for the investigation and implementation of remedial radiation reduction measures has been underway since March 1978 in Bancroft, Ontario. Bancroft is a small town approximately 250 km northeast of Toronto with a population of about 2,000 people; although as many as two or three times that population live in the surrounding areas. The Bancroft area is primarily a tourist region where uranium mining, although very active in the early sixties, is presently limited to one operating facility.

A preliminary survey of "uranium mining communities" conducted by the Federal-Provincial Task Force on Radioactivity examined over 1,100 sites in the Bancroft area. As a follow-up investigation, the present program initially considered 412 sites found to exceed 0.010 Working Level (WL). Subsequently, the program has been expanded to include over 900 sites such that, in total, approximately 1,600 sites will have been considered in the entire investigation. This report is intended to update our previous report of February 1979 employing an expanded data base of 364 sites with complete radon daughter surveys, and over 560 sites with complete gamma surveys.

The source of radon in any particular structure cannot be easily defined as there exists too many variables. Individual factors, such as building materials, local soil, bedrock and construction techniques, are thought to effectively combine to create elevated concentrations of radon within the structure. In the neighbouring structure the probability of observing elevated levels is dependant on the new combination of factors and on the magnitude of the effect of the individual factors. For example: a site having an earthen basement floor may have elevated concentrations while the neighbour with a good quality concrete floor may not.

In the Bancroft project, although there is a small probability of finding uranium-bearing mineralizations throughout the area, they predominantly occur in a very distinct region. It is believed that the effect of the local soil and bedrock containing uranium minerals, increases the probability that a structure within this region may have elevated radon concentrations. The naturally situated uranium-bearing minerals can be found in both the bedrock and the glacial till which

form the overburden in the area. However, to identify the natural minerals as the major source at a particular site is impossible due to variations such as mineral placement, fractures, overburden and the incomplete knowledge of radon migration. The only absolute proof, source removal, is impossible.

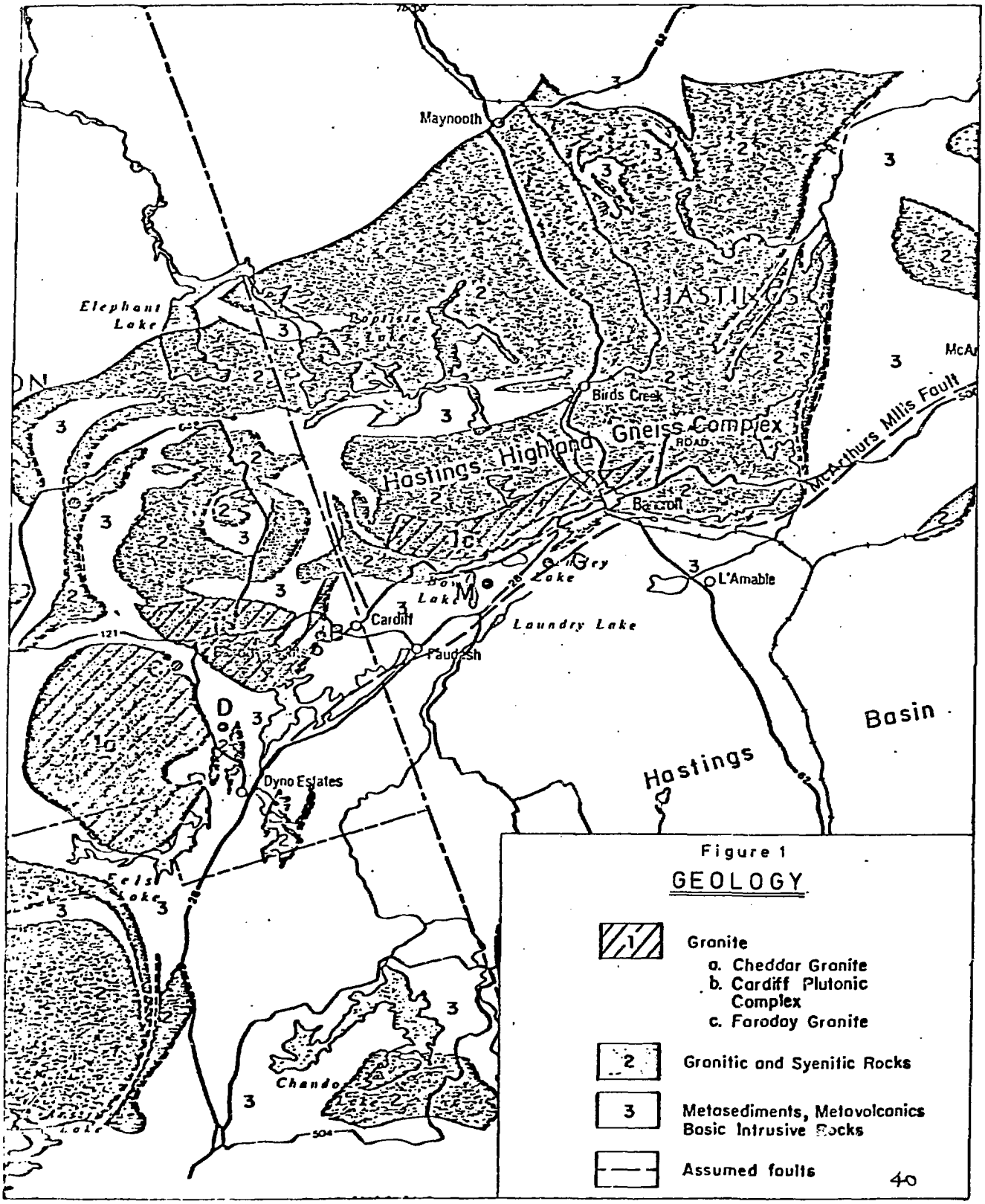
Technologically displaced minerals in the form of waste mine rock has also been isolated as a source in a number of cases. Similarly, as source removal is not always practical or possible, such cases can only be qualitatively justified and acknowledged as being at least partially effected by waste rock.

In general the source of elevated radon concentrations cannot be identified on a individual site basis but requires a more extensive approach where the total representation is considered. The Bancroft program is ideal for this purpose due to the large project area (80 km in diameter) which includes fairly distinct geological regions which either do or do not contain radioactive minerals.

GEOLOGY

Bancroft is a very complex geological region at the western extremity of the Grenville province. The area is composed of two metamorphic terrains originally laid down in pre-cambrian seas: the north is a very highly metamorphosed formation called the Hastings Highland Gneiss Complex, while to the south are the less intensely metamorphosed sediments of the Hastings Basin which are divided by the MacArthurs Mills Fault (Fig. 1).

Within the Highland Complex there has intruded a series of three plutonic plates: the Cheddar, Cardiff and Faraday granite complexes. Uranium mineral deposits have been generally found within 4 km of the contact of these plutonic plates. The deposits are primarily found in granitic bodies of either intrusive or replacement origin within the country rock; although metasomatic and hydrothermal deposits have also been found. However independant of the origin, most deposits can be characterized to be small and very localized. They are erratic and discontinuous in placement and usually cannot be established from surface gamma measurements. Thus specifically positioning deposits is very difficult from the surface except in the few cases where highly concentrated minerals are exposed.


Maynooth
Elephant Lake
Baptiste Lake
HASTINGS
Highland
Gneiss Complex
Hastings
Birds Creek
ROAD
McArthurs Mills Fault
Bancroft
L'Amable
Grey Lake
Bow Lake
Cardiff
Laundry Lake
Paudash
Dyno Estates
Basin
Hastings
Chandos
Figure 1
GEOLOGY
Granite
a. Cheddar Granite
b. Cardiff Plutonic Complex
c. Faraday Granite
Granitic and Syenitic Rocks
Metasediments, Metavolcanics Basic Intrusive Rocks
Assumed faults

However, rather than attempting to map out precise deposits, a potential for the occurance of radioactive minerals deposits in general areas has been attempted based on information from known deposits, airborne radiometric surveys and known geological formations. This mineral potential map, devised by the Ontario Ministry of Natural Resources, has only a very qualitative design; presenting general areas and vague definitions such that well defined boundaries do not explicitly exist (Fig. 2). These areas are described as follows:

High Uranium-Thorium Mineral Potential Area

This area contains identified deposits of present economic importance with numerous minor deposits which lack either tonnage or grade to be of significance at this time. A cursory examination of airborne radiometric surveys indicate locally averaged uranium concentrations of 2-20 ppm eU* in these areas.

Medium Uranium-Thorium Mineral Potential Area

In this area numerous minor deposits exist and the geology still remains favourable. Airborne radiometric surveys indicate average concentrations range from 1-3 ppm eU.*

Unrated Uranium-Thorium Mineral Potential Area

In this area very few deposits exist but it is still geologically possible to find mineral deposits or glacially transported material. Concentrations range from 0.4 to 2 ppm eU.*

RADON/RADON DAUGHTER SURVEYS

Within the Bancroft project, 364 sites have had complete surveys to establish mean annual interior radon daughter concentrations. A complete survey composes approximately 10 visits per site over a 2-3 month period; although as many as 20-25 visits have been performed over 6-12 months, with two parallel radon/radon daughter measurements taken during each visit.

*FOOTNOTE: Equivalent uranium concentration estimates, which are intended for quantitative comparisons, were obtained from airborne radiometric surveys where concentration is averaged over an area of approximately 700,000 m^2. As the deposits are much more localized they will be of a much higher concentration.

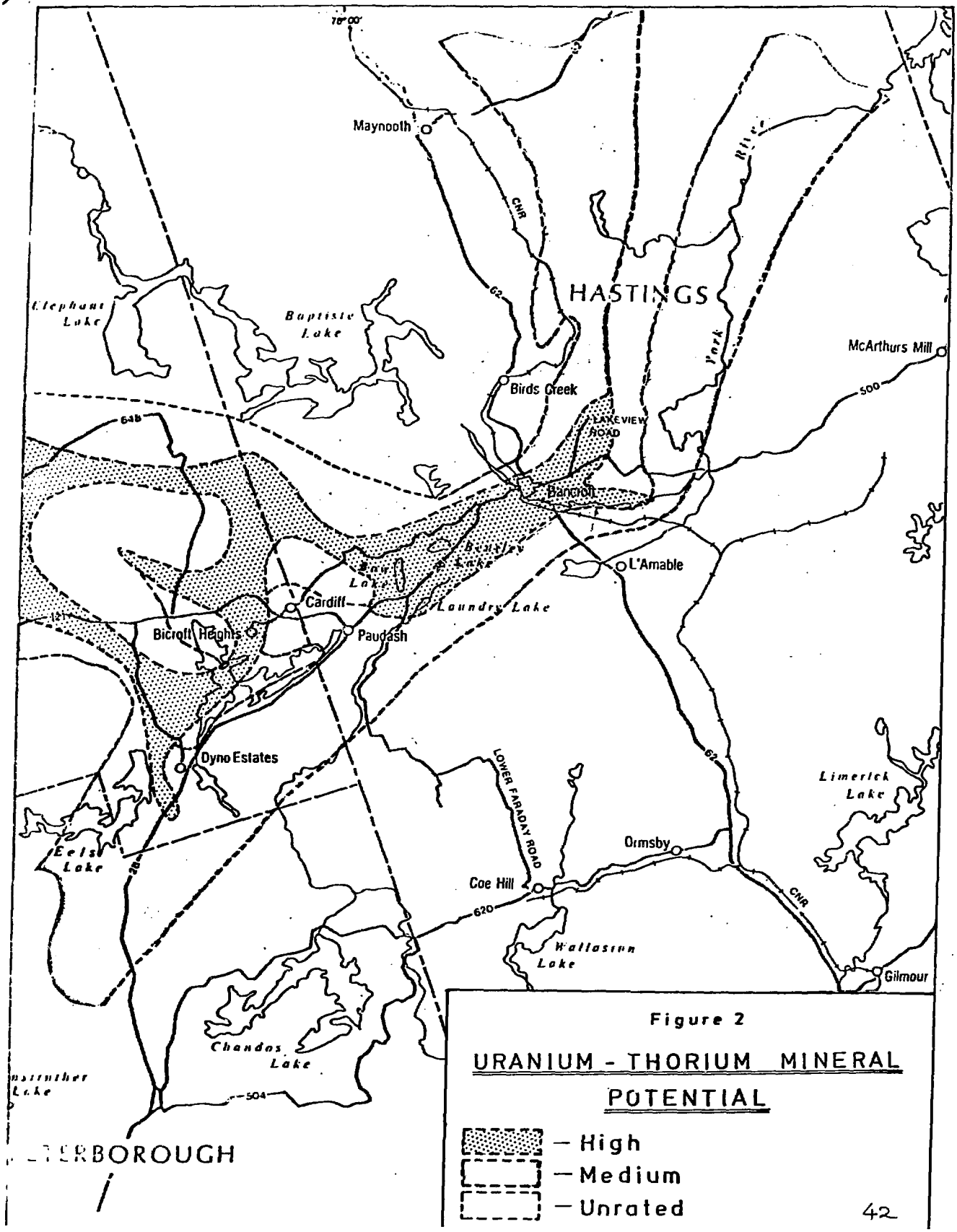


Figure 2

URANIUM - THORIUM MINERAL POTENTIAL

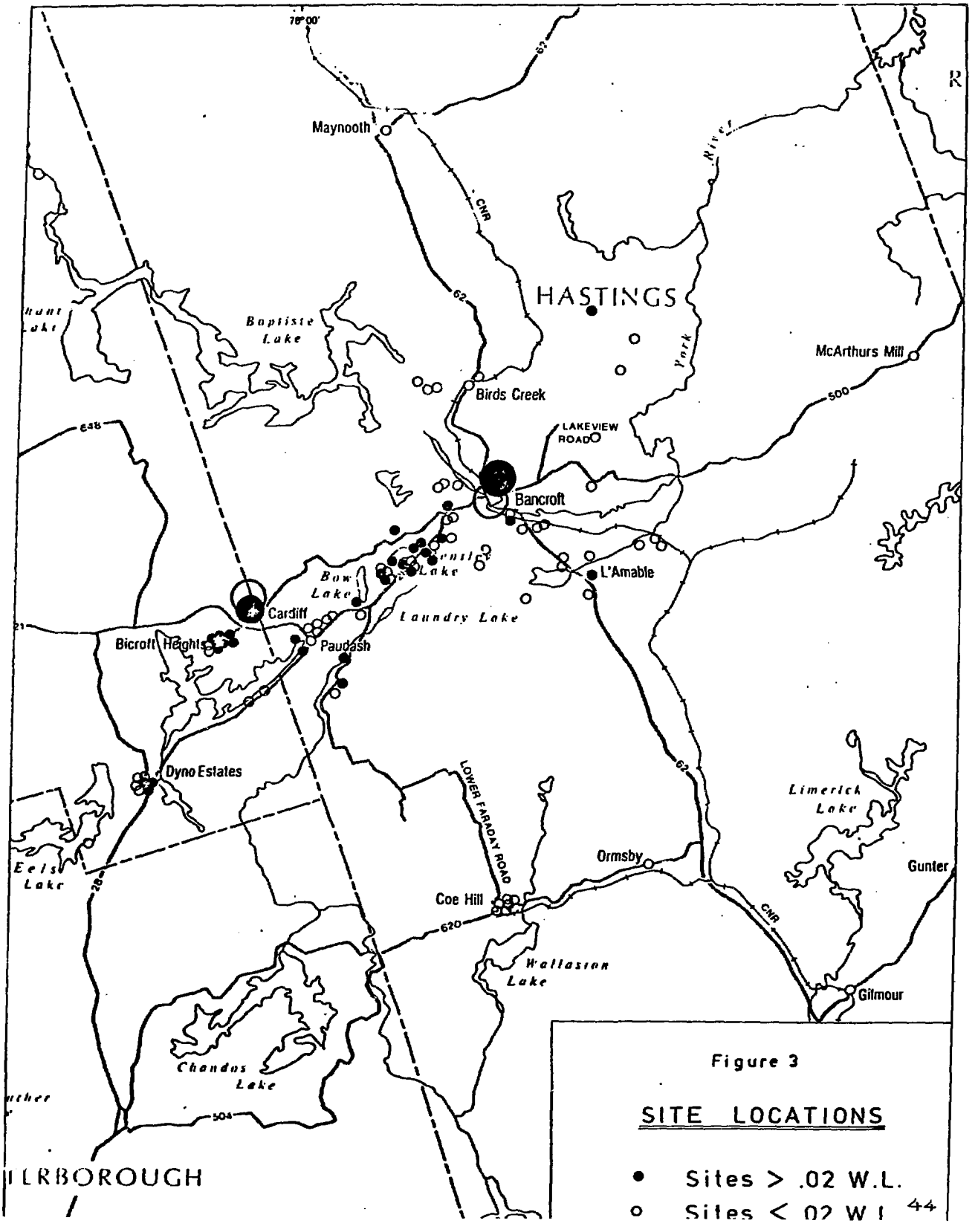
— High
— Medium
— Unrated

The sites surveyed have been located in many of the various regions within the project area: Bancroft, Bicroft Heights, Cardiff, Dyno Estates, Bird's Creek, Paudash, Maynooth, Detlor, L'Amable and Coe Hill. Arranging individual site locations on a regional map allows a visual impression of the distribution of investigated sites (Fig. 3). Points on the map only represent general locations and in high density areas, such as Bancroft and Cardiff, points are only an unproportional representation of the actual number. It can be observed from the map that many sites for which mean annual radon daughter concentrations exceed the 0.02 WL criterion, are located in the region near the contact of the three plutonic plates: particularly Bancroft, Bicroft Heights and Cardiff. However, this absolute number reflects the high population density along the highway #28 corridor and a more meaningful comparison may be made relative to the total number of sites. The frequency distribution of sites with respect to the estimated mean annual radon daughter concentration when examined for each regional sample group indicates that the high incidence of above-criterion sites is dependant of population density (Fig. 4.1-4.9).

The greater tendancy of sites to exceed the criterion in areas favourable to uranium-bearing minerals suggests a relationship may exist. The uranium-thorium mineral potential areas allow the formation of larger sample groups suitable for meaningful comparisons. As the mineral potential areas are only generally defined, site regions as opposed to each individual site, were grouped into the mineral potential areas. Thus within the high uranium-thorium mineral potential are found sites in Bancroft and Bicroft Heights. In the medium potential area Cardiff, Paudash, Dyno Estates and Monteagle areas were grouped. The unrated uranium-thorium potential group includes Maynooth, Bird's Creek, Detlor, L'Amable and Coe Hill. These larger sample groups can then be examined as a unit (Fig. 5).

The high uranium-thorium mineral potential sample group forms the largest group with 229 sites. This distribution is log-normal with a gecmetric mean of 0.012 WL and a very large geometric standard deviation of 2.6. Thus the 68% confidence interval extends up to 0.032 WL and 29% of the sites have mean annual concentrations in excess of 0.020 WL.

The moderate uranium-thorium mineral potential group includes 107 sites. This distribution has a geometric mean of 0.011 WL but has a small geometric standard deviation so that the 68% confidence interval extends up to 0.024 WL. Thus, although 28% of the sites exceed the criterion, the average magnitude of the excess is less.


Maynooth
CNR
HASTINGS
Baptiste Lake
Birds Creek
York River
McArthurs Mill
500
LAKEVIEW ROAD
Bancroft
L'Amable
Bow Lake
Cardiff
Laundry Lake
Bicroft Heights
Paudash
Dyno Estates
LOWER FARADAY ROAD
Ormsby
Limerick Lake
Gunter
Eels Lake
Coe Hill
620
Wallaston Lake
Gilmour
Chandos Lake
504
ILRBOROUGH
Figure 3
SITE LOCATIONS
• Sites > .02 W.L.
o Sites < .02 W.L.

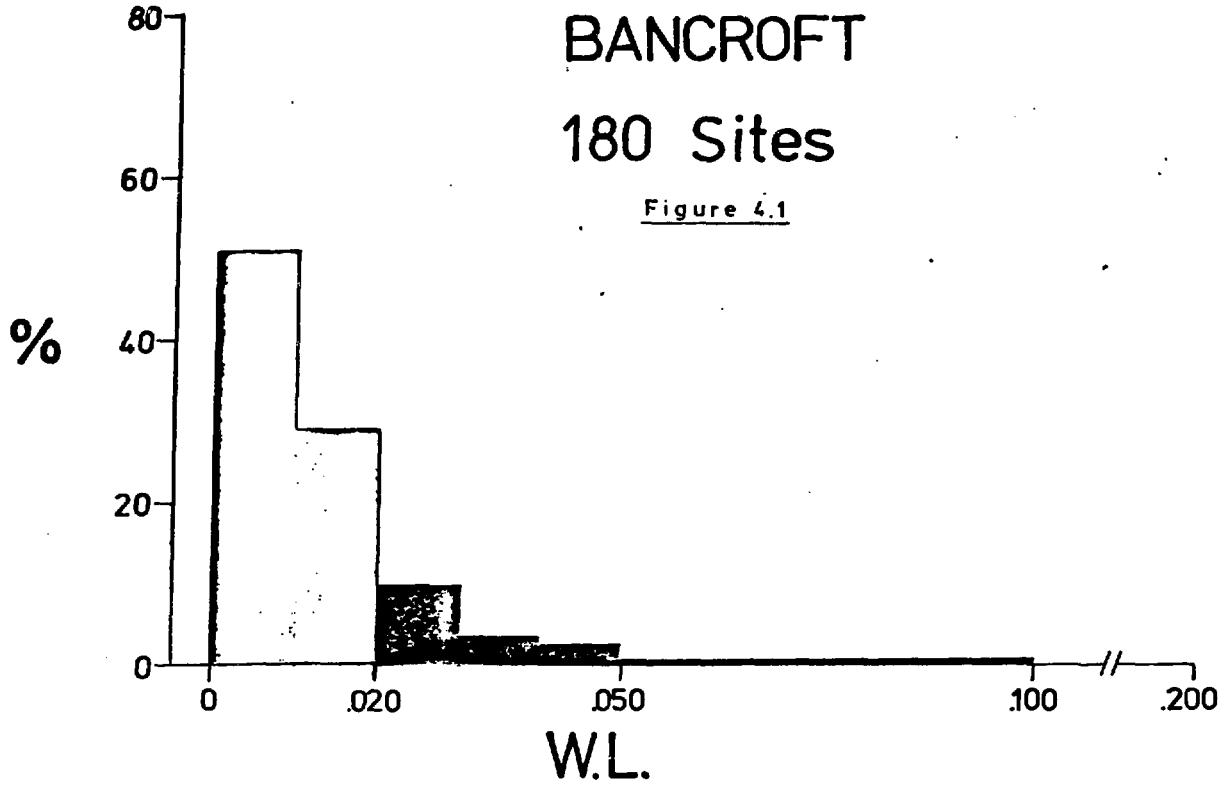


Figure 4.1

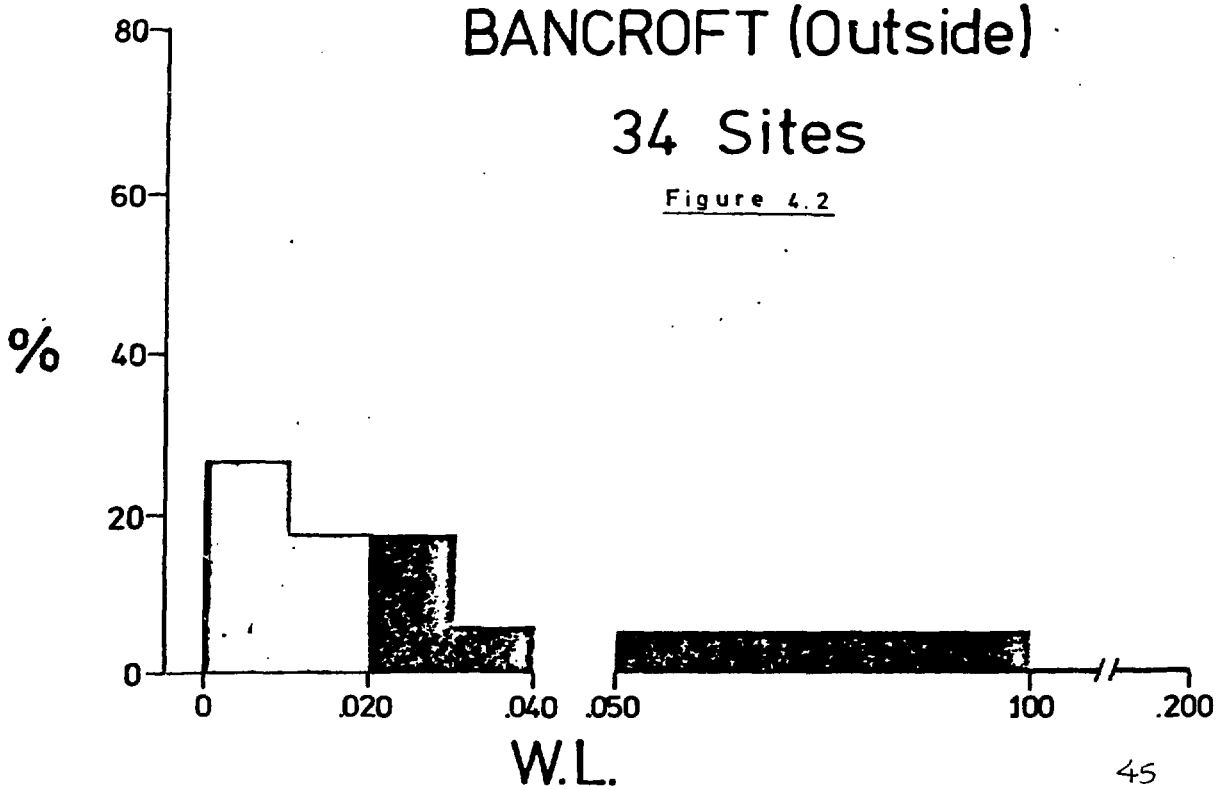
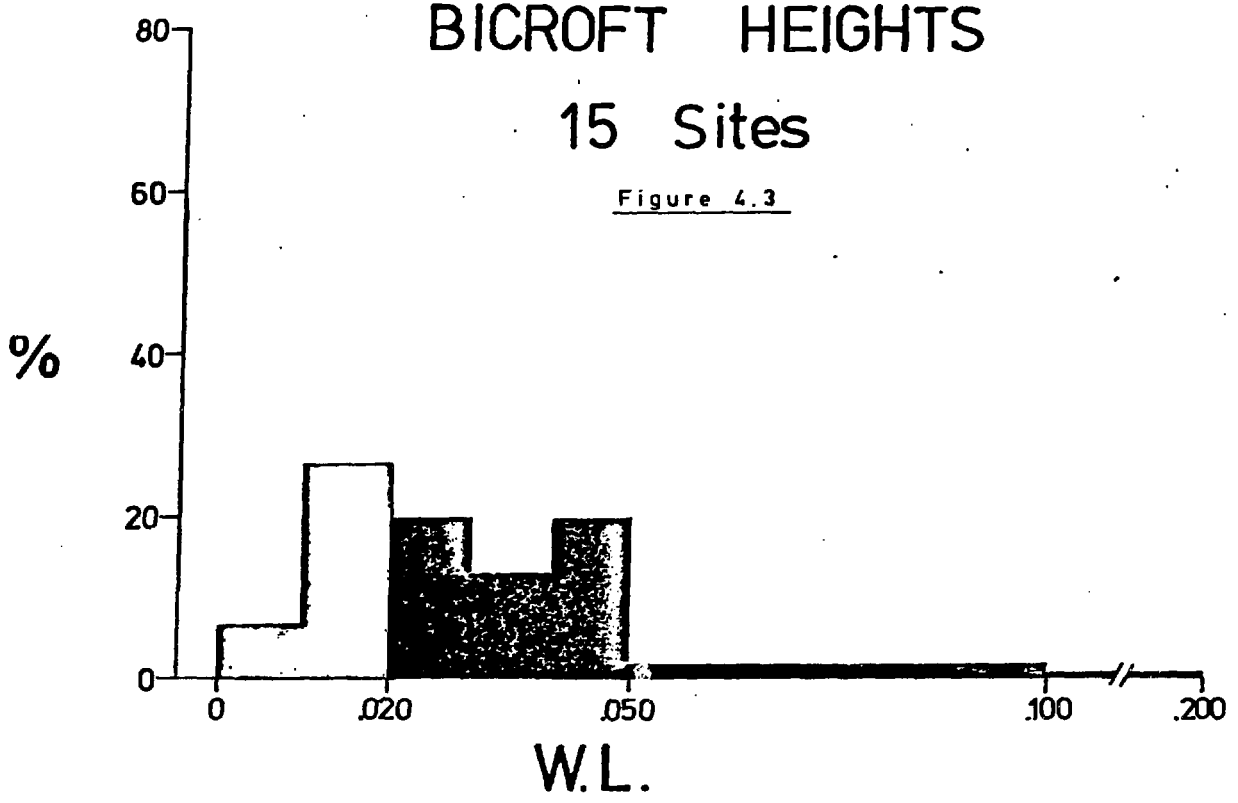


Figure 4.2

BICROFT HEIGHTS

15 Sites

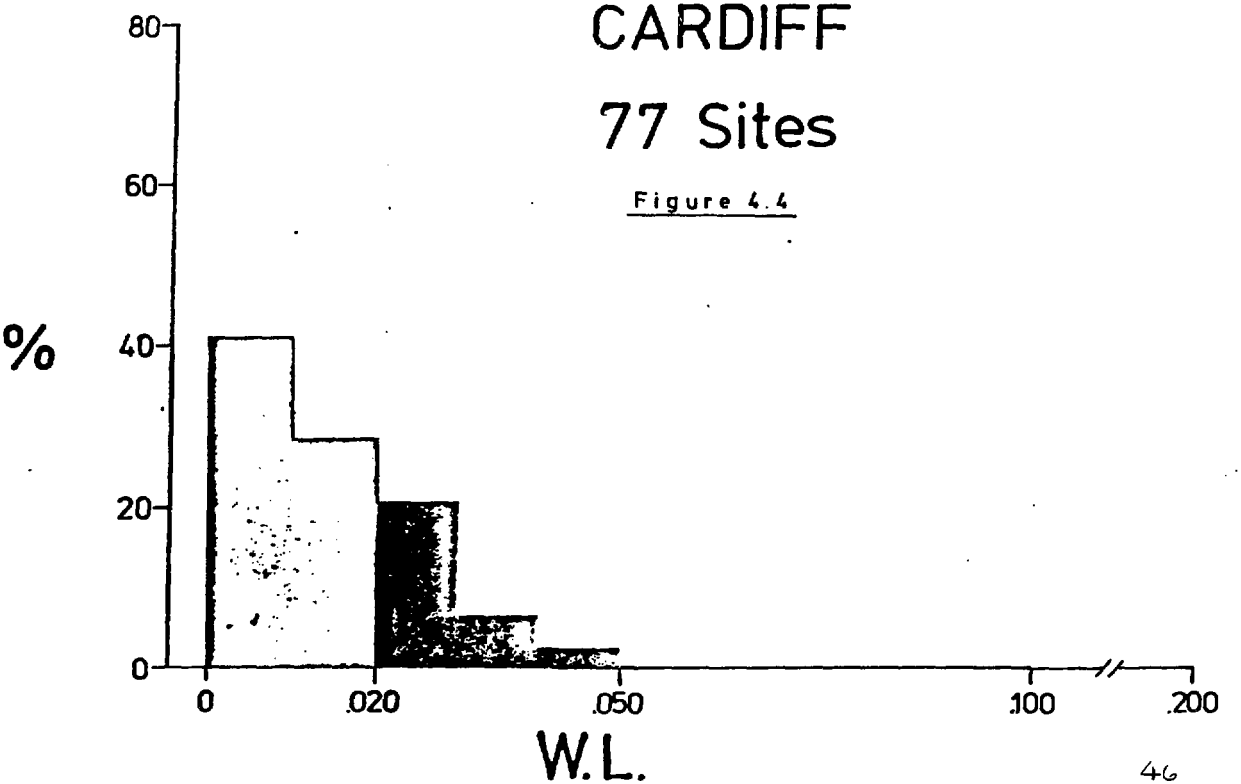
Figure 4.3



CARDIFF

77 Sites

Figure 4.4



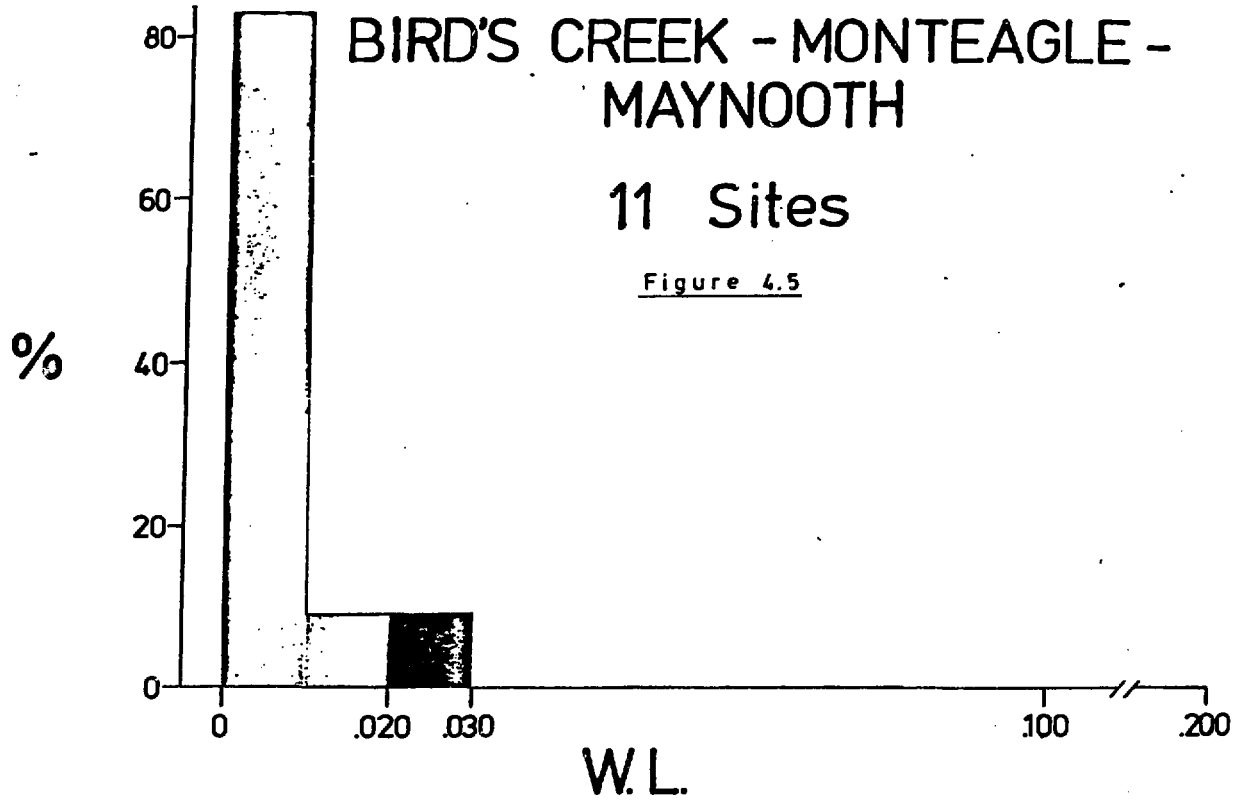


Figure 4.5

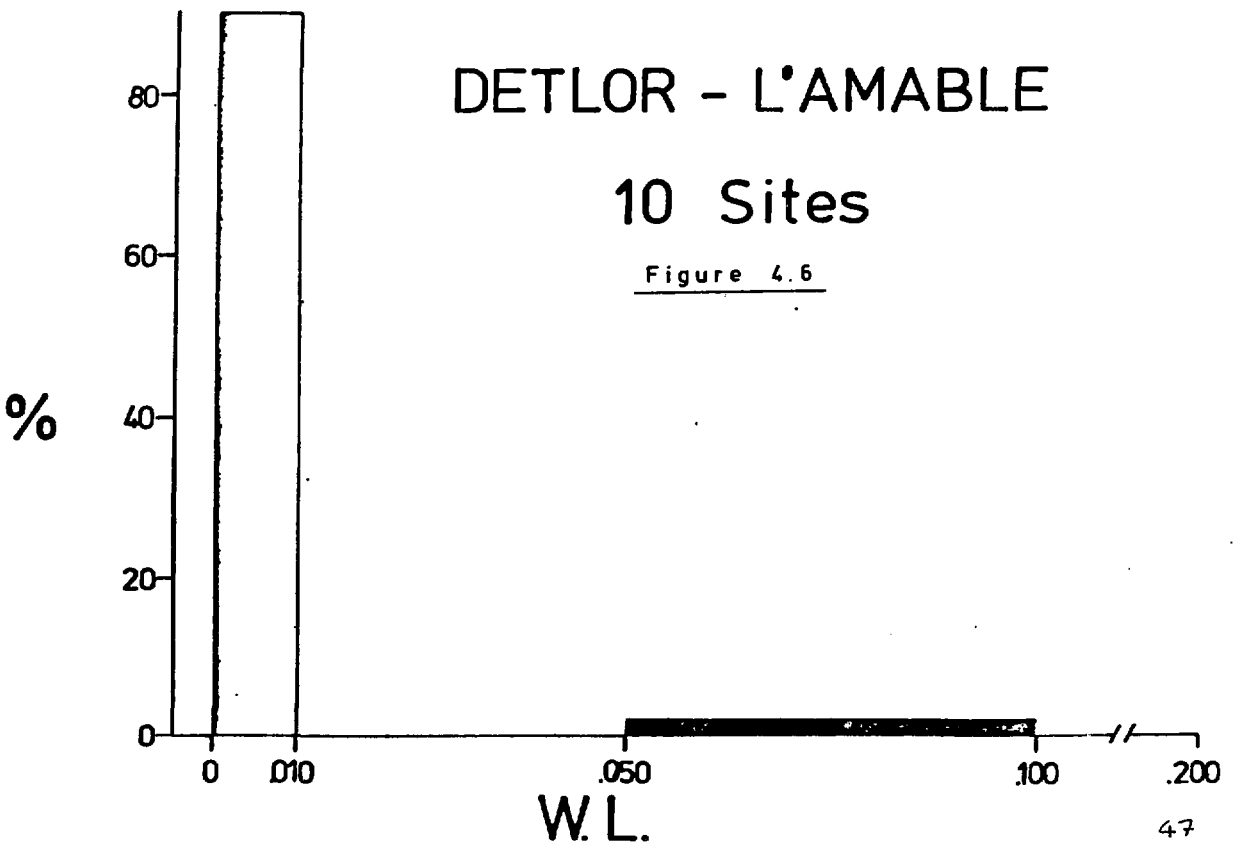
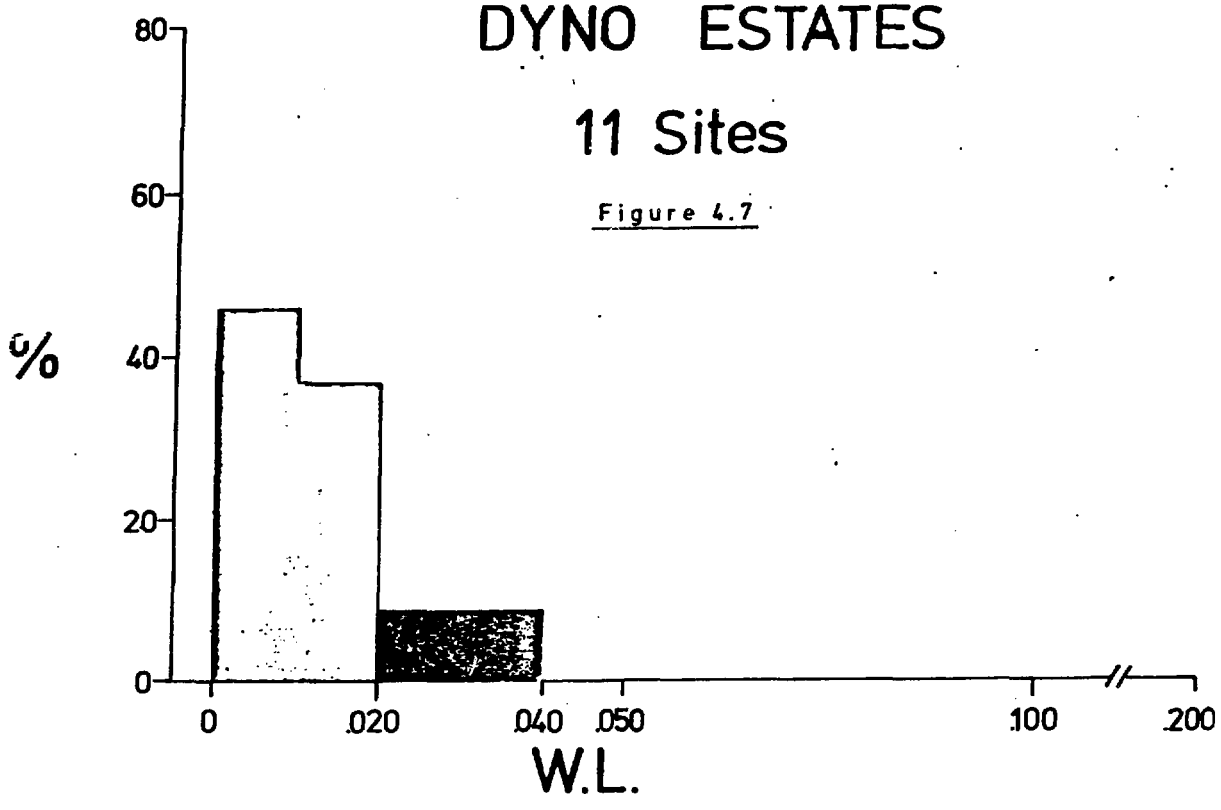


Figure 4.6

DYNO ESTATES

11 Sites

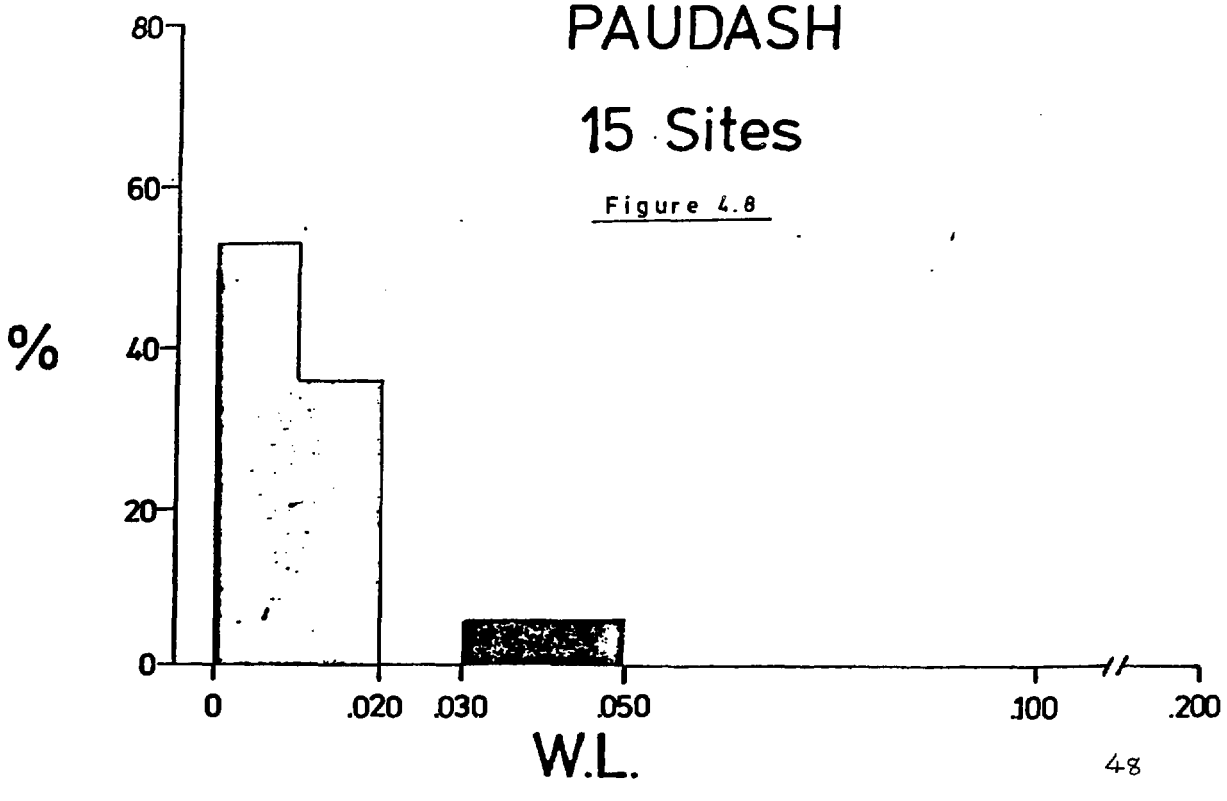
Figure 4.7

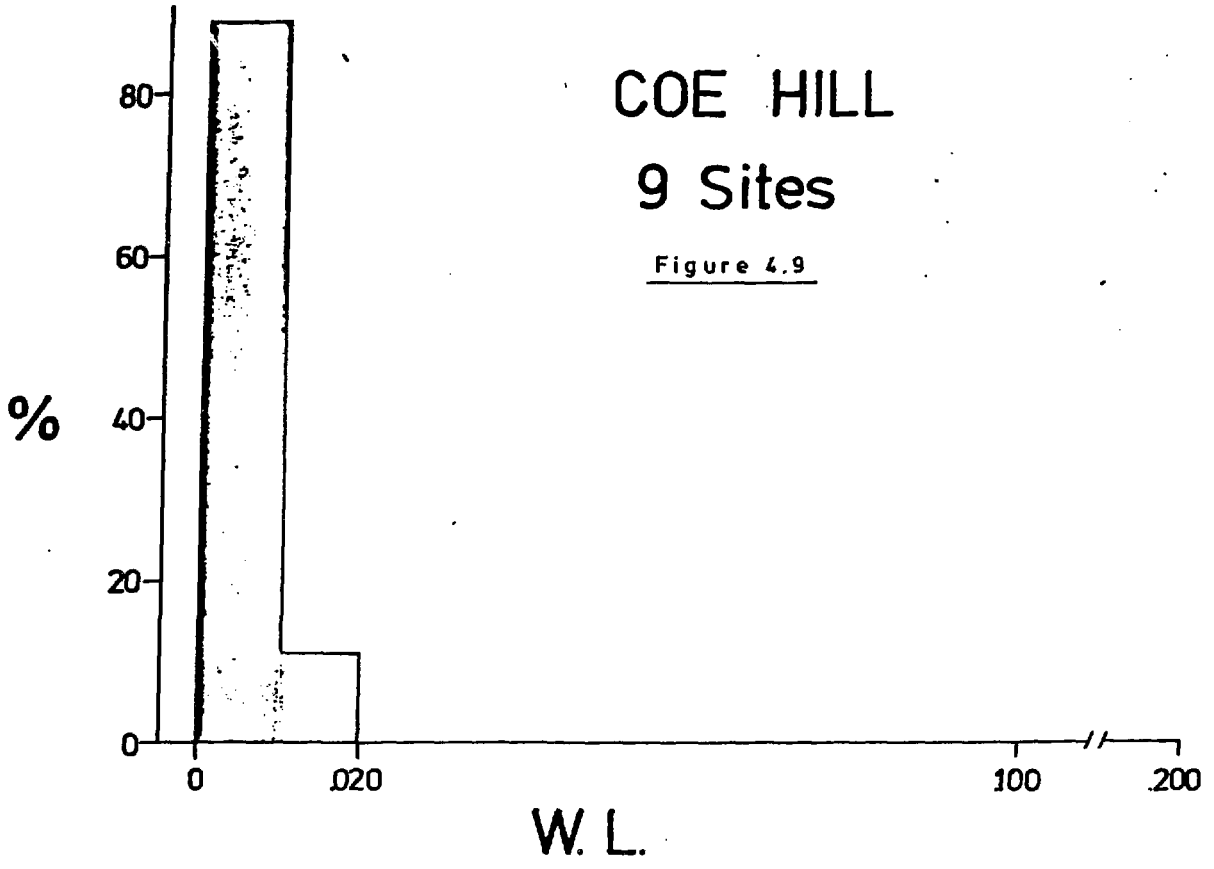


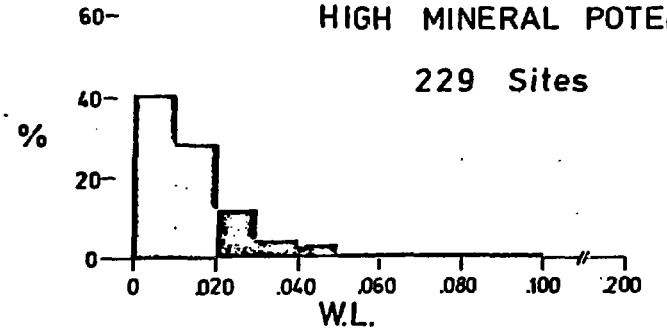
PAUDASH

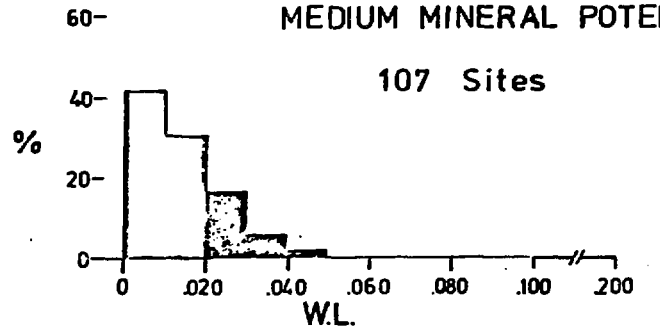
15 Sites

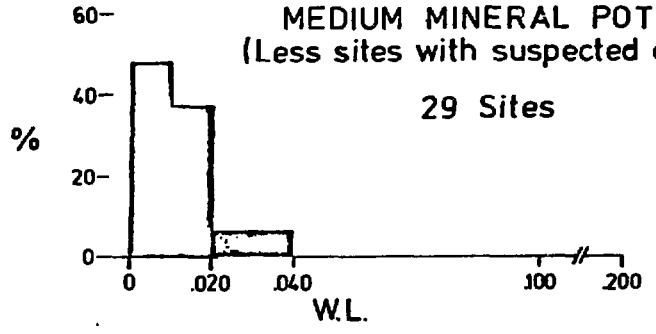
Figure 4.8

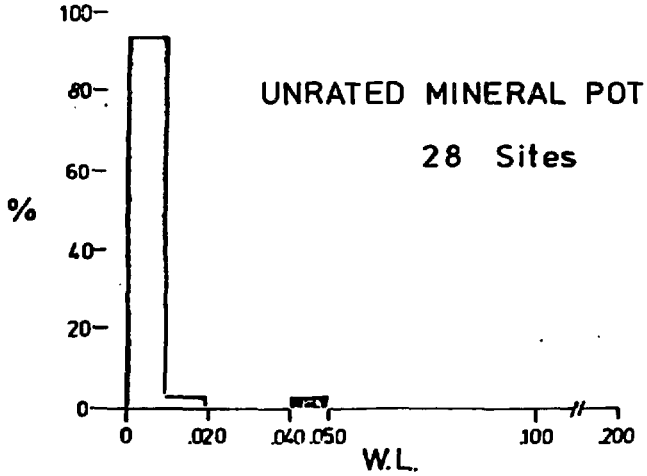



COE HILL
9 Sites
Figure 4.9
%
80
60
40
20
0
0
.020
.100
.200
W. L.


HIGH MINERAL POTENTIAL
229 Sites
60-
40-
20-
0
%
0
.020
.040
.060
.080
.100
.200
W.L.


MEDIUM MINERAL POTENTIAL
107 Sites
60-
40-
20-
0
%
0
.020
.040
.060
.080
.100
.200
W.L.


MEDIUM MINERAL POTENTIAL
(Less sites with suspected cultural sources)
29 Sites
60-
40-
20-
0
%
0
.020
.040
.100
.200
W.L.


UNRATED MINERAL POTENTIAL
28 Sites
100-
80-
60-
40-
20-
0
%
0
.020
.040
.050
.100
.200
W.L.

This group, however, is biased by a large portion of sites which are thought to have a technologically displaced radon source. If these sites are deleted, a second modified distribution can be formed. This sample group is much smaller with only 29 sites and a geometric mean of 0.010 WL. With a smaller geometric standard deviation, the 68% confidence interval includes up to 0.019 WL and only 7% of the sites exceed the criterion.

The final group, the unrated uranium-thorium potential group is also a small sample group with only 28 sites but has almost normal characteristics. The geometric mean is smaller at 0.006 WL and the geometric standard deviation is also much smaller at 1.6. Thus the 68% confidence interval includes up to 0.009 WL and only 2% of the sites exceed criterion.

From these graphs certain observations can be made. There is a significantly greater incidence of sites whose mean annual concentrations exceed the criterion in areas with a high probability of finding uranium-thorium mineral occurrences. However, the geometric mean of the various frequency distributions range from 0.006 WL to 0.012 WL which, on a class interval of 0.010 WL, is not signficantly different. The incidence of above criterion sites is indicated by a large geometric standard deviation; that is pronounced log-normal characteristics in distribution with a high incidence and almost normal features in the distribution with a low incidence.

Thus it can be generalized that the greater the occurrences of uranium-bearing minerals, the greater the probability of sites exceeding the criterion in the area. There is however, a certain probability that sites will exceed criteria in areas with low radioactive mineral potential.

Remedial measures have been attempted on approximately 100 sites based on the hypothesis of a natural external source. The continuing work on the over 500 remaining sites will expand the project area into regions more remote from the high uranium-thorium mineral potential area and on the other hand examine in more detail specific locations where a high incidence of above-criterion sites have been observed. By the end of the project a more complete understanding of the situation should be available.

SUMMARY OF URANIUM CITY, SASKATCHEWAN

REMEDIAL MEASURES

FOR

RADIATION REDUCTION

WITH

SPECIAL ATTENTION TO VENT FAN THEORY

BY

KEITH CONSULTING

PRESENTED TO THE

WORKSHOP

ON

RADON AND RADON DAUGHTERS

IN

URBAN COMMUNITIES ASSOCIATED WITH

URANIUM MINING & PROCESSING

PORT HOPE, ONTARIO

MARCH 12 - 13 - 14, 1980

KEITH CONSULTING
Regina - Prince Albert
Saskatchewan

File 3067

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1. SUMMARY & CONCLUSION

1. SUMMARY AND CONCLUSION

Various remedial measures have been initiated and carried out in Uranium City with varying degrees of success in radiation reduction in buildings. The methods used are:

1. Source material removal
2. Passive ventilation system of crawl spaces
3. Sub-floor ventilation
4. Complete epoxy coating of the entire basement
5. Use of sealants for floor-wall joints and cracks in basements.
6. Electrostatic precipitors
7. Mechanical ventilation
8. Sealing and grouting concrete block plenums in basement walls.

The type and condition of structures encountered in Uranium City as well as the relative isolated geographic location of the town clearly indicates that mechanical ventilation is the most long term cost effective method of reducing concentration of radon and radon gas progenies in the majority of buildings requiring remedial work.

Gamma source removal has been a relatively minor phase of the overall radiation reduction program in Uranium City and will not be detailed in this report.

2. REMEDIAL MEASURES

2. REMEDIAL MEASURES

2.1 INTRODUCTION

Keith Consulting initiated the investigative surveys in late July 1977 in Uranium City and remedial work was started in the fall of that year and will be completed this year.

Uranium City housing that we have encountered varies a great deal and shows little evidence of standard construction techniques.

The houses may have full or partial basements combined with crawl space or crawl spaces only. The combinations of materials used in lower level construction seem to be innumerable. Full basements may be cast-in-place concrete floors and walls or concrete block walls with concrete floors. Partial basements combined with crawl spaces are common. Walls may be cast-in-place concrete, concrete block or timber or any combination thereof. Floors may be timber or earth. Crawl spaces normally have a small area excavated deeper to accommodate the furnace, hot water heater, fuel tank, etc.

Remedial measures undertaken are dependent on the individual characteristics of each building.

2.2 SOURCE REMOVAL

Removal of source material is the obvious solution where high gamma producing rock is evident. This, however, is limited in Uranium City since the majority of problems are a result of radiation from alluvial soil in the area.

2.3 PASSIVE VENTILATION

This method involves the installation of louvres to maintain a flow of fresh air through the crawl space of a building. This remedial measure is effective, however, it is limited to sites where there is suf-

ficient headroom to physically insulate the main level floor and utility lines in the crawl space. We have found that regardless of the amount of insulation installed, homeowners seal off the louvres during cold weather, thus rendering the system inoperable in the winter months.

2.4 SUB-FLOOR VENTILATION

This system has been put into operation in one house and consists of a system of perforated plastic pipe under the basement floor connected to a six inch plastic pipe exhaust manifold. The chimney effect operates the system and has been found to be fairly effective. This system was installed in conjunction with a passive ventilation system in a basement/crawl space combination. When the vent system is closed off, the sub-floor ventilation is insufficient to reduce concentration levels below criteria, in this particular house.

2.5 FULL EPOXY SEALANTS

Two full cast-in-place basements have been completely sealed with an epoxy sealant. One basement was completely finished and the other had minimal finishing. In both cases, the application of seamless epoxy sealant was very effective.

2.6 PARTIAL EPOXY SEALANTS

The full epoxy sealant was modified to seal all visible cracks and the floor-wall joints in cast-in-place concrete basements. The sites selected showed a marked reduction in concentrations. However, most of the concrete is rather porous and usually of minimal thickness, thus prone to additional cracking, and this remedial measure is not considered effective in the long term.

2.7 ELECTROSTATIC PRECIPITATORS

One of our problem buildings was a church, relatively large and occupied on a regular but not continuous basis. Electrostatic precipitators were installed and connected directly into the lighting system so that they are operative only when the building is occupied. This is effective as long as proper maintenance procedures are followed.

2.8 MECHANICAL VENTILATION

A mechanical ventilation system has been installed in houses of various types and has been found to be very cost-effective compared to other remedial measures. Details of this system are given in Section 3.4.

2.9 OTHER METHODS

Concrete block walled basements were thoroughly investigated and various remedial measures were carried out. Partial and total sealants were used as well as sealing, venting and grouting the block plenums were carried out with negligible effect on concentrations. Details of methods employed are given in Reference 1 in Appendix 2.

2.10 TYPICAL RESULTS OF REMEDIAL MEASURES *

Remedial Measure	Site No.	Mean / S.D.			
		Radon Concentration		Working Level	
		Remedial		Remedial	
		Pre-	Post-	Pre-	Post-
Source Removal	188	38.3/15.8	3.6/1.1	0.172/.006	0.005/0.004
Passive Ventilation	98	19.72/11.85	2.349/2.611	0.043/0.042	0.002/0.0015
Sub-Floor Ventilation	99	29.7/3.7	4.25/2.68	0.099/0.050	0.009/0.008
Full Sealant	318	35.9/6.80	6.8/0.6	0.049/0.013	0.002/0.002
Partial Sealant	338	7.0/2.2	4.8/1.4	0.027/0.011	0.015/0.002
Precipitators	381	7.0/3.3	4.9/1.9	0.927/0.015	0.015/0.004

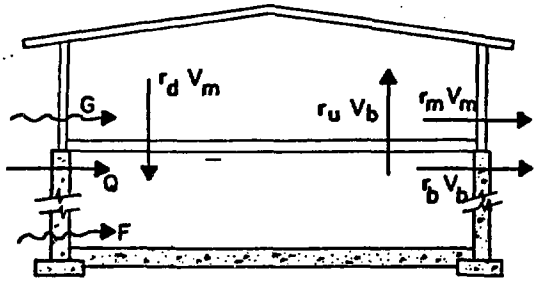
* Mechanical ventilation results are given on page 10.

3. VENTILATION UNITS

3. VENTILATION UNITS

3.1 GENERAL THEORY

In analyzing the problem of gas movement through a dwelling it has proven useful to use a two level model as shown below:



The variables are:

C_m - Concentration of gas on main level.

C_b - Concentration of gas in lower level.

V_m - Volume main level.

V_b - Volume lower level.

F and G - influx of gas into lower level and main level respectively.

r_m - air exchange rate for main level to outside.

r_d - air exchange rate for main level to lower level

r_u - air exchange rate for lower level to main level.

r_b - air exchange rate for lower level to outside.

Q - fan flow rate.

' - primes indicate fan running

Starting at first principles, consider the number of gas particles on a particular level (i) is such that N_i (t) = N_i (t=0) + number entering - number leaving. The i subscript can be read as either m or b.

Taking the time derivative of the above we obtain:

$$\frac{d N_i (t)}{dt} = \frac{\text{number entering}}{\text{unit time}} - \frac{\text{number leaving}}{\text{unit time}}$$

or in mathematical terms:

$$V_m \frac{dC_m}{dt} = r_u C_b V_b - r_m C_m V_m - r_d C_m V_m + G \quad \text{for the main level and}$$

$$V_b \frac{dC_b}{dt} = r_d C_m V_m + F - r_b C_b V_b - r_u C_b V_b \quad \text{for the lower level.}$$

3.2 RADON FLOW AND RELATED FAN SIZE ASSIGNMENT

Consider radon flow through a house. Assuming that the system is in an equilibrium state, such that all time derivatives equal zero, the result is the following equations:

$$r_u C_b V_b + G = r_m C_m V_m + r_d C_m V_m$$

$$r_d C_m V_m + F = r_b C_b V_b + r_u C_b V_b$$

It should be noted that to be absolutely correct it should be taken into account that the system deals with a radioactive gas so that a $\lambda_{Rn} C_i V_i$ term should be added to the right hand side of each of the above equations but since $\lambda_{Rn} \ll r_i$ it has been excluded.

The following assumptions are now made about the introduction of a fan inducing radon-free air into the system at a rate Q.

1. The added air flow due to the fan will travel between the main level and lower level proportionally to the air exchanges as they were before. In mathematical terms:

$$r'_u V_b + r'_b V_b = Q + r_u V_b + r_b V_b$$

$$\frac{r'_u}{r'_b} = \frac{r_u}{r_b}$$

and $$r'_m V_m = r'_u V_b + r_m V_m - r V$$

2. The added air flow due to the fan will for the most part exit through the basement. The mathematical terms for this would be:

$$r_b' V_b = Q + r_b V_b$$

The second assumption is applicable when louvres are introduced into the lower level and particularly when there is a reasonable barrier between lower and main level.

The equation resulting from the first set of assumptions is:

$$Q = \frac{r_m V_m (C_m - C_m') + r_b V_b (C_b - C_b')}{C_b' + \frac{r_u (C_m' - C_b')}{r_u + r_b}}$$

From past experience it has been found that $C_m' = C_b'$; therefore

$$C_b' >> \frac{r_u (C_m' - C_b')}{r_u + r_b}$$

This being the case the second term from the denominator is dropped to give:

$$Q = \frac{r_m V_m (C_m - C_m') + r_b V_b (C_b - C_b')}{C_b'}$$

This is the exact solution using the second set of assumptions.

Using this theory, instances occur where fan sizes larger than 120 CFM are derived but not actually required due to the existence of a second mechanism which attenuates the amount of radon entering the building. Measurements are being made to discern whether this attenuation is a product of a change in the pressure gradient. Initial measurements taken with an inverted box manometer indicate that pressure changes are a result of fan flow but exact measurements were unattainable with

this instrument. Further studies using a pressure transducer are to be undertaken to assure a solid basis for the theory. See Reference 3.

This secondary mechanism indicates that fan sizes smaller than 120 CFM could be installed. The heaters in the ventilating units require a minimum air flow velocity across the elements to prevent them from burning out. This minimum flow rate dictates a minimum fan size of 120 CFM.

To analyze this second mechanism, an emperical approach was undertaken for expediency. Two vacant houses were installed with variable speed fan units. The units were set at controlled speeds and the radon concentrations were measured over a minimum seven day period. The radon influx was then calculated using the equation:

$$F + G = C'_b r_b V_b + r_m V_n C'_m + \frac{Q}{r_u + r_b} (C'_b r_b + r_u C'_m)$$

The data obtained is shown below:

For site 247, $r_m = 0.31$, $r_b = 0.41$, $r_u = 0.706$

CFM	Flux (pCi.ft^3/min.)
-109*	4170.25
0	1126.2
98	652.01
254	99.56

For site 302, $r_m = 0.5$, $r_b = 0.3$, $r_u = 0.5$

CFM	Flux (pCi.ft^3/min.)
0	1057.61
98	524.46
116	380.57
197	322.58

*signifies exhaust fan system.

It should be noted that large fan size reduces the radon levels to such low levels that they are experimentally meaningless. This occurs when the experimental error of the concentration surpasses the actual measurement.

The data was then analyzed by linear regression through a number of functions. The best resulting function is the exponential:

$$F + G = (F' + G') \cdot \exp.^{\left(\frac{Q}{Dr_T V_T}\right)}$$

where:

r_T is the volume weighted average of r_m and r_b

V_T is the total volume of dwelling

D is structural dependent member

Determination of D is dependent on whether the lower level is directly exposed to the surrounding soil or whether it has an enclosure of concrete or concrete block. If lower level is concrete or block construction D = 2. If it is simply a crawlspace D = 4.

The equation for the derivation of fan sizes becomes:

$$Q = \frac{\exp.^{-\frac{Q}{Dr_T V_T}} (r_m V_m C_m + r_b C_b V_b) - r_m V_m C'_m - C'_b r_b V_b}{C'_b}$$

This transcendental equation was solved by use of Newton's Method.

In assigning fan sizes to the dwellings the values $r_m = 0.4$ and $r_b = 0.5$ were used. Since the air exchange rates may vary from the above suggested values, radon concentrations may not be reduced to the level suggested by the theory. The implementation of make-up unit will lower the equilibrium factor to the 8% - 15% range which results in working levels below the criterion.

Three pre-remedial and post-remedial examples of working levels and radon gas are:

Site #/Item	Radon (pCi/l)		Working Level	
	Pre-Remedial	Post Remedial	Pre Remedial	Post Remedial
# 1 Mean	5.9	1.77	0.0205	0.0032
# 1 S.D.	5.66	1.1	0.0209	0.0021
# 1 S.E.	1.79	0.45	0.0066	0.0008
#296 Mean	12.01	— 4.5	0.0375	0.0047
#296 S.D.	4.77	3.21	0.0211	0.0036
#296 S.E.	1.11	0.92	0.0049	0.001
#302 Mean	14.02	2.58	0.0868	0.0044
#302 S.D.	6.93	1.17	0.0457	0.0018
#302 S.E.	1.94	0.414	0.0095	0.0007

3.3 EXPERIMENTAL DETERMINATION OF VARIABLES

3.3.1 Radon Concentration for Fan Calculations

Radon concentrations and radon daughter samples were measured simultaneously on both levels. In order to have a realistic value to use in the calculations seven to ten samples were taken at each site in question. If, from the data obtained, the standard deviation approximates the value of the actual measurements, more measurements are required to obtain a valid value for the calculations.

The data was collected using EDA scintillation flasks that were subject to a ten minute background count before use. The flasks were counted in EDA RD-200 Radon Gas Counters for two consecutive ten minute intervals. The calibration and initial analysis of the counts is explained in detail in Reference 4.

3.3.2 Air Exchange Rates

Air exchange rates are determined by releasing a tracer gas at different levels in the house and studying the decrease in concentration as a function of time.

Sulfur-Hexaflouride is used as a tracer gas. This gas is released from small balloons on either or both levels. Air samples are collected at predetermined time intervals to a maximum of seven samples. The procedure initially was to wait 30 minutes prior to the first sampling to allow the tracer gas to diffuse throughout the level. This initial 30 minute interval was reduced to 15 minutes with the additional samples taken at intervals of 30, 30, 30, 60, 60 and 90 minutes respectively.

Initially approximate equal concentrations of the tracer gas were released on both levels. The concentrations were assumed to decrease according to the equation $C = C_o e^{-rt}$, where C_o is the initial concentration and r is the air exchange rate. The data was analyzed by a linear regression using the equation $\ln(\frac{C_o}{C}) = rt$.

Presently gas is released on only one level and samples are taken on both levels in the time sequence previously mentioned.

The log plots (see figures 1 and 2) of the data can be subdivided into two clear segments, particularly that corresponding to the level that on which the gas is released, in this case the lower level. The result of a linear regression of part (a) the second graph can be interpreted as the combined air exchange rates on that level $(r_u + r_b)$. Note that this interpretation of (a) is only valid when the concentration on the main level has not reached a concentration substantial enough to feed back into the lower level via r_d. If it is

further assumed that $r_u \approx r_d$ then the slope at the latter part of both log curves (c) and (d) will yield the air exchange rate for each level. This method of analysis is adequate and reasonable where $r_b \approx r_m$. These assumptions do not hold true when ventilation units are operating or air exchanges are greater on one level.

To circumvent the discrepancy, differential equations governing the flow of a tracer gas through a building are used. To restate, these equations are:

$$\frac{V_m dC_m(t)}{dt} = r_u C_b(t) V_b - r_m C_m(t) V_m - r_d C_m(t) V_m \text{ for the main level,}$$

and $$\frac{V_b dC_b(t)}{dt} = r_d C_m(t) V_m - r_b C_b(t)\ V_b - r_u C_b(t)\ V_b \text{ for the lower level.}$$

Using numerical analysis the data was curve fitted for each level with two exponential functions to obtain $C_b(t)$ and $C_m(t)$. These resulting functions were inserted into the differential equations to obtain the air exchange rates.

This method showed good results except in cases where r_u and r_d approaches zero. In these cases the exponentials do not approach a good fit to the data points and the computer program used diverged from a solution.

Upon applying Lapace transforms to the aforementioned dual differential equations exact solutions are obtained. The solutions are:

$$C_m(t) = \frac{e^{(b-a)t}}{2b}\left[\frac{r_u C_{bo} V_b}{V_m} + C_{mo}(A - a + b)\right] - \frac{e^{-(a+b)t}}{2b}$$
$$\left[-\frac{r_u C_{bo} V_b}{V_m} + C_{mo}(A - a - b)\right] \text{ for the main level.}$$

$$C_b(t) = \frac{e^{(b-a)t}}{2b}\left(\frac{r_d C_{mo} V_m}{V_b} + C_{bo}(B - a + b)\right)$$

$$- \frac{e^{-(b+a)t}}{2b}\left(\frac{r_d C_{mo} V_m}{V_b} + C_{bo}(B - a - b)\right) \quad \text{for the lower level.}$$

where:

$$A = r_u + r_b$$

$$B = r_m + r_d$$

$$a = \frac{r_u + r_d + r_b + r_m}{2}$$

$$b = \frac{\sqrt{(r_u + r_b + r_m + r_d)^2 - 4(r_u r_m + r_b r_m + r_b r_d)}}{2}$$

These functions are fitted to the data using a standard gradient search technique using the first data point at C_{io}. Due to the high degree of non-linearity of the functions this program is somewhat limited but provides good results to reasonable data.

TABLE 1

MAIN LEVEL DATA

VOLUME - 1.94×10^5 litres

Time	Actual Conc.	Gradient Curve fit (conc.)	Temperature in °C	Temperature out °C
9.66	885	885	23.5	22
10.16	1270	1360.0	23.6	21.8
10.66	1303	1347.2	24	21.5
11.16	1152	1169.4	24	21.5
12.16	776	762.6	25	22
13.46	422	398.2	27	22
14.76	219	202.3	28	22

LOWER LEVEL DATA

VOLUME - 0.97×10^5 litres

RELEASE TIME: 9.183 hours

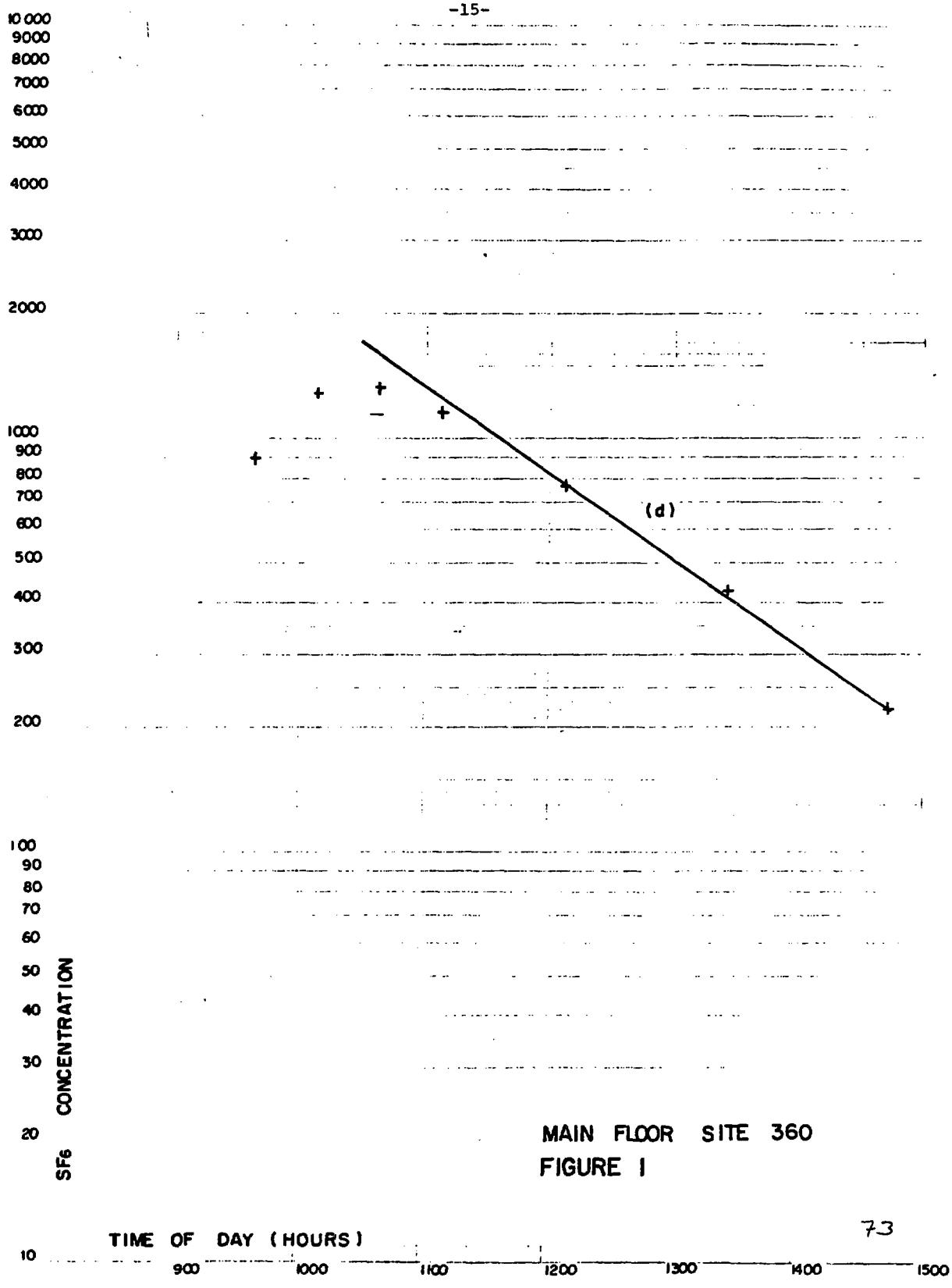
Time	Actual Conc.	Gradient Curve fit (conc.)	Temperature in °C	Temperature out °C
9.68	4557	4557	20	22
10.18	2089	2069.7	20	21.8
10.68	931	953,7	21	21.5
11.18	433	449.8	21.5	21.5
12.18	147	112.9	21	22
13.48	50	27.5	22.5	22
14.78	30	10.3	22.5	22

	Gradient Search	Linear Regression	Correlation
r_b	0.58	0.994	0.976
r_m	0.526	0.326	0.911
r_u	1.017		
r_d	0.024		

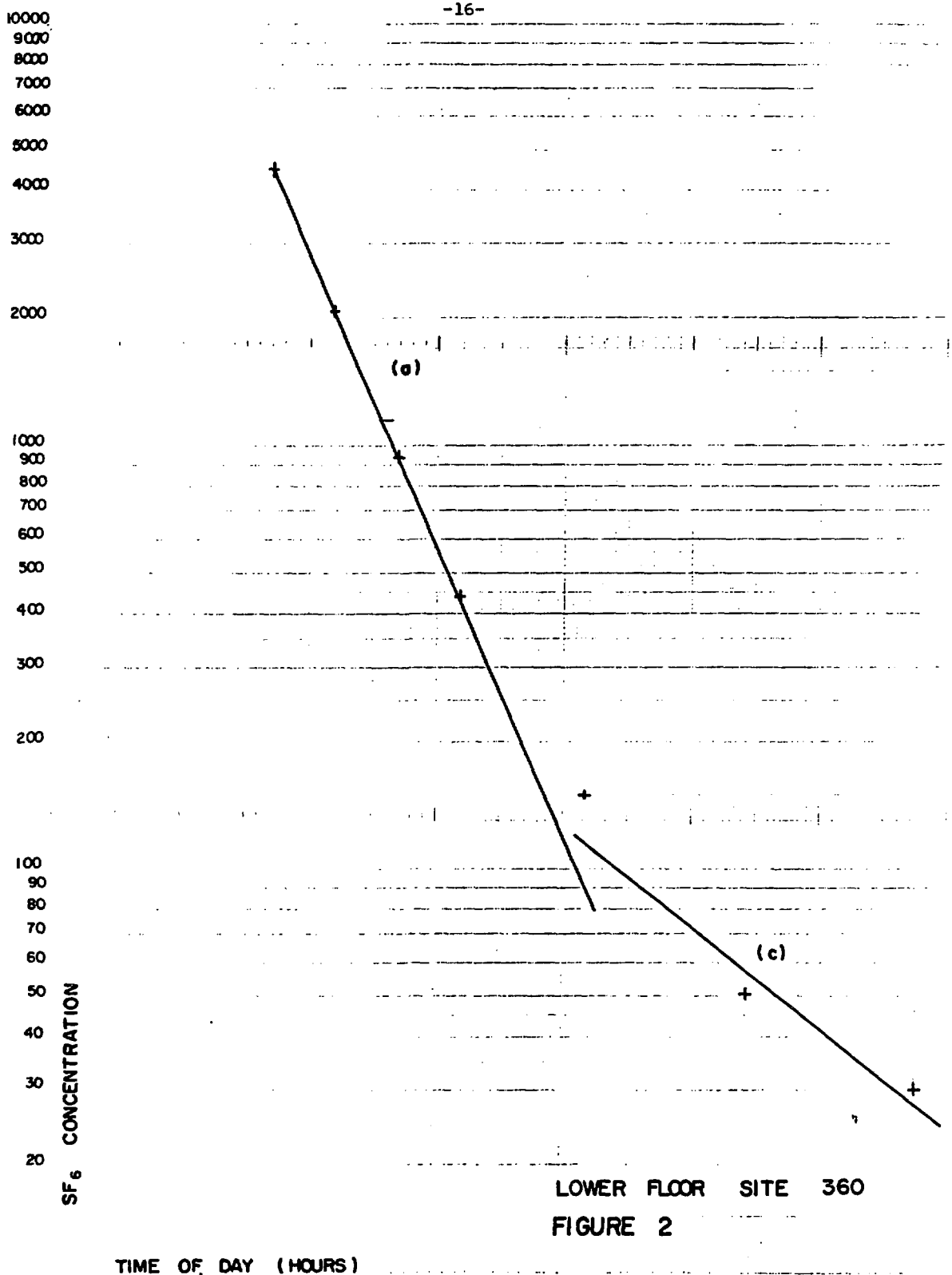
Least Square fit 4868.306

Fan Flow 0 CFM

TABLE 1 SITE 360

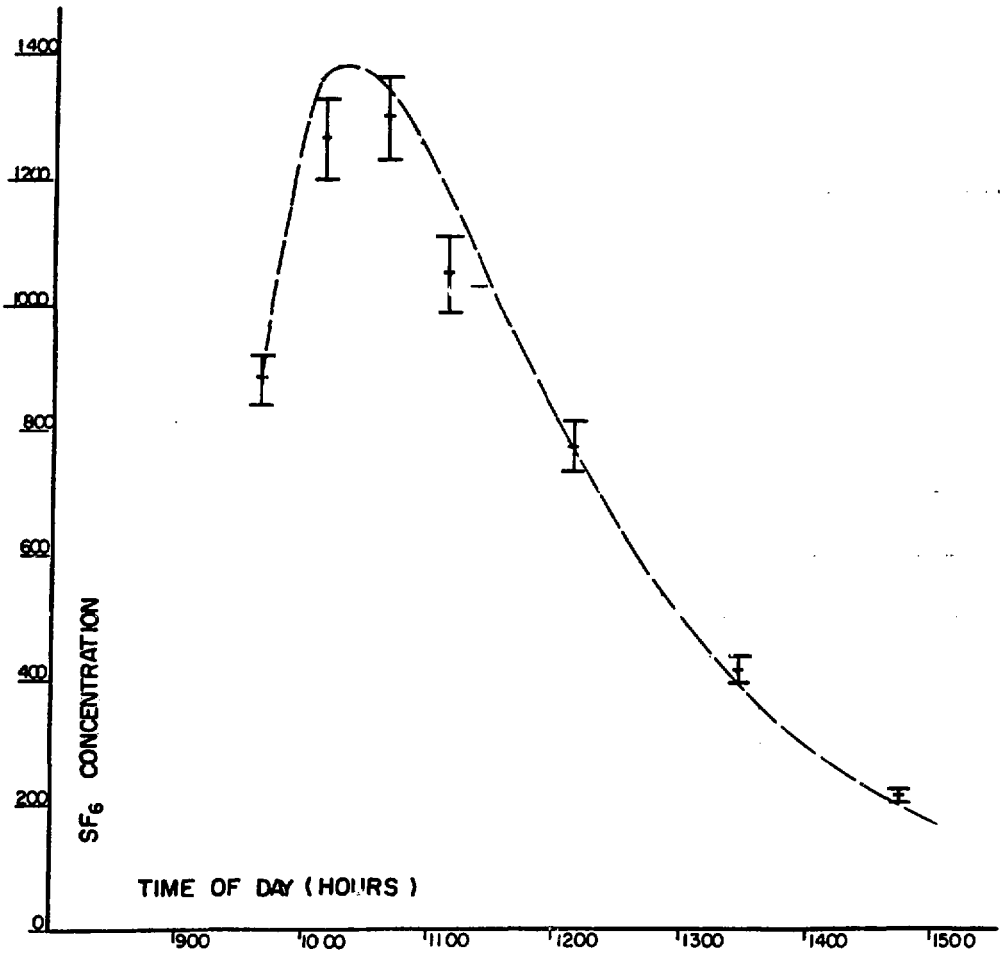


MAIN FLOOR SITE 360
FIGURE 1

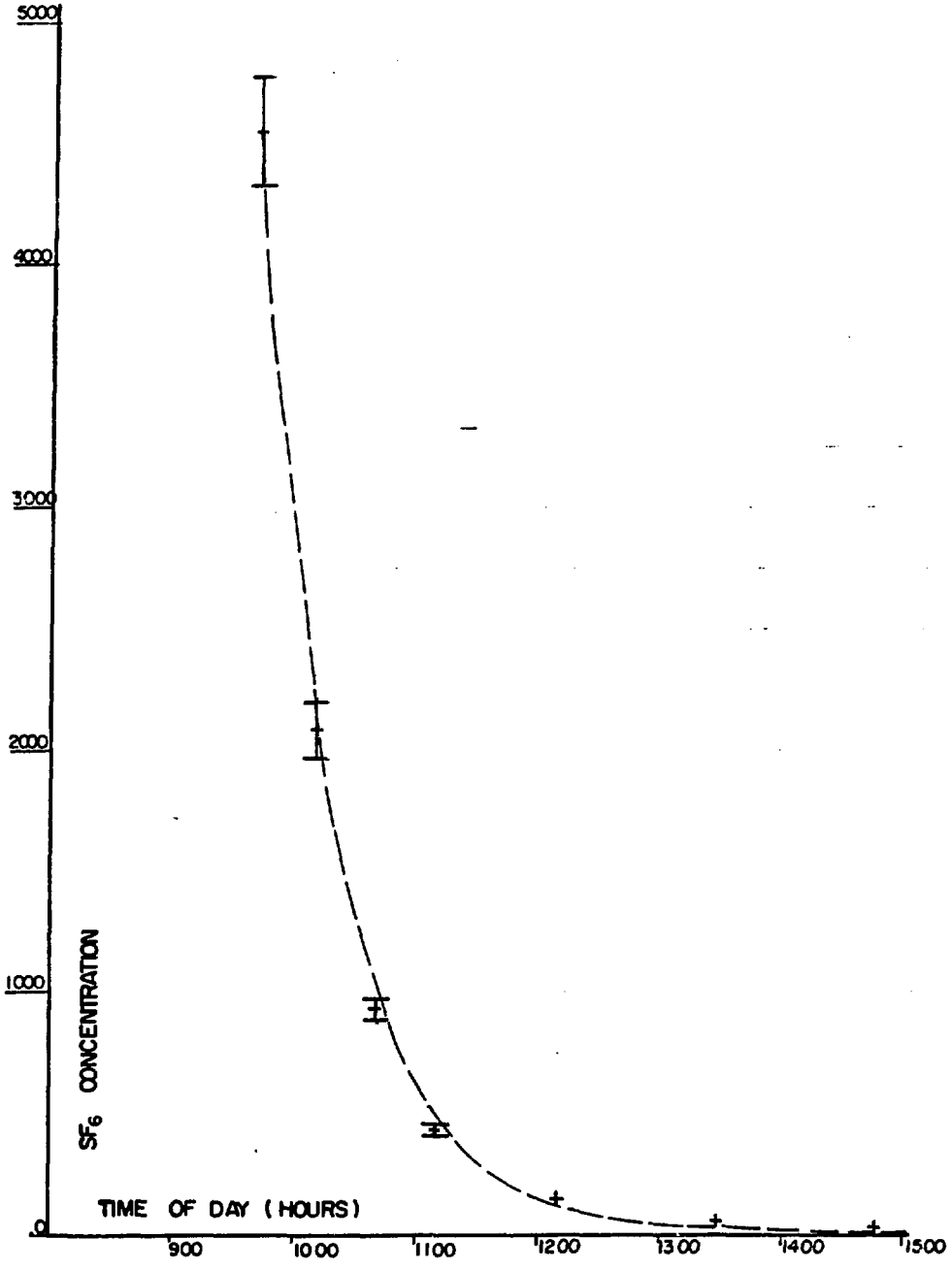


LOWER FLOOR SITE 360

FIGURE 2



MAIN FLOOR SITE 360
FIGURE 3



LOWER FLOOR SITE 360

FIGURE 4

3.4 UNIT DESCRIPTION, OPERATION & MAINTENANCE

3.4.1 Unit Description

The make-up air units are manufactured on a standard physical configuration, compatible with the ventilation requirements of the individual residences. The physical size of the components is identical for all units. Modifications to the ductwork are made where applicable. The unit consists of the following equipment.

1. Fan and motor - 120 volt single phase - 120 or 250 CFM c/w overload protection.

2. Electric Duct Heater - three element type c/w element contractors, manual and automatic reset high limit cutouts, and terminal blocks for all remote wiring.

3. Interconnecting duct - 8" x 14" with flanges for intake and discharge ducts.

4. Discharge duct - 3¼" x 10".

5. Fresh air intake - 8" x 14" - The exterior portion of the intake duct is installed to accommodate the inlet above snowline. The intake contains a permanent washable filter. The interior portion of this intake duct is insulated.

6. Control package is premanufactured and include:

   a. low limit cut out

   b. fan differential pressure switch

   c. terminals for remote outside air temperature sensor and discharge air temperature thermister.

   d. Alarm relay, remote alarm sonalert module and fan restart.

   e. Triac proportional controller

   Terminals for all power wiring.

The control package is contained in heavy gauge, lockable metal box. It is mounted near the fan, and heater unit with all sensors positioned and connected. All power wiring connected on site. Modifications to the individual residence electrical service entrances consist of installation of a separate meter socket and load centre for the make up air unit with all the necessary power wiring.

3.4.2 Installation and Maintenance

The units are easily installed in any basement or crawl space. The heater elements and the fan motor must be installed horizontally. This installation is co-ordinated with the home owner and/or tenant to the specific aesthetic and functional requirements of each residence.

A maintenance program is being established and tentatively includes:

1. Fan inspection on semi-annual basis which includes removal of dust accumulation from fan blades and motor.

2. Filters inspected and cleaned on a monthly basis.

3. Alarm conditions as required. Fault determined by thorough unit inspection. Faulty equipment replaced if required.

3.4.3 Unit Operation

The heat output of the system is controlled by a Honeywell R7308 (40A) or an R7393 (25A) current valve. The current valve has a cycle frequency of approximately two seconds. The amount of time the current valve is on relative to the time it is off is referred to as

the duty cycle. A 50% duty cycle has the current valve on for 50% of the time. The duty cycle of the current valve is regulated by the series resistance of the thermister, used as the temperature sensor, and a set point potentiometer. With the cycle time of the current valve so high, compared to the heat output response time of the heater, and the input response time of the thermister so small, due to its small mass, the output of the heater can be considered essentially proportionally controlled.

With the proportionality band set at $1^{o}C$ the setting time is less than five minutes and the temperature fluctuations less than $0.5^{o}C$.

An outside air temperature probe is installed to regulate the heater and limits its operation to temperature below $16^{o}C$.

A pressure differential sensor is placed across the fan, one probe upstream and one probe downstream. In the event of fan failure, resulting in no flow, the pressure differential switch deactivates the heating system and activates the alarm.

Downstream from the heater is the low temperature limit probe. This probe detects the failure of the heating system. If the discharge temperature falls below the set point temperature, the low limit switch will shut the fan off and this in turn triggers the pressure differential switch and activates the alarm.

Upon initial start up or resumption after a power failure the alarm will sound for a few seconds until normal operation of the system is resumed. If the low limit sensor has cooled excessively, the fan unit will not start automatically on resumption of power. The fan restart button, located on the alarm module, is then held in until

the discharge air has warmed the low limit probe sufficiently to allow normal operation.

The discharge air is allowed to freely travel throughout the basement or crawl space and the main level. Louvres installed in partitions and walls allow the air to flow freely where it was previously seriously impaired.

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4. ACKNOWLEDGEMENTS

4. ACKNOWLEGEMENTS

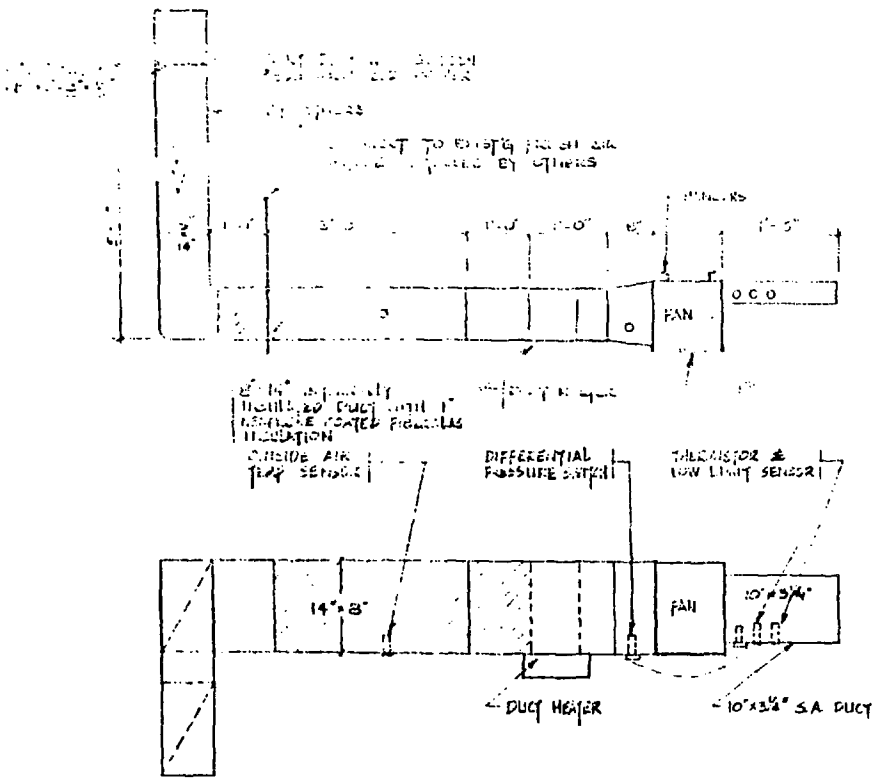
We wish to acknowledge the co-operation and assistance we have received in the preparation of this report - Agencies such as the Atomic Energy Control Board, the Saskatchewan Department of the Environment and the Saskatchewan Research Council. The assistance and advice of Mr. A. Scott and Ms. D. Smith of DSMA, and M.K. Leung is also gratefully acknowledged.

APPENDIX 1

DRAWINGS & SKETCHES

MECHANICAL VENTILATION UNITS

1. M-1 Unit Fabrication Detail
2. M-2 Unit Control Schematic
3. Site #1 Unit Installation
4. Site #296 Unit Installation
5. Site #320 Unit Installation



MECHANICAL SPECIFICATIONS

UNIT	140 C.F.M	220 C.F.M
DUCT HEATER	LENNOX ED 8-014-6 5·5 KW 240 V/1φ	LENNOX ED 8-1014-8 7·4 KW 240 V/1φ
FAN	GREENHECK SP-17 140 CFM @ ·125" S.P. 1550 R.P.M. MOTOR 1/50 H.P. 115 V/1φ	GREENHECK SP-25 220 C.F.M @ ·125" S.P. 1050 R.P.M. MOTOR 1/40 H.P. 115 V/1φ
FILTER	RP - 14" x 8" x 1/4" ALUMINUM MESH	

PROFESSIONAL ENGINEER
T.D. HARLE
REGINA
SASKATCHEWAN

LEGEND	REVISIONS				
	NO	DESCRIPTION	DATE	APP

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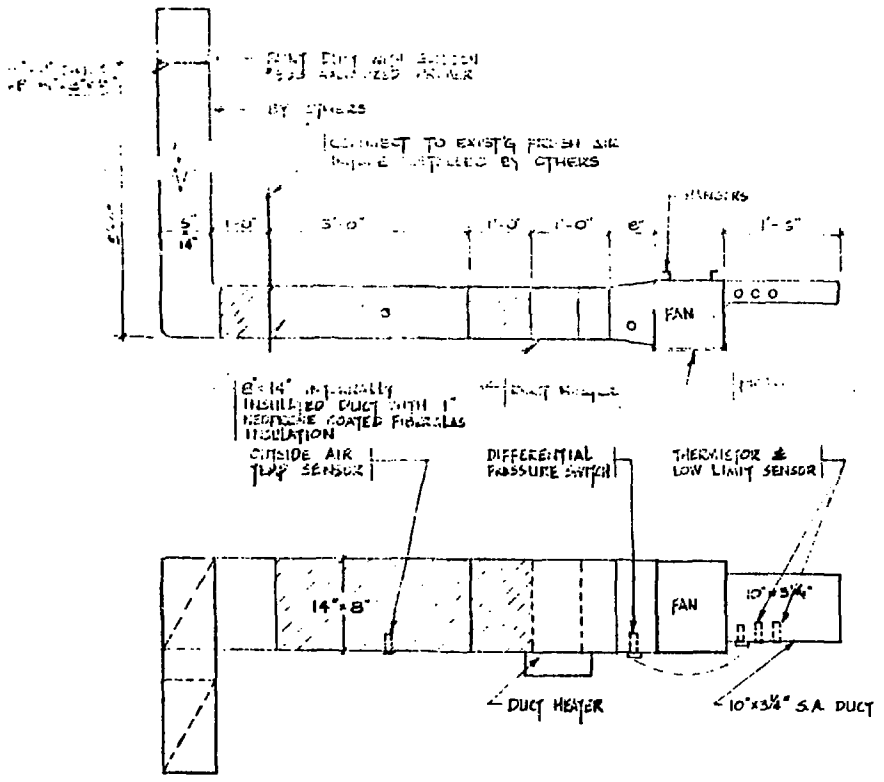
CRAWLSPACE VENTILATION
UNIT FABRICATION DETAIL

scale	3/4" = 1'-0"
drawn by	RW
design by	TH
checked by	
approved by	
dwg. no.	M-1



MECHANICAL SPECIFICATIONS

UNIT	140 C.F.M	220 C.F.M
DUCT HEATER	LENNOX ED 8-814-6 5.5 KW 240 v/1ϕ	LENNOX ED 8-1014-8 7.4 KW 240 v/1ϕ
FAN	GREENHECK SP-17 140 c.f.m @ .125" S.P. 1550 R.P.M MOTOR 1/30 H.P. 115 v/1ϕ	GREENHECK SP-25 220 C.F.M @ .125" S.P. 1050 R.P.M MOTOR 1/40 H.P. 115 v/1ϕ
FILTER	RP - 14" x 8" x 1/4" ALUMINUM MESH	

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T.D. HARLE
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UNIT FABRICATION DETAIL

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design by	T.H.
checked by	T.H.
approved by	T.H.
dwg. no.	M-1

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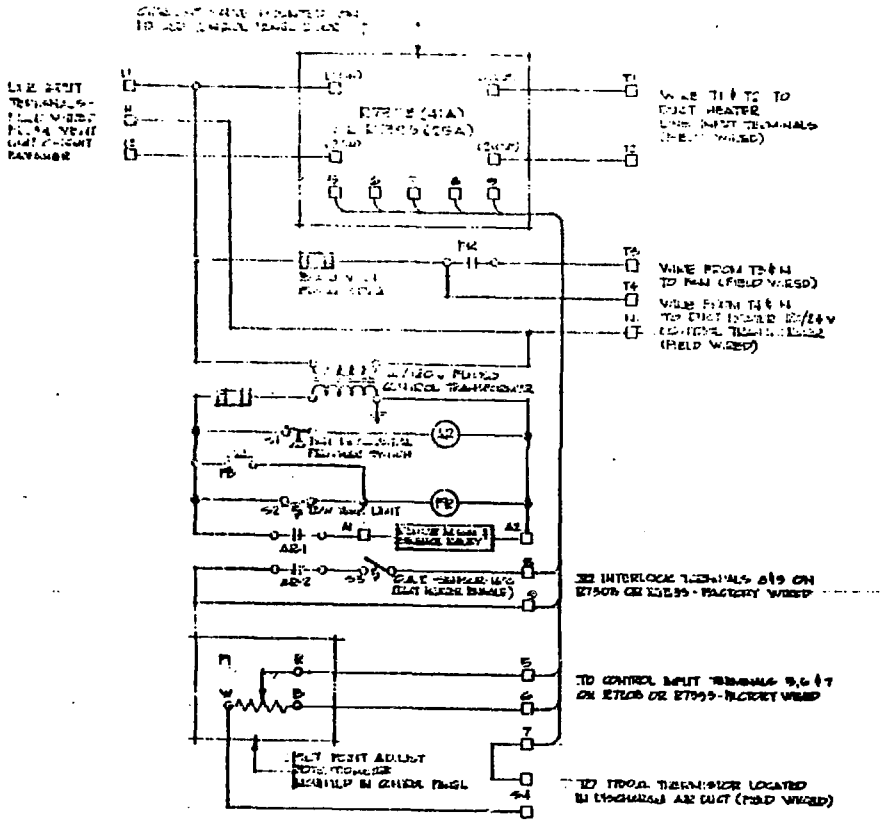

NOTES:

1. CONTROL ENCLOSURE TO BE COMPLETE WITH REMOVEABLE HINGED DOOR.
2. E7506 OR E7599 CURRENT VALVE TO BE MOUNTED ON CONTROL ENCLOSURE AND FACTORY WIRED TO LINE, LOAD AND CONTROL TERMINAL BLOCKS WITHIN CONTROL ENCLOSURE.
3. SET POINT ADJUST POTENTIOMETER TO BE MOUNTED WITHIN CONTROL ENCLOSURE. CURRENT VALVE CALIBRATION CONTROL TO BE ADJUSTED TO PROVIDE 50% DUTY CYCLE WITH SET POINT ADJUST POTENTIOMETER AT MIDPOINT.
4. SENSOR DESCRIPTION
   - S1 — FAN DIFFERENTIAL PRESSURE SWITCH. TO OPERATE ON 0.0625" S.P. ACROSS FAN
   - S2 — LOW TEMPERATURE LIMIT CONTROL - ADJUSTABLE - NOMINAL SETTING 5°C - OPENS ON TEMPERATURE DROP BELOW SET POINT. LOCATED IN DISCHARGE AIR DUCT.
   - S5 — OUTSIDE AIR TEMPERATURE SENSOR - ADJUSTABLE - NOMINAL SETTING 16°C - CLOSES ON TEMPERATURE DROP BELOW SET POINT. LOCATED IN INLET AIR DUCT.
   - S4 — 1700 OHM THERMISTER AT 24°C - 50 OHM/°C NEGATIVE TEMPERATURE COEFFICIENT. LOCATED IN DISCHARGE AIR DUCT.
5. S1, S2 & S5 CONTROLLERS MOUNTED IN CONTROL PANEL. PROVIDE EDITED OPENING IN CONTROL PANEL FOR SENSOR BULBS AND CAPILLARIES TO BE ROUTED TO LOCATION.
6. REMOTE ALARM TO CONSIST OF HONEYWELL R4184A ALARM SILENCE RELAY WITH 90 dB SCHANUET MOUNTED ON RELAY ENCLOSURE.

PROFESSIONAL ENGINEER — M. C. O'KRANCY — REGINA — SASKATCHEWAN

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CRAWL SPACE VENTILATION
— VENTILATION UNIT CONTROL SCHEMATIC —

scale	N.T.S.
drawn by	J.M.
design by	M.C.O.
checked by	
approved by	
dwg. no.	M-2

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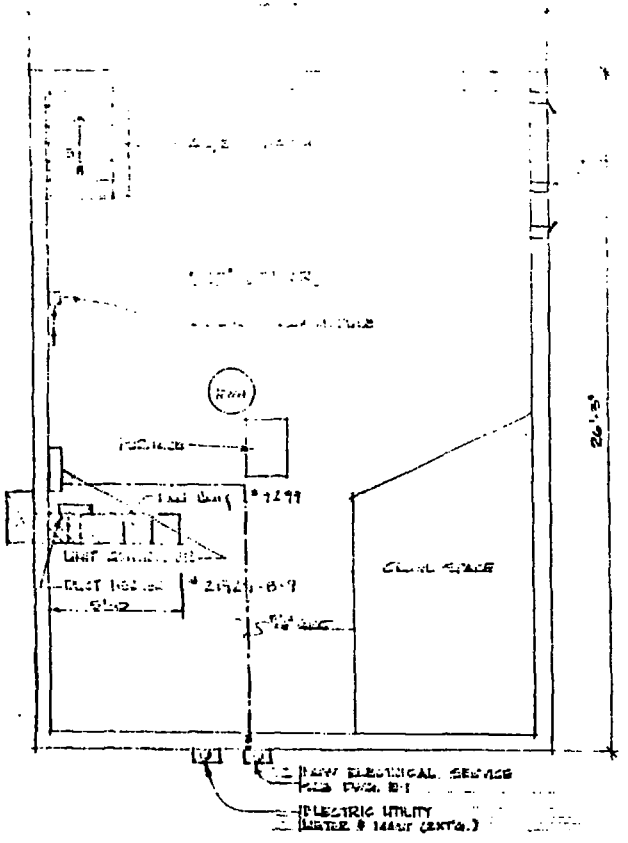
VENTILATION UNIT
FAN - 120 CFM
DUCT HEATER - 5.5 kW
SERVICE ENTRANCE - 40 AMP - 120/240 VOLT



BASEMENT PLAN

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NO.	DESCRIPTION	DRAWN BY DATE	APP
	PLAN OF RECORD		

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CRAWL SPACE VENTILATION
--- SITE 296 ---

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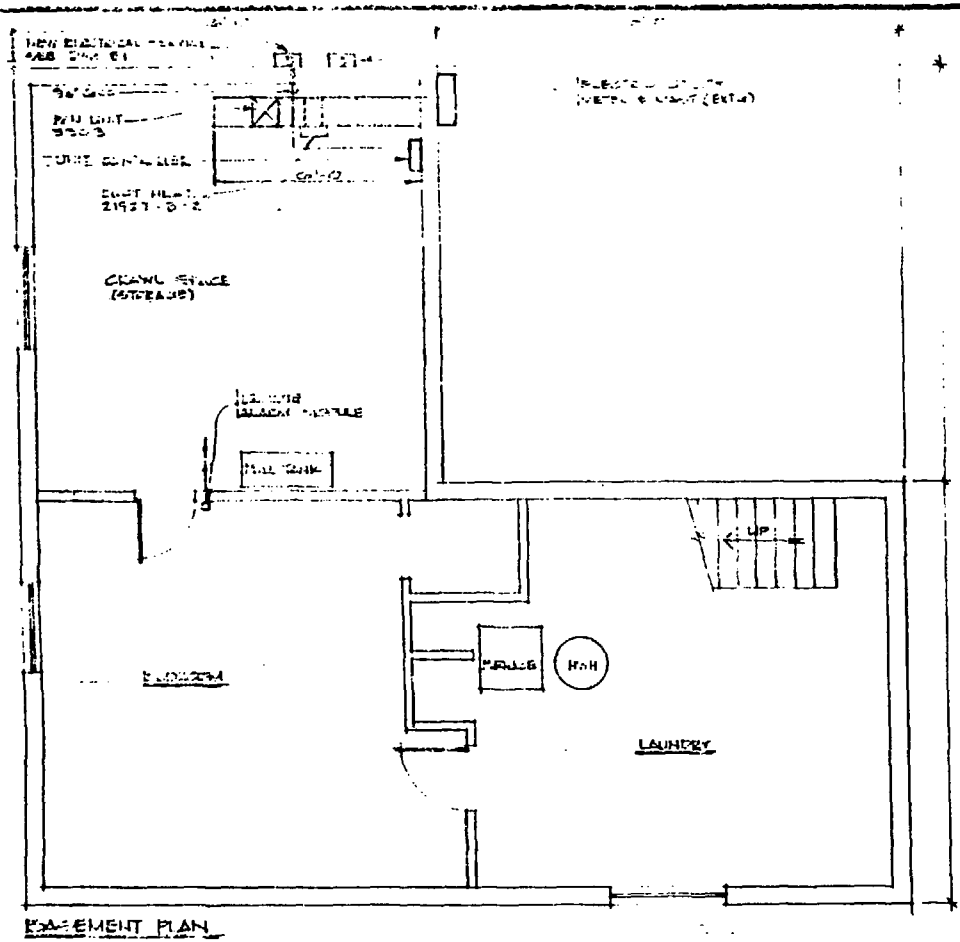

BASEMENT PLAN

VENTILATION UNIT
FAN - 120 CFM
DUCT HEATER - 5.5 kW
SERVICE ENTRANCE - 40 AMP - 120/240 VOLT

LEGEND:

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	PLAN OF RECORD	March 80	

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CRAWL SPACE VENTILATION
— SITE 320 —

scale	1/4"=1'-0"
Drawn by	J.M.
design by	
checked by	
approved by	
dwg. no.	320-1

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APPENDIX 2

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2. Further Efforts at Remedial Measures for Houses with Block Walls, Concrete Porosity Test Results, and Intercomparison of Kuznetz Method and Tsivoglou Method by E. Haubrich, M.K. Leung and R. Mackie, January 1980

3. Proposal for Low Pressure Transducer and Readout by E. Haubrich, December 10, 1979.

4. Calibration of Radiation Measuring Equipment and Intercomparisons by M.K. Leung, December 1979

URANIUM CITY RADIATION REDUCTION PROGRAM

FURTHER STUDIES ON REMEDIAL MEASURES AND RADON INFILTRATION ROUTES FOR HOUSES WITH BLOCK WALLS

BY

M.K. LEUNG

KEITH CONSULTING
766 Angus Street
Regina, Saskatchewan

File: 3067

December, 1979

NOTICE

The results of this report are of a preliminary nature. Further efforts may change the results in this report.

TABLE OF CONTENTS

FURTHER STUDIES ON REMEDIAL MEASURES AND RADON INFILTRATION ROUTES FOR HOUSES WITH BLOCK WALLS

I) Introduction

Subsequent and concurrent to our report in Bancroft, Ontario on infiltration studies of radon into houses with concrete block walls (reference 1), we carried out further experimental remedial measures and studies on radon infiltration for houses with concrete block walls. These include partial sealing, in situ testing of radon migration through the concrete web in blocks, laboratory testing of concrete blocks, testing of migration of radon through block walls under pressure, venting of the plenums as a remedial measure, and venting the whole house as a remedial measure. This report describes the results of the partial sealant method and the test results of radon migration through block walls. These tests were carried out to find a combinational (venting plus sealing) approach toward a remedial measure for houses with block walls. The results from these efforts do not represent an ultimate approach to remedial actions for houses with block walls. This report also includes some laboratory tests on the effectiveness of concrete blocks as a radon barrier. These concrete blocks were found in the Uranium City area and were generally used for basement walls. We have very little data on this and we cannot generalize our results.

II) Further Efforts in the Partial Sealant Approach

In Bancroft, Ontario, we reported that we were able to reduce the radon concentration and working level by thirty percent for an experimental site by foaming and grouting the plenums. The original

plan for this site (referred to as address 1 in subsequent literature) was to coat the interior surface of the block walls with some form of sealant, monitor the radon level and carry on further remedial work if necessary. However, due to the late arrival of a suitable sealant, and change-over in personnel, the partial sealant approach was abandoned for this site. During the previous year, we tried the partial sealant measure at another site with concrete block walls. In this house (referred to as address 2 later on) half of the basement was developed into an apartment suite. The apartment has gypsum boards on the walls and linoleum over wooden false floor. Initially, we sealed the floor drain and were unable to reduce the radon concentration and the working levels. We then sealed all the cracks on the exposed floor surface, some exposed surfaces where the radon flux was found to be high, all the cracks on the block walls, all the mortar joints between the blocks and the gap between the top of the plenum and the baseplate. All the cracks were sealed by using epoxy sealant. The gap was first sealed by polycement and later on sealed by epoxy. This did not reduce the radon level nor the working level to below criterion. In late March, holes were drilled into plenums in the exposed part of the basement walls and the lower parts of the plenums were filled by urethane foam and grout. Generally the amount of foam injected reaches waist height and six inches or more of grout was poured on top of the foam. The grout acts as a radon barrier as well as fire hazzard retardant. Later on the same wall surfaces were coated by epoxy. The radon concentration and W.L. went down to below criterion for about two weeks, then went back to above criterion in the third

week. We stopped monitoring after the third week. It was then decided that venting should be used as a remedial measure for address 2, if venting experimentation at other sites with block walls proved to be successful. It was estimated that the cost of tearing down, sealing, and refurbishing the apartment suite would cost far more than venting plus maintenance costs.

III) Further Studies on Radon Infiltration Routes Into Basements with Block Walls

i) Air Flow and Pressure in Block Wall Plenums

As a continuation of our past studies, we tried to determine the flow velocity in the plenums. The velocity was measured by using an ALNOR Velometer. The velocity of air was approximately 20 cm/s over a one day period. The furnace and fan operations seem to have no influence on this velocity. Table I shows the data taken during late April at address 2 on air velocity in a plenum and the conditions of the furnace and fan during these measurements. The air flow was upward through the plenum.

It was also observed that when a hole was drilled into the plenum, air flowed into the basement. There was a slight pressure differential between the plenums and the basement, with the pressure in the plenum on the high side. This pressure as well as the upward movement of the air through the plenum was observed both before and after the lower cores of the plenums were filled with urethane foam and grout. The pressure was very small and we could not make any accurate measurements even on the most sensitive scale on the ALNOR Velometer. The furnace and the fan operations in the house did not seem to influence the pressure differential. The direction of the air

TIME	VELOCITY IN PLENUM	DIRECTION	FAN CONDITION	FURNACE
9:30	≈ 20 $^{cm}/S$	Upward	ON	ON
10:00	≈ 20 $^{cm}/S$	Upward	OFF	ON
10:30	≈ 20 $^{cm}/S$	Upward	OFF	OFF
11:30	≈ 20 $^{cm}/S$	Upward	OFF	ON
13:00	≈ 20 $^{cm}/S$	Upward	OFF	ON
13:15	No measurement		ON	ON
13:20	≈ 20 $^{cm}/S$	Upward	ON	ON
13:40	≈ 20 $^{cm}/S$	Upward	ON	ON
14:25	≈ 20 $^{cm}/S$	Upward	OFF	OFF
15:00	≈ 20 $^{cm}/S$	Upward	ON	ON
15:30	≈ 20 $^{cm}/S$	Upward	OFF	ON
16:30	≈ 20 $^{cm}/S$	Upward	ON	ON

Table I AIR VELOCITY MEASUREMENT INSIDE PHENUM AT ADDRESS 2 - APRIL, 1979

≈ - approximately

flow was constantly into the basement. We could feel the air flowing inwards but could not measure the flow rate through the holes. Some of the observations together with the condition of the furnace and fan are listed in Table II.

ii) In Situ Test of Blocks as a Radon Barrier

The flow measurements in the plenums showed that one potential route of radon entry is through the gap at the top of the plenums. The mortar joints were all coated with epoxy. We already filled the lower plenums with foam and grout and yet the radon concentration in dwelling address 1 was reduced by only thirty percent. The blocks themselves had never been tested for effectiveness against radon penetration. This prompted us to test, both in situ and in the laboratory, the effectiveness of concrete blocks as a radon barrier. Several tests were carried out; the conclusion we drew from these limited tests was that concrete blocks commonly found in the Uranium City area did not act as an effective radon barrier. The tests were described in the following paragraphs.

a) In Situ Diffusion Test of Concrete Block Walls

In address 1 all the mortar joints between the blocks were sealed by using epoxy sealant. A metal box with dimensions of 6" x 8" x 16" was constructed to test the effectiveness of the blocks in address 1 as radon barrier. The length of the box was twice the length of a single block and the width of the box was slightly larger than the width of a concrete block. Three copper tubes were inserted into the box and the joints sealed by epoxy glue. The dimensions were such that the box fitted snuggly onto the epoxied

TIME	FURNACE	FAN	AIR FLOW	PRESSURE
14:05	ON	ON	INTO BASEMENT	SMALL, CONSTANT
14:10	OFF	ON	INTO BASEMENT	SMALL, CONSTANT
14:13	ON	ON	INTO BASEMENT	SMALL, CONSTANT
14:18	OFF	ON	INTO BASEMENT	SMALL, CONSTANT
14:20	ON	ON	INTO BASEMENT	SMALL, CONSTANT
14:25	OFF	OFF	INTO BASEMENT	SMALL, CONSTANT
15:30	ON	OFF	INTO BASEMENT	SMALL, CONSTANT

Table II OBSERVATION ON PLENUM PRESSURE AND FURNACE FAN CONDITIONS AT ADDRESS 2

mortar joints on the block wall. Figure 1 shows a schematic diagram of the metal box glued onto the wall. The whole assembly was held in place by a rope hanging from the ceiling. In later studies, the same set up was used for air flow measurements. The manometer and the pump were used for these purposes.

For the diffusion test, the rubber hose at locations 1, 2 and 3 were closed off by clamps. The box was then sealed onto the epoxied mortar joints. The initial radon concentration in the box and in the plenum was taken. The box was then left on the wall for more than three weeks and then the radon concentration in the box as well as in the plenum was resampled. The three weeks waiting period was to insure that the measured concentrations were the concentrations at equilibrium (e.g. reference 1). The data on April 19 showed that after the three weeks the radon concentration in the metal box to be 215.34 pCi/L and the radon concentration in the plenum to be 201.87 pCi/L. The initial reading in the box was an order of magnitude lower than that in the plenum. This showed that the blocks did not offer a great deal of resistance to radon migration into occupied houses.

iii) Laboratory Tests for Blocks

Due to the small pressure differential between the plenums and the basement, the previous test may not be a true measure for the effectiveness of the block against radon diffusion. To test the diffusivity of radon through the block, we put some radon producing uranium ore inside the plenums of a block. We

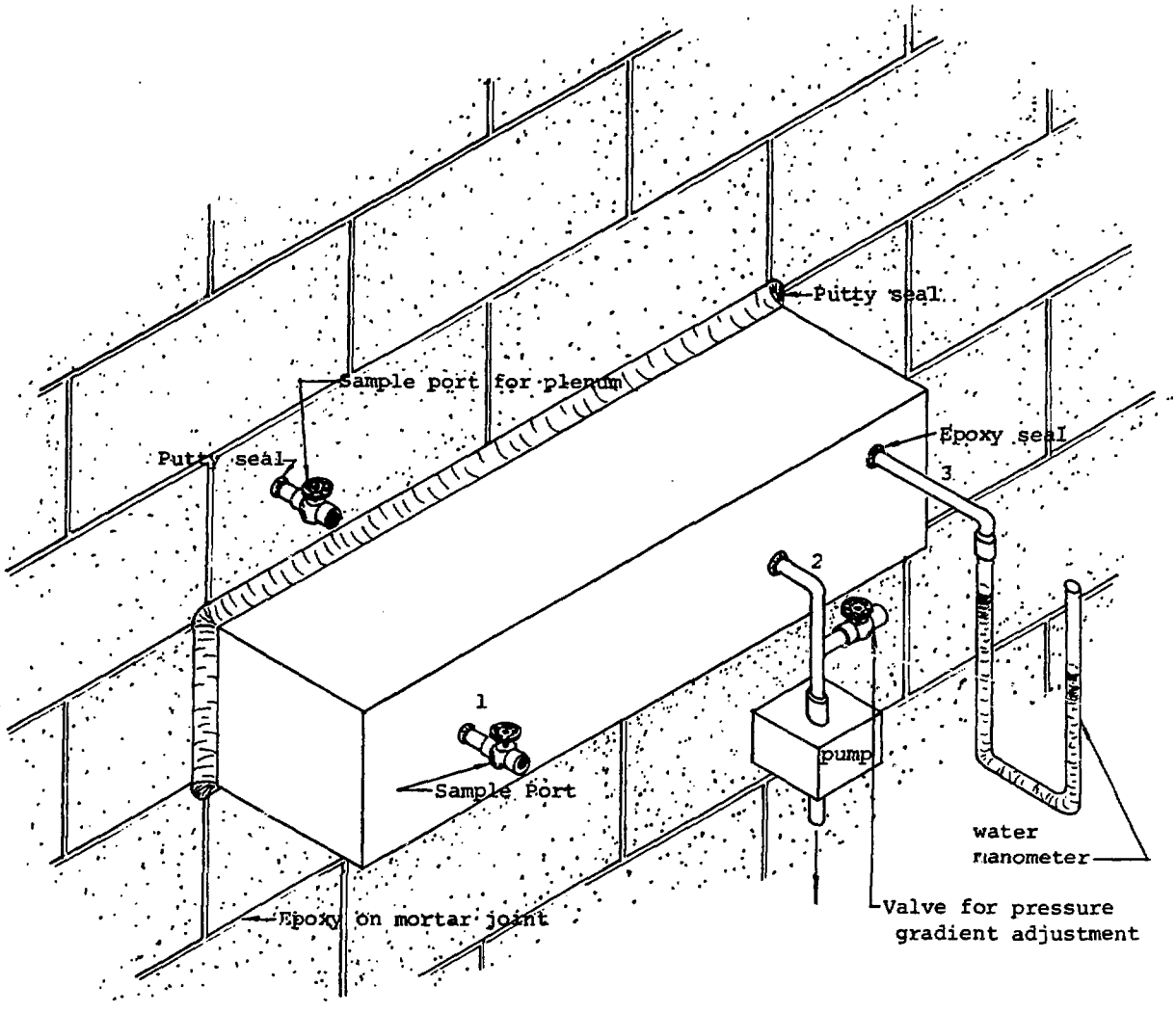


Figure 1 DIAGRAM OF METAL BOX FOR IN SITU RADON BARRIER TEST ON BLOCK WALLS

then drilled a hole into the separation between the plenums. Four paint cans, the circumference of which covered the girth of the plenums were used to seal off the plenums. The radon concentration measured in these cans are referred to as the ore concentrations in this report. Four other cans were then sealed onto the concrete surfaces of the masonry block. The radon concentrations in these cans are referred to as top left, bottom left, top right, and bottom right in this report. A schematic diagram of the set up is shown in Figure 2. The whole assembly was then left standing for more than three weeks and the radon concentration in the cans were then sampled daily for several days. We found that there was little difference between the concentrations sampled in the ore cans and the cans on the left and right of the ores. Table III showed the results obtained in one of these tests. It can be seen that there was no appreciable radon reduction by the presence of the concrete. To ensure that the radon concentrations do not come from the radium content in the concrete mix, we left the masonry block in a sealed flux can for a few weeks and measured the radon concentration in the can. The volume of the flux can is approximately four times that of a paint can. The highest level of radon concentration measured was 24.5 pCi/L. This contribution was insignificant compared to that due to the ore. The radon concentration due to the ore was approximately ten thousand (10,000) pCi/L. Two concrete blocks were tested this way. These blocks were chosen at random. Our test indicated some of the available masonry blocks from the Uranium City area were very permeable to radon migration. We did not spend a great deal of time to test a

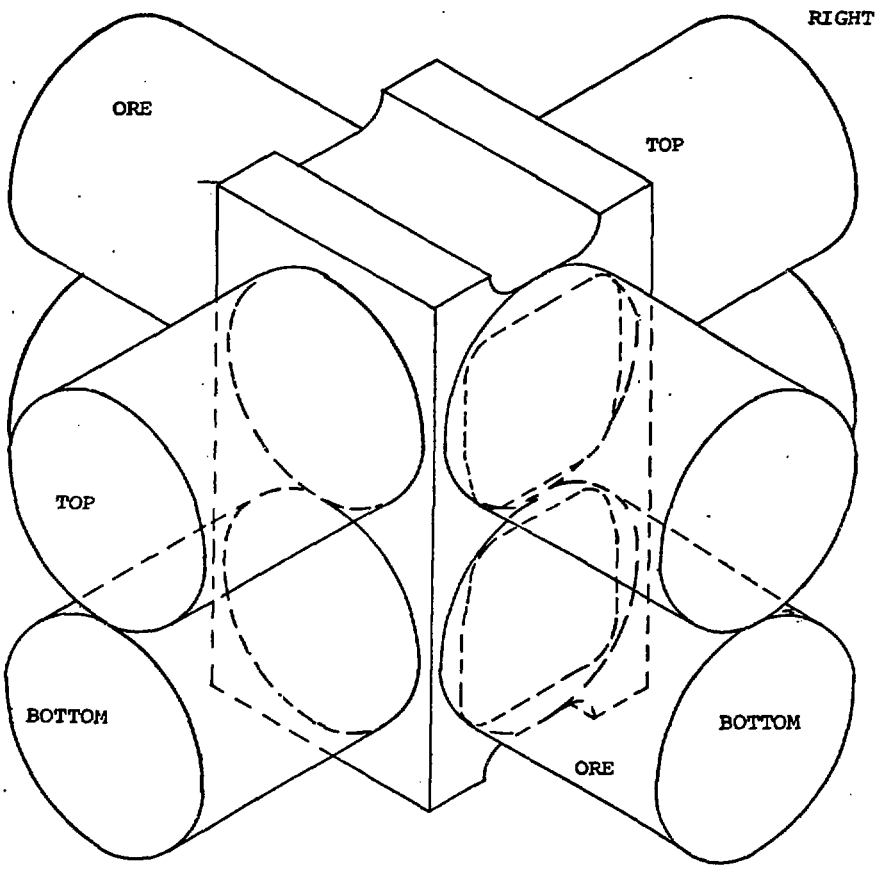


Figure 2 SCHEMATIC DIAGRAM FOR TESTING RADON DIFFUSIVITY THROUGH MASONRY BLOCKS

large number of blocks this way, and we cannot assert the general effectiveness of block walls in acting as a radon barrier.

In the basement of address 1, we randomly tested different blocks on all the walls. All the results showed that, in addition to the chimney effect of plenums which may introduce radon into houses, the concrete blocks would transmit radon. The metal box was placed below ground level where the lower cores had been blocked by urethane foam and grout. Figure 3 showed a schematic diagram of the positioning of the metal box relative to the ground level and the grouted area. This indicated that a certain amount of radon migrates into the basement laterally.

iv) In Situ Test to Determine Air Flow Through Blocks

As mentioned earlier there was a small pressure differential between the plenums in the block walls and the basements. By evacuating the metal box, we could produce a pressure differential between the plenum and the box. We decided to examine the flow characteristics of the blocks when a pressure differential existed. The experimental set-up is shown in Figure 1. The test was carried out in two ways.

Initially the box was evacuated until a pressure difference of 18 inches of water existed between the plenum and the box. The pump was then sealed off and the water column height at different times (in seconds) was taken until the initial pressure differential was reached. By assuming that the flow rate was a linear function of pressure differential, the flow rate across the concrete barrier between the plenum and the basement could be calculated. The assumption was a consequence of the

RADON CONCENTRATION pCi/L						
LEFT		ORE		RIGHT		
TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM	
10624	7972	9193	9088	9494	8038	Day 1
8128	7819	10524	8508	9714	8703	Day 2
10096	6893	8551	8084	8805	6970	Day 3

Table III RADON CONCENTRATIONS IN MASONRY BLOCK TEST

ideal gas law. References 2 and 3 were the general references for fluid flows and gas behavior. The equations used were:

$$\frac{dn}{dt} = k\Delta h \quad (1)$$

$$k = -\frac{V}{ATR\Delta t} \ln\left(\frac{\Delta h_2}{\Delta h_1}\right) \quad (2)$$

$$Q = A\frac{dn}{dt}\frac{RT}{P} \quad (3)$$

Where A : Area of box in ft^2

T : Room temperature in degree Kevin

Δt : Time interval in sections

$\ln\left(\frac{\Delta h_2}{\Delta h_1}\right)$: Logarithmic pressure ratio

R : ideal gas constant

$\frac{dn}{dt}$: flux in gm/ft^2 second

Q : flow rate in litre/second or ft^3/second

P : barometric pressure in inches of water

Δh : pressure differential in inches of water

Equation (1) was the assumption and (2) followed from the Avogadro's gas law PV = nRT. We did three tests in situ and arrived at flow rates of 2.42×10^{-4} l/s, 5.34×10^{-4} l/s, and 5.06×10^{-4} l/s for different locations on the block wall. The concentration of radon in the box as a function can be given by:

$$C(t) = \frac{C_o V_B + C_w Q T}{V_B + QT} \quad (4)$$

Where C_o : original radon concentration in box pCi/L

V_B : Volume of box litre

C_w : radon concentration in plenum pCi/L

Q : flow rate litre/second

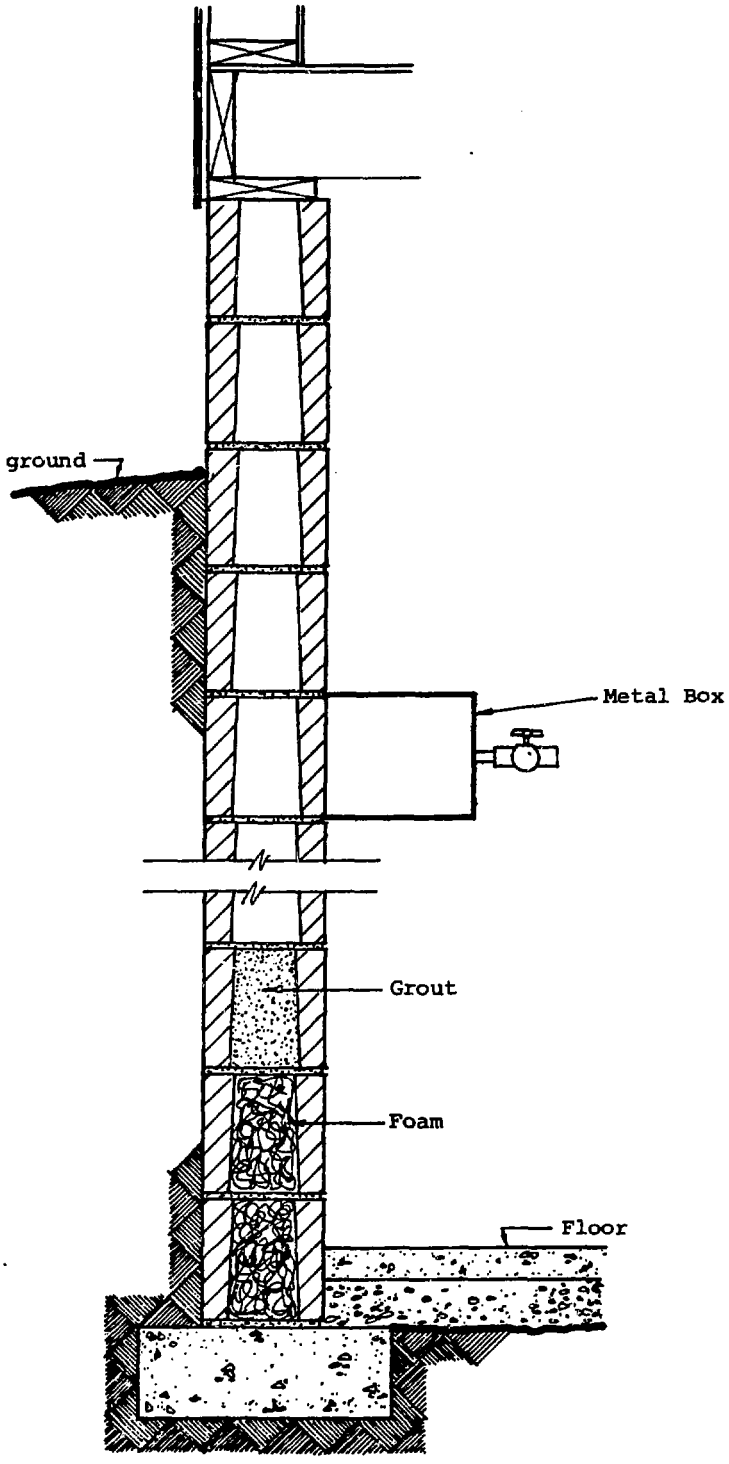


Figure 3 METAL BOX ON BLOCK WALL
ON ADDRESS 1

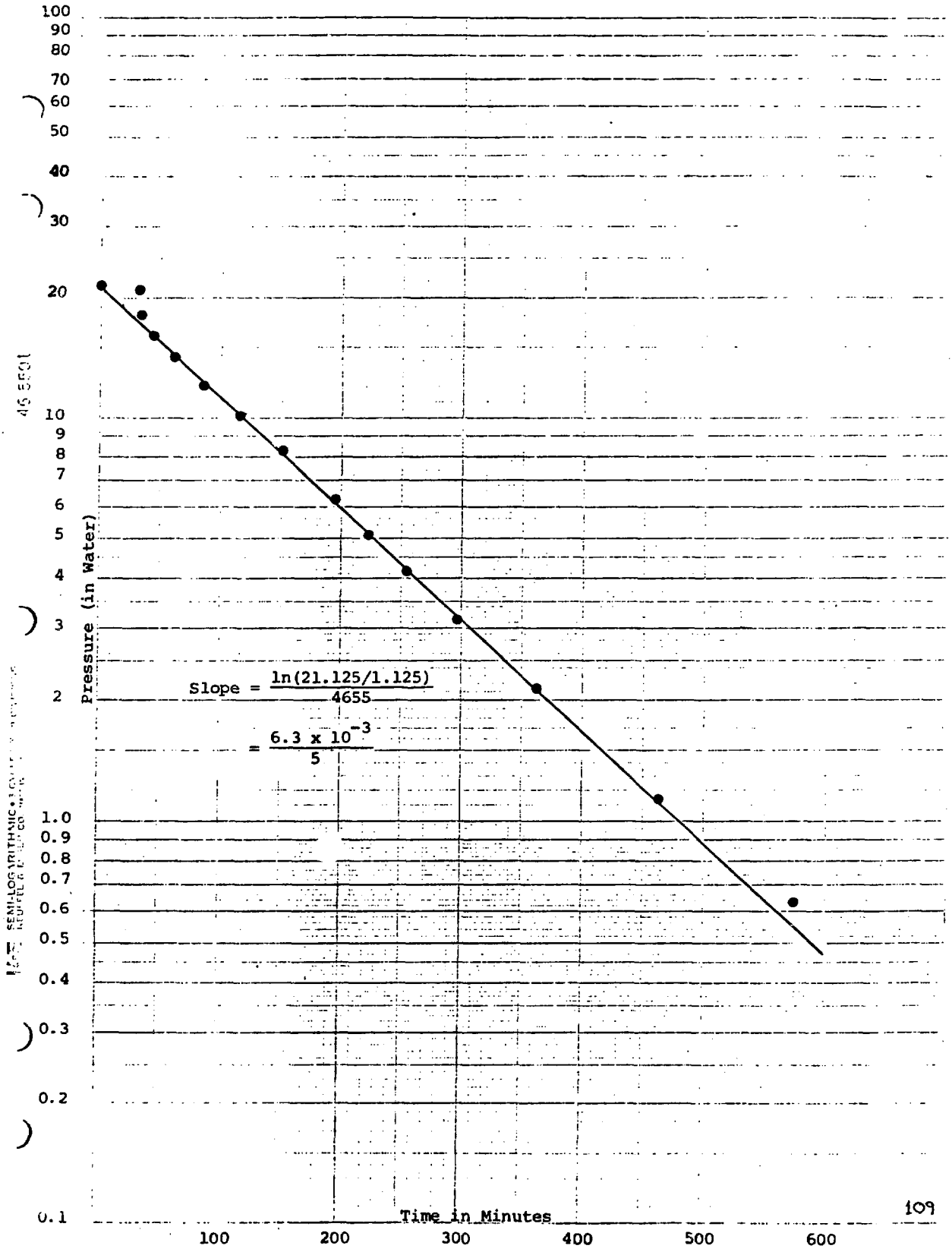
We have performed a number of preliminary calculations to associate the observed radon concentration in the box using the experimentally determined flow rate. In most instances the calculated concentration is higher than that was measured. We do not have an explanation for this discrepancy at this time. This maybe due to a number of reasons, the box was not properly sealed onto the wall and small leakages developed as the time interval exceeded a few hours. Table IV lists the experimental data on March 13, 1979, for the changing in pressure versus time. The room temperature as well as the barometric pressure 15 also given. Figure 4 shows the logarithmic pressure differential ratio versus time. Figure 5 shows the calculated value for radon concentration using equation (4) with Q values calculated by equation (3) versus experimentally measured radon concentration as a function of time. The agreement for shorter time intervals was good.

Barometric Pressure 772 mm Hg

Room Temperature 14°C

TIME IN SECONDS	HEIGHT INCHES OF WATER
1	21.125
34	18.125
44	16.125
64	14.125
89	12.125
117	10.125
154	8.125
196	6.125
223	5.125
256	4.125
296	3.125
361	2.125
465	1.125
574	0.625

Table IV TIME VERUS PRESSURE MEASUREMENTS IN ADDRESS 1


Pressure (in Water)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Slope = ln(21.125/1.125) / 4655
= 6.3 x 10^-3 / 5
Time in Minutes
100
200
300
400
500
600

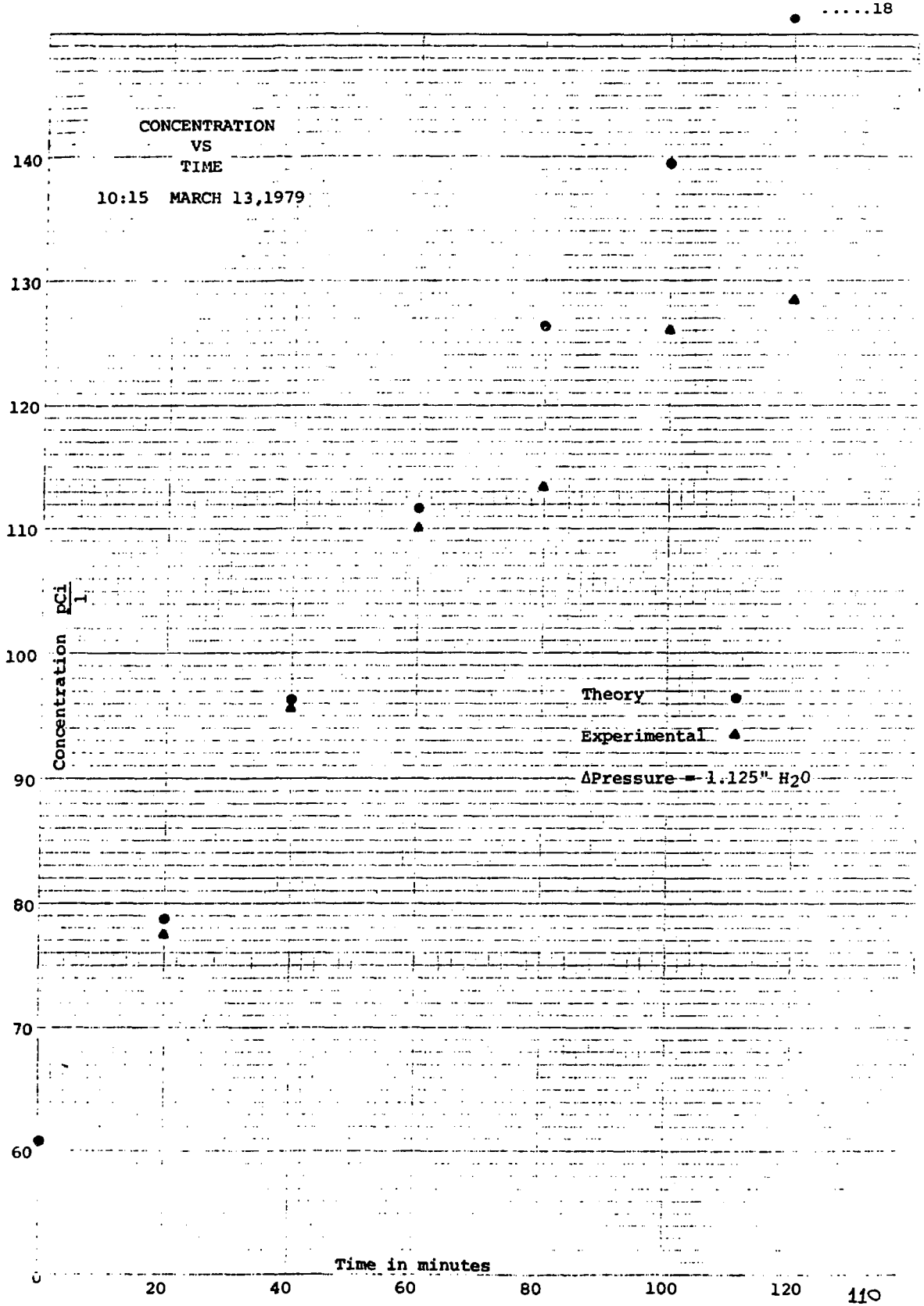


Figure 5 Concentration as a Function of Time

REFERENCE:

1. Radon Infiltration into a House with Concrete Block Walls Radon Workshop March 1979

2. An Introduction to the Kinetic Theory of Gases J. Jeans Cambridge University Press 1962

3. Elementary Fluid Mechanics Vennard and Street John Wiley and Sons 1975

URANIUM CITY RADIATION REDUCTION PROGRAM

FURTHER EFFORTS AT REMEDIAL MEASURES FOR HOUSES WITH BLOCK WALLS, CONCRETE POROSITY TEST RESULTS, AND INTERCOMPARISON OF KUZNETZ METHOD AND TSIVOGLOU METHOD

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January 29, 1980

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I) Introduction

At the Bancroft Workshop in March 1979 held in Bancroft, Ontario, we reported our attempt at reducing the radon concentration and working level by the partial sealant approach (reference 1). At that workshop, we reported that this approach was not successful. In May and June 1979, we attempted to vent the plenums in the block walls as a remedial measure. This report summarized the results and approaches we had taken. The preliminary results showed that this approach was not successful. We also tried using a single venting unit to vent the whole house as a remedial measure for a house with block walls. This proved to be quite successful. The results on the ventilation of houses are published in another report that deals with our experience in ventilation studies. This report also deals with some data on our porosity tests on concrete blocks, part of the results were reported by us in the Bancroft workshop.

II) Description on the Construction of the House

We shall reiterate some of the salient features of house, some of which were missing from the Bancroft report. The basement plan of the house is shown in Figure 1. As of April 1979, the block walls on the west side, north side and east side of the

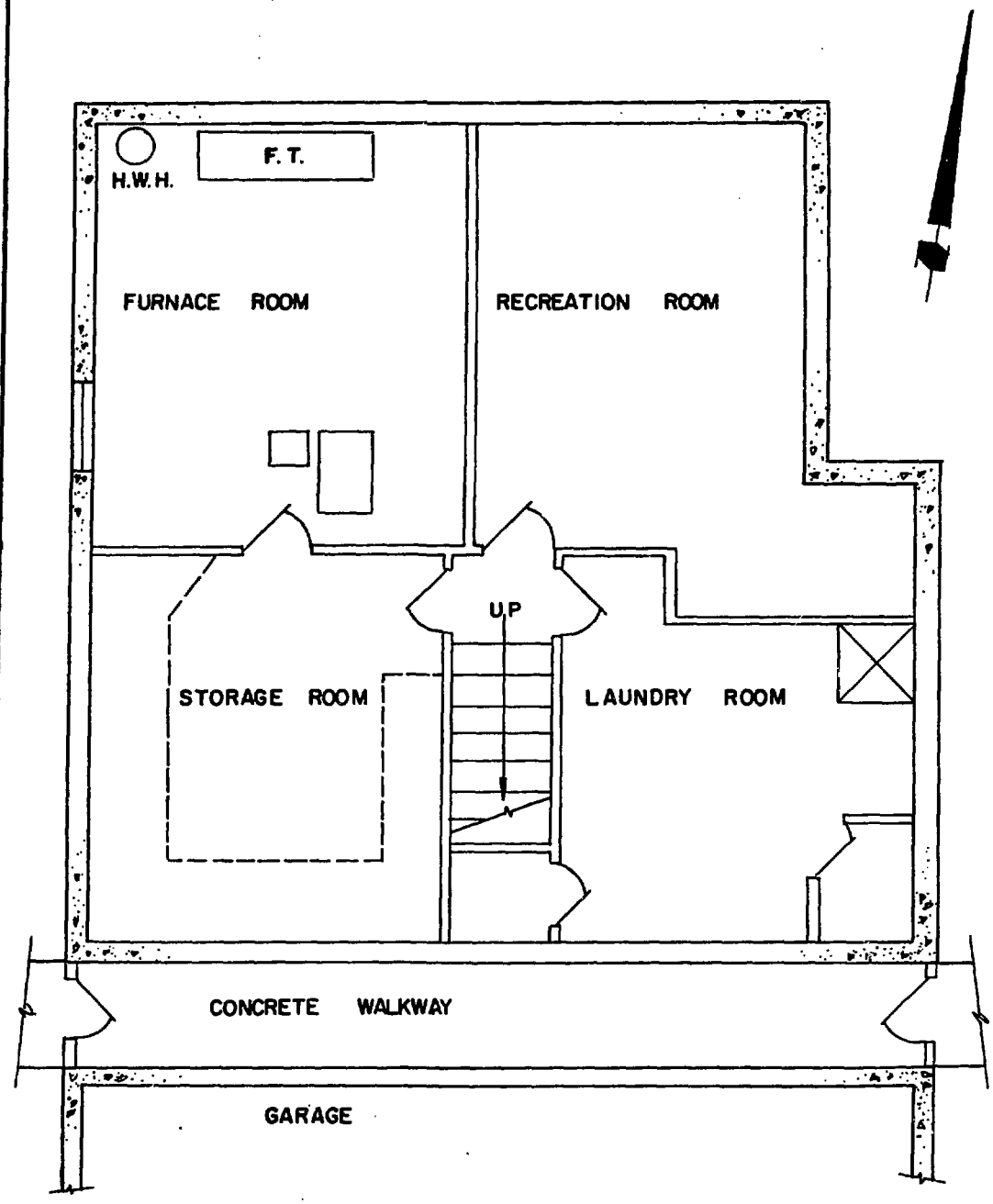

FIG. I
RELATIVE POSITION – GARAGE TO BASEMENT

house had been filled with foam and grout to a height of 3-4 feet. The south wall has a retaining wall adjacent to it. The retaining wall is cast-in-place concrete, quite porous, and has a thickness of approximately five inches. The height is about seven feet. The height of the block walls is about eight feet. On the south side of the house is a storage garage. The slab on which the garage was built extended up to the south wall thus forming a concrete walkway between the garage and the house of about 3½ feet wide. The walkway is sheltered by the extended roof of the house. The walkway is separated from the outside by two partition doors, one on the west side and one on the east side.

III) Further Efforts at Remedial Measures

i) Natural Ventilation of the South Wall

We did not try to fill the south wall with foam and grout, in part due to the uncertainty of the effectiveness of the foam and grout combination and in part due to the difficulties envisioned by the workers in administrating the foaming and grouting process. The chief concern was that the foam and grout wall would have to be injected from a considerable height above the basement floor level. There was the possibility that the grout would solidify and leave very little room for grout. The grout is required both for fire retardation and to augment the radon impedance of the foam. Some air samples from the south wall were taken. The concentration varied between 20 pCi/l to 100 pCi/l, which was the same as observed in other walls previously.

Since previously we had some success in radon and working level reduction by venting the plenums through natural means (reference 1), we enlarged the sample ports to 1/4" in size and left the holes open. This did not reduce the radon or working level in the house. The air samples in the plenum were taken again and the radon concentrations were found to be the same.

ii) General Descriptions on Approaches

It was then decided that we should try to vent the plenums of the block wall to see if this could be an effective remedial measure. The estimated total air volume on the west wall is approximately two thousand litres. The plenums are interconnected through cracks in mortar joints (Reference 1). We aimed for an air exchange rate of one per hour for the combined plenum voids on a single wall.

The make-up air venting of plenums can be achieved in two ways. Firstly, by suction on the plenum voids and introducing the make-up air through the basement, through the top of the plenums block walls. The ground offers much greater impedance to air movement than the empty basement, most of the make-up air will come from the basement. The concentrations in the plenum voids are an order of magnitude higher than that in the basement. The combined volume of the plenum voids is much smaller than the total house volume. The plenums will maintain its relative high temperature in winter. In the case of gas pockets adjacent to the walls, the initial radon concentration may change due to the surge influx of soil gas, however, the replenishing of radon through the soil matrix

eventually brings the radon level to lower levels. Figure 2 showed a schematic diagram of the envisioned make-up air flow when suction was applied to the plenums. The success of this remedial measure depends on the direction of flow of the make-up air into the plenums.

The second method of introducing the make-up air is to pump fresh air directly into the plenums. In winter, when outside temperature reaches -30 to -40°C the input air has to be preheated. In view of the fact that we were developing a ventilation system with preheated air as make-up air, we felt that it was best to test the adequateness of the whole house venting system first.

In these considerations we tested the first approach toward a remedial measure. The attraction of this method is that due to the slight overpressurization of the plenums, the total radon influx would be substantially reduced. The migration of radon through porous media under pressure is the topic of another report. The fan size may be reduced if this approach is taken.

iii) General Arrangement of the Venting System and Results

An axial flow propeller fan was attached onto a one gallon paint can. Five garden hoses with an I.D. of one inch were attached onto the paint can. The joints between the hoses and the can were sealed by epoxy glue and then by putty. The joint between the fan and the paint can was sealed by tape and putty. Five holes were drilled into the plenums approximately 6" above grade on 4'-0" centres. The

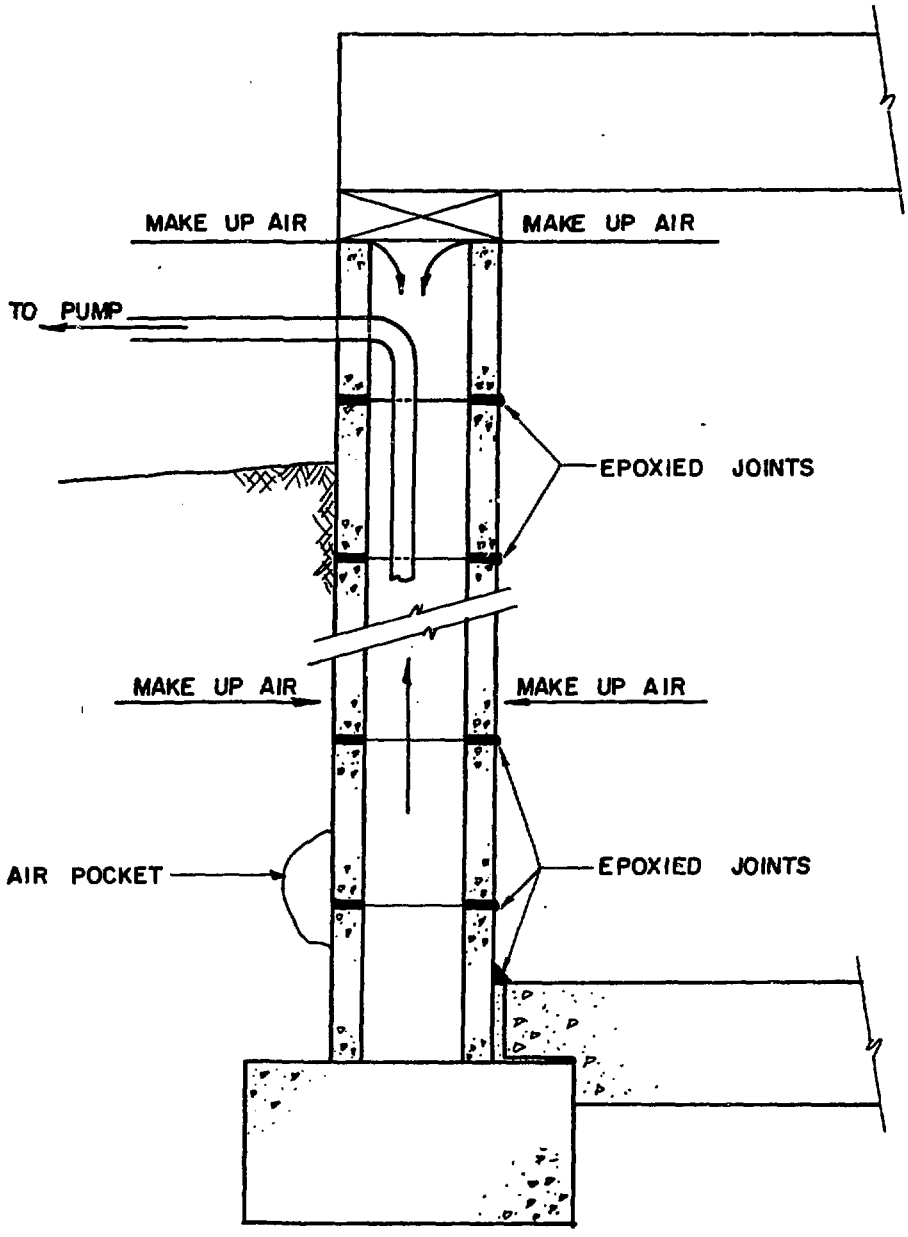

FIG. 2

SCHEMATIC OF MAKE UP AIR FLOW FOR PLENUM VENTING

hoses were forced into the drilled holes until they extended approximately 12" below the drill holes. The joints on the plenum were then sealed by putty. The lengths of the garden hoses varied between 6' and 10'. Two thermometers were also inserted into the plenums at different locations to see if the ventilation would change the overall temperature in the plenums. Figures 3 and 4 show a schematic diagram of this arrangement. The fan was rated at 250 CFM. No further information was available on the volume, CFM versus S.P. and BHP curves for the fan. The garden hoses were obtained locally from the hardware stores in Uranium City. A general reference on fans and performance can be found in Reference 2.

The ventilation assembly was left on the west wall for a week. The west wall was chosen because it had the highest radon concentration in its plenums. After the first day, water was found in two of the rubber hoses. The assembly was dismantled, the water removed and the fan turned on again. Also during the first week, the tenant turned the fans off for two days. The weather turned warm at the same time and the occupants of the house left the windows and doors open during the day. The radon and radon daughter concentration fluctuated wildly over this period. After the water had been removed from the garden hoses, we injected smoke into the hose and visually checked the migration of the smoke to determine the flow rate through the hoses. For the shorter ones the observed speed of the smoke migration was approximately 1.2 m/sec and for the longer hoses the speed was observed to be approximately 0.9 m/sec. The es-

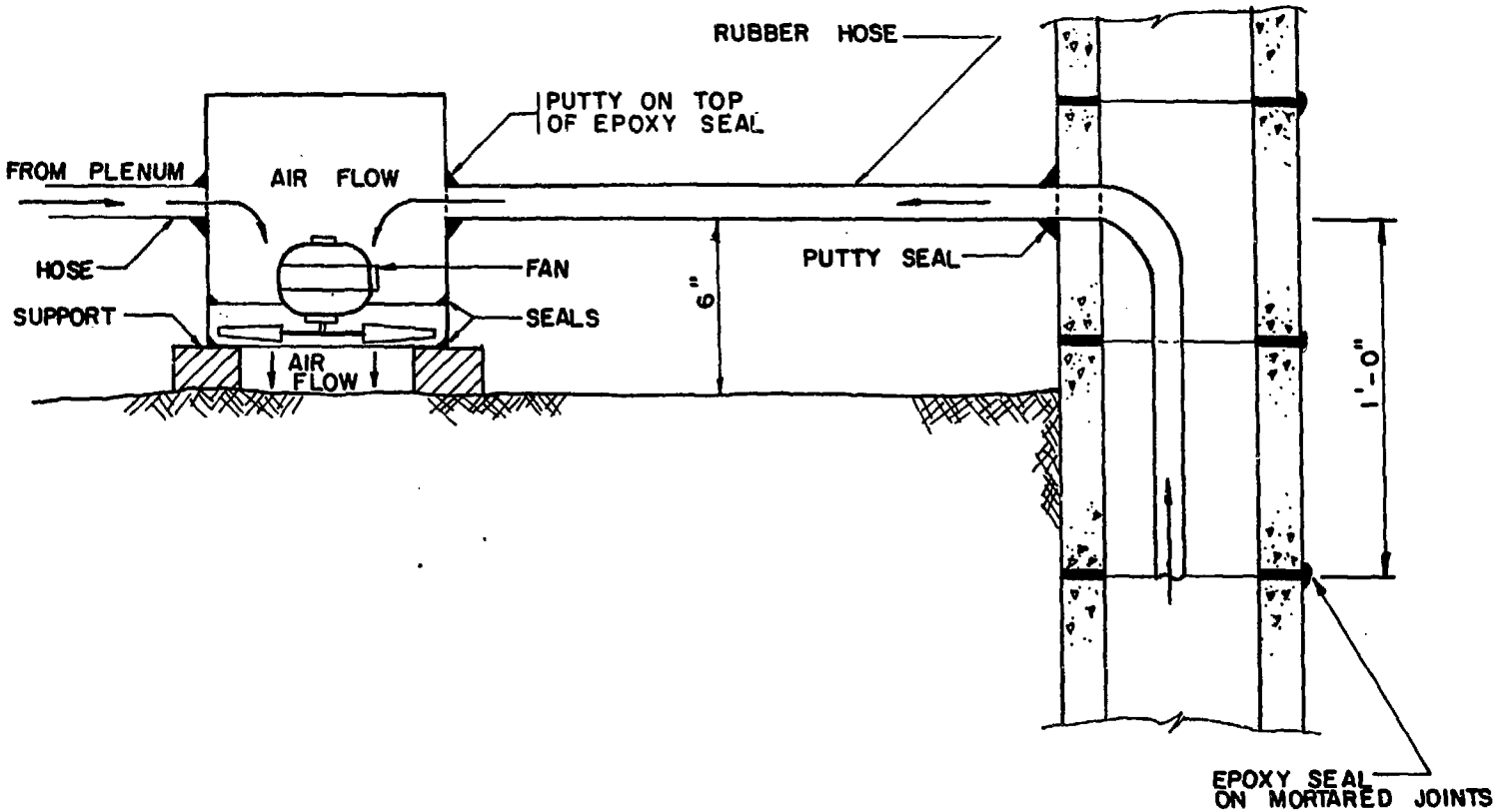

FIG. 3

SCHEMATIC CROSS SECTIONAL VIEW OF FAN ARRANGEMENT FOR PLENUM VENTING

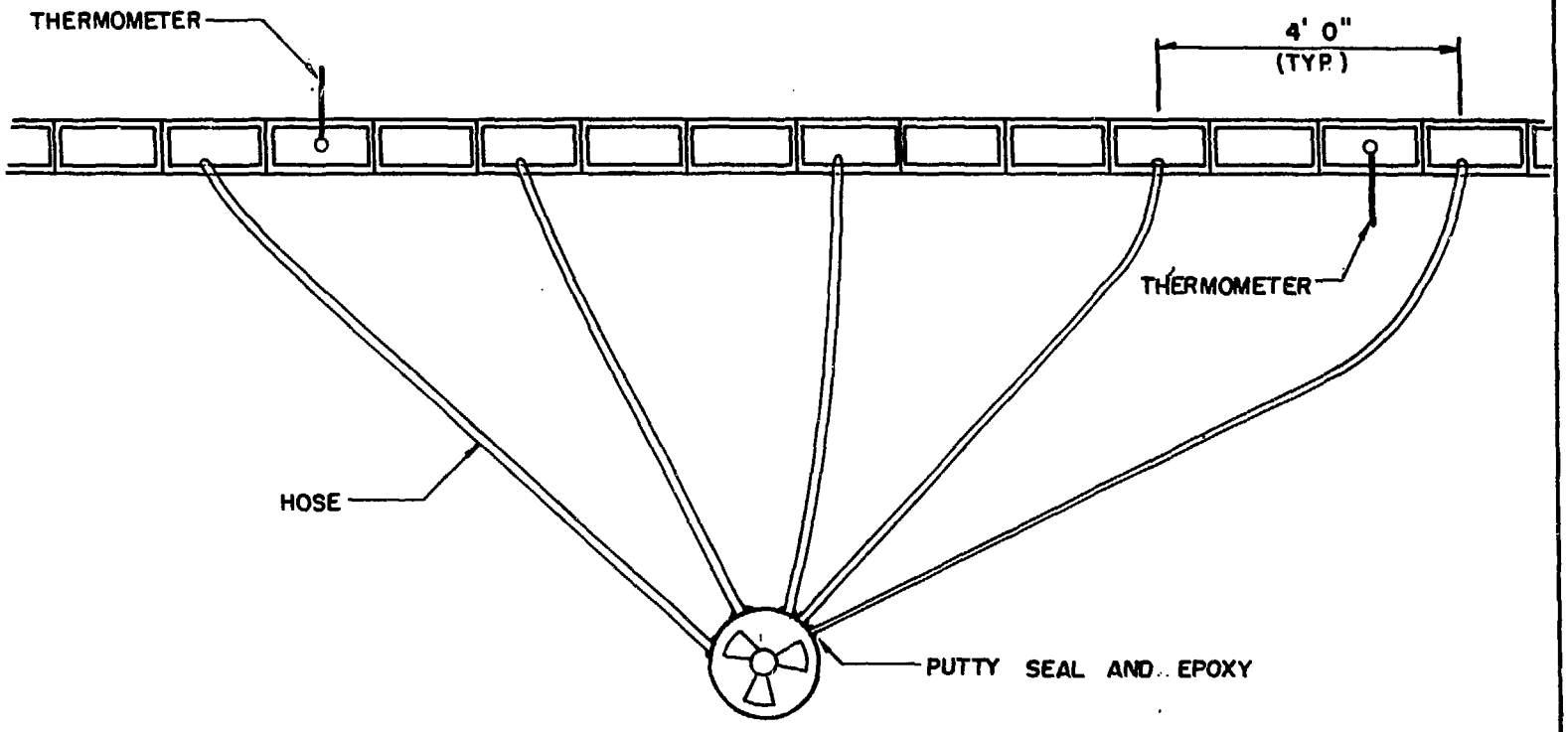

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FIG. 4
SCHEMATIC PLAN VIEW OF FAN
ARRANGEMENT FOR PLENUM VENTING

timate by flow rate per hose varies between 5.4 l/m to 7.2 l/m. This would give an air exchange rate of two an hour for the combined plenum voids in the west wall.

We then enlarged the holes on the north wall and tried to vent the north wall and the west wall. The fan size used and the flow rates were about the same as used on the west wall. The venting on the two walls were continuously carried out for two weeks. The radon and radon daughter concentration did not decrease significantly. To give a final test on the method, another venting unit was set up on the west wall and the three units left on for another week. Still, there was no reduction in radon and working level concentration. We then decided that this approach was not a good remedial method. At the same time, it was observed that the temperature in the plenum voids did not change, and the radon concentration in the plenums did not change substantially. It was then decided that the make-up air in the plenums came mostly through the ground. The radon infiltrating through the joints between the blocks and the footing were sealed partially by grout and foam. There was the possibility that the south wall was supplying most of the radon due to chimney effect. However, the air velocity and the radon concentration in the plenums in the south wall remained relatively unchanged. The testing was terminated in early June and we awaited the testing of the whole house as a remedial measure. Figure 5 shows the data collected between May 22 and June 13, 1979. It can be seen that the radon and radon daughter concentra-

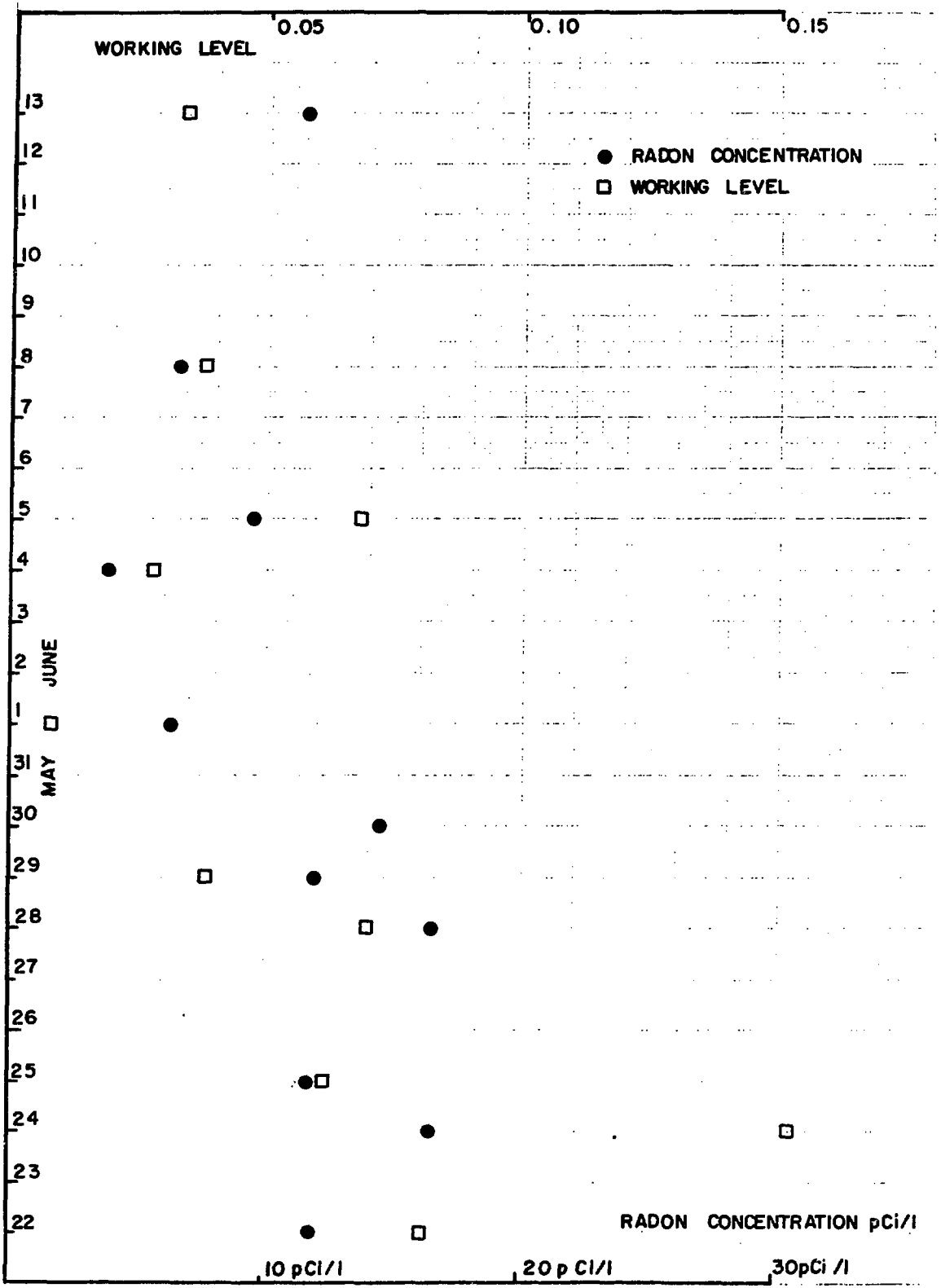


FIG. 5 RADON CONCENTRATION AND WORKING LEVEL

tion did not change during this period.

IV) Results from Porosity Tests on Concrete Slabs

As reported in Bancroft, we found an average value of 12 percent for the water porosity of our test slabs. We then sent the slabs to Saskatoon to the PFRA (Prairie Farm Rehabilitation Agency) Geotechnical Laboratory to have the porosity of the concrete tested. They performed the tests according to the procedures as designated in ASTM: C642-75. The voids percent measured were 13.75%, 14.83%, 19.85% and 15.27%. This gives an average porosity percentage of 15.9%. The air void porosity was estimated by us as approximately 34%. Table I gives some values of porosities for concrete cores taken from basements of houses in Uranium City. A rough average of these numbers gives an average porosity of 11.5 percent. The true air porosity is probably much larger since the mechanism of water migration through concrete pores is quite different from that of air.

V) Tsivoglou Method and Intercomparison with Kuznetz Method

To randomly check our calculations of the working levels, we measured the W.L. by using the Tsivoglou method and comparing the results of Kuznetz Method. The data was taken by two workers with two sets of equipment working side by side. We have not tried to extract further information from the daughter concentrations in the Tsivoglou method. Table II shows a sample comparison between the two methods.

SITE		PERCENTAGE
Address 1		8.9
Address 2		14.5
Address 3		4.2
Address 4		12.5
Address 5		9.4
Unknown		9.7
Address 6		15.4
Address 7		8.6
Address 8		14.7
Address 9		9.4
Address 10		10.4
Standard		17.3
Address 11		11.3
Address 12		15.3
	MEAN	11.5
	S.D.	3.56

TABLE I Void Percentage of Concrete Cores From Uranium City as Tested by Water Saturation Method

ADDRESS	Rn (pCi/l)	W.L. KUZNETZ	W.L. TSIVOGLOU	RaA/Rn	RaB/Rn	RaC/Rn
Address 1	2.44	0.0083	0.0083	0.3175	0.3167	0.3741
Address 2	24.4	0.0535	0.0535	0.536	0.190	0.172
Address 3	33.6	0.1458	0.1441	0.8170	0.4342	0.3146
Address 4	1.12	0.0026	0.0018	0.135	0.120	0.222
Address 5	1.34	0.003	0.0027	0.435	0.232	0.095
Address 6	4.08	0.0066	0.0076	0.402	0.201	0.107
Address 7	6.21	0.0210	0.0218	0.52	0.38	0.27

TABLE II Sample Comparison Between Kuznetz and Tsivoglou Method

References: 1. AECB 1164

Second Workshop on Radon and Radon Daughters in Urban Communities Associated with Uranium Mining and Processing. Bancroft, Ontario 12-14 March, 1979.

2. Industrial Ventilation
A Manual of Recommended Practice 1978
Edwards Brothens.

URANIUM CITY RADIATION REDUCTION PROGRAM

PROPOSAL FOR

LOW PRESSURE

TRANSDUCER AND READOUT

BY

ED HAUBRICH

KEITH CONSULTING
766 Angus Street
Regina, Saskatchewan

FILE: 3067-

DECEMBER 10, 1979

RECOMMENDATIONS

1. Following is the equipment we recommend be purchased:

   (i) 1-PT-310 Series Pressure Transducer $685.00

   (ii) 1 - MOTR - 3506 Digital Transducer Readout $696.00

2. The low pressure sensor is required to accurately monitor and thereby determine radon flux dependence on pressure, pressure dependence on fan size and pressure dependence on interfloor sealing vents, furnaces, fireplaces.

SUMMARY

In the original vent theory the assumption that the flux remained constant was made, but from the data collected we determined that as the fan flow increases the radon flux decreased significantly.

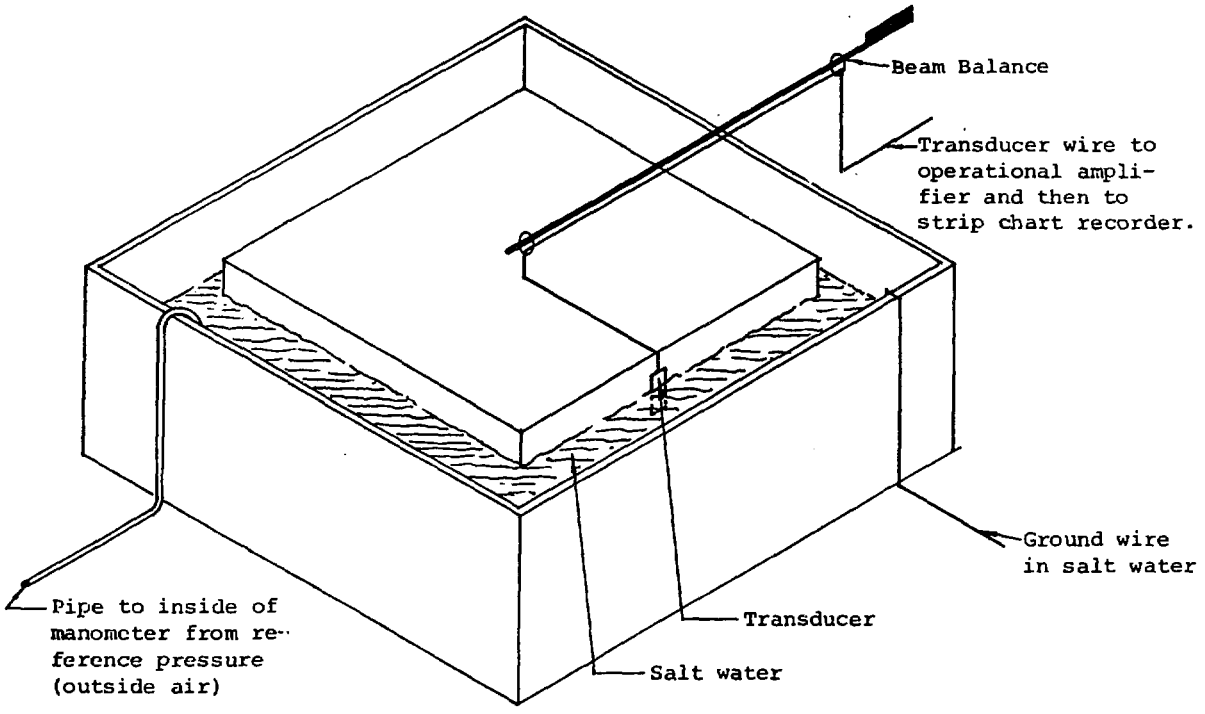
We assumed a pressure dependence on the flux. We built a thick wall manometer to measure pressure changes, and a description of the apparatus is attached. The absolute calibration of this instrument is very rough but the relative pressure measurements are good.

With this manometer we were able to observe a dependence of flux upon pressure but due to inaccuracy of the manometer and the small amount of data, the exact dependence was not determined.

With the purchase of a pressure transducer of sufficient resolution we will be able to better understand the flux dependence upon pressure and the pressure dependence on fan size.

From this understanding a better application of the vent theory and a more efficient method for determining fan size can be applied.

THICKWALLED INVERTED MANOMETER

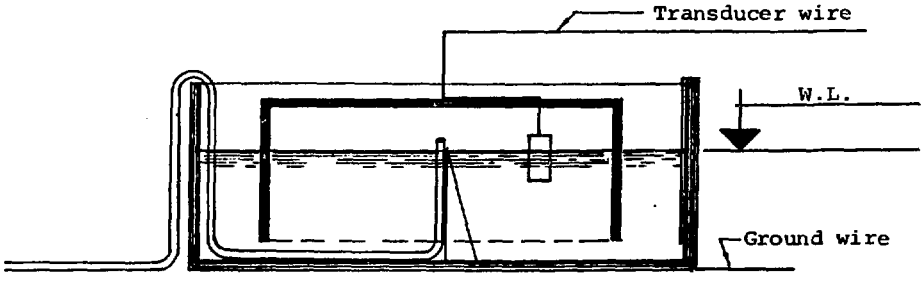


Dimensions in Cm 20x80x30

Strip Chart Recorder Controlled by 1802 Micro-Processor

The transducer wire is connected to an operational amplifier and then to a strip chart recorder.

The timing of the strip chart recorder was controlled by #1802 Micro-Processor.



Calibration of Chart Recorder and Manometer

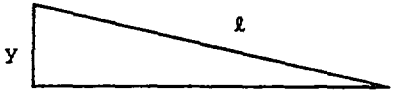
November 27, 1979 [redacted]

BOX HEIGHT	WATER HEIGHT	ΔH	AVERAGE PRESSURE	SCALE
15.2	34.8	19.6	0.0	Ave.
13.5	34.8	21.3 Ave. 20.45	0.0	2.1
13.75	34.7	20.95	+ vent @ 191 CFM out	9.0
14.00	34.8	20.8	o vent Normal Pressure	8.2

$$\frac{9.0 - 2.1}{(20.95 - 20.45)} = \frac{13.8 \text{ scale Recorder}}{\text{units}}$$

Calibration of Inverted Manometer using Inclined Manometer

$y = 91.4 - 95.3$
$\ell = 110.5$



$$\frac{\Delta y}{\Delta x} = \frac{y}{\ell}$$

$y = 0.0353X$

Zero Reading 15.00 4'5/8

BOX HEIGHT	WATER HEIGHT	ΔH	ℓ.	Δℓ = ℓ
8.5	49	40.5	14 1/8	4 6/8
39.2	49	9.8	15 2/8	3 6/8
		30.7 units	1.125 + 1.0	= 2.125"

True Pressure

$$\Delta y = \frac{(0.0353)(2.125")}{30.7 \text{ units}} = \frac{0.075" \ H_2O}{30.7 \text{ units}}$$

Pressure Conversion Factor for Inverted Manometer

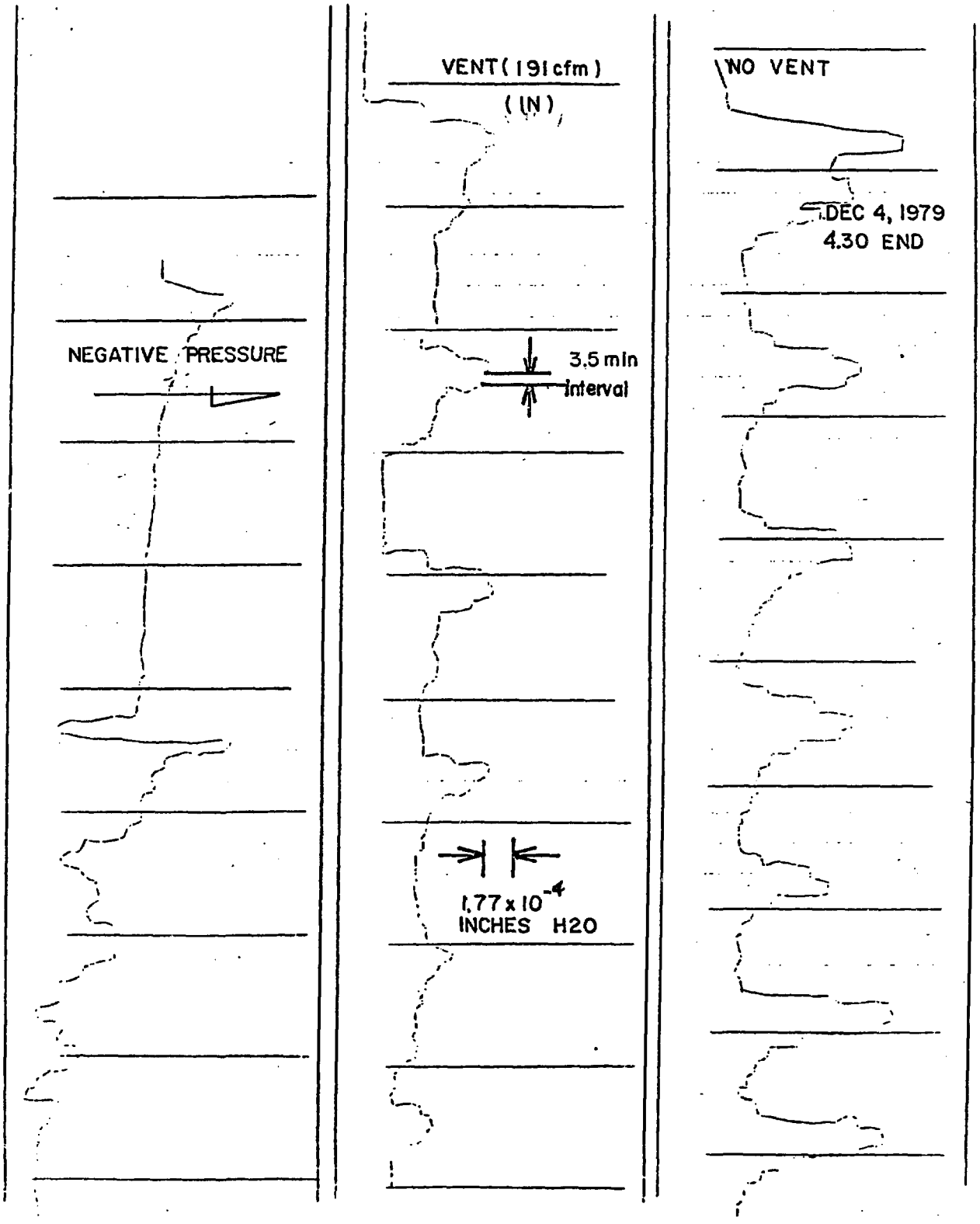
$$\frac{0.00244" \ H_2O}{1 \text{ scale unit}} \qquad 1 \simeq 15 - 20\%$$

Combined Conversion

$$\frac{0.0024" \ H_2O}{\text{Scale Unit}} \quad \frac{\text{Units}}{13.8 \text{ Recorder}}$$

$$= 1.771 \times 10^{-4}" \quad \frac{H_2O}{\text{Unit on Recorder}} \qquad \pm \simeq 20 - 25\%$$

For November 27, 1979 from 20:26 and any time after.


NEGATIVE PRESSURE
VENT (191 cfm)
(IN)
3.5 min
interval
1.77 x 10^-4
INCHES H20
NO VENT
DEC 4, 1979
4.30 END

$V_m = 1.74 \times 10^5$ [redacted]

$V_b = 1.22 \times 10^5$ [redacted]

	CONC.		AIR EXCHANGE/hr.		
C.F.M.	M.	B.	M.	B.	FLUX pCi/min.
0	17.9	18.97	0.317	0.435	33,234
254	0.2257	0.457	1.016	1.079	1,669
98	5.03	2.77			12,430
180	3.2	1.6			10,465
-191	20.64	21.74			91,232

This assumes a linear dependance on air exchange with fan flow between 0 & 254 C.F.M.

Where at zero CFM, $r_b = 0.435/hr$, $r_m = 0.317/hr$.

and at 254 CFM, $r_b = 1.079/hr$, $r_m = 1.016/hr$.

Will assume that a fan blowing air out will produce the same air exchange as a fan blowing in.

Therefore,

$$Flux = (QM_m + B_m)\ V_m C_m + (QM_b + B_b)\ V_b C_b$$

WHERE: Q = FAN FLOW IN CFM

M = SLOPE OF AIR EXCHANGE VERSUS FAN FLOW

B = INTERCEPT OF AIR EXCHANGE VERSUS FAN FLOW

C = CONCENTRATION

SUBSCRIPTS:

m = MAIN FLOOR

b = BASEMENT

$V_m = 1.56 \times 10^{5} \ell$

$V_b = 1.7 \times 10^{5} \ell$

Q	RADON CONC. pCi/ℓ		AIR EXCHANGE ℓ/hr		FLUX pCi/min
C.F.M.	MAIN	BSMT.	MAIN	BSMT.	pCi/min.
0	10.39	19.34	0.516	0.362	33,775
98	2.91	3.18			7,177
116	2.12	1.75			4,647
123	2.53	2.11			5,437
306	0.78	0.85			1,927

This assumes the main floor air exchange remains constant and the basement air exchange is caused by the vent fan unit and the original basement air exchange.

This approximation is fairly good but it would most likely underestimate the true flux by a small amount.

Therefore,

$$r_m V_m C_m + r_b V_b C_b + QC_b = \text{FLUX}$$

WHERE: Q = Flow in Liters Per Hour

r = Air Exchange Rates

V = Volume Basement

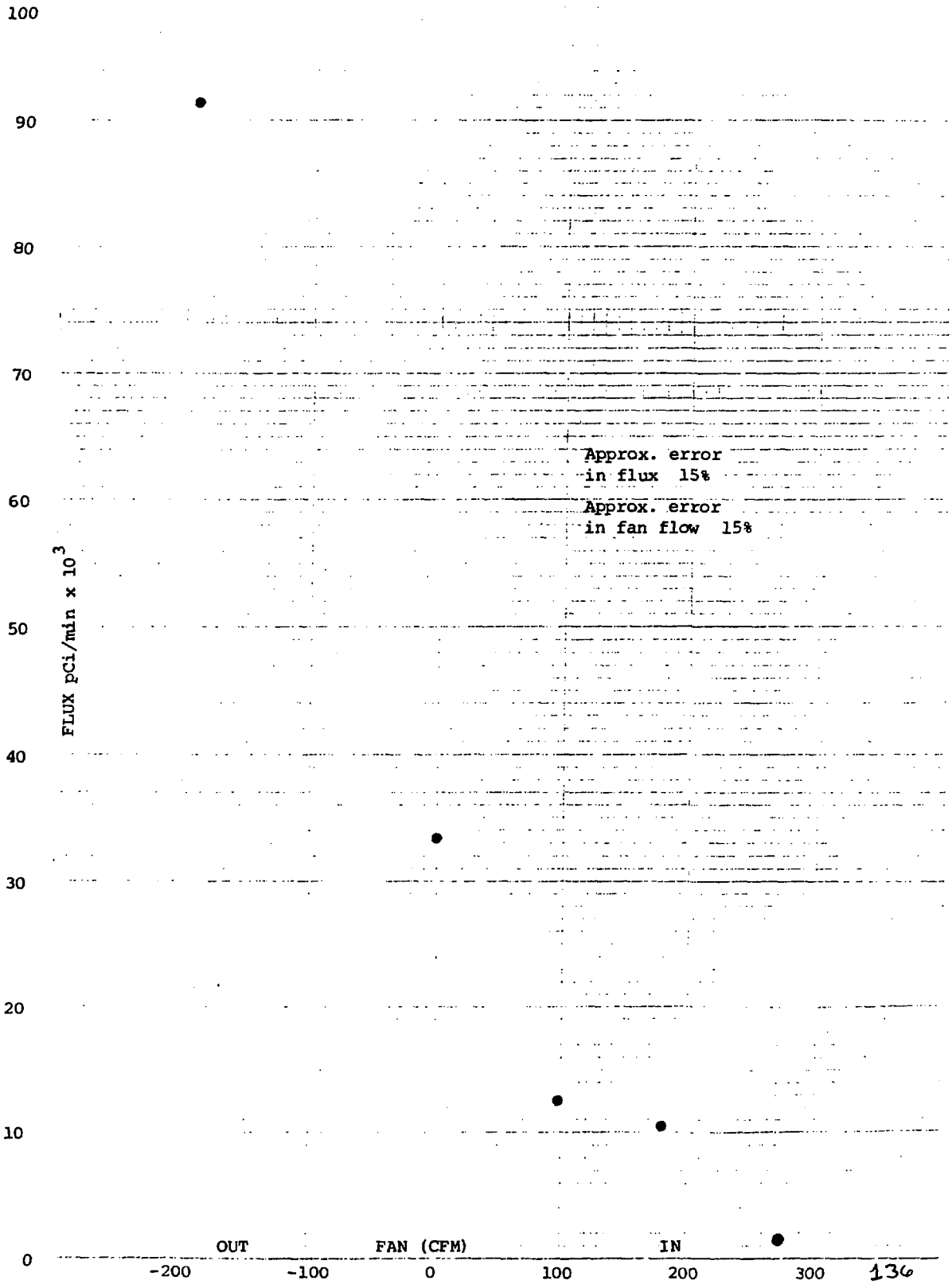
C = Concentration of Radon

SUBSCRIPTS:

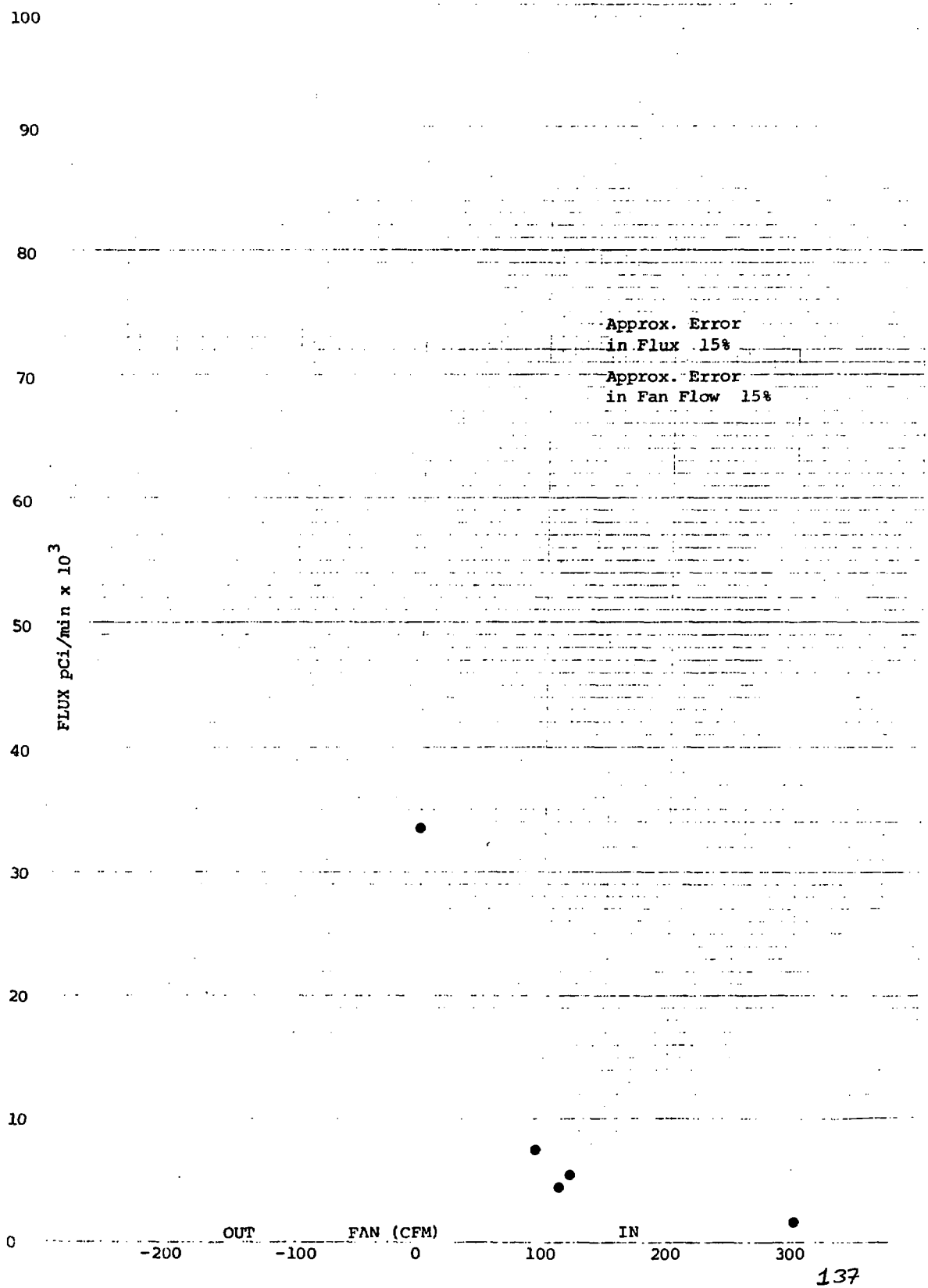
m = Main Floor

b = Basement

FLUX VS. FAN FLOW [redacted]



FLUX VS. FAN FLOW [redacted]



[redacted]

FAN CFM	PRESSURE H_2O in.	FLUX pCi/min.
0	-3.5×10^{-4}	33,775
98 IN		7,177
116 IN	-1.7×10^{-4}	4,647
123 IN		5,437
306 IN		1,927

The strip chart data on 113 Rix shows a sinusoidal effect due to the furnace.

Whether this effect is due to the furnace fan or the furnace burner and its exhaust up the chimney we have not determined at this time.

We have also not determined how much natural ventilation out the chimney contributes to the negative pressure in the basement.

Main floor pressures have also not been taken.

[redacted]

FAN CFM	PRESSURE H_2O	FLUX pCi/min.
191 OUT	-4.2×10^{-3}	≈ 91,232
0	-2.41×10^{-3} S.D. = 3.3×10^{-4}	33,234
80 IN	-7.92×10^{-4}	
98 IN		12,430
180 IN		10,465
215 IN	7.9×10^{-5} S.D. = 7.0×10^{-4}	
254 IN		1,669

Estimated Errors

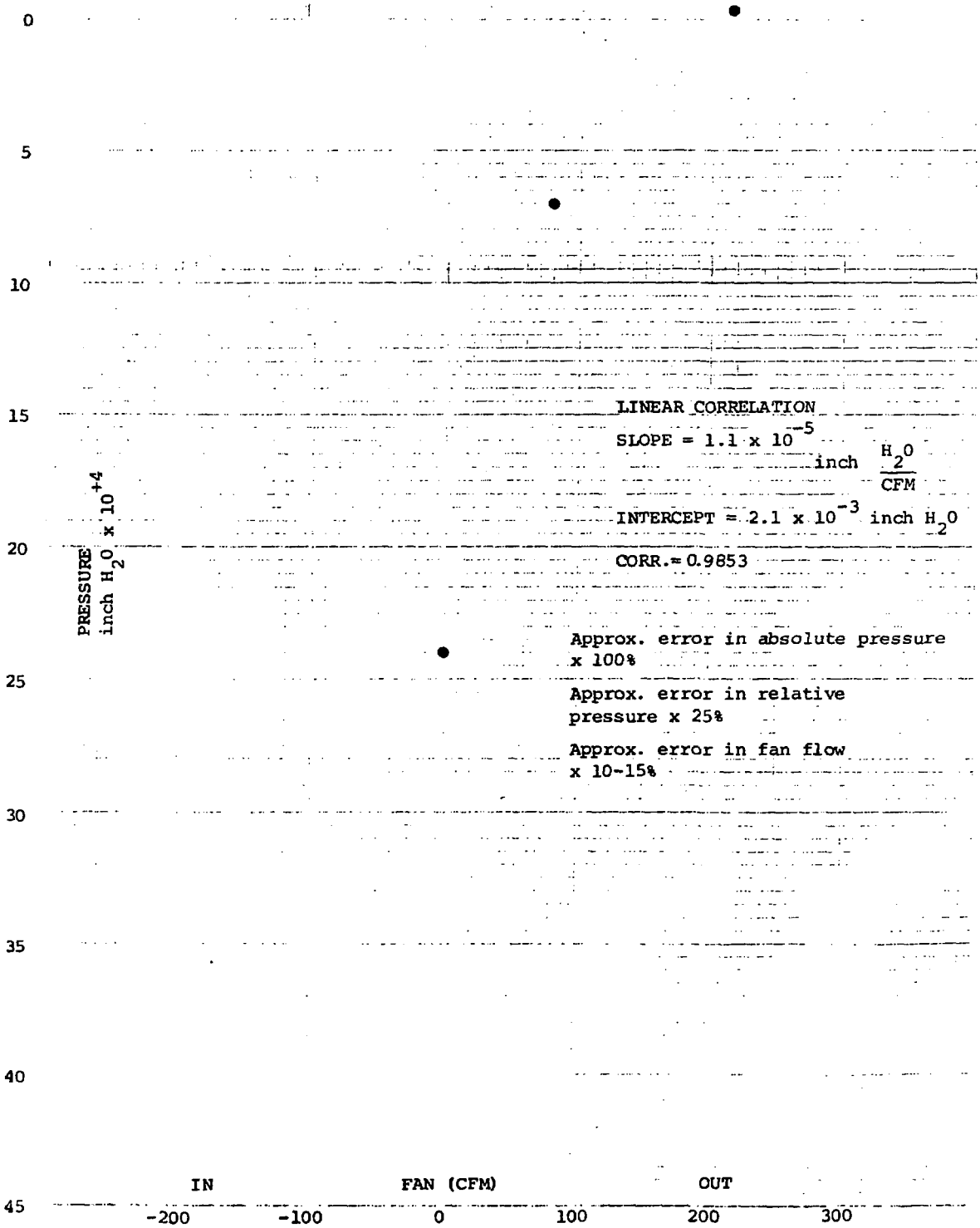
Fan Speeds ≈10%

ABSOLUTE pressures ≈100%

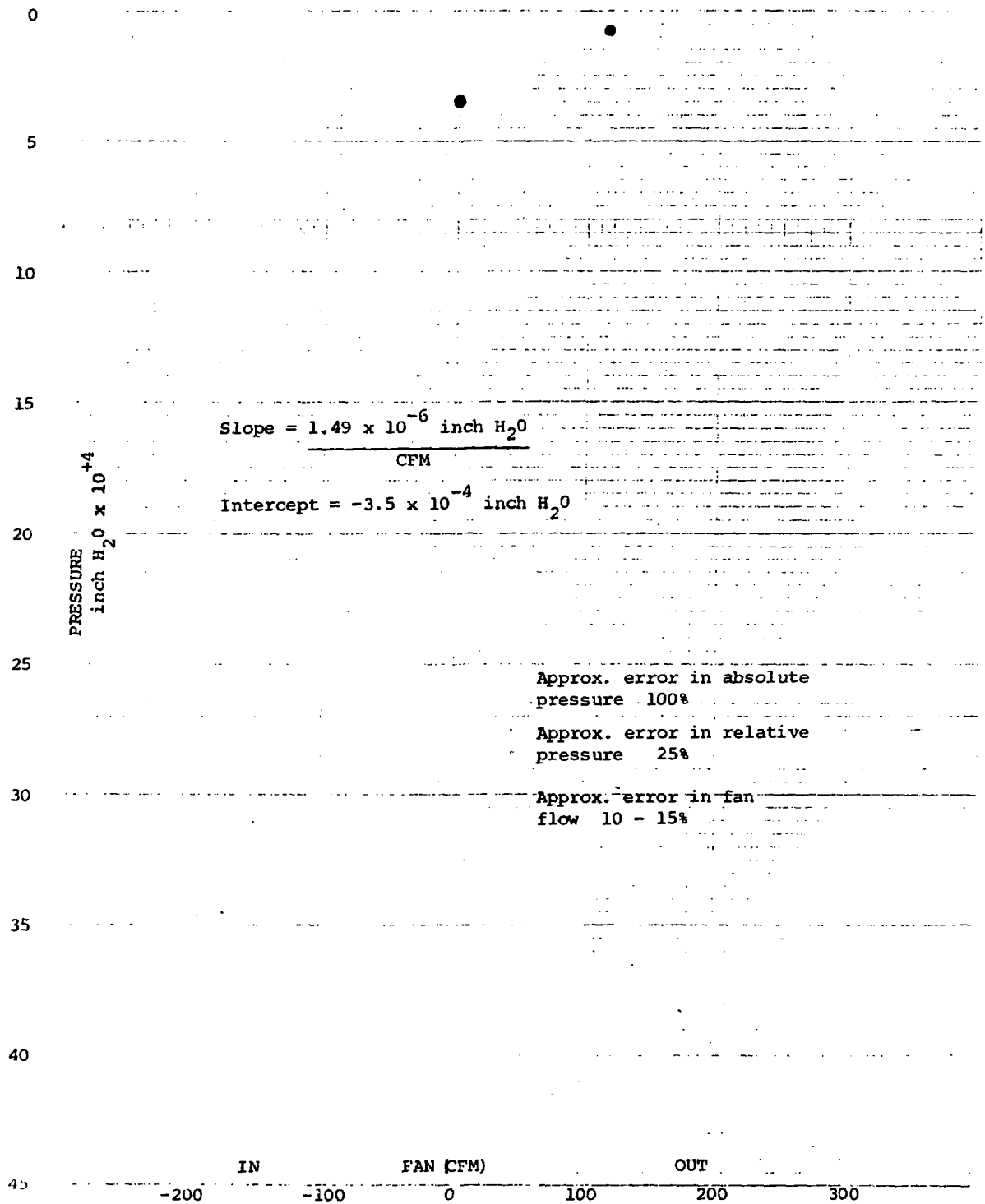
RELATIVE pressures ≈25%

Flux ≈15%

ALL PRESSURES RELATIVE TO OUTSIDE


0
5
10
15
20
25
30
35
40
45
PRESSURE x 10^{+4} inch H_2O
LINEAR CORRELATION
SLOPE = 1.1×10^{-5} inch $\frac{H_2O}{CFM}$
INTERCEPT = 2.1×10^{-3} inch H_2O
CORR.= 0.9853
Approx. error in absolute pressure x 100%
Approx. error in relative pressure x 25%
Approx. error in fan flow x 10-15%
IN
FAN (CFM)
OUT
-200
-100
0
100
200
300

PRESSURE VS. C.F.M. [redacted]



URANIUM CITY RADIATION REDUCTION PROGRAM

CALIBRATION OF RADIATION MEASURING EQUIPMENT AND INTERCOMPARISONS

BY

M.K. LEUNG

KEITH CONSULTING
766 Angus Street
Regina, Saskatchewan

File: 3067

December, 1979

NOTICE

The results in this report are constantly re-evaluated. Further accumulated data may change some of the results quoted in this report.

TABLE OF CONTENTS

CALIBRATION OF RADIATION MEASURING EQUIPMENT AND INTERCOMPARISONS

I) Introduction

In the radiation reduction program in Uranium City, we have to use a number of instruments to measure the radiation levels in houses. These include gamma radiation, radon gas concentration measurements, and working level measurements. This report gives an overview on the calibration procedures, results of calibrations on these instruments, and intercalibration results with other groups. The instruments include EDA RD-200 radon gas counters, EDA scintillation cells, TM-372 alpha counters, PRM-7 gamma meters, and a number of radioactive sources. For the RD-200 counters and EDA cells, the primary standardization is done by the Saskatchewan Research Council (SRC) in Saskatoon. This is carried out semi-annually. One of the radioactive sources is also calibrated by the SRC on an annual basis. The gamma meters are calibrated by the radiation safety officer at the University of Saskatchewan in Saskatoon. This is done annually. The primary standardizations are then used for intercalibration of the other instruments. Cross calibration is done routinely every four to eight weeks. Gamma meters are calibrated every three months.

II) Radon Measuring Equipment

i) Build up and Decay Factor Study

a) Introduction The recommended waiting period for counting radon gas is 3 hours. We have measured and derived the expression for the alpha build up as a function of time in a gas cell to study the possibility of shortening the waiting interval. We have

also combined the build up factor with the radon decay to give an overall factor to convert counts per minute into activity. This overall factor is referred to as the decay factor in subsequent paragraphs and reports. As a consequence of this study, we have decided to lower the waiting period from three hours to between ninety minutes and three hours to give us more flexibility in our counting schedules.

b) Theoretical Considerations The original decay factor given assumes the presence of a constant source of radon gas. The sealed off EDA gas cell is not a constant source of radon. Due to the long half life of radon (3.62 days), the discrepancy in the results between the two assumptions is not very large. We have decided to investigate and implement the results for an isolated source of radon.

For a constant source of radon, with an initial activity of I_o, the amount of activities of Radium A (I_1), Radium B (I_2), and Radium C (I_3) as a function of time are given by:

$$I_1(t) = I_o\ (1 - e^{-\lambda_1 t}) \qquad (1)$$

$$I_2(t) = I_o\ (1 - \frac{\lambda_1}{\lambda_1-\lambda_2} e^{-\lambda_2 t} - \frac{\lambda_2}{\lambda_2-\lambda_1} e^{-\lambda_1 t}) \qquad (2)$$

$$I_3(t) = I_o\ (1 - \frac{\lambda_2}{\lambda_2-\lambda_1}\ \frac{\lambda_3}{\lambda_3-\lambda_1} e^{-\lambda_1 t} - \frac{\lambda_1}{\lambda_1-\lambda_2}\ \frac{\lambda_3}{\lambda_3-\lambda_2} e^{-\lambda_2 t}$$

$$- \frac{\lambda_1}{\lambda_1-\lambda_3}\ \frac{\lambda_2}{\lambda_2-\lambda_3} e^{-\lambda_3 t}) \qquad (3)$$

The same equations can also be found in reference 1.

For an isolated source of radon, the corresponding cascade equations for the chain decay are:

$$I_1(t) = \frac{\lambda_1 I_0}{\lambda_1-\lambda} (e^{-\lambda t} - e^{-\lambda_1 t}) \quad (4)$$

$$I_2(t) = \frac{\lambda_2 I_0}{\lambda_1-\lambda} \left\{ \frac{\lambda_1}{\lambda_2-\lambda} (e^{-\lambda t} - e^{-\lambda_2 t}) - \frac{\lambda_1}{\lambda_1-\lambda_2} (e^{-\lambda_2 t} - e^{-\lambda_1 t}) \right\} \quad (5)$$

$$I_3(t) = \frac{\lambda_2 I_0}{\lambda_1-\lambda} \left\{ \frac{\lambda_1}{\lambda_2-\lambda} \{ \frac{\lambda_3}{\lambda_3-\lambda} (e^{-\lambda t} - e^{-\lambda_3 t}) - \frac{\lambda_3}{\lambda_2-\lambda_1} (e^{-\lambda_1 t} - e^{-\lambda_3 t}) \} \right.$$

$$\left. - \frac{\lambda_1}{\lambda_1-\lambda_2} \{ \frac{\lambda_3}{\lambda_2-\lambda_3} (e^{-\lambda_3 t} - e^{-\lambda_2 t}) - \frac{\lambda_3}{\lambda_3-\lambda_1} (e^{-\lambda_1 t} - e^{-\lambda_3 t}) \} \right\} \quad (6)$$

The notations are:

I_o : initial radon activity

I_1 : Activity of first decay product at time t

I_2 : Activity of second decay product at time t

I_3 : Activity of third decay product at time t

λ : Decay constant of initial nuclei (1/t)

λ_1 : Decay constant of first decay product (1/t)

λ_2 : Decay constant of second decay product (1/t)

λ_3 : Decay constant of third decay product (1/t)

For radon:

$$\lambda = \frac{1}{7920} \quad \frac{1}{\text{min}} \qquad \text{Radon} \qquad (7)$$

$$\lambda_1 = \frac{1}{4.39} \quad \frac{1}{\text{min}} \qquad \text{Radium A} \qquad (8)$$

$$\lambda_2 = \frac{1}{38.6} \quad \frac{1}{\text{min}} \qquad \text{Radium B} \qquad (9)$$

$$\lambda_3 = \frac{1}{28.4} \quad \frac{1}{\text{min}} \qquad \text{Radium C} \qquad (10)$$

The percentage alpha build up at time t in a scintillated alpha counter compared to the total alpha counts at three hours for an isolated radon source is given by:

$$\text{FACTOR} = \frac{I_{Rn}(t) + I_1(t) + I_3(t)}{I_{Rn}(3) + I_1(3) + I_3(3)} \quad (11A)$$

in the equation, the unit for time t is in hours.

The corresponding equation for a constant radon source is given by:

$$\text{FACTOR} = \frac{I_o + I_1(t) + I_3(t)}{3I_o} \qquad (11B)$$

c) Experimental Results and Comparisons with Theoretical Calculations To test the validity of the equations (11A) and (11B) and the comparison between the two, three radon scintillation cells were chosen at random and three different samples of radon of different concentrations were taken. These cells were then counted in different RD-200 counters chosen at random. For two of the cells, counting was started five to ten minutes after the radon sampling was taken. The last cell was counted 50 (fifty) minutes after the radon sample was taken. For all cells, counting was done by taking counts in one minute intervals until three hours had elapsed from the end time of the radon sampling. The counts per minute varied from approximately one hundred and fifty to ten thousand. To obtain an averaged $I_{Rn}(3) + I_1(3) + I_3(3)$, the mean for the counts taken during the last ten minutes of the counting period was used. The results are plotted in Figure 1. The results from computation from equations (11A) and (11B) are also plotted in Figure 1. It can be seen that the experimental data agrees quite well with equation 11A. We have not done a chi-square comparison of the data to the two theoretical curves. It can also be seen that the relative alpha build up percentage at 90 minutes is close to 92 percent. It was then decided that a waiting period between one hour and a half and three hours does not change the accuracy of

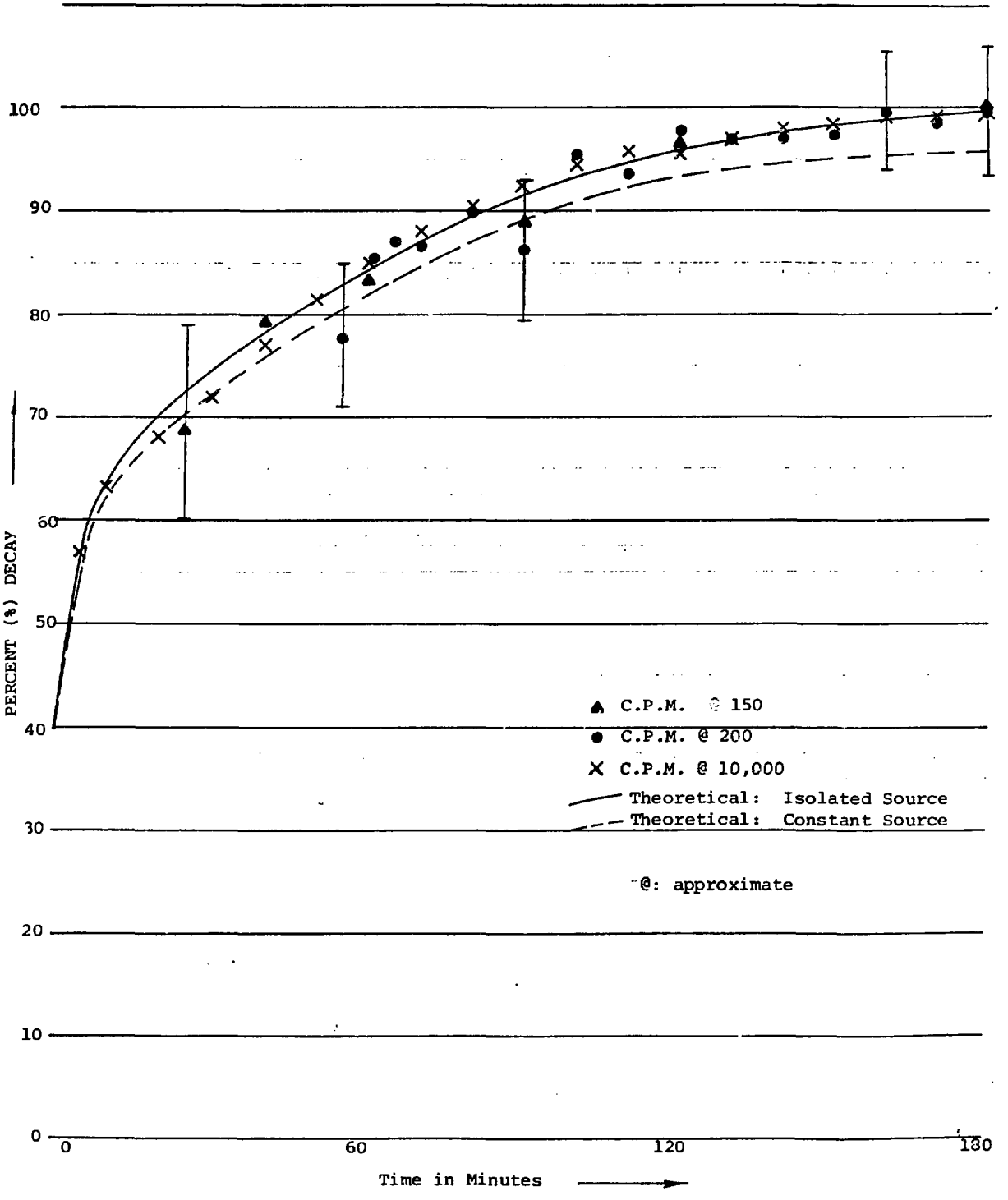


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Figure 1 DECAY FACTOR CURVE

the data, and we changed our waiting period accordingly.

ii) Cell Efficiencies

The net counts per minute is converted into concentration in pCi/L by the following equation:

$$CONC = \frac{\text{Net Counts Per Minute}}{(Y)\ (\text{Decay Factor})} \qquad (12)$$

We have already dealt with the decay factor in (i). The yield factor Y, alternately referred to as the cell efficiency in this report are calibrated by the Saskatchewan Research Council (SRC) in Saskatoon. These are done semi-annually. Each time ten to fifteen cells were sent to the SRC for calibration. These cells are then used to cross calibrate the other cells. The cross calibration has been done in the following way.

a) In the initial stage, approximately twenty cells were assigned to a particular RD-200 counter. These were grouped to a certain counter because they had favourable plateau characteristics on that counter. Cells sent away for calibration came from each of these groups. The standardized cells in this group are used to cross calibrate the rest of the cells in the group.

b) Cross calibrations between the groups were then carried out to check the dependence of groups to counters. After extensive cross calibration of this nature, we have decided that most cells can be used on all counters.

c) During calibrations, and sometimes randomly, cells are checked for leakages. When leakages occur we attempt to

repair the cells. The repaired cells are recalibrated.

d) Table I shows the results of a sample standardization by the Saskatchewan Research Council.

e) For 1978, the averaged efficiency over 94 cells was 0.598 with a standard deviation of 0.084 and a standard error of 0.0086.

f) The most recent calibration was carried out in late September 1979. The cross calibration is almost finished. This data has not yet been evaluated.

g) Table II shows a sample cross calibration of cells on different RD-200 counters. Most of the efficiences quoted for the cells are averaged values over two or more readings.

h) In August 1979 an intercomparison was carried out together with Mr. A.J. MacKay, Radiation Health Officer, Department of Labour, Province of Saskatchewan. Table III lists part of the results taken during the intercomparison. Mr. MacKay uses an overall yield factor of 1/4 and a decay factor due to a constant source of radon. For radon concentration of 5pCi/L and above, the agreement between the two sets of data is good. No attempts had been made to compare the data when the counts per minute from the air samples is very close to cell backgrounds.

III) W.L. Measurements

i) Introduction The W.L. measurements are carried out by using the modified Kusnetz method. The filters are counted in RD-200 counters or TM-372 alpha counters. The efficiency

TABLE I

CELL NO.	MEASURED EFFICIENCY	AVG. EFFICIENCY
RD-7	0.63	0.63
RD-9	0.619, 0.622, 0.617	0.62
RD-26	0.564, 0.566	0.57
RD-27	0.579, 0.583	0.58
RD-29	0.605	0.61
RD-45	0.650	0.65
RD-46	0.635	0.64
RD-61	0.655, 0.659	0.66
RD-63	0.684	0.68
RD-64	0.719, 0.700	0.71

Table I SAMPLE STANDARDIZATION BY SRC - AUGUST 1978

TABLE II

CELL NUMBER	EFFICIENCY RD-200 NUMBER						MEAN	S.D.	S.E.
	1104	1200	1176	1249	1261	1171			
26	0.53	0.51	0.55	0.49	0.57	0.54	0.53	0.03	0.01
35	0.53	0.53	0.56	0.51	0.61	0.56	0.55	0.04	0.02
47	0.66	0.62	0.64	0.63	0.67	0.65	0.65	0.02	0.01
63	0.66	0.68	0.70	0.64	0.68	0.69	0.68	0.02	0.01
64	0.64	0.60	0.69	0.62	0.71	0.68	0.66	0.04	0.02
61	0.62	0.62	0.60	0.59	0.66	0.65	0.62	0.03	0.01
67	0.63	0.64	0.71	0.62	0.68	0.66	0.66	0.03	0.01
81	0.60	0.60	0.63	0.59	0.62	0.64	0.61	0.02	0.01
82	0.64	0.63	0.69	0.66	0.68	0.65	0.66	0.02	0.01
83	0.66	0.62	0.64	0.65	0.66	0.66	0.65	0.02	0.01
84	0.66	0.65	0.66	0.64	0.67	0.67	0.66	0.01	0.01
88	0.65	0.63	0.67	0.66	0.66	0.67	0.66	0.02	0.01

Table II SAMPLE COUNTER VERSUS CELL CALIBRATION

TABLE III

ADDRESS	DATE 1979	A.J. MACKAY SASK. DEPT. OF LABOR		KEITH CONSULTING	
		PCi/L	CPM	PCi/L	CPM
A	Aug.16	7.14	4.0	7.54	4.13
		2.68	1.5	ø 1)	ø 1)
B	Aug.16	15.35	8.6	13.85	9.77
		15.89	8.9	14.36	8.50
		13.39	7.5	15.16	9.60
		11.25	6.3	12.87	8.40
C	Aug.16	8.03 2)	4.5 2)	4.03	3.27
		4.11	2.3	4.46	3.03

1) Cell background same order as air sample contents.

2) Data taken using hand pump instead of mechanical pump.

Table III RADON CONCENTRATION COMPARISON

of the phosphors are calibrated by using a ^{241}Am source obtained from the A.E.C.B. This source is also calibrated annually by the Saskatchewan Research Council. Between 1978 and 1979 the count rate of the source has decreased about 8 percent. In August 1978 the source had an activity of 3471 d/m and in September 1979 the source had an activity of 3210 d/m. Due to this reason, we have decided to calibrate this source semi-annually. In addition, calibrations of the phosphors are carried out at four to eight week intervals. During the routine checks, if the efficiency of the phosphors has changed drastically, the source and the counter is checked for damage.

ii) The Staplex pumps were calibrated by using a Brookes flow meter from the A.E.C.B. We have not been able to find an independent source for flow rate calibrations. Accurate flow meters are very expensive and we have not purchased any meters for this purpose.

iii) In August 1979, W.L. comparisons were also made with Mr. MacKay. Most of the readings taken agree within statistical limits. Table IV shows the results of some of these comparisons.

IV) Gamma Meters

Gamma meters PRM-7 are calibrated by using a ^{137}Cs source rated at 5000μC at contact. Independent calibration is also carried out by the Radiation Safety Officer at the University of Saskatchewan in Saskatoon.

TABLE IV

ADDRESS	DATE 1979	A.J. MACKAY SASK. DEPT. LABOUR			KEITH CONSULTING		
		W.L.	CPM	STAT.	W.L.	CPM	STAT.
A	Aug.14	0.011	11	0.0033	0.0078	39.6	0.0012
		0	0	0	0.0003	1.38	0.00025
B	Aug.14	0.017	15	0.004	0.014	69.6	0.0016
		0	0	0	0.0002	0.75	0.0002
C	Aug.16	0.060	51	0.0084	0.0795	309.1	0.005
		0.091	91	0.0091	0.081	350	0.004
		0.093	77.5	0.010	0.071	343.3	0.0035
		0.076	77.5	0.010	0.074	250	0.0044
		0.021	16	0.005	0.0258	96.9	0.0026
		0.041	31	0.007	0.0336	135.7	0.003

Table IV WORKING LEVEL COMPARISON

REFERENCE

1) R.D. EVANS, Health Physics 17 (1969) 229

Summary of Uranium City Remedial Measures

Questions/Comments:

W. Nazaroff: What is the cost of providing heat for the mechanically ventilated houses?

R. Mackie : We feel that it will cost approximately $400 per annum for the 120 CFM unit and $500 per annum for the 220 CFM unit.

Question : What temperature do you heat to?

R. Mackie : We heat to approx. 18°C, 18°C to 20°C depending upon the wishes of the homeowner. We enquire as to what is an acceptable temperature to the homeowner and we also monitor the temperature in the home prior to fan-vent installation. The general range of heating is from 18°C to 23°C.

Question : What are the electrical rates in Saskatchewan?

R. Mackie : 2.2 cents

K. Cliff : Has anyone considered the use of air to air heat exchangers? (i.e. for Uranium City)

R. Mackie : Some consideration is being given to the use of heat exchangers in treatment of larger commercial buildings.

CHANGING REMEDIAL MEASURES

CHANGING REMEDIAL MEASURES

By W. O. Findlay & R. Boychuck

Soil gas enters basements by three types of routes: holes, cracks or joints, and from exposed ground. The materials through which the gas passes--concrete, concrete block, rock and soil--form the physical nature of the openings. These come in many varieties. It has been found possible to categorize common routes and to devise suitable standard treatments. The current list is shown in Table 1.

The materials involved in each fix have been tested in Acres laboratory in Niagara Falls. Each treatment is then field tested. At each step, any changes which make the treatment more practical or economic are incorporated. Finally, the standardized remedial measure is incorporated in a contract for a contractor to install.

As is usual, not everything turns out as expected. Nearly 2 years have elapsed since the remedial program was started and changes and improvements have been made. In addition, with the experience gained, it has been possible to assess the long-term durability of some of the measures. A description of the changes made to the standard remedial methods is given in the following sections.

1 - FLOOR DRAINS

The route of entry was the free discharge of the weeping tile into the floor drain. The solution was to insert a running trap between the weeping tile and the drain. The original arrangement is shown on SK 1.

Several details were considered to be inadequate in preventing the entry of soil gas.

(a) The adhesion of concrete to concrete cannot be considered as gastight, even with the use of bonding agent.

The adhesion of concrete to ABS and other plastics is also suspect. This applies to the drain and the cleanout.

(b) The cleanout has proved to be an alternate entry point on two counts. Firstly, it provides a further opening through the concrete and, secondly, a cap can be opened by the homeowner and not properly replaced.

(c) The connection of the bleeder to the drain could be a route of entry from below the slab into the drain and hence into the house.

The steps taken to overcome these conditions are shown on SK 2 and 3.

(a) Concrete Adhesion to Concrete and Plastic

The lack of bonding is dealt with by one of two solutions dependent on the thickness of the floor slab. If the slab is thick enough, i.e., greater than 3 inches, it is preferred to put in a subslab, coat it with a membrane which seals to drain and to the old concrete. A topping slab is then poured to slab level. The new subslab is poured so that it comes up the old concrete some 1/4 inch and allows a vertical seal between old and new concrete. A horizontal seal is more difficult to complete due to the viscosity of the membrane. The advantage of this method is that the membrane provides the seal and the slabs provide protection. The slabs can move and crack without damaging the seal.

When there is less than 3 inches of concrete, the integrity of the sealing slab cannot be guaranteed and, therefore, only a filler slab is poured with a depth of at least 5 inches. This is sealed to the old concrete and the drain inserts by a membrane and filler.

Adherence of the concrete to the plastic plumbing is ensured by roughening the plastic over the contact area.

(b) The Cleanout

The problem has been solved by elimination. The location of the components has been changed. The weeping tile is connected between the drain and the sewer without a cleanout. The sewer has a cleanout on it, and the drain can be used to rod the line between the drain and cleanout.

(c) The Bleeder Connection

As a first step the bleeder was relocated from the drain to the trap. This eliminated the problem of gas entry into the basement, but it raised questions on the necessity for an air gap on the line. With the revised plumbing, the bleeder is run in concrete into the top of the floor drain.

2 - SUMPS

The route of entry was the same as in the floor drain--untrapped weeping tile. The solution was the same--to insert a running trap between the weeping tile and the sump. Since a new sump was required, a standard plastic crock was selected.

It was found that the number of locations where the standard crock could be used was limited. Many of the sumps had been installed by CMHC (who had become owner as a result of the depressed state of the town) as part of upgrading the weeping tile system prior to selling the house. The sumps were custom-made of poured-in-place concrete and for particular reasons, capacity and rock levels being the most common. The most satisfactory method of replacing the sump was by a locally fabricated metal unit. It is now policy to replace all sumps with this type of unit.

The same conditions of possible gas entry were identified

- Concrete to concrete
- Concrete to plastic
- Cleanout
- Bleeder connection

and the solutions are the same. These are shown on SK 4.

The cleanout has been eliminated as it is not required with direct access from the sump.

3 - SEALING CRACKS AND OPENINGS

Three occurrences showed that rigid fillers were not an adequate material for long-term sealing.

(a) Fresh cracking, extensions to old cracks and the formation of new cracks adjacent to old cracks filled with epoxy fillers were noted in houses adjacent to a foundation excavation formed by blasting.

(b) At the same time as houses close to an excavation formed by blasting were being monitored, a control house remote from the blasting area showed cracks and new extensions to cracks during the spring thaw period.

(c) Epoxy fillers were found to fail occasionally. The cause was the difficulty of achieving, under field conditions, the exactness of the proportioning which the manufacturers admitted was necessary to ensure reliable performance from the materials. For these reasons, the method of dealing with cracks was changed to the routing out of the crack, covering the exposed crack line with a flexible membrane and topping with a cementatious filler.

Openings are treated in the same way, except that a filler may be necessary to plug the opening initially.

4 - WALL FLOOR JOINT

As shown on SK 5, the methods initially developed remain essentially unchanged.

For sealing in existing houses, the joint is cleaned, primed, a flexible membrane coating applied, and the whole protected with fibre-reinforced latex cement.

Where new slabs are poured, a recess is formed in the slab at the junction with the wall, and it is subsequently filled with a urethane rubber caulk.

5 - SEAL EXTERIOR SURFACE OF BASEMENT WALLS

This method was tried at two houses. The results showed the method to be satisfactory but expensive. In both cases, fortunately, no interior work on such items as the floor wall joint was required. The backfill around the house consisted of "r[illegible] rockfill" including broken rock up to 5 tons in weight and was difficult and expensive to remove. This type of backfill is the norm in Elliot Lake.

6 - COVER EXPOSED EARTH IN BASEMENTS

No change has been necessary in this method whereby a concrete slab is poured over the open ground and sealed to the surrounding walls or slabs.

7 - SEALING ROCK SURFACES

The original concept of placing a layer of high strength concrete over the rock was a qualified success. Of three places where gunite was used, two were successful and one was not.

Two alternative methods have been tried and both have been successful. In one, a reinforced concrete slab was poured over the rock. In the other, hollows in the rock were filled with concrete, then the surface was coated with a membrane sealant and the whole coated with a fibre-reinforced latex concrete.

In all cases, water relief channels were provided.

The selection of which method to use is dependent upon the extent and condition of the rock.

8 - SEAL INTERIOR SURFACES

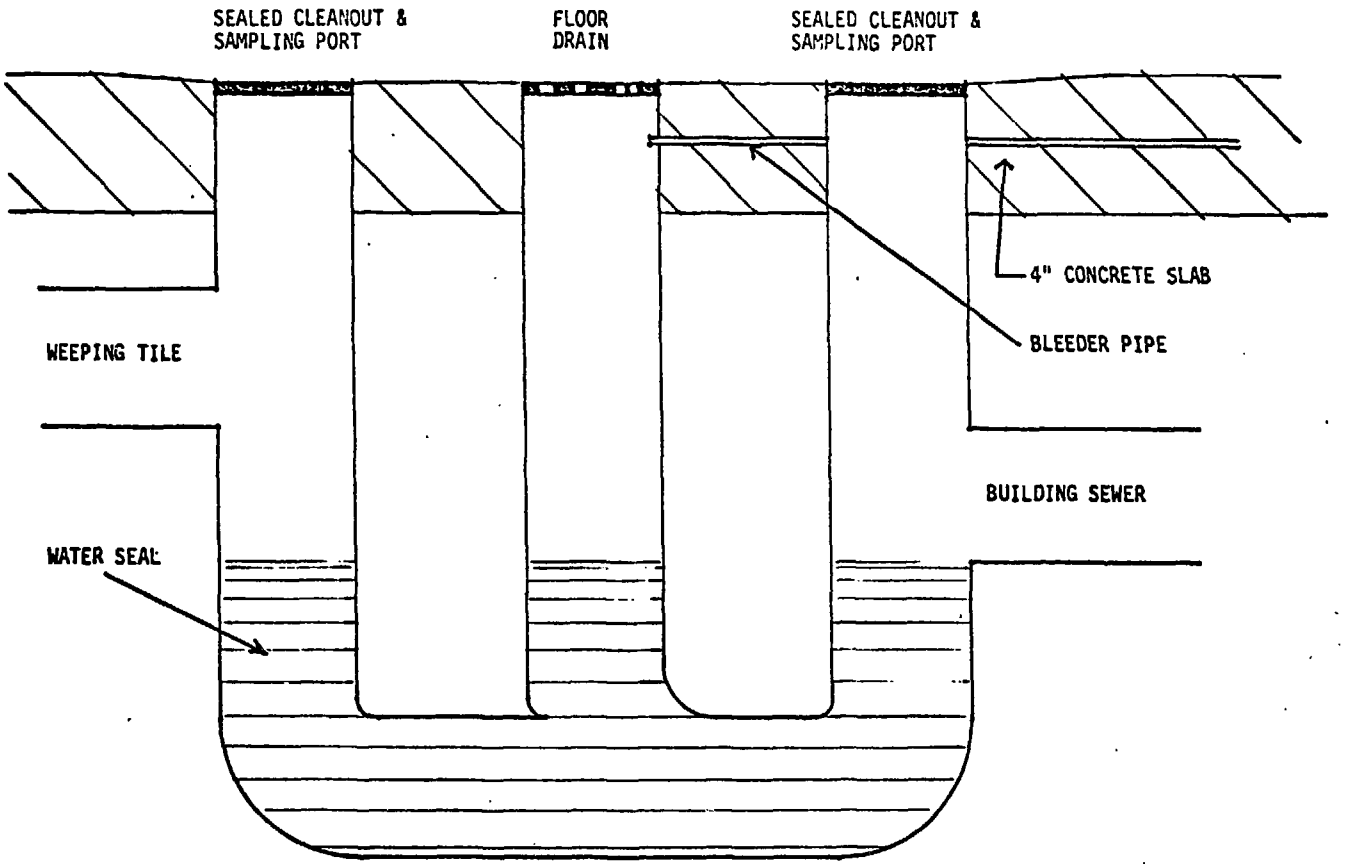
No change has been found necessary.

9 - CONCRETE BLOCKS

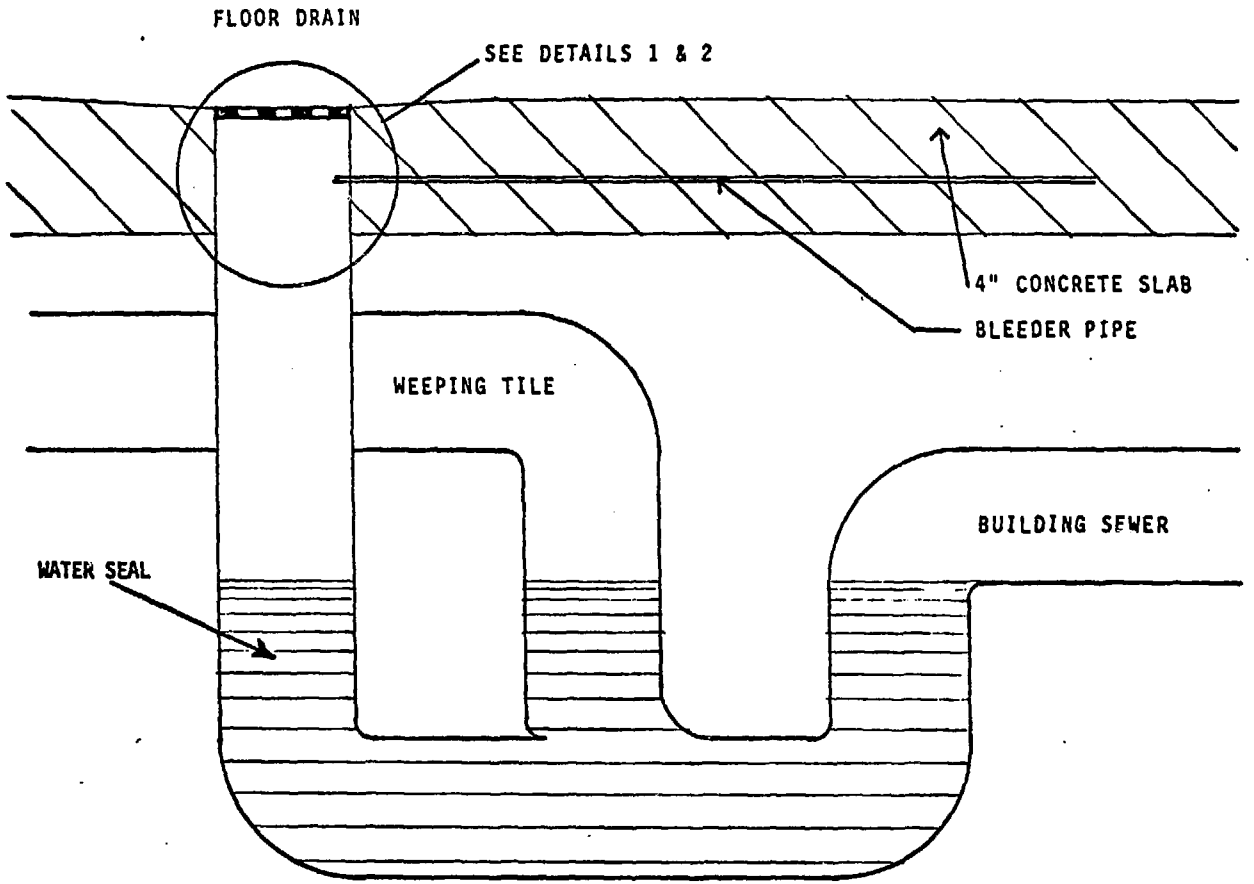
A demonstration program was conducted to find and prove a method of dealing with block walls. To date, the work has shown that it is possible to grout the cavities in the blocks successfully. However, three factors have to be considered. Firstly, the cost is relatively high. Secondly, finished basements present a problem since the grout will flow from every unsealed opening in the interior. If the openings are masked by finish, then considerable damage will be done. Thirdly, chimneys have been found in the vertical mortar joints which will allow soil gas to bypass the sealing at the floor wall joint. In one location, a flow containing 6,000 pCi/litre was discovered.

10 - UNDERFLOOR SYSTEM

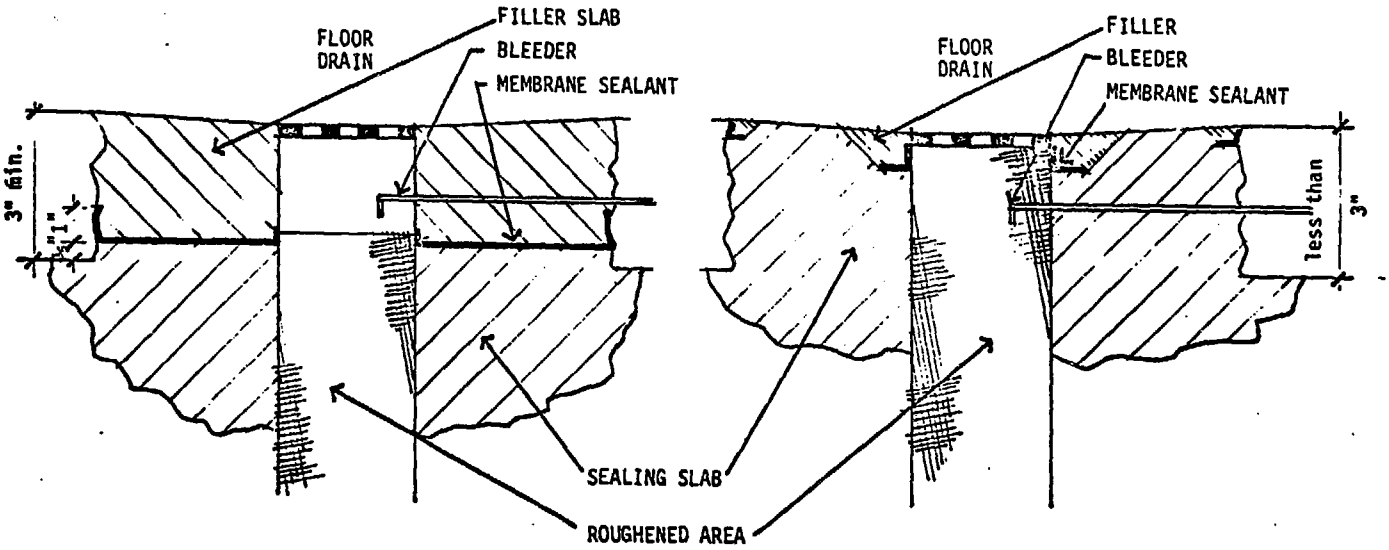
To overcome the high cost involved in obtaining access to routes of entry in houses with finished basements, tests are being conducted on a simplified underfloor ventilation system. Some success has been achieved by exhausting from the fill under the basement floor slab through a pipe sealed into the floor, and discharging to the outside, as shown on SK 7. There is no underfloor pipe system. Initial results indicate that a fan in the range 50 to 200 cfm and exhausting from a point in the middle of the floor will reduce levels satisfactorily. It may be possible to replace the fan by a cowl. Tests are underway in several houses.


SEALED CLEANOUT & SAMPLING PORT
FLOOR DRAIN
SEALED CLEANOUT & SAMPLING PORT
4" CONCRETE SLAB
BLEEDER PIPE
WEEPING TILE
BUILDING SEWER
WATER SEAL

SKETCH #1

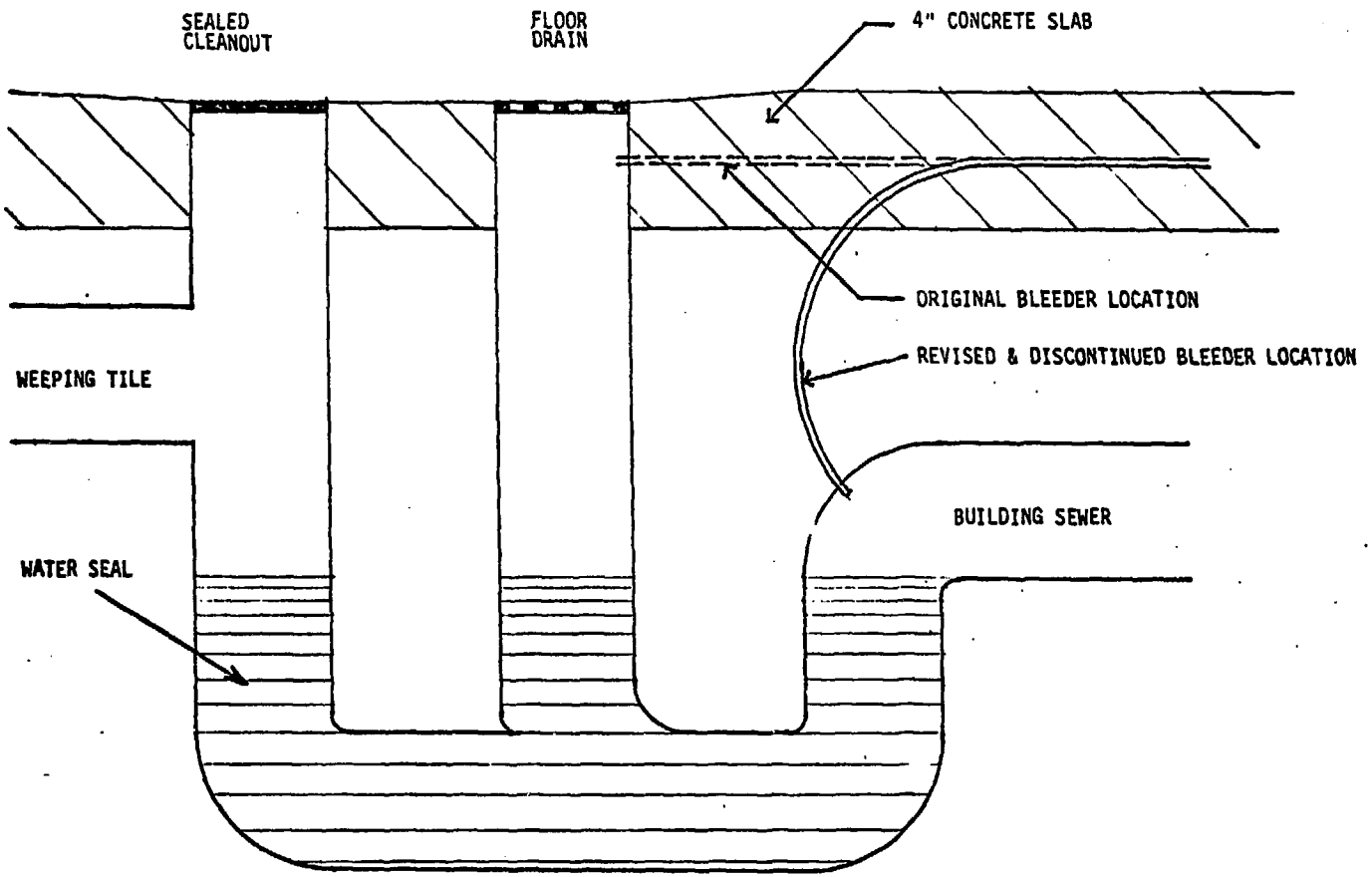

FLOOR DRAIN
SEE DETAILS 1 & 2
4" CONCRETE SLAB
BLEEDER PIPE
WEEPING TILE
BUILDING SEWER
WATER SEAL

SKETCH #2

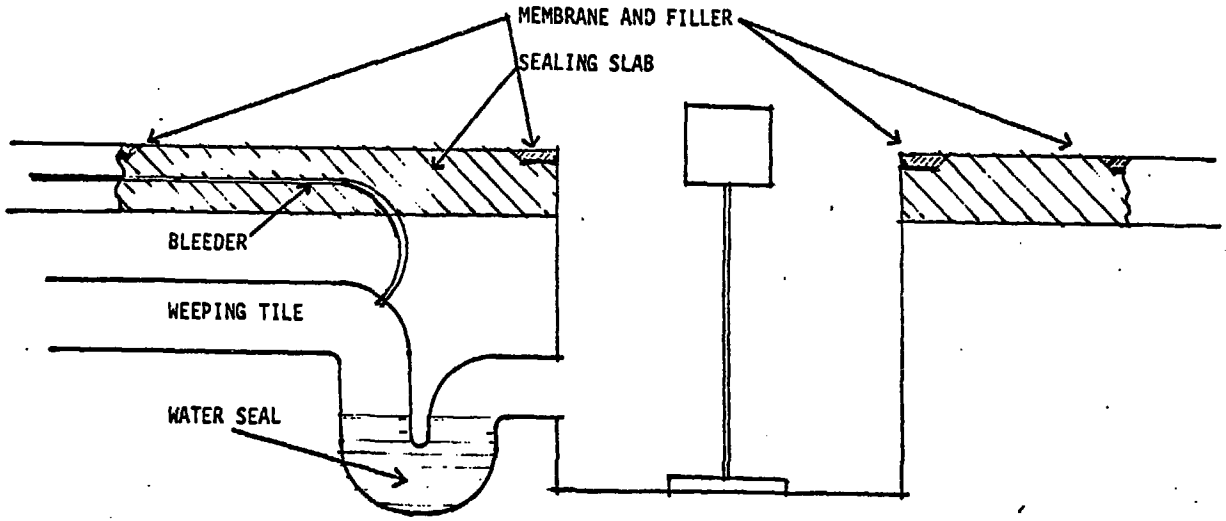


SKETCH #3
DETAIL 1

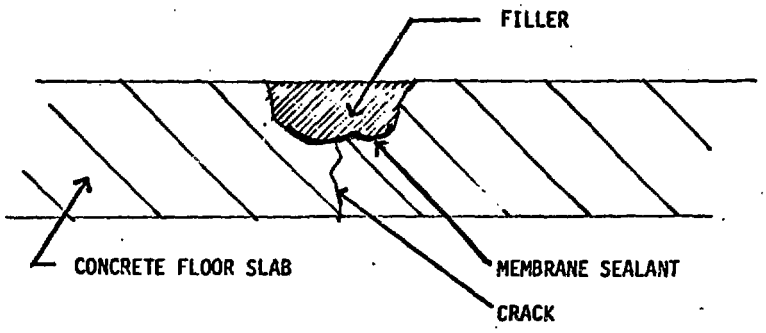
SKETCH #3
DETAIL 2

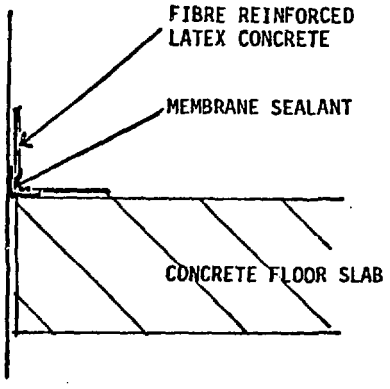


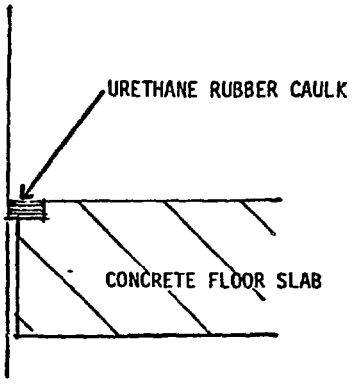
SKETCH #3
DETAIL 3


MEMBRANE AND FILLER
SEALING SLAB
BLEEDER
WEEPING TILE
WATER SEAL

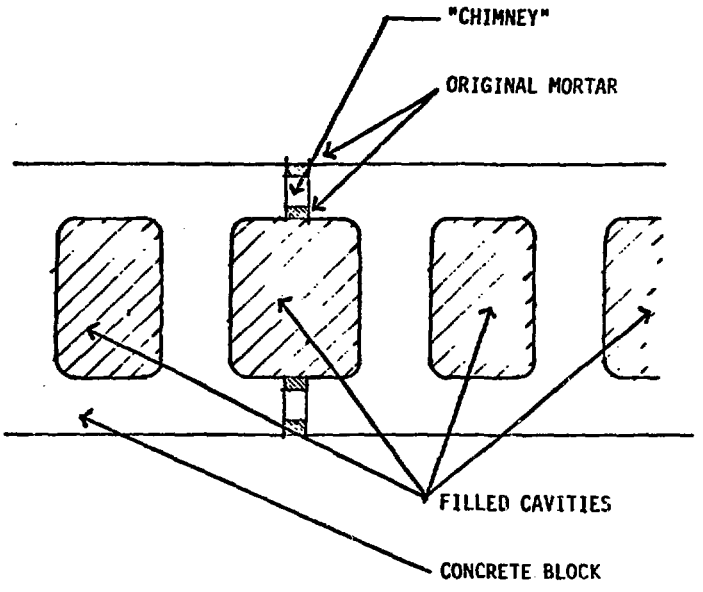
SKETCH #4


FILLER
CONCRETE FLOOR SLAB
MEMBRANE SEALANT
CRACK

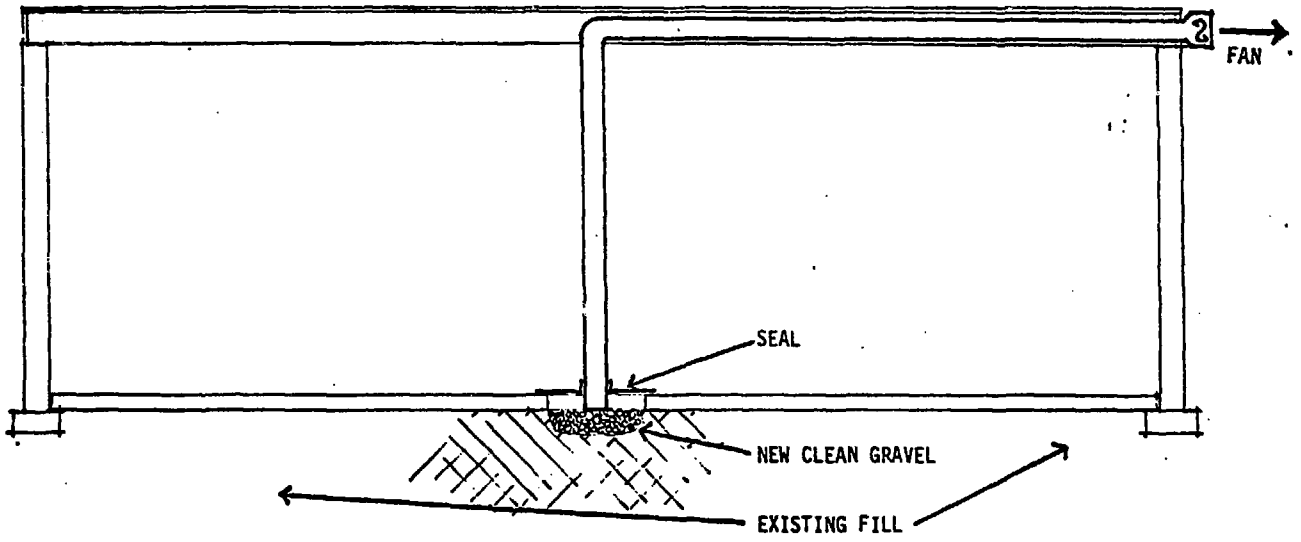

FIBRE REINFORCED
LATEX CONCRETE
MEMBRANE SEALANT
CONCRETE FLOOR SLAB


URETHANE RUBBER CAULK
CONCRETE FLOOR SLAB

SKETCH #5



SKETCH #6



UNDER FLOOR EXHAUST TEST FACILITY

SKETCH #7

Seasonal Variations in f Factor

L. R. Haywood
5215 Incorporated
Chalk River, Ontario

Presented in draft form at the Third
Workshop on Radon and Radon Daughters
in Urban Communities Associated with
Uranium Mining and Processing,
Port Hope, Ontario, Canada,
March 12-14, 1980.

March 1980

Seasonal Variations in f Factor

1. Effect of Indoor/Outdoor Temperature Difference

A mean soil temperature was estimated as being the average of air temperature and an assumed constant temperature of 7°C six feet below grade. Over the elevation of a structure, the effective outdoor temperature was taken to be the mean of soil temperature and air temperature weighted 6 to 14.

Similarly, the effective indoor temperature was taken to be the mean of basement and upstairs temperature weighted 8 to 12.

The difference (ΔT) between these effective indoor and outdoor temperatures was considered, for the purpose of this work, to determine the thermal draft which would contribute to structure ventilation.

In earlier studies by the same author, summer and winter have been defined as the months of May, June, July, August, September; and October, November, December, January, February, March, April, respectively. For the purposes of the analyses reported herein, a summer day was defined as one during which the morning outside temperature exceeded 10°C, it being arbitrarily assumed that heating would not be on under such a condition. A winter day is thus one for which the morning outdoor temperature is less than 11°C.

Using the experimental data of Tamura and Wilson[1], the air change rate may be expressed in terms of ΔT for summer conditions, viz.

$$v = 0.032(\sqrt{\Delta T}+1)\text{hr}^{-1}$$

where ΔT is in Centrigrade degrees. This formulation allows somewhat more for incidental air change rate than was found by Tamura and Wilson. For winter conditions, v may be expressed as

$$v = 0.032(\sqrt{\Delta T}+1+0.1\Delta T)$$

where at $\Delta T = 40$°C, an oil burner with a 0.5 GPH nozzle would run nearly full time. It is a generous allowance.

For electrically heated houses, v may be expressed as

$$v = .032(\sqrt{\Delta T}+0.5)$$

in summer which assumes that a chimney accounts for one-half of the incidental air change rate in other than electrically heated structures.

Figure 1 shows the geometric mean of f factors in Bancroft structures during the period Oct/78 to Sept/79 as a function of corresponding air change rates determined as has already been described. It is noted that the effect of adding $0.1\Delta T$ for draft produced by a furnace is to make the winter relation consistent with that for the summer.

Figure 2 shows, for Bancroft structures (Oct/78 - Sept/79), the relation between f and ΔT for various short ranges of absolute indoor humidity. It may be noted that, in general,

1) the magnitude of f is higher for higher humidity

and

2) the effect of ΔT on f, per degree change, is markedly decreased when ΔT exceeds about 16°C.

2. The Effect of Humidity

Figure 3 shows, for Bancroft structures (Oct/78 - Sept/79) the relation between f and absolute indoor humidity for various short ranges of ΔT. It may be noted that, in general,

1) the magnitude of f is higher for lower values of ΔT

and

2) the effect of humidity on f per unit change in humidity is markedly reduced above about 65 gr/lb. It appears also that a low slope may be effective in the range 33 to 50 gr/lb.

3. Combined Effects of Air Change Rate and Humidity

Figure 4 shows, again for Bancroft in the same period, the monthly means of the f factor, absolute indoor humidity and ΔT.

Using the slope of f vs ΔT (Fig 2) for corresponding monthly means of ΔT and humidity, it is possible to estimate the change in f which would occur for a change in ΔT month-to-month. Similarly, changes in f due to humidity may be estimated. Figure 5 portrays the cumulative contributions of month-to-month changes in ΔT and humidity to the month-to-month change in f. The combined contributions plus a base value of f = 0.47 for October 1978 sum to estimated monthly f's which are quite comparable to measured values.

4. Discussion - variations in f factor

Porstendörfer et al[2] has provided sophisticated expressions for the equilibrium factors between free and attached daughters and the parent radon. These expressions recognise the effects of air change, deposition and attachment rates.

For the purposes of this discussion, these expressions are stated in simplified form on page 4 of this report.

The f factor would be

$$f = 0.1\ (A_f + A_a) + 0.52\ (B_f + B_a) + 0.38\ (C_f + C_a)$$

X, the attachment rate is directly proportional[2] to the concentration and diameter of attachment centres. The concentration would be dependent upon air borne particulate levels and humidity. As the dew point depression approached zero it would be reasonable to expect a reduction in concentration of water molecules or groups of molecules as they come together or further come together preparatory to condensation. One might reasonably expect that the concentration of particulate would be dependent to some extent upon the air change rate viz.

$$X_p = \frac{p}{vV} + P_a$$

where p is the production rate of particulate in the structures, V is the volume and P_a is the concentration in outdoor air. A typical value of X is 100 hr^{-1}.

Expressions for Equilibrium Fractions of Free & Attached Daughters

$$A_f = \frac{13.9}{13.9 + X + q_f}$$

$$A_a = \frac{X\, A_f}{13.9 + v}$$

$$B_f = \frac{1.55\, A_f + 1.29\, A_a}{1.55 + v + X + q_f}$$

$$B_a = \frac{0.26\, A_a + X\, B_f}{1.65 + v}$$

$$C_f = \frac{2.11\, B_f}{2.11 + v + X + q_f}$$

$$C_a = \frac{2.11\, B_a + X\, C_f}{2.21 + v}$$

where

- A_f to C_a are equilibrium fractions for free and attached Ra A to Ra C
- X is an attachment rate (hr^{-1}) for free daughters
- q_f is a deposition rate (hr^{-1}) for free daughters
- v is an air change rate (hr^{-1})
- 0.1 has been added to the decay constants (1.55 & 2.11) for Ra B & Ra C as an allowance for the deposition rate of attached daughters
- the fraction of alpha emitting daughters becoming free by recoil from attached particles is taken to be 0.83[2].

q_f is directly proportional to the deposition velocity[2] and the ratio of the surface area to the volume of the space under consideration. The deposition velocity depends upon the diffusion coefficient[3] and the air velocity[4]. The air change rate would be expected to contribute to air velocity. Thus q_f may well be some function of v. Kotrappa et al[5] have indicated little or no dependence of the diffusion coefficient on relative humidity. Porstendörfer[6] reports a dependence only for relative humidities less than 30% (presumably his work and that of Kotrappa were done at normal indoor temperatures). A typical value of q_f is $150hr^{-1}$.

The range of monthly averages of air change rate in the basements under consideration is about 0.1 to $.3hr^{-1}$. Were it even so much as .05 to 0.6, the reduction in f from summer to winter through the direct occurrence of v in the expression on page 4 would amount to 0.17 which is less than 70% of the reduction estimated herein as being due to v (see Figure 5). It is thus likely that the air change rate is also effective through q_f.

There are variables other than humidity and temperature which will affect f e.g. particulate concentration. However, it appears that these two variables are, at the least, amongst the principal influences on f.

References

1. "Air Leakage and pressure measurements on two occupied houses" Research Paper No. 207 of the Division of Building Research NRC, Dec. 1963.

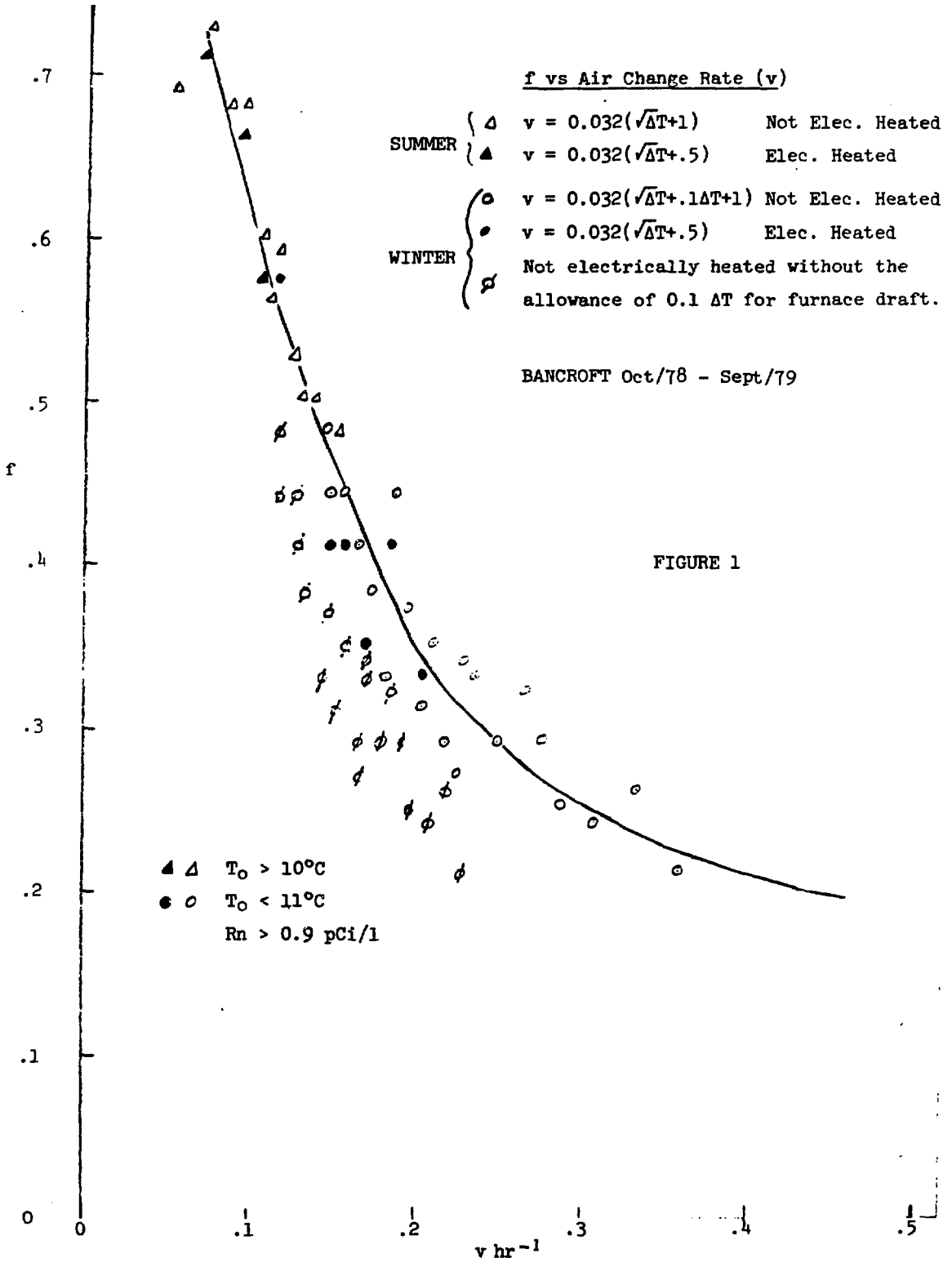
2. "The Influence of Exhalation, Ventilation and Deposition Processes upon the Concentration of Radon, Thoron and their Decay Products in Room Air" Health Physics Vol. 34, pp 465-73.

3. "Mechanisms of Transport from the Atmosphere to Earth's Surface" Möller and Schumann, Journal of Geophysical Research Vol. 75 No. 15, May 1970.

4. "Transport of Particles to Surfaces" Clough, Aerosol Science 1973, Vol. 4.

5. "Diffusion Coefficient for Unattached Decay Products of Thoron-Dependence on Ventilation and Relative Humidity" Health Physics 1976, Vol. 31 pp 378-380.

6. Porstendörfer and Mercer, Health Physics Vol. 37 (Aug) pp 191-199, 1979.


f vs Air Change Rate (v)
SUMMER
v = 0.032(√ΔT+1) Not Elec. Heated
v = 0.032(√ΔT+.5) Elec. Heated
WINTER
v = 0.032(√ΔT+.1ΔT+1) Not Elec. Heated
v = 0.032(√ΔT+.5) Elec. Heated
Not electrically heated without the allowance of 0.1 ΔT for furnace draft.
BANCROFT Oct/78 - Sept/79
FIGURE 1
T_o > 10°C
T_o < 11°C
Rn > 0.9 pCi/l
f
v hr^{-1}
0
.1
.2
.3
.4
.5
.6
.7

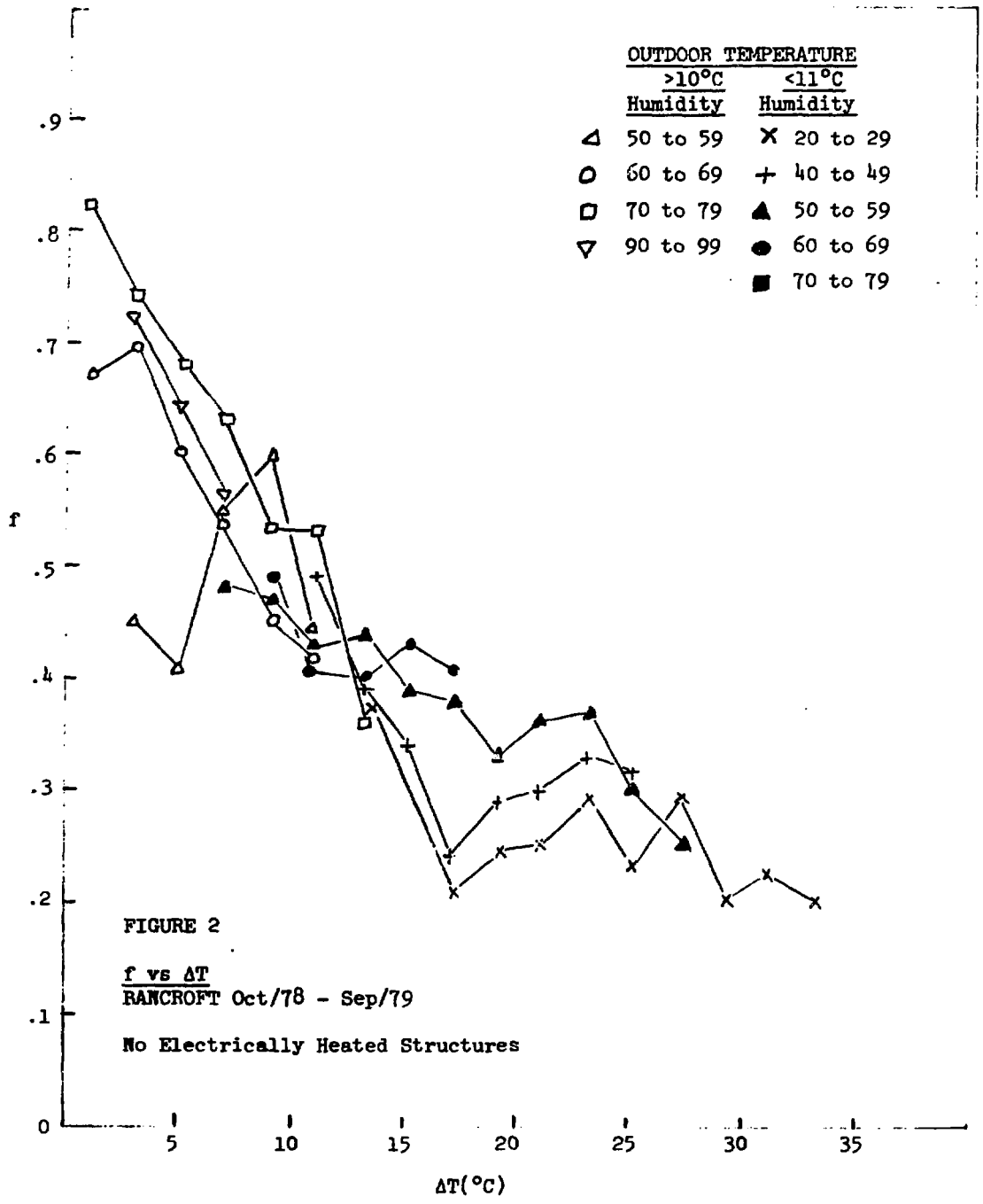


FIGURE 2

f vs ΔT
RANCROFT Oct/78 - Sep/79

No Electrically Heated Structures

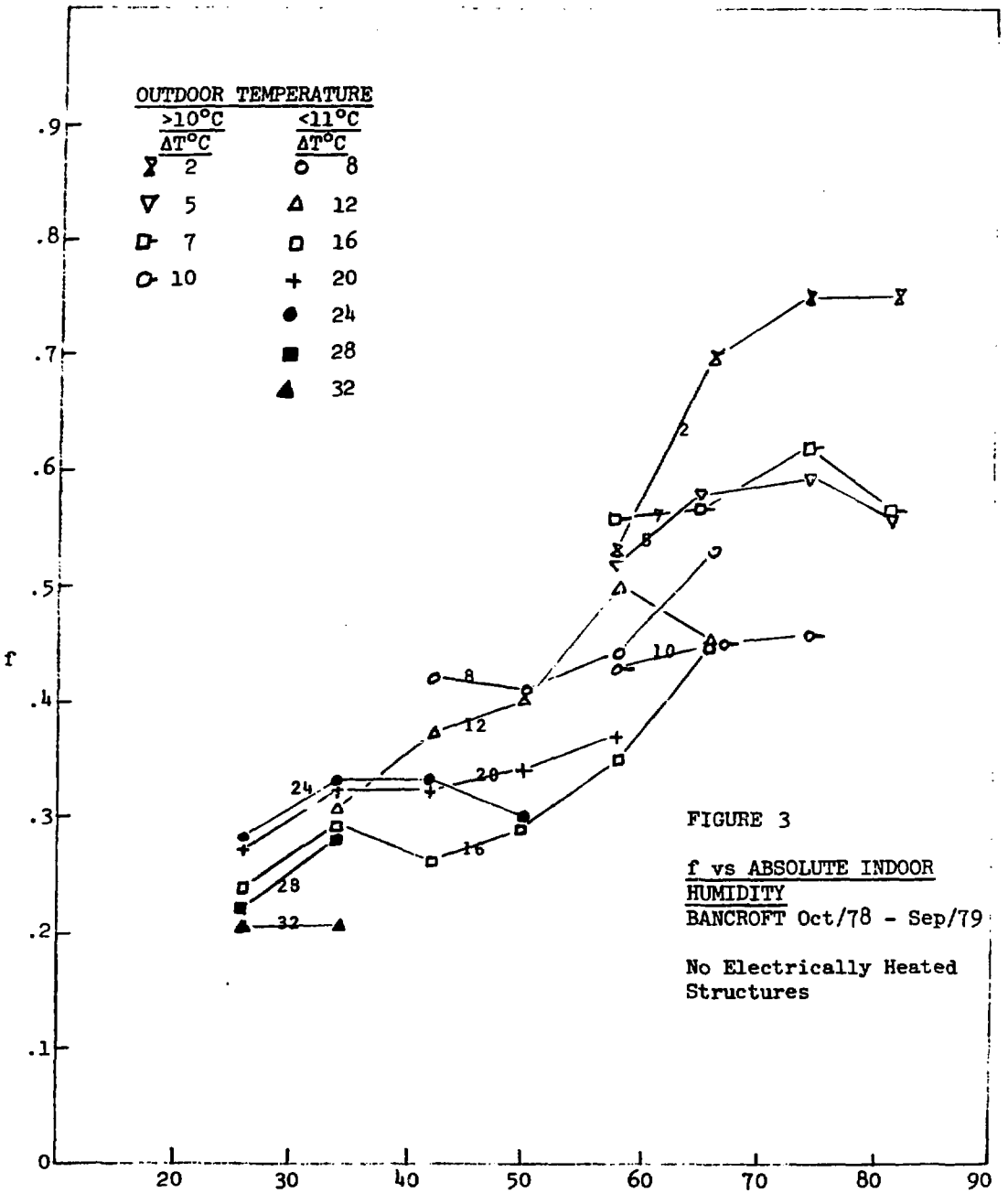
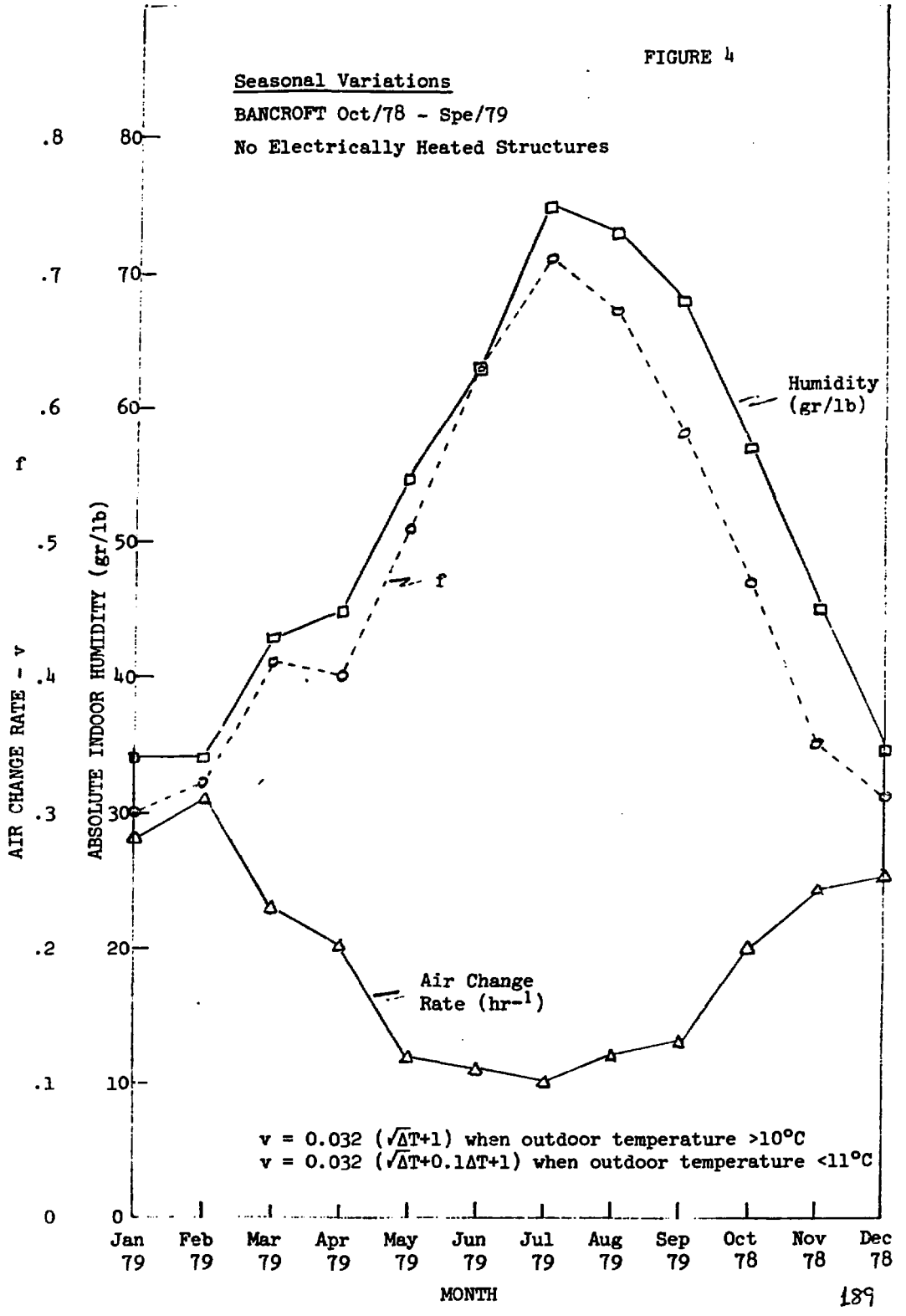


FIGURE 3

f vs ABSOLUTE INDOOR HUMIDITY
BANCROFT Oct/78 - Sep/79

No Electrically Heated Structures

FIGURE 4


Seasonal Variations
BANCROFT Oct/78 - Spe/79
No Electrically Heated Structures
AIR CHANGE RATE - v
f
ABSOLUTE INDOOR HUMIDITY (gr/lb)
.8
.7
.6
.5
.4
.3
.2
.1
0
80
70
60
50
40
30
20
10
0
Humidity (gr/lb)
f
Air Change Rate (hr^{-1})
v = 0.032 ($\sqrt{\Delta T}$+1) when outdoor temperature >10°C
v = 0.032 ($\sqrt{\Delta T}$+0.1ΔT+1) when outdoor temperature <11°C
Jan 79
Feb 79
Mar 79
Apr 79
May 79
Jun 79
Jul 79
Aug 79
Sep 79
Oct 78
Nov 78
Dec 78
MONTH

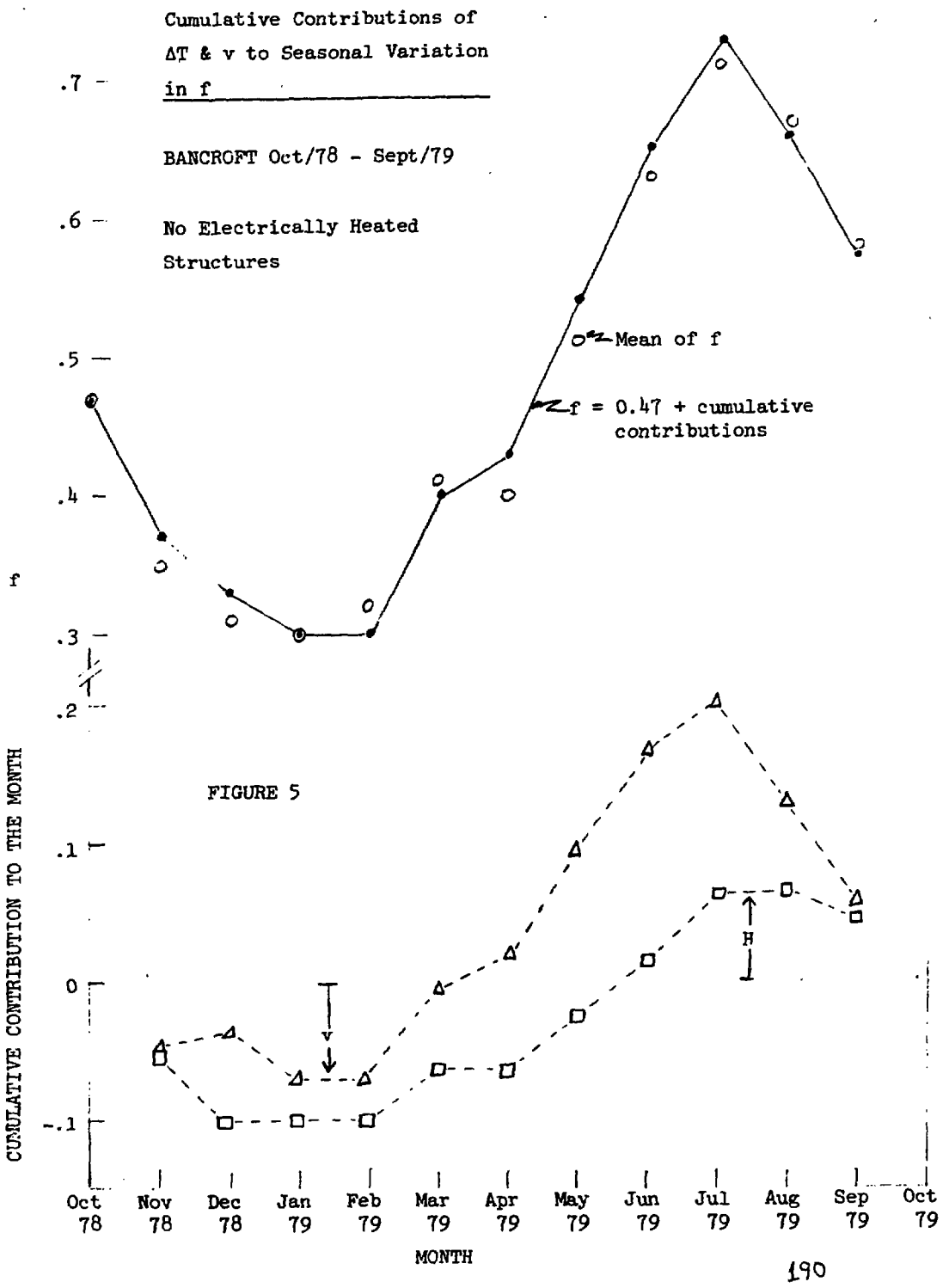

Cumulative Contributions of
ΔT & v to Seasonal Variation
in f
BANCROFT Oct/78 - Sept/79
No Electrically Heated
Structures
Mean of f
f = 0.47 + cumulative
contributions
f
.7
.6
.5
.4
.3
.2
.1
0
-.1
V
H
CUMULATIVE CONTRIBUTION TO THE MONTH
Oct 78
Nov 78
Dec 78
Jan 79
Feb 79
Mar 79
Apr 79
May 79
Jun 79
Jul 79
Aug 79
Sep 79
Oct 79
MONTH

FIGURE 5

PRESENTED TO

THIRD WORKSHOP ON RADON AND RADON DAUGHTERS
IN URBAN COMMUNITIES ASSOCIATED WITH
URANIUM MINING AND PROCESSING
AT PORT HOPE, ONTARIO

MARCH 12-14, 1980

THORON AND RADON MEASUREMENTS IN HOUSES

C. GAUTHIER

DSMA/ACRES
ELLIOT LAKE

THORON AND RADON MEASUREMENTS IN HOUSES

Last year at the Bancroft seminar there were some discussions about the presence of thoron daughters in occupied houses in Bancroft and in unoccupied houses at Elliot Lake. As a result we decided to conduct a program to determine what effect thoron daughters were having on working level measurements in occupied houses at Elliot Lake.

Figure 1 shows the decay of thoron and daughters. Thoron gas is a decay product of thorium, and has a short half life of only 54.4 S. It alpha decays to ThA which is very short lived. ThA alpha decays to ThB. This nuclide has a relatively long half life of 10.6 hours and beta decays to ThC. Thorium C has a half life of about 60 minutes, and decays to ThD with both alpha and beta decay. Due to the short life of ThA, only the alphas from the decay of ThC can be counted. With our counting equipment, the alphas from the decay of ThC cannot be distinguished from those of RaC.

The standard procedure for measuring alpha activity in the air is to draw 100 litres of air through a filter which collects airborne daughters. The total alpha disintegration rate is determined forty to ninety minutes after sampling. The Kusnetz Method is used to calculate the working level.

Figure 2 shows the decay of collected alpha activity with time after sampling from a typical house atmosphere with both radon and thoron daughters present. The thoron daughters cause an overestimate of the working level.

The decay of radon daughters is much more rapid than that of thoron daughters. Six hours after sampling radon daughters are no longer present on the filter. If a count of alpha activity was made later than six hours after sampling this must be due to the C in transient equilibrium with ThB, and the concentration can be

simply extrapolated back to the time of the Kusnetz count. This results in a slight overestimate of the thoron daughter contribution to the working level, for Thorium C does not reach transient equilibrium with Thorium B until about 2 hours after sampling.

This procedure was adopted to estimate the contribution of thoron daughters to routine WL measurements. To obtain a reasonably random sample group the first twelve filters collected in a normal days' survey were retained for counting. One hundred and seventy four filters from ninety-five different houses were counted for thorium daughters. Some houses were sampled more than once.

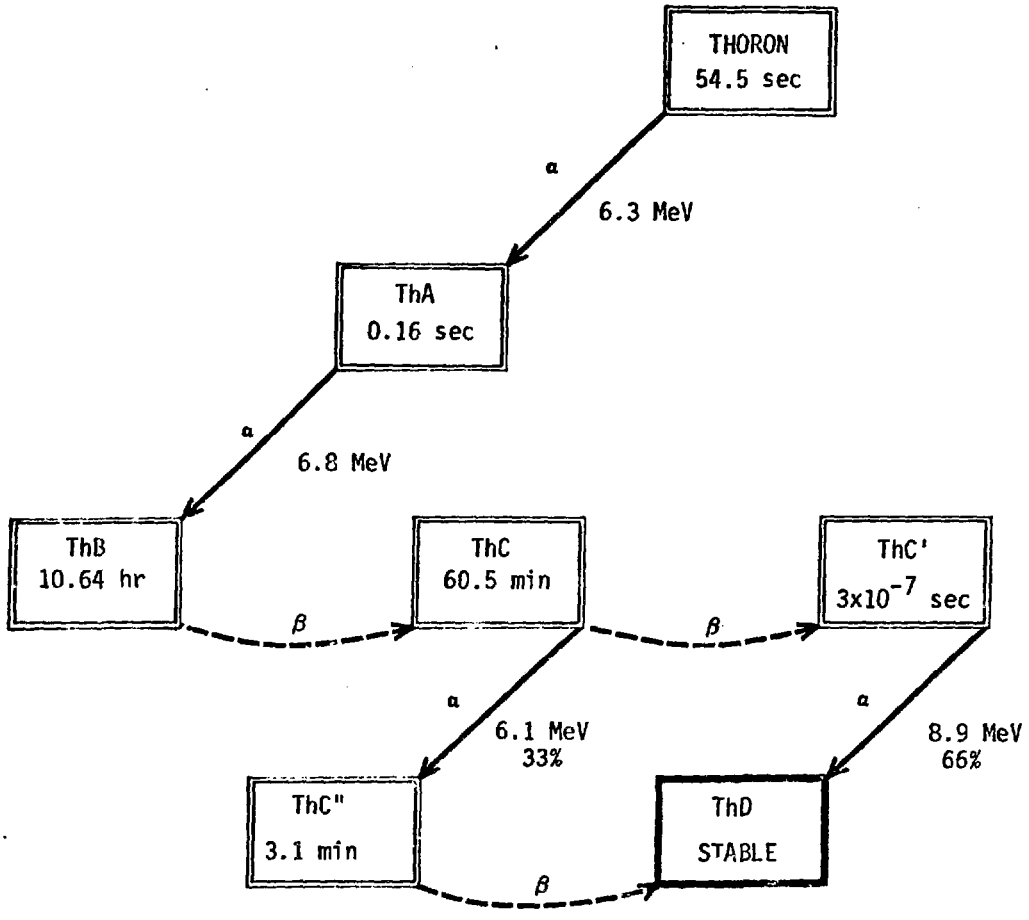
Figure 3 shows the cumulative frequency distribution of the true working level is reasonably log-normal with a GSD of 2.4. This is similar to that obtained from a radon sample of houses, and suggests that there was no significant bias in the choice of houses.

Filters were counted forty to ninety minutes after sampling,the working level estimated using the Kusnetz Method, and the filters were counted the next day. The second count rate and the time interval between counts was used to calculate the number of counts contributed by thoron alpha's at the time of the Kusnetz count. These were converted to mWL equivalent thoron contribution by dividing by the same Kusnetz factor.

Figure 4 shows the cumulative frequency distribution of the thoron contribution expressed as mWL equivalent to the working level estimate. In seventy percent of the samples the thoron contribution was no more than one mWL equivalent. The statistical counting error in estimating working levels of 15 mWL's is at least 1 mWL. The error in the estimation of working levels even close to the criterion produced by the presence of thoron daughters is no larger than the statistical error of the estimate, so no special correction for their presence is necessary.

The correlation coefficient between the true working level and the thoron contribution to it is 0.13, which is so low that it is not likely that one is the cause of the other. This suggests that thoron and radon are not simultaneously carried into the house by the soil gas. This is not surprising,for the brief half life of thoron gas mean that the gas can migrate only short distances. The source of thoron must be very close to the house interior; probably in the building materials. The long lived ThB is more sensitive to removal mechanism than radon daughters, so again one would expect that the ThB-ThC concentrations would be low.

It is only in buildings with very low ventilation rates and large areas of exposed concrete that correction for the presense of thoron may be necessary.



THORON DECAY CHAIN

FIGURE 1

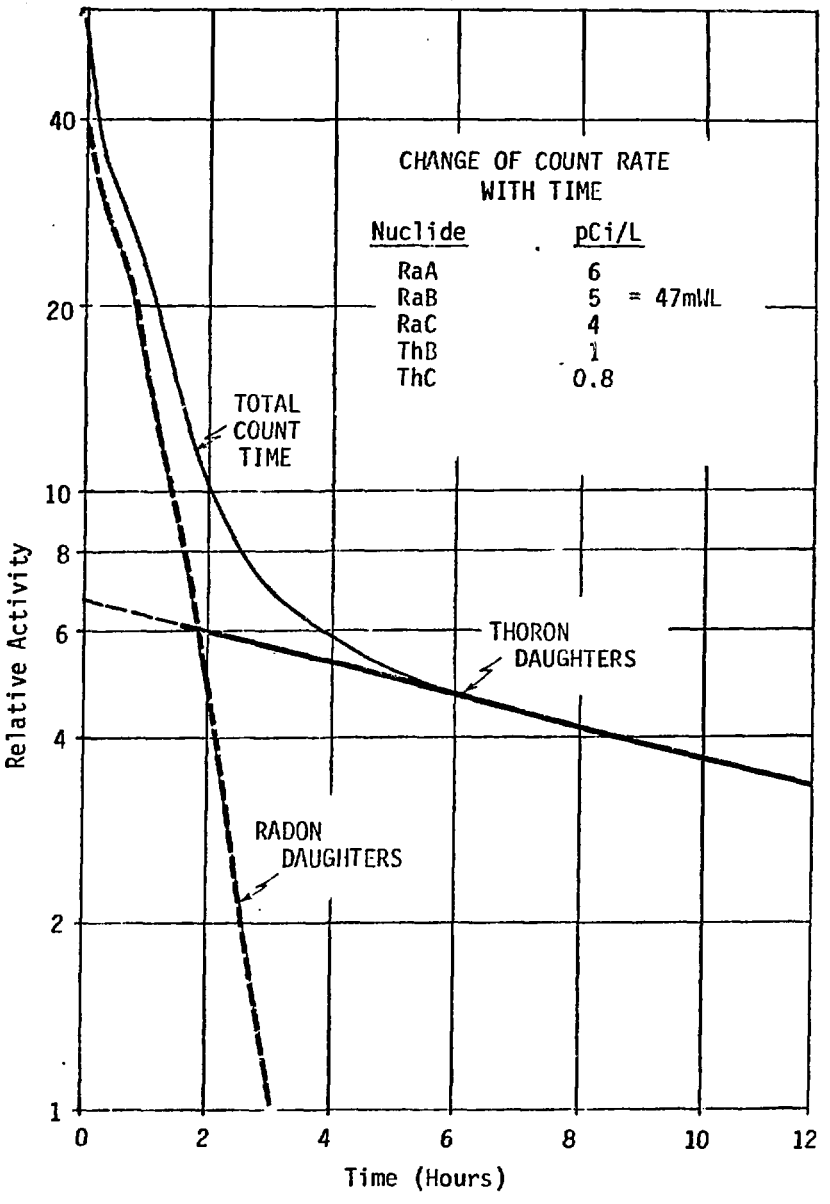

CHANGE OF COUNT RATE
WITH TIME
Nuclide
pCi/L
RaA
RaB
RaC
ThB
ThC
6
5
4
1
0.8
= 47mWL
TOTAL
COUNT
TIME
THORON
DAUGHTERS
RADON
DAUGHTERS
Relative Activity
Time (Hours)
40
20
10
8
6
4
2
1
0
2
4
6
8
10
12

FIGURE 2

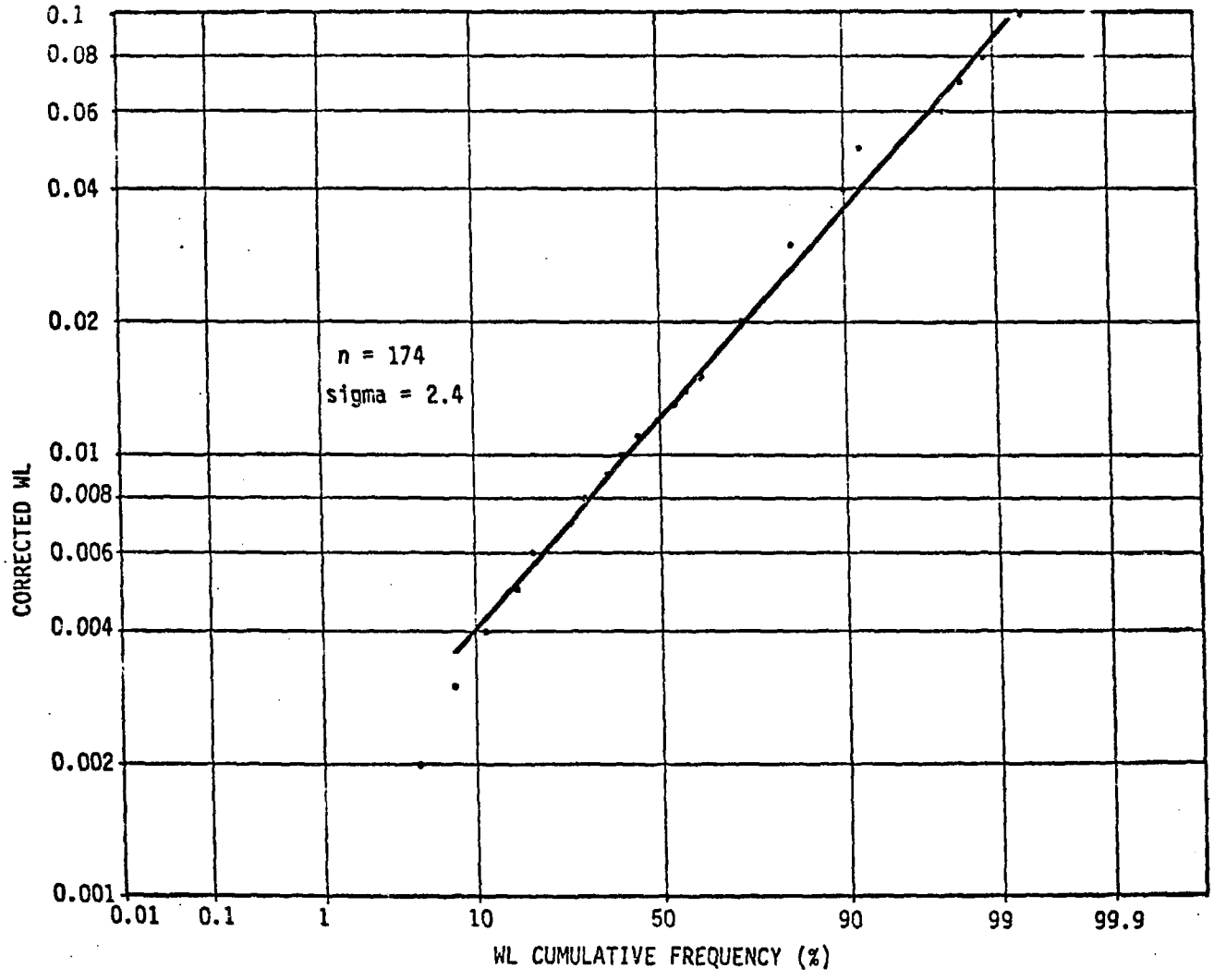


FIGURE 3

CUMULATIVE FREQUENCY DISTRIBUTION OF TRUE WORKING LEVEL

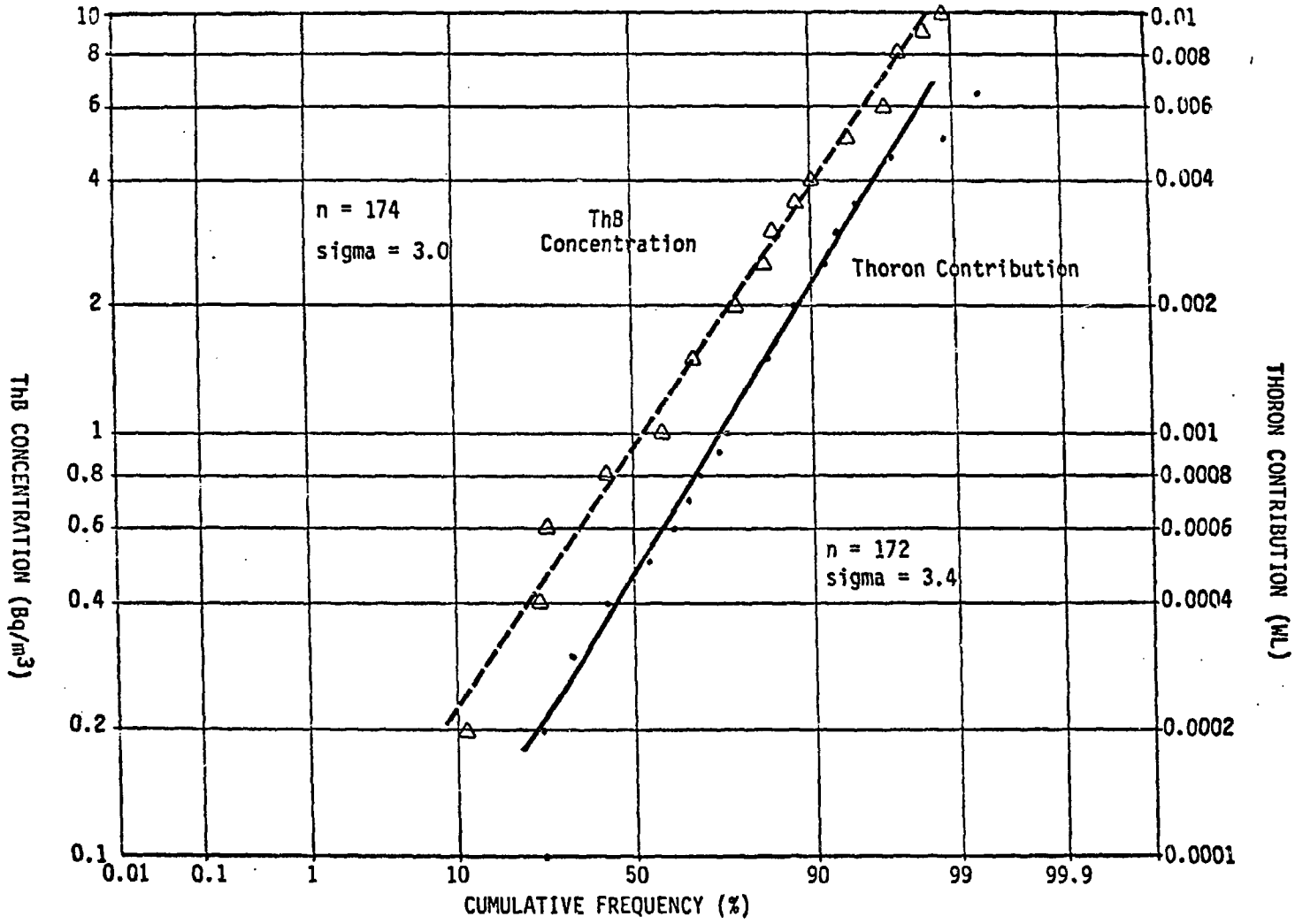


FIGURE 4

CUMULATIVE FREQUENCY DISTRIBUTION OF THE ThB CONCENTRATION AND THORON CONTRIBUTION TO WL ESTIMATE

Presented in draft form at the Third
Workshop on Radon and Radon Daughters
in Urban Communities Associated with
Uranium Mining and Processing,
Port Hope, Ontario, Canada,
March 12-14, 1980.

Revised and Edited March 17, 1980.

SELECTION OF A RADON LEVEL CORRESPONDING TO 0.02 WL

L.R. Haywood
5215 Incorporated

Work Carried Out
Under Contract To
ATOMIC ENERGY CONTROL BOARD

February 1980

Selection of a Radon Level Corresponding to 0.02 WL

1. Introduction

The Canadian Federal Government through the Atomic Energy Control Board (A.E.C.B.) requires that the concentration of radon daughters in occupied structures in communities associated with nuclear facilities be less than 0.02 working level.

The A.E.C.B. has been interested in the possibility of using measurements of radon concentration rather than of working level for compliance at 0.02 WL. The question of identification of the radon concentration which would correspond to the compliance working level is addressed herein, the work being done under contract to the A.E.C.B.

2. Summary

For a number of reasons there is no radon concentration which corresponds to 0.02 WL over a typical range of field conditions. These reasons principally concern the range of physical characteristics of structures, of heating methods, of living habits and of outdoor temperatures.

3. The f Factor

A great many simultaneous measurements of working level and radon concentration were made in many structures in Bancroft, Elliott Lake, Port Hope and Uranium City during the last three years. The ratio of these simultaneous measurements times 100 is commonly known as the f factor. This factor is somewhat a measure of the extent of equilibrium between the concentrations of radon and its short-lived daughters as a group.

In the discussion which follows the data is limited to pre-remedial measurements in basements in Bancroft, Elliott Lake and Port Hope.

4. Diurnal Variations of f

Almost all the measurements at Bancroft and Port Hope were made in the morning, the median time being 10 A.M. At Elliott Lake, on towards 40% of the measurements were made in the afternoon particularly in the early months of the program. Examination of a large number of f factors for Elliott Lake taken both in the A.M. and the P.M. indicates that f is some 10% lower for afternoon measurements.

5. House to House and Day to Day Variations

Within the mass of data for the three sites, there are surprisingly few cases where simultaneous working level and radon measurements were made on several houses on the same several days in the same month. A typical example of such a matrix from the Elliott Lake data for January, 1979 is shown in Table 1.

Table 1

f Factor - Six Houses on Six Days

Structure	Day							
Numbers	2	5	9	12	14	16	μ	σ
271	.51	.44	.52	.53	.66	.51	.53	.07
313	.22	.39	.25	.27	.22	.22	.26	.07
320	.42	.30	.40	.48	.43	.38	.40	.06
330	.30	.43	.26	.62	.68	.13	.40	.21
372	.26	.39	.55	.65	.30	.25	.40	.17
511	.53	.45	.42	.60	.60	.54	.52	.08
μ	.37	.40	.40	.53	.48	.34		
σ	.13	.13	.13	.14	.19	.17		

Although the matrices are small, a reasonable conclusion from inspection of several is that the dispersion in f, house-to-house on the same day,

is not small compared to that day-to-day in the same house.

6. Month-to-Month Variations

In an examination for month-to-month variations, care must be taken to avoid skewing of the results by the occurrence of a large number of measurements in a structure for which f is comparatively high or low. To avoid this problem, an E factor was calculated for each structure in each month, E being 100 times the ratio of the average working level to the average radon concentration during the month.

Figure 1 shows the month-to-month variation of E for three sites during the entire program period. The corresponding geometric standard deviations are listed in Table 2.

Table 2

Variation of E Month-to-Month

	ELLIOTT LAKE		BANCROFT		PORT HOPE	
	GM	GSD	GM	GSD	GM	GSD
Jan	.36	1.8	.30	1.5	.26	1.5
Feb	.41	1.6	.30	1.7	.25	1.7
Mar	.39	1.5	.35	1.6	.35	1.6
Apr	.38	1.7	.34	1.7	.33	1.6
May	.41	1.7	.48	1.5	.40	1.6
Jun	.46	1.8	.54	1.5	.48	1.5
Jul	.48	2.1	.62	1.4	.50	1.8
Aug	.39	1.8	.57	1.5	.48	1.6
Sep	.37	2.0	.52	1.7	.44	1.5
Oct	.45	2.2	.48	1.5	.32	1.8
Nov	.38	2.1	.30	1.8	.29	1.6
Dec	.39	1.9	.29	1.8	.23	1.6

7. Effect of Temperature

A mean soil temperature was estimated as being the average of air temperature and an assumed constant temperature of 7°C six feet below grade. Over the elevation of a structure, the effective outdoor temperature was taken to be the mean of soil temperature and air temperature weighted 6 to 14.

Similarly, the effective indoor temperature was taken to be the mean of basement and upstairs temperature weighted 8 to 12.

The difference (ΔT) between these effective indoor and outdoor temperatures was considered, for the purpose of this work, to determine the thermal draft which would contribute to structure ventilation.

Figure 2 shows, for Bancroft structures, the relation between the f factor and ΔT for constant indoor humidity. The range of ΔT evident from Table 3 could, were it alone effective, account for the seasonal variation in the f factor.

8. Effect of Humidity

Figure 3 shows, for Bancroft structures, the relation between the f factor and the indoor absolute humidity for constant values of the difference between the effective outdoor and indoor temperatures. For the indicated slopes, a normal annual range of indoor humidity (Table 3) could, if effective alone, easily account for the measured seasonal variation of f. Table 4 lists outdoor humidity and temperature for the three sites.

Apparently, as might have been expected, both air change rate and humidity are effective in determining the f factor. The effects are sufficiently large that a radon concentration corresponding to 0.02 WL would be specific as to humidity and ΔT.

9. Month-to-Month Variation in Radon Concentration and Working Level

Table 5 shows the geometric mean of the radon concentrations and working levels in a large number of houses in Bancroft during the program period.

Table 3

Average Indoor/Outdoor Temperature Difference

BANCROFT Oct/78 - Sept/79

	ΔT	INDOOR ABSOLUTE HUMIDITY (gr/lb)
Jan	27	34
Feb	28	34
Mar	17	45
Apr	15	46
May	8	54
Jun	7	65
Jul	5	77
Aug	8	74
Sep	9	68
Oct	14	56
Nov	20	49
Dec	21	34

Table 4

Mean Temperature and Humidity

	Port Hope[1]		Bancroft[1]		Sudbury[2]	
	T (°C)	AH (gr/lb)	T (°C)	AH (gr/lb)	T (°C)	AH (gr/lb)
Jan	- 8	11	-11	NA	-13	6
Feb	- 8	12	-13	NA	-12	7
Mar	- 7	22	0	NA	- 6	12
Apr	- 1	37	6	NA	3	22
May	11	51	12	40	11	35
Jun	17	71	16	56	16	49
Jul	21	91	19	76	18	62
Aug	19	83	17	65	17	62
Sep	15	63	13	51	12	48
Oct	9	51	7	~36	6	32
Nov	4	38	1	NA	- 1	21
Dec	0	38	- 4	NA	- 9	9

1) J.F. MacLaren Site Data Oct/78 - Sept/79

2) MNR Data

10. Electrically Heated Structures

The mean monthly f factors for electrically heated structures and for those otherwise heated are tabulated below.

	Electrically Heated	Otherwise Heated
Jan	.40	.30
Feb	.44	.32
Mar	.45	.41
Apr	.33	.40
May	.58	.51
Jun	.64	.63
Jul	.67	.71
Aug	.70	.67
Sep	.64	.58
Oct	.53	.47
Nov	.50	.35
Dec	.49	.31

It is of interest to note that electrically heated structures have higher f factors even in summer. It is suggested that this is due to the absence of a chimney as a consequence of which the air change rate could be expected to be lower in summer.

11. Finished and Unfinished Basements

f factors for finished basements are somewhat higher than those for unfinished basements even though the surface area available for plate-out of daughters would be higher.

Table 5

Radon Concentrations and WL, Month-to-Month

BANCROFT

	# Houses	R (pCi/l)		WL	
		GM	GSD	GM	GSD
Jan	36	3.1	2.1	.009	2.1
Feb	40	4.3	2.2	.013	2.3
Mar	61	3.3	2.6	.012	2.8
Apr	69	3.1	2.0	.01	2.2
May	82	3.7	2.5	.018	2.7
Jun	95	2.9	2.6	.016	2.9
Jul	103	3.0	2.5	.018	2.8
Aug	127	3.0	2.2	.017	2.4
Sep	82	3.3	2.1	.017	2.1
Oct	78	3.6	2.0	.017	1.9
Nov	43	3.7	2.0	.011	2.0
Dec	33	4.4	2.3	.013	2.1

It is to be noted that the average radon concentration and working level are respectively 12% lower and 42% higher for the summer months than for the winter months (O N D J F M A).

12. Means of Selection of a Radon Level for Compliance

Were a radon concentration to be used for the purpose of compliance with 0.02 WL, it should be such that an acceptable fraction of the structures exceeding compliance were identified for remedial work. To meet this requirement, the frequency of occurrence of working level in excess of 0.02 for radon concentrations in excess of R pCi/l was determined for summer and winter seasons for each of the sites. It needs to be recognised that some structures would have radon concentrations in excess of the selected level whilst having working levels less than 0.02. For these structures remedial work would be indicated but unecessary. To

determine the extent of this eventuality, the frequency of occurrence of working level less than or equal to 0.02 for radon concentrations in excess of R pCi/l was also determined. Figures 4, 5 and 6 portray the results of these analyses for Elliott Lake, Bancroft and Port Hope.

Referring to Figure 6, for example, it will be seen that the radon compliance level (R_c) such that, whether summer or winter in Port Hope, 95% of the measurements of radon in excess of R_c correspond to working levels in excess of .02 would be 3 pCi/l. For such a compliance level, 95% of the winter measurements correctly indicate working level in excess of .02 while 37% of the winter measurements and 10% of the summer measurements incorrectly indicate working level in excess of .02. 77% of all the working level measurements were $\leq$ 0.02. For Bancroft and Elliott Lake the percentages of working level measurements $\leq$ 0.02 were 60% and 63% respectively.

The R_c for 95% occurrence of radon > R_c for working level > .02, summer or winter, is 2.4, 2.7 and 3 respectively for Elliott Lake, Bancroft and Port Hope.

It is to be noted that the difficulty of surely indicating structures for which working levels exceed 0.02 without incorrectly indicating structures at less than 0.02 is not based solely on seasonal variation. Referring again to Figure 6 an R_c of 4 pCi/l would pick up 95% of the winter levels > .02 WL but 26% of those $\leq$ .02 would be incorrectly picked up.

The results are those which might reasonably be expected in view of the seasonal variations shown in Figure 1 and the data in Tables 3 and 4.

The relation between summer and winter for working level > 0.02 is different for Elliott Lake than for Bancroft and Port Hope. It is believed that this is a consequence of the comparatively great attention to high WL structures at Elliott Lake in the winter of 77/78.

13. Cost Effectiveness of Compliance by Radon Level

Annual averaging of radon is considered to be less costly than annual averaging of working level. However there are some costs involved in the potential consequences e.g. houses not remedied which should have been and remedied where it was unnecessary.

$a_>$ - fraction of all houses in which WL > .02.

b - selected confidence level in identifying houses > .02 by Rn method at R_C.

c - fraction of houses below .02 with Rn > R_C.

C_R - cost of remedial work per house.

S_C - social cost of not remedying house at > .02.

j - ratio of S_C to C_R.

S_{CU} - social cost of remedying a house unnecessarily, assumed to be <<< C_R.

C - net cost per house of administering compliance by Rn.

Then $C = [c\ (1 - a_>) + (1 - b)\ (j - 1)\ a_>]\ C_R$

For Bancroft and Elliott Lake, given that j is as small as 2, C ranges from 0.16 to 0.2 C_R and from 0.18 to 0.27 C_R respectively as the confidence level is increased from 80 to 95%. For values of j greater than 2, C would increase.

Thus, the saving per house to be made by administering by radon must exceed at least some 20% of the average cost of remedial work per house.

It is to be noted that, in other than mineralized areas, c would probably be higher than for Bancroft and Elliott Lake.

14. Data Base

All the data used for the considerations reported herein are for grab samples taken principally in the morning. Had they been taken throughout the day, the results might have been somewhat different. Since nighttime temperatures are lower, the finding reported in Section 8 would support an expectation that f over all time would be lower than for just the daytime in which case a suitable R_c would be higher.

Some cross comparison of grab sample results with radon averaging units has been carried out. The results are inadequate for the purpose of assessing the relation between the time-averaged radon level and the average of grab samples. No work for comparison of the time average of working level to the average of working level grabs is known to have been done. Since the compliance level is an annual average, confidence in any radon level selected for compliance purposes and based on grab sample data would require assurance of the relevancy of grab sample averages to all-year averages.

As part of this investigation a cross comparison of radon measurements was made between Port Hope and Elliott Lake and of working level measurements between Port Hope and Bancroft. The consistency of measurements was found to be better than ± 10%. Uncertainties arising from counting statistics range up to 30 or 40% for low radon levels particularly with small cells and low concentrations. In the range of working level and radon of interest for compliance purposes, counting uncertainty is better than ± 15%.

15. Conclusions

1. A radon level of 2.4 pCi/l would indicate 95% of the instances at the three sites when working level exceeded 0.02. However, much remedial work would be indicated where none was necessary. This would be the case even if an R_c were selected for each season at each site. The probable consequence of such unnecessary work would be considerable wasted monetary and social cost.

2. Were a function of thermal conditions for the average house to be identified which principally determined f regardless of site, it would be possible to state an R_c for compliance purposes for each particular thermal condition (i.e. given the thermal condition, the radon level corresponding to .02 WL would be known. Possible development of an R_c on this basis would not, however, solve the problem inherent in living conditions. As is suggested in Section 5, even were structures and thermal conditions identical, f may be significantly influenced by family characteristics and living styles. It would be necessary to test the function of thermal conditions against a range of resident characteristics to be assured that the thermal conditions principally determined f over the full range of both physical and occupancy characteristics.

3. As an incidental conclusion, it is noted that the data suggest that some decisions, to remedy based on summer data or not to remedy based on winter data, are likely to be incorrect. Table 6 shows, for Bancroft, the ratio of monthly grab sample averages of working level to the annual average which may be inferred from the data in Table 5.

Table 6

	Ratio of Monthly Grab Sample Average to Implied Annual Average	Implied Annual Average for Monthly Grab Sample Average = 0.02 WL
Jan	.63	.032
Feb	.91	.022
Mar	.84	.024
Apr	.70	.029
May	1.26	.016
Jun	1.12	.018
Jul	1.26	.016
Aug	1.19	.017
Sep	1.19	.017
Oct	1.19	.017
Nov	.77	.026
Dec	.91	.022

Although there were more than 32 structures represented in the data, it would be necessary to determine that each monthly set was representative of all houses before rigorously using such an Implied Annual Average corresponding to .02 WL for compliance purposes. However, it would be reasonable, even with the evidence in hand, not to remedy structures with marginally high summer readings and to remedy structures with marginally low winter readings.

16. Recommendations

Provided that the need for identification of a suitable radon level for compliance purposes warrants additional work, further study of the dependence of f upon thermal conditions should be carried out. If not, compliance should continue to be based on WL grab sampling or time-averaging WL units.

If compliance is to continue to be based on grab samples during only at most a few successive months, the existing data based should be re-examined to determine the monthly grab sample average which corresponds to an annual average of 0.02 WL.

In any event, either data is needed over a full year or the ΔT and H needs to be measured to assist in determining annual average.

Supplement

1. Electrically Heated Structures

The mean monthly f factors for electrically heated structures and for those otherwise heated are tabulated below.

	Otherwise Heated	Electrically Heated
Jan	.30	.40
Feb	.32	.44
Mar	.41	.45
Apr	.40	.33
May	.51	.58
Jun	.63	.64
Jul	.71	.67
Aug	.67	.70
Sep	.58	.64
Oct	.47	.53
Nov	.35	.50
Dec	.31	.49

It is of interest to note that electrically heated structures have higher f factors even in summer. It is suggested that this is due to the absence of a chimney as a consequence of which the air change rate could be expected to be lower in summer.

2. Finished and Unfinished Basements

f factors for finished basements are somewhat higher than those for unfinished basements even though the surface area available for plate-out of daughters would be higher.

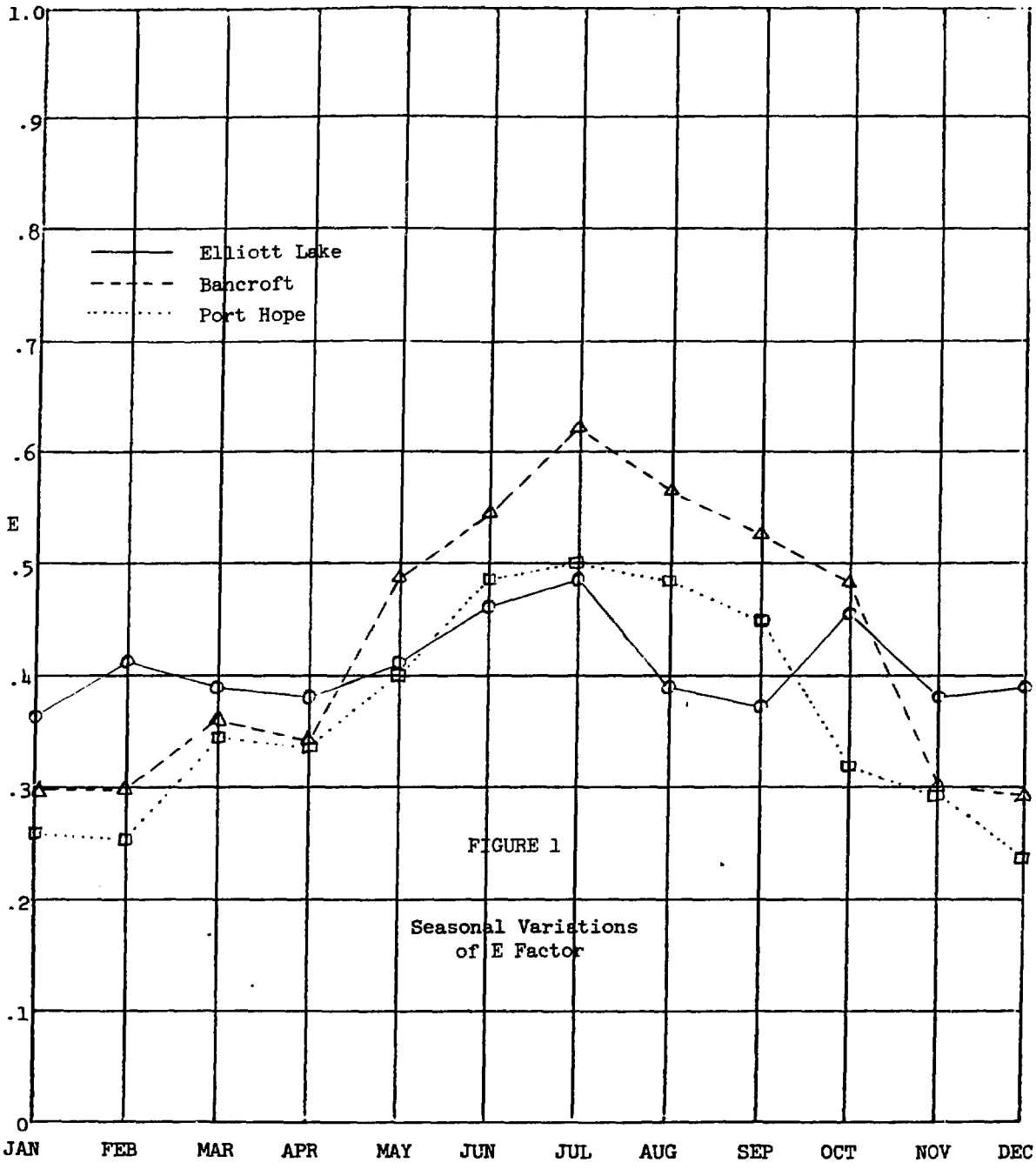


FIGURE 1

Seasonal Variations of E Factor

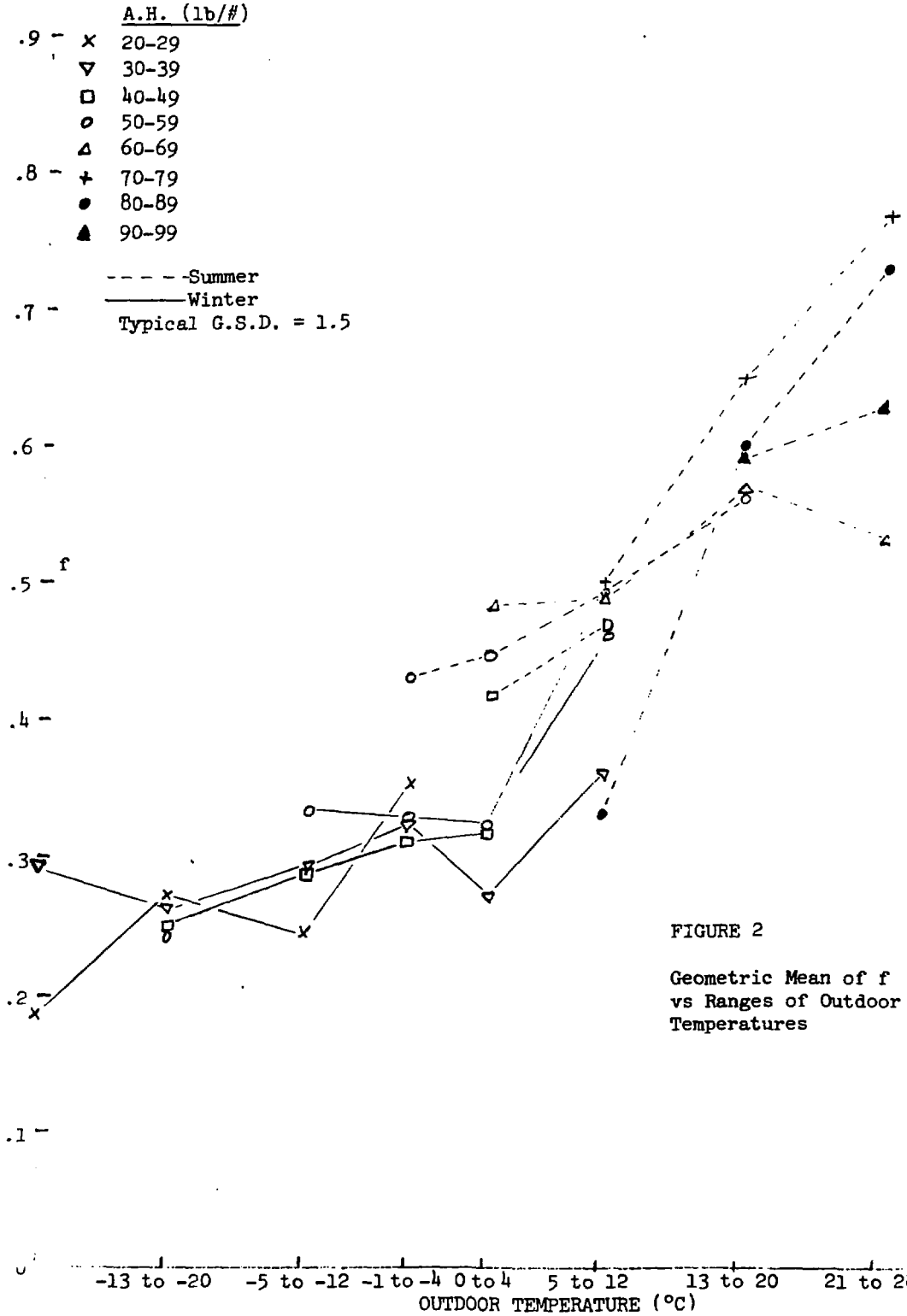


FIGURE 2

Geometric Mean of f vs Ranges of Outdoor Temperatures

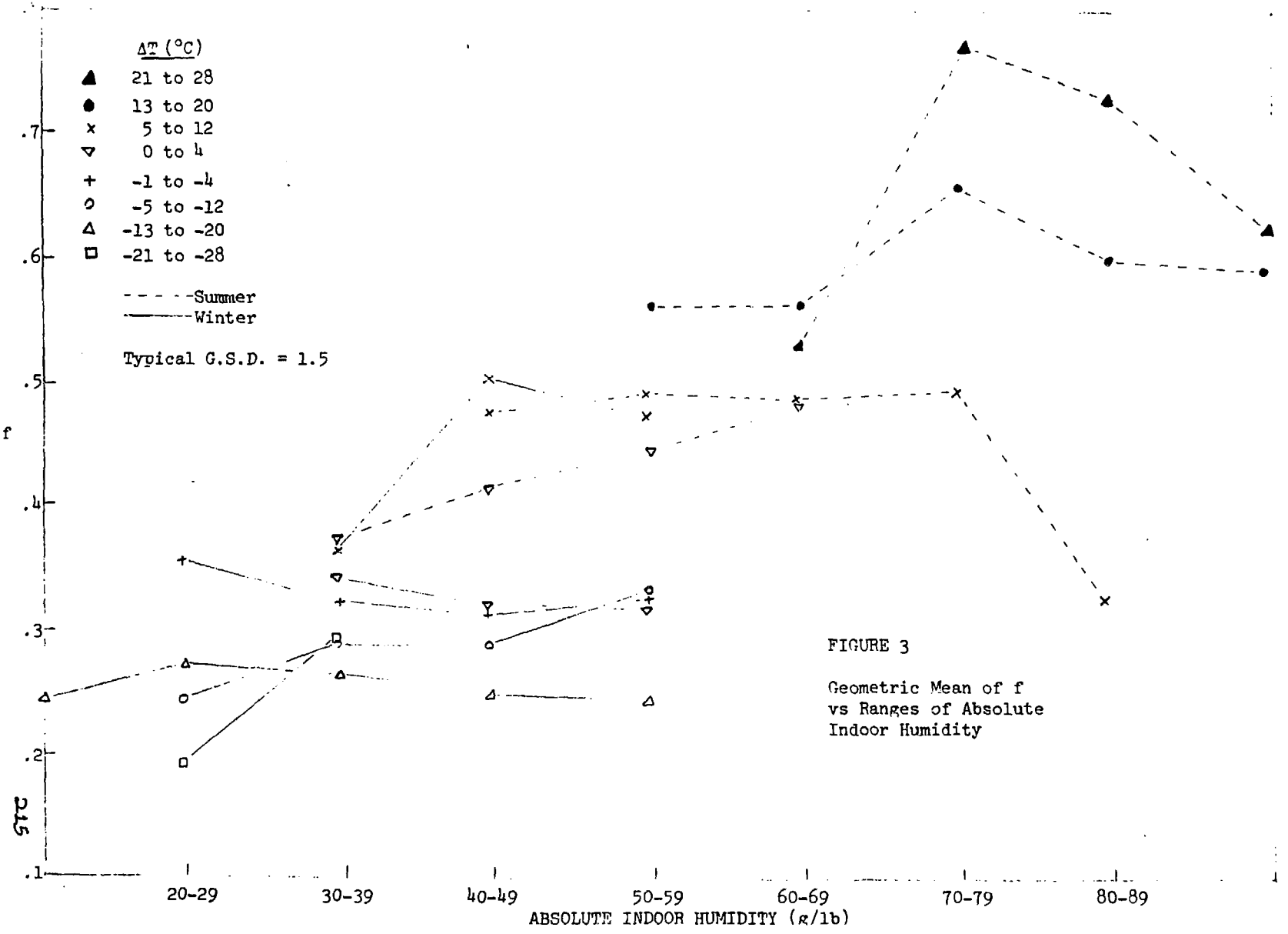
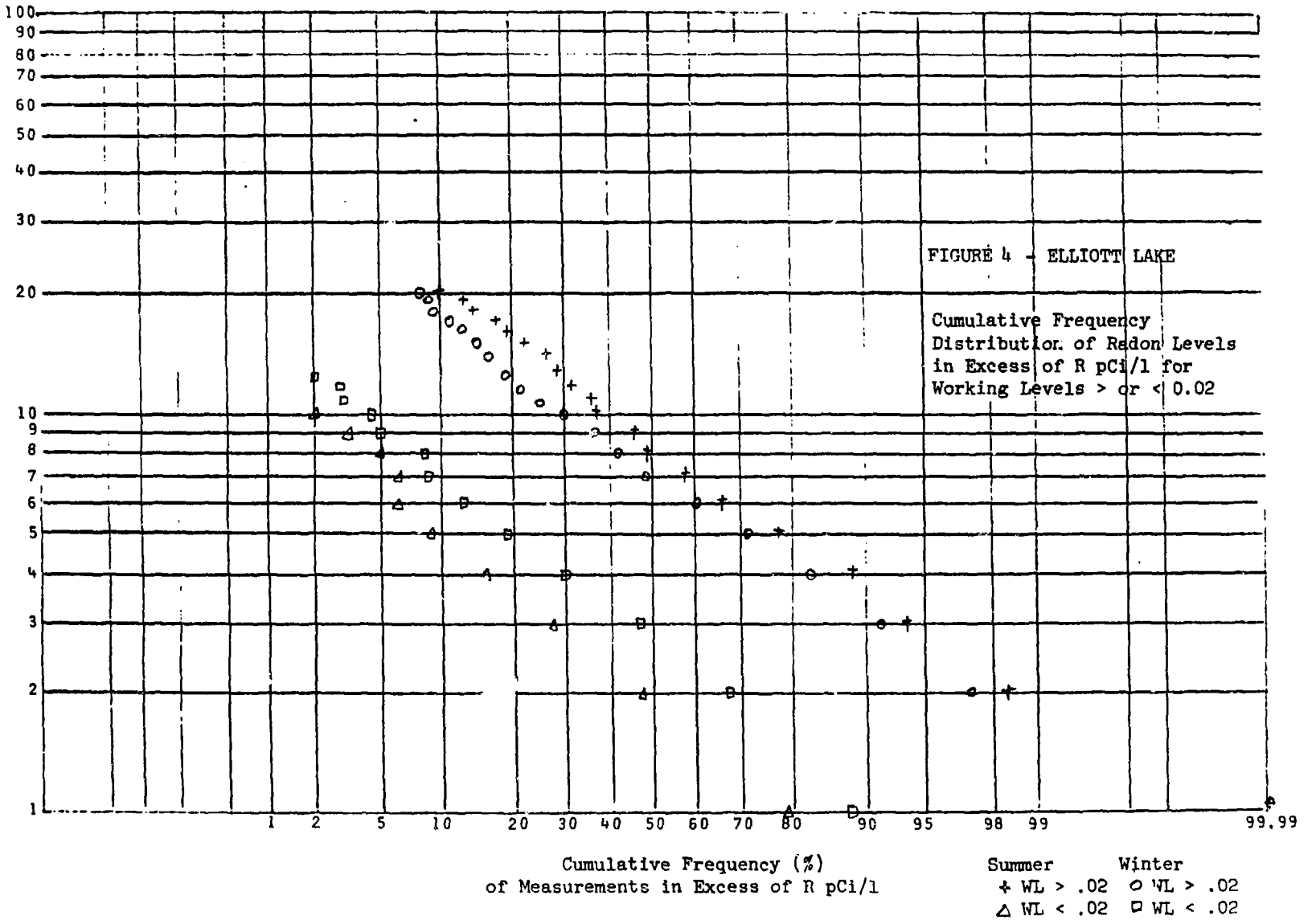


FIGURE 3

Geometric Mean of f
vs Ranges of Absolute
Indoor Humidity


100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
R pCi/1
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.99
Cumulative Frequency (%)
of Measurements in Excess of R pCi/1
FIGURE 4 - ELLIOTT LAKE
Cumulative Frequency Distribution of Radon Levels in Excess of R pCi/1 for Working Levels > or < 0.02
Summer
+ WL > .02
△ WL < .02
Winter
○ WL > .02
□ WL < .02

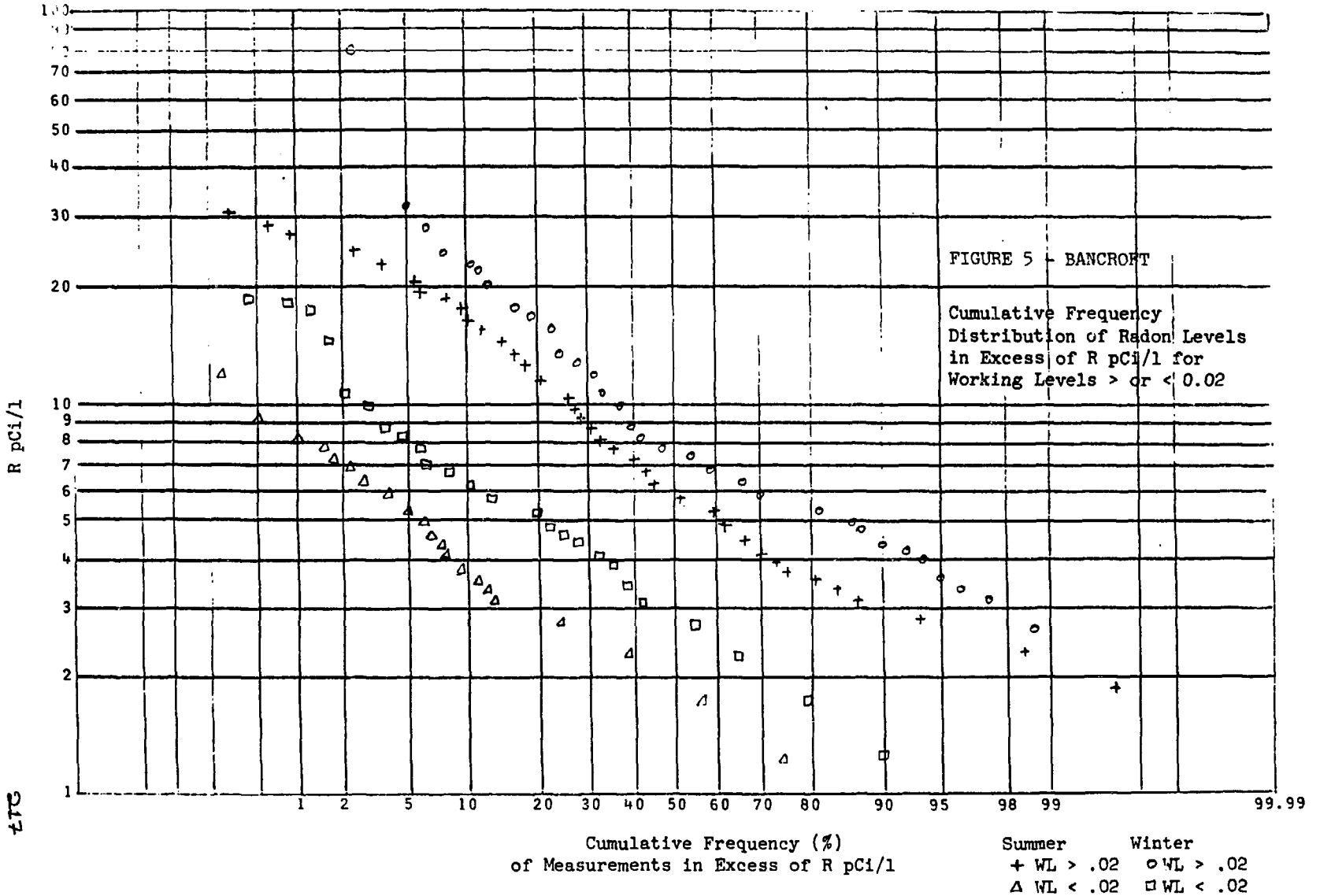
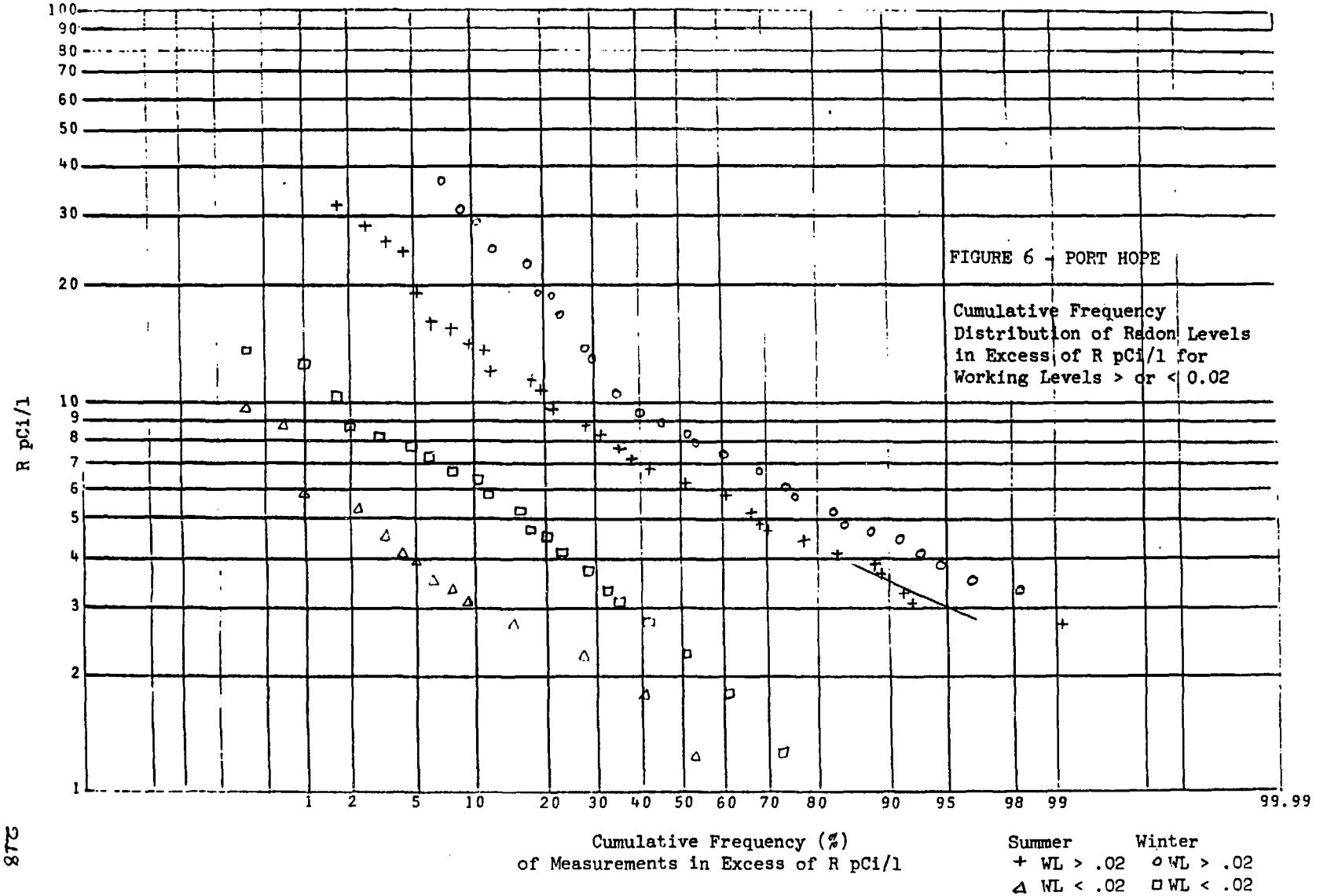


FIGURE 5 - BANCROFT

Cumulative Frequency Distribution of Radon Levels in Excess of R pCi/l for Working Levels > or < 0.02


100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
R pCi/l
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.99
Cumulative Frequency (%)
of Measurements in Excess of R pCi/l
FIGURE 6 - PORT HOPE
Cumulative Frequency Distribution of Radon Levels in Excess of R pCi/l for Working Levels > or < 0.02
Summer
+ WL > .02
Δ WL < .02
Winter
o WL > .02
□ WL < .02

PRESENTED TO

THIRD WORKSHOP ON RADON AND RADON DAUGHTERS
IN URBAN COMMUNITIES ASSOCIATED WITH
URANIUM MINING AND PROCESSING
AT PORT HOPE, ONTARIO

MARCH 12-14, 1980

WHAT DOES THE EQUILIBRIUM FRACTION MEAN IN HOUSES?

ARTHUR G. SCOTT

BSMA/ACRES
ELLIOT LAKE

What does the Equilibrium Fraction mean in Houses?

The equilibrium fraction (F) for coexisting concentrations of radon and short lived daughters is given by the ratio of the total potential alpha energy of the existing daughters to the total potential alpha energy of daughters that would be in equilibrium with the existing radon. The maximum value possible is one. However, the equilibrium fraction cannot be measured directly, but must be estimated from the ratio of two measurements. In practice, the actual potential alpha energy of the daughters is estimated by filtering an air sample of 100 litres or more collected over a period of several minutes, measuring the alpha disintegration rate on the filter, and then converting that according to some assumed ratio of daughters to total potential alpha energy (WL). The radon concentration is estimated from the count rate of a few hundred cm^3 air sample collected in a scintilation flask over an effective period of 10 to 20 seconds.

Table 1 shows the cumulative frequency distribution of estimated equilibrium fractions at Elliot Lake in 1979. The values are very variable, as shown by the log normal distribution, with a GDS of 1.6. This is comparable to the variation of radon levels.

A partial explanation for this variability is random error, particularly as many measurements are made at relatively low levels of activity where the statistical counting error can be a major component of total error. Typically, the random errors in the estimation of WL amount to a 1 sigma uncertainty of about 5-10%, including the uncertainty in daugher ratio, and about 10-20% for estimations of radon concentration. This is not enough to explain more than about 40% of the variation observed and so we must regard most of the variation as genuine.

There is a systematic error in the measurements in that the concentrations of radon and radon daughters measured are not

coexisting. If there are fluctuations in radon concentration with period shorter than the radon daughter sample time, it follows from sampling theory that the variability of radon samples will typically be about 5 times higher than the variability in WL measurements. Figure 2 shows the change in concentration of SF_6 at one end of a basement after a balloon containing SF_6 was burst at the other. Samples of two seconds duration were taken every minute. It took the SF_6 only 3 minutes to travel the length of the basement, and within 10 minutes of the release, the concentration had reached its maximum. In this case the mixing period in the basement is clearly only a few minutes. Concentration fluctuations with periods of less than a minute are therefore possible, as is demonstrated by a 16% reduction in concentration lasting for two minutes just before the end of the measurement period. It is difficult to know how often radon concentration fluctuations of this magnitude occur, but this is a major uncontrolled variable when F is estimated from measurements on non-coexisting concentrations. It should be remembered in addition to these artefacts of sampling, if the radon concentration is increasing or has increased in the hour or so before a measurement, the value of F will be lower than the final value. The daughter activity depends on the radon concentration some 20-40 minutes earlier, and so it takes some time before increases in radon concentration are fully reflected in increases in WL. However, even if the errors in estimation of F are large, they are not so large that all variation in the measured radio can be ascribed to errors of one type or another. We can safely assume that F does genuinely vary from time to time, though perhaps not as much as appears at first sight.

What do we learn from the measurements? The most important fact is that F is about 0.4, i.e. there are on average less than half the daughters present in the air than the radon concentration can produce. Traditionally, the equilibrium fraction has been interpreted either as an indication of the age of the radon, or

as a ventilation rate. A low value of F would mean either that the radon had just entered and the daughters had not time to grow in, or else that the ventilation rate was sufficiently high to keep the mean life of a radon atom in the house low. Figure 3 shows that the mixing period in a house in winter is typically 40 minutes, so fresh radon is rapidly mixed into the old radon already in the house, and that the ventilation period is several hours - too long for ventilation to be the cause of these low values of F. There must be other causes for these low values, that is, there must be other radon daughter removal mechanisms.

Variation in the attached fraction and surface deposition rate caused by variation in CN concentration has long been popular culprit when variations in F are discussed. As most radon daughters are attached to CN, the removal rate of CN will also influence the removal rate of daughters. Figure 4 shows the measured removal period of cigarette nuclei both summer and winter is about 1.3 hours. If this removal period is typical of the natural aerosol in the house, then this provides part of the removal mechanism needed to produce the observed values of F. Unfortunately, it cannot be a complete explanation, for as Figure 5 shows, the distribution of F does change and is higher in the summer than in the winter. The CN concentration also varies, and is on average higher during the winter as shown in Figure 6. As increased CN concentration should lead to higher values of F, the variation of F is in the wrong direction to be caused by variation in CN. It therefore seems that the conventional removal mechanisms are not adequate to explain both the low values of F, and the summer-winter variation, and an additional removal mechanism is needed. As low values of F are predominantly found in the winter, it seems most likely that an additional removal mechanism operates during the winter. Although the humidity drops by a factor of two or three from summer to winter, Mr. Haywood's analysis shows that the changes of F with humidity during summer and winter are small. It seems more likely that

operation of the heating system (which is not considered by existing theory) provides a major daughter removal mechanism. As the daughters that are not in the air are deposited on surfaces in the house, as can be shown by direct measurement of the surface alpha activity, operation of the heating system must increase the deposition rate somehow. We intend to carry out work in the coming year to get a better understanding of this effect.

In summary, the reason for the low F values measured in houses is not understood at the moment, and existing theoretical treatments are not adequate to explain the seasonal variations. If the variations are caused by the operation of the heating system, then determination of an average value of F in a house with sufficient accuracy to use average radon measurements as an alternative to WL measurements for compliance purposes will be more difficult than expected for then F will not only be influenced by house specific factors, but also by the weather. However, if the parameters can be well enough defined, it might be possible to correct for variations during the averaging measurement period so that the estimated WL was as accurate as the present estimate from spot sampling. Radon averaging as a method of estimating WL is certainly convenient and the convenience may compensate for a precision in the WL estimate no higher than the present spot sampling methods.

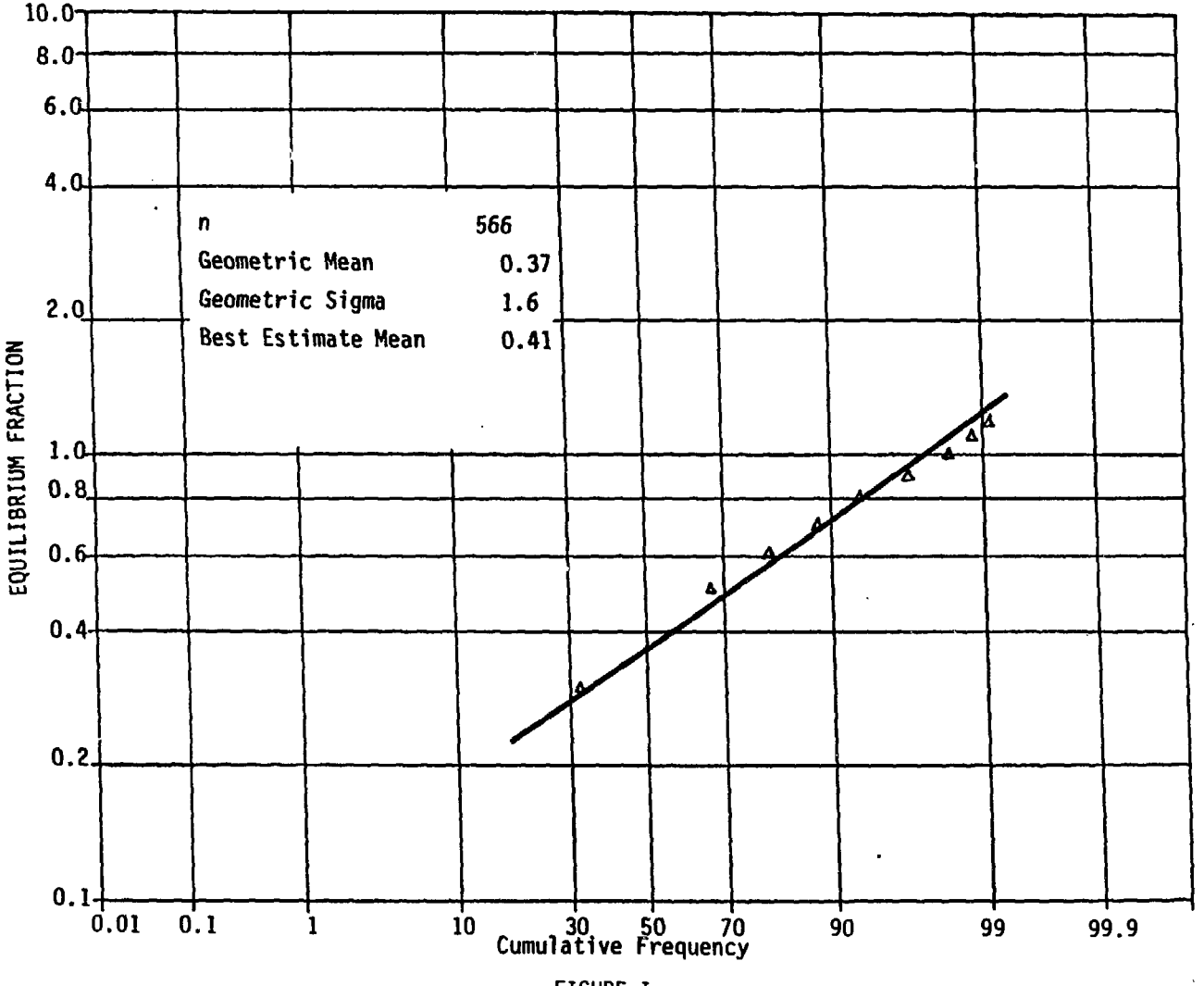
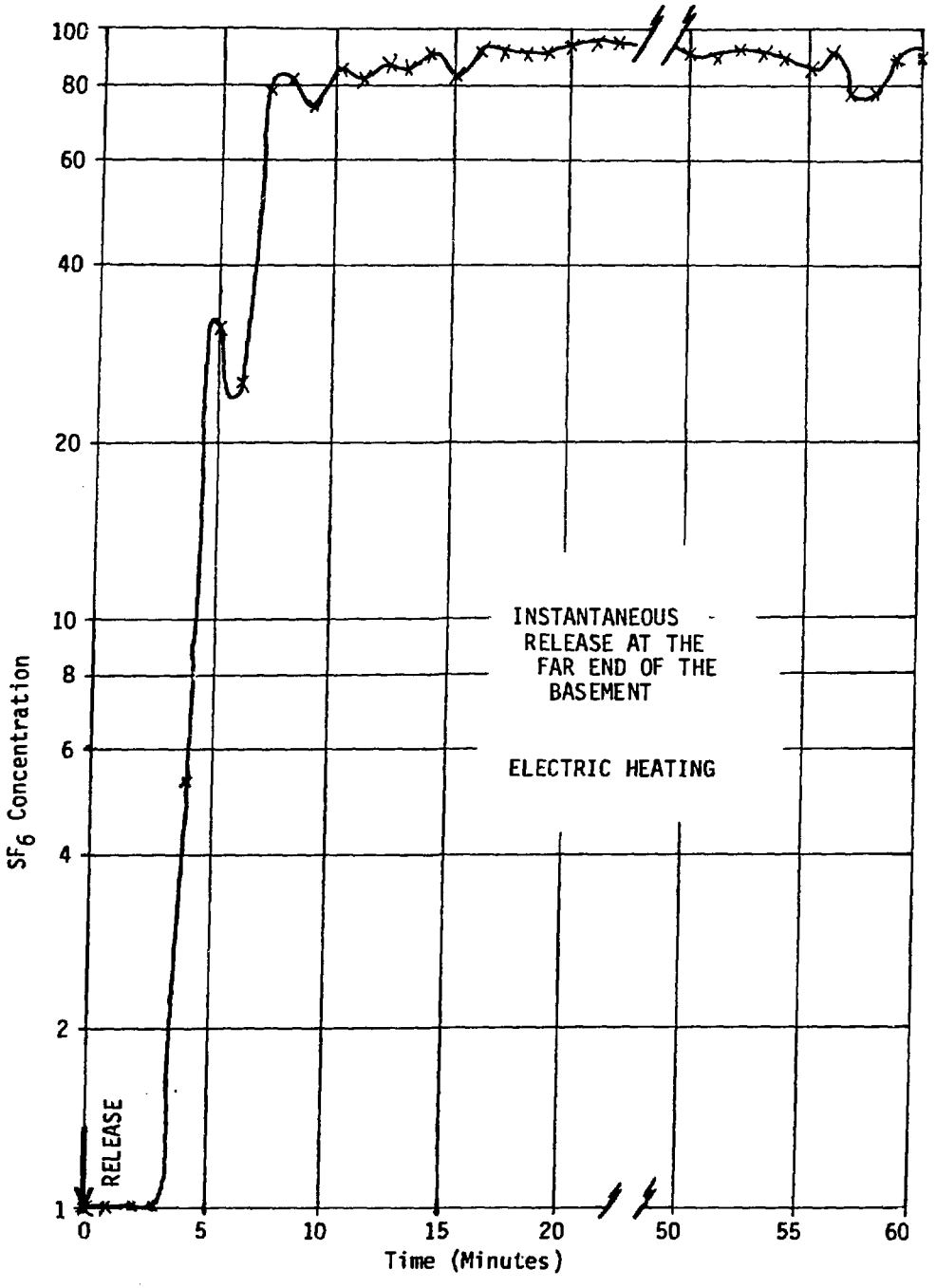
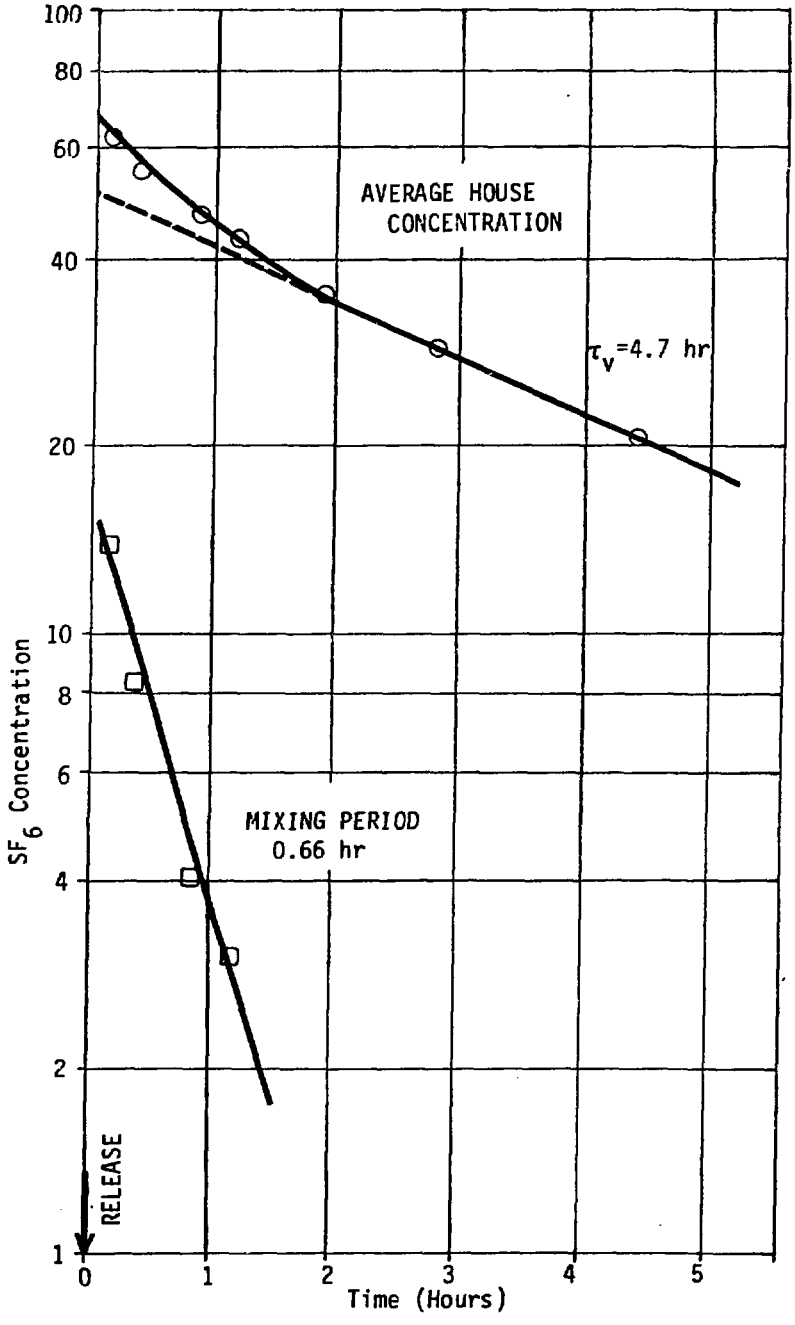


FIGURE I

OVERALL DISTRIBUTION OF EQUILIBRIUM FRACTION

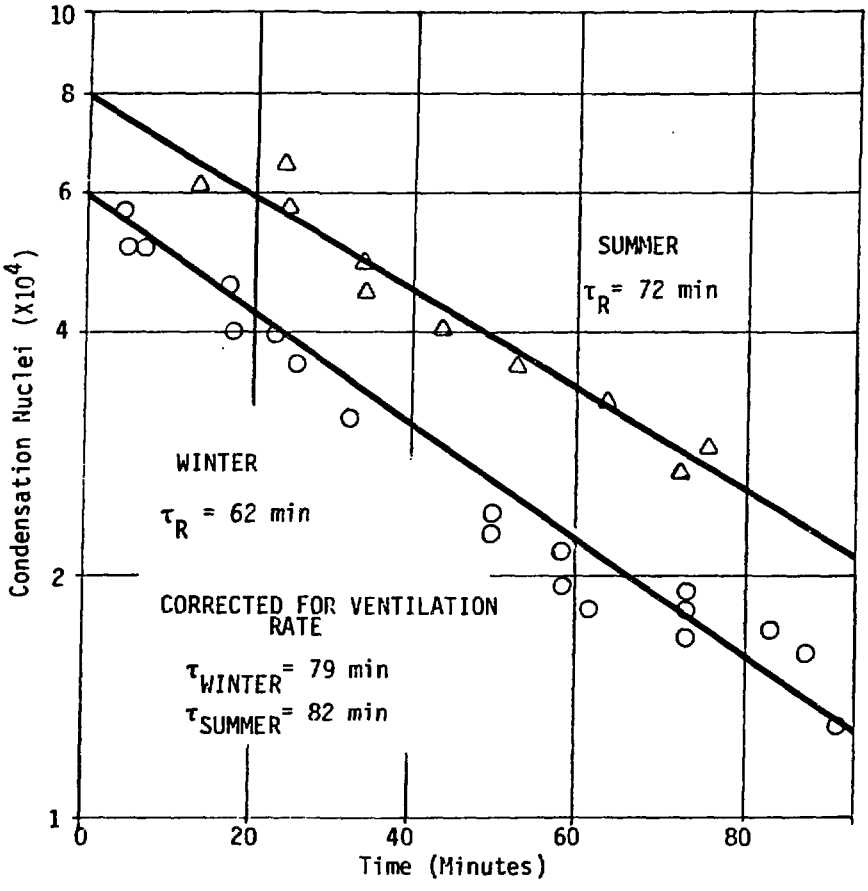


ROOM MIXING PERIOD TEST
FIGURE 2



HOUSE MIXING PERIOD TEST
WINTER - FAN IN OPERATION
BASEMENT RELEASE

FIGURE 3



REMOVAL RATE OF CIGARETTE CONDENSATION NUCLEI

FIGURE 4

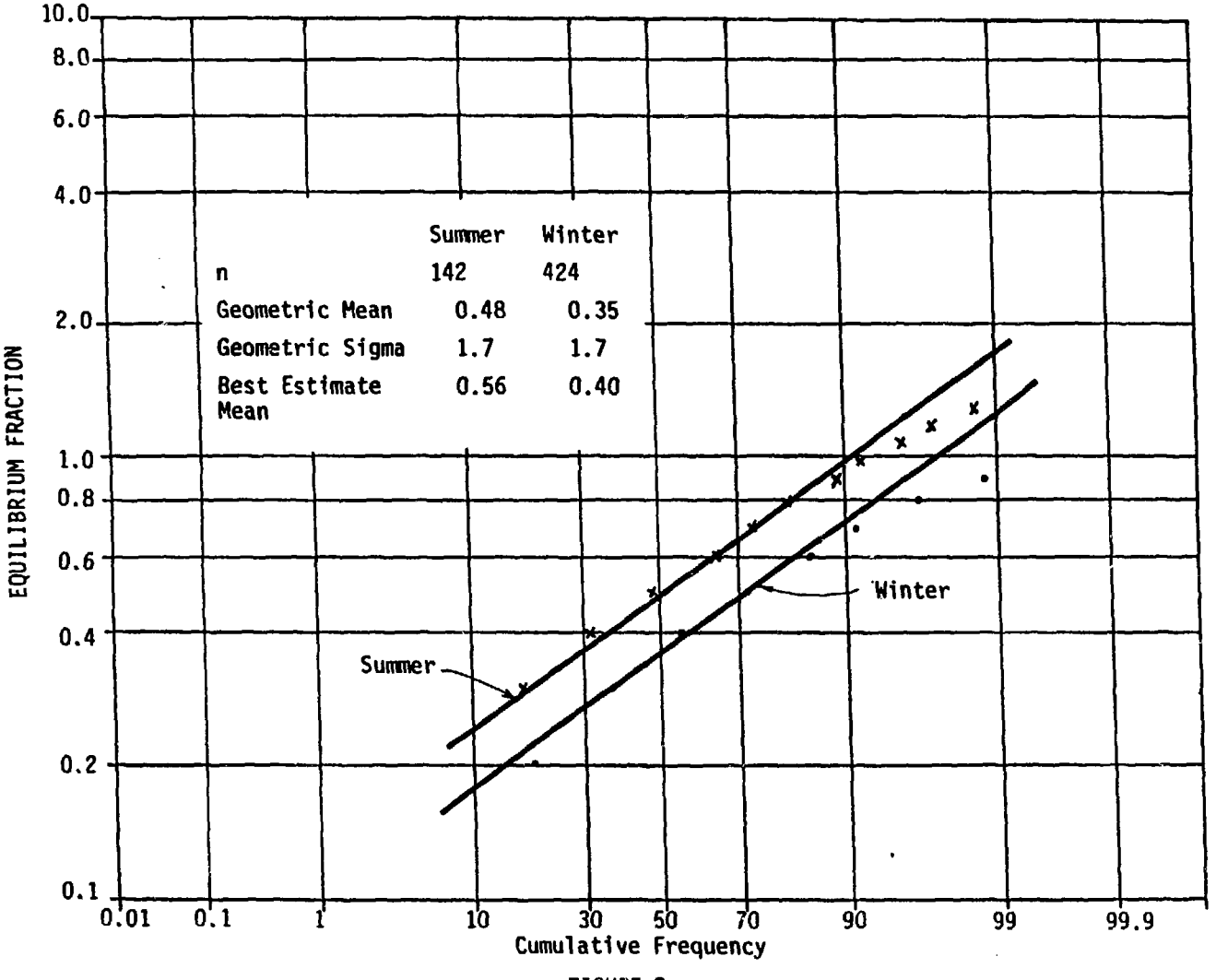
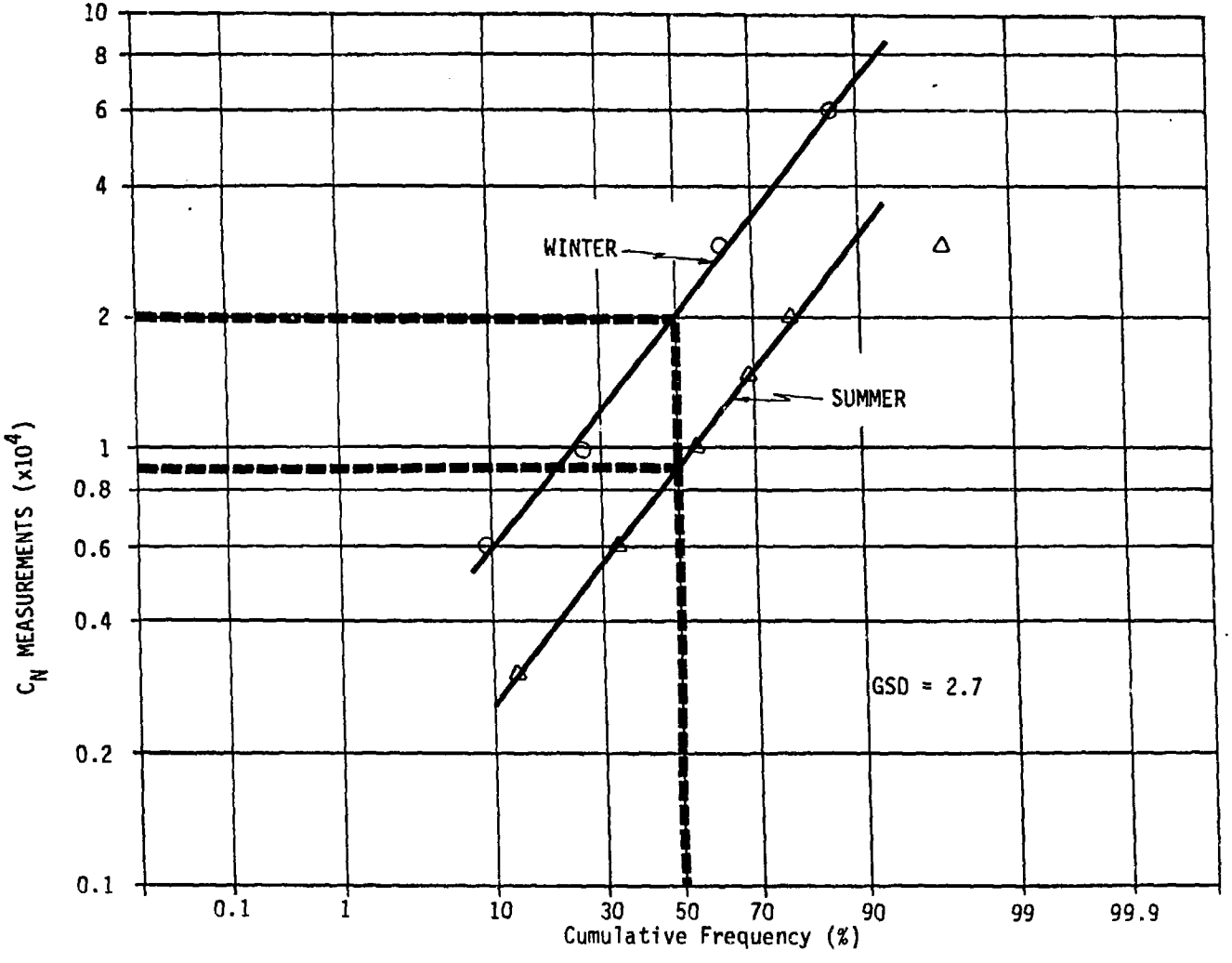


FIGURE 5

VARIATION OF EQUILIBRIUM FRACTION WITH SEASON



CUMULATIVE DISTRIBUTION OF C_N MEASUREMENTS

FIGURE 6

What Does The Equilibrium Fraction Mean in Houses?

Question/Comments:

K. Cliff: What concentration of condensation nuclei did you find in dwellings?

A. Scott: The median value found was approx. 1 x 10^4 during summer and 2 x 10^4 during winter.

K. Cliff: What did you measure (CN concentration) with?

A. Scott: A Gardner & Associates CN Counter.

MORTALITY AND INDOOR RADON DAUGHTER CONCENTRATIONS IN 13 CANADIAN CITIES

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Department of National Health and Welfare
Ottawa, Ontario
Canada

ABSTRACT

A study was carried out to determine if lung cancer and general mortality rates in 13 Canadian cities were significantly correlated with average indoor radon daughter concentrations. The radon daughter measurements were obtained from a study of 10,000 homes chosen in a statistically valid grab sample basis.

Cancer deaths by year of death, sex, age, and cause were retrieved for each of the cities for the period 1957-1976. Age specific and age standardized mortality rates were calculated.

The results showed no evidence of any substantial association between general or lung cancer mortality rates and indoor radon daughter concentrations.

The limitations of this study and the feasibility of a common international program of epidemiology of radon daughter exposure are discussed. A proposal is made for the use of case control studies of lung cancer to assess the relative importance of smoking, occupational and domestic exposure to radon daughters.

INTRODUCTION

The Radiation Protection Bureau of the Department of National Health and Welfare surveyed 9,999 homes in 14 Canadian localities during the summers of 1977 and 1978 (one locality was excluded from this study - see below). These surveys were done according to a random sampling system established by Statistics Canada.[1] The objective of the survey was to sample a wide cross-section of Canadian homes to obtain information on the levels of naturally occurring radon. All studies were done during the summer when students could be hired to do the survey and the field work was considerably easier. The results of this study are presently in press with the Health Physics Journal.[2]

The results showed statistically significant geographical differences. The highest concentration of radon was found to be 75 pCi/l; the highest concentration of radon daughters was 0.233 W.L.

Because of the small size of one city and the lack of adequate data for that area, it was omitted from the study. Thirteen cities were chosen for the present study to determine if cancer mortality rates were significantly correlated with the average indoor concentration of radon daughter products.

METHODS

Cancer deaths by year of death, sex, age and cause were retrieved for each of the 13 study locations for the period 1957 to 1976 from data supplied by the Health Division of Statistics Canada. The study locations were defined by their 1976 boundaries. Populations by sex and age for the census years 1961 and 1971 were obtained for each study location from Statistics Canada publications[3,4]. Age-specific death rates were calculated by determining the average annual number of deaths in each age and sex group during two time periods (1957 to 1965, and 1966 to 1976) and dividing by the mid-year population for the relevant age and sex group. Age-standardized mortality rates (ASMRs) were calculated by the direct method using the 1971 Canadian population as a standard. The standard errors of ASMRs were calculated by the method of Chiang[5].

RESULTS

The geometric mean of the radon daughter concentration varied from .0009 to .0036 W.L. The percentage of homes exceeding .02 W.L. for each city was: St. John's, Nfld. 0.7; Charlottetown 0.9; Halifax 5.2; Fredericton 3.3; St. John, N.B. 2.8; Montreal 1.0; Quebec 2.1; Sherbrooke 6.4; Sudbury 6.9; Thunder Bay 2.2; Toronto 0.9; Calgary 0.2; Vancouver 0.0.

There was a strong correlation between the mean radon concentrations by city and the percentage of homes in which the radon daughter concentrations exceeded 0.02 W.L. In view of the skewed distribution of radon daughter concentrations, the

percentage of homes in which radon daughter concentrations exceeded 0.02 W.L. was chosen as the radiation exposure index for correlation with cancer mortality rates.

GENERAL CANCER MORTALITY

Basic population and cancer mortality data from the 13 study locations are presented in Table 1. The reader will note the wide variation in city size with 1971 populations ranging from about 25,000 to almost 3,000,000. Crude mortality rates ranged from 90.8 to 175.1 for the period 1957 to 1965 and from 100.2 to 200.9 for the recent period.

Age-standardized mortality rates (ASMRs) and comparative mortality figures (CMFs) for all cancers combined are presented in Table 2. ASMRs for males generally increased over time while those of females generally declined. However, the changes were only statistically significant for males living in the largest cities. The CMFs represent the relative change in ASMRs across time; the CMF for males in St. John's, Newfoundland indicates that the ASMR during the period 1966 to 1976 was 91% of that during the earlier period.

The correlation between ASMRs for all cancers combined and radon daughter concentrations (RDCs) by city is presented in Figures 1 and 2 and Table 3. There were no statistically significant correlations between RDC and any of the indices of cancer mortality: mortality rates for each of two time periods ($ASMR_1$ = 1957-1965, $ASMR_2$ = 1966-1976, the absolute change in mortality rates over time ($ASMR_2 - ASMR_1$) or the relative change ($ASMR_2 \div ASMR_1$).

LUNG CANCER MORTALITY

ASMRs and CMFs by city for lung cancer are presented in Table 4. ASMRs increased with time in all cities in both males and females. In general, the absolute and relative changes in lung cancer ASMRs were greatest for those cities for which ASMRs were lowest during the first time period. Thus there were strong negative correlations between $ASMR_1$ and CMF ($r = 0.91$ for males, $r = 0.78$ for females).

Correlations between lung cancer mortality indices and RDCs are presented in Table 3 and Figures 3 and 4.

ALL-AGE LUNG CANCER MORTALITY

The results show essentially no correlation in either sex between lung cancer ASMRs in either time period and RDCs by city. This impression is confirmed by the low correlation coefficients presented in Table 4. There were weak positive but statistically insignificant correlations between the indices of time trend for male lung cancer ASMRs and RDCs ($r = 0.26$ for $(ASMR_2 - ASMR_1)$ versus RDC, $r = 0.28$ for CMF versus RDC).

The corresponding correlation coefficients for female lung cancer are also positive but weak (r = 0.25 and 0.10, respectively).

MALE LUNG CANCER MORTALITY, AGES 25 TO 54

Lung cancer ASMRs and CMFs for males aged 25 to 54 were calculated and the correlation between these rates and RDCs were plotted. There was essentially no correlation between any of the mortality indices and RDCs by city.

MALE LUNG CANCER MORTALITY, AGES 55 TO 69

Data similar to those above for males aged 55 to 69 were calculated. There was a weak negative correlation (r = -0.17) between ASMRs for the period 1957 to 1965 and RDCs and a weak positive correlation (r = 0.23) between ASMRs for the recent time period and RDCs. There were also weak positive correlations between the indices of time trend and RDCs (r = 0.30 for $(ASMR_2-ASMR_1)$ versus RDC, r = 0.26 for CMF versus RDC).

MALE LUNG CANCER MORTALITY, AGES 70 AND OLDER

Results for lung cancer in older males were calculated. There was essentially no correlation between RDC and any of the mortality indices except CMF (r = 0.27).

MALE LUNG CANCER MORTALITY CONTROLLED FOR CITY SIZE

The observed ASMRs for lung cancer (all ages) by city and those expected based on city size were calculated. The CMFs provide an index of lung cancer mortality adjusted for city size. There were weak positive correlations between the CMFs and RDCs by city for both males (r = 0.26) and females (r = 0.37). The latter correlation coefficients are higher than those between lung cancer ASMRs (unadjusted for city size) and RDCs (r = 0.19 for both males and females, see Table 4).

LEUKEMIA

ASMRs and CMFs for leukemia were calculated. There was some tendency for ASMRs for females to decline over time but none of the changes in either sex were statistically significant. Correlations between leukemia mortality indices and RDCs by city were plotted. There was a statistically significant negative correlation between the ASMR for males during the period 1957 to 1965 and RDCs by city (r = -0.59, $p<0.05$) but essentially no correlation during the recent time period (r = -0.06). There were statistically significant positive correlations between RDCs and both indices of time trend (r = 0.56 for $(ASMR_2-ASMR_1)$ versus RDC, r = 0.62 for CMF versus RDC). Thus there was a statistically significant tendency for male leukemia ASMRs to increase more rapidly over time in cities with higher RDCs compared to cities with lower RDCs. However, no such tendency was observed for female leukemia ASMRs.

DISCUSSION

The study was based on the assumption that the relative differences in household radon daughter concentrations by city have not changed substantially over the past 30 years or more.

The radon daughter surveys were carried out during the summer. The study design was based on the assumption that the relative difference between radon daughter concentrations between the cities were not influenced by seasonal variations.

Data on smoking habits by city would be useful since tobacco smoking is by far the strongest known risk factor for lung cancer in the general population. The absence of such data is a major weakness in the present study.

The mortality rates were based on deaths of persons who were usual residents of the study cities at the time of death. Migration of persons in and out of cities over a period of time will have reduced the chance of observing any correlation between mortality and radon daughter concentrations.

The radon daughter concentrations were relatively low. No matter which model is used to estimate the risk of lung cancer from exposure to radon daughters, the risk will also be minimal. The numbers of excess lung cancer deaths due to such exposures in Canadian cities are probably too low to be detected by the present study.

The size and labour force compositions of the city varied substantially. Lung cancer is known to be associated with city size and certain occupations. Inability to adjust adequately for these variables would tend to obscure any association with radon daughter concentrations.

CONCLUSIONS AND PROPOSAL FOR CASE CONTROL STUDY

In view of the limitations stated above, it is very probable that the present study design could only detect a very strong association between radon daughter concentrations and mortality. The negative results of this study can only be interpreted as indicating in a qualitative manner, that radon daughter concentrations do not have a dominant effect on lung cancer mortality in Canadian cities studied. Although the radon daughter concentrations were generally very low in the three highest risk cities, over 5% of all homes had radon daughter concentrations exceeding 0.02 W.L. Long-term residents in such homes could accumulate relatively high radon daughter exposures during a lifetime. It is suggested, therefore, that a case-control epidemiological study of lung cancer should be performed in one or more of the highest risk cities. This study would be designed to determine if household exposure to radon and radon daughters is a significant risk factor for lung cancer after adjustment for other factors including smoking and occupation.

The cases might consist of residents of the city studied who had developed or died of lung cancer during the past 10 years; controls could be persons matched for sex, age and smoking habits.

As it is expected that the radon daughter concentrations would not vary significantly over the years in the city studied, all cases and controls (or relatives) would be interviewed to determine the period of residence in various homes which would be surveyed for radon daughters. Lifetime radon daughter exposures would be estimated for each individual and each control. A questionnaire would be designed and administered to surviving cases and controls and relatives of deceased. The questionnaire would include items on smoking habits, lifetime occupations, lifetime places of residence, medical history and family history. It would be desirable to have all interviews conducted by one trained interviewer. This approach of actual measurements of radon daughter concentrations would overcome the major defect of the paper by Axelson et al.[6] based on a case control study of the possible impact of exposure to radon and its daughters in dwellings. It has been well shown in Canada that radon daughter concentrations are not related to the type of dwelling or building materials used but are related to geographical area and the geology of the ground on which the house is actually located.

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(3) POPULATION - SPECIFIC AGE GROUPS AND SEX, Statistics Canada catalogue 92-525, Ottawa, 1963.

(4) POPULATION - SPECIFIC AGE GROUPS AND SEX, Statistics Canada catalogue 92-772 (SP-2), Ottawa, 1973.

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(6) Axelson, Olav, Edling, Christer, Kling, Hans, LUNG CANCER AND RESIDENCY - A CASE-REFERENT STUDY ON THE POSSIBLE IMPACT OF EXPOSURE TO RADON AND ITS DAUGHTERS IN DWELLINGS; Scand. J. Work Environment and Health 5, pp. 10-15, 1979.

TABLE 1

CHARACTERISTICS OF STUDY LOCATIONS

Study Location	Population 1961	Population 1971	Cancer Deaths 1957-1965	Cancer Deaths 1966-1976	Crude Cancer[1] Death Rates 1957-1965	Crude Cancer[1] Death Rates 1966-1976
St. John's, Nfld.	66,418	95,320	964	1,491	161.3	142.2
Charlottetown	21,633	25,245	341	531	175.1	191.2
Halifax	139,477	186,825	1,517	2,915	120.8	141.8
Fredericton	22,916	37,365	303	554	146.9	134.8
Saint John, N.B.	69,001	89,050	1,049	1,968	168.9	200.9
Montreal	2,048,282	2,729,170	27,429	47,700	148.8	158.9
Quebec	385,637	500,975	4,159	7,748	119.8	140.6
Sherbrooke	74,174	101,040	941	1,548	141.0	139.3
Sudbury	95,185	150,265	778	1,656	90.8	100.2
Thunder Bay	90,490	108,400	1,213	1,965	148.9	164.8
Toronto	1,868,821	2,611,875	24,675	41,223	146.7	143.5
Calgary	272,088	403,310	2,893	5,173	118.6	116.6
Vancouver	822,735	1,078,630	12,813	20,367	173.0	171.7

[1] Deaths per 100,000 per year (not adjusted for age).

Note: populations are based on 1976 boundaries.

TABLE 2

GENERAL CANCER MORTALITY

Study Location	Males $ASMR_1$	Males $ASMR_2$	Males CMF	Females $ASMR_1$	Females $ASMR_2$	Females CMF
St. John's, Nfld.	214.0	195.7	91	168.6	127.6	76
Charlottetown	162.3	179.2	110	131.4	123.9	94
Halifax	164.6	189.8	115	127.3	131.7	103
Fredericton	165.2	177.5	107	132.9	110.9	83
Saint John, N.B.	168.2	188.0	112	138.7	131.8	95
Montreal	190.5	211.6	111**	143.5	140.4	98
Quebec	172.1	204.9	119**	126.5	127.8	101
Sherbrooke	173.3	199.0	115	150.3	124.3	83
Sudbury	159.1	186.2	117	96.5	123.5	128
Thunder Bay	172.7	182.4	106	115.9	110.8	96
Toronto	172.6	183.7	106**	122.8	119.5	97
Calgary	147.4	165.6	112*	119.1	115.7	97
Vancouver	155.7	171.2	110**	116.9	115.7	99

* $p<0.05$

** $p<0.01$

Note: 1. $ASMR_1$ = 1957-1965, $ASMR_2$ = 1966-1976

2. CMF = $(ASMR_2 \div ASMR_1) \times 100$

TABLE 3

CORRELATION BETWEEN MORTALITY AND RADON DAUGHTER CONCENTRATION

	Males				Females			
	$ASMR_1$	$ASMR_2$	$ASMR_2$-$ASMR_1$	CMF	$ASMR_1$	$ASMR_2$	$ASMR_2$-$ASMR_1$	CMF
All Cancer	-0.15	0.24	0.46	0.48	-0.18	0.12	0.26	0.35
Lung Cancer All Ages	0.10	0.19	0.26	0.28	-0.07	0.19	0.25	0.10
25-54	-0.06	-0.07	-0.04	0.11	-	-	-	-
55-69	-0.17	0.23	0.30	0.26	-	-	-	-
70+	0.00	0.09	0.15	0.27	-	-	-	-
Leukemia	-0.59*	-0.06	0.56*	0.62*	0.12	0.21	-0.02	-0.04

* $p<0.05$

Note: 1) the data are Pearson correlation coefficients based on linear regression of mortality indices and RDCs by city.

2) $ASMR_1$=1957-1965, $ASMR_2$=1966-1976, $CMF=(ASMR_2 \div ASMR_1)\times 100$.

TABLE 4

LUNG CANCER MORTALITY RATES (ALL AGES)

Study Location	Males			Females		
	$ASMR_1$	$ASMR_2$	CMF	$ASMR_1$	$ASMR_2$	CMF
St. John's, Nfld.	25.1	47.0	188*	4.1	4.4	107
Charlottetown	25.4	54.1	213	1.9	7.7	405
Halifax	27.8	49.6	178**	3.8	10.9	287**
Fredericton	18.7	48.1	257*	1.7	5.7	329
Saint John, N.B.	30.2	59.2	196**	4.2	8.7	207
Montreal	38.0	59.6	157**	5.3	9.2	174**
Quebec	26.3	55.3	210**	3.1	7.0	226**
Sherbrooke	19.1	49.9	261**	3.1	8.3	268
Sudbury	39.4	56.8	144	4.7	9.9	211
Thunder Bay	37.7	52.5	139	3.7	7.7	205
Toronto	39.6	52.1	132**	4.5	9.0	200**
Calgary	21.2	39.7	187**	2.9	9.3	321**
Vancouver	34.6	51.6	149**	5.1	10.8	212**

* $p<0.05$

** $p<0.01$

Note: $ASMR_1$=1957-1965, $ASMR_2$=1966-1976, $CMF=(ASMR_2 \div ASMR_1)\times 100$

FIGURE 1

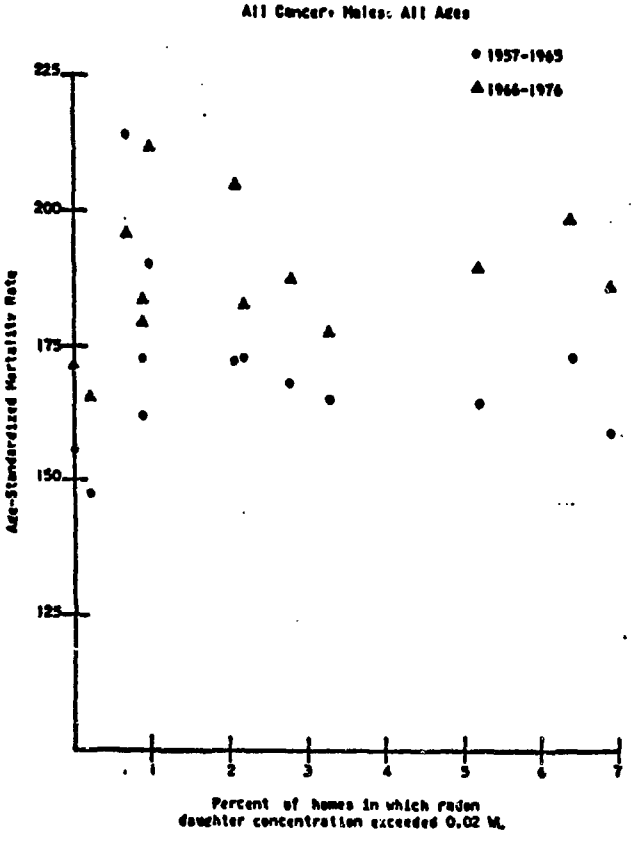


FIGURE 2

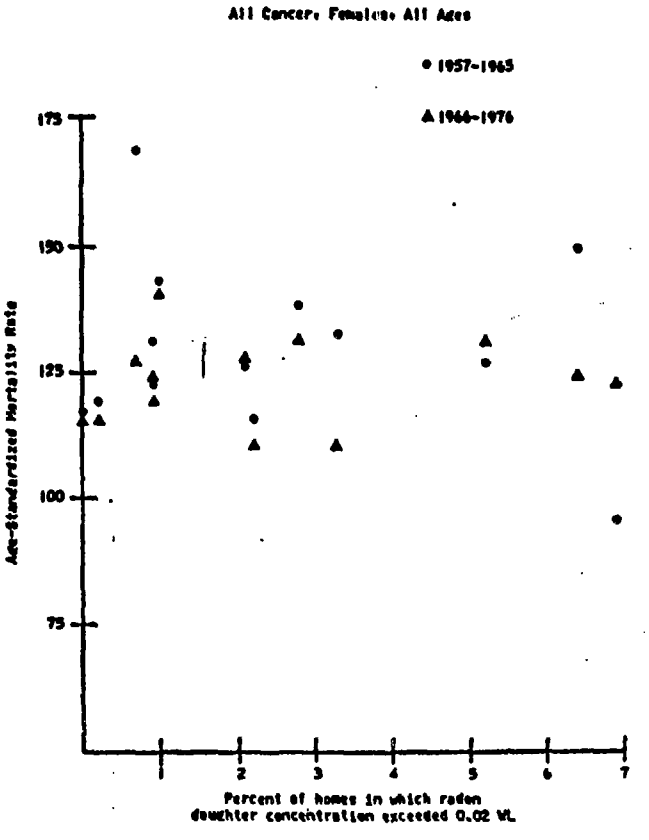


FIGURE 3

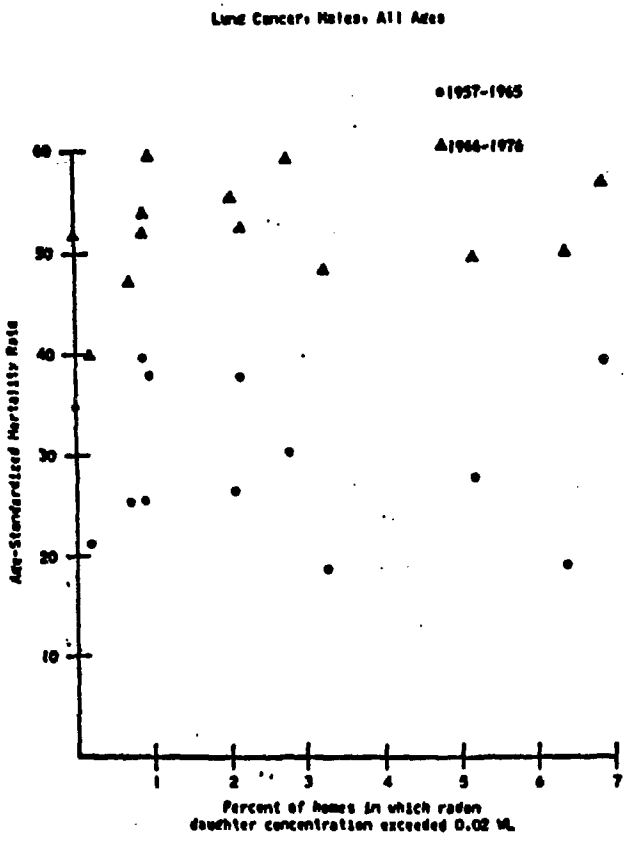
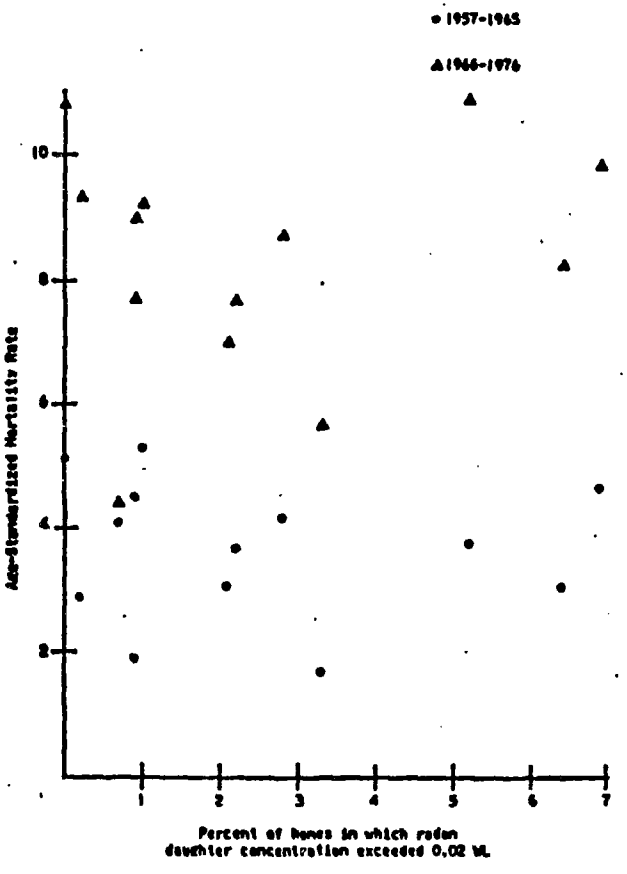


FIGURE 4



Mortality and Indoor Radon Concentration in 13 Canadian Cities:

Questions/Comments

R.S. Eaton : Your survey of WL across the country led you, I think, to a prediction of the number of houses across Canada that might be above .02 WL. What % was this?

R. McGregor : Approximately 5% of the total.

Rod Hendrickson : Were the measurements taken in the "highest" area of the home?

R. McGregor : Yes

R.S. Eaton : Have you speculated on the reasons why some houses have higher radon levels than others?

R. McGregor : We believe that there are underlying geological differences we can attribute it to, particularly in the East through the Appalachians. There are high concentrations of radon in groundwater throughout the Maritimes, as well as in areas in Halifax county.

The Castlegar-Trail studies we did showed the geological setting more markedly. The Trail geometric standard deviation for radon daughter concentration was similar to the national trend of about .0025 WL. However, the Castlegar community is approx. three times higher than the national figure and we attribute this to the known uranium mineralization in the area. We feel, as Ron Maruska mentioned earlier regarding the Bancroft area, that areas of higher uranium mineralization, even though not of economic ore grade, are areas of higher radon.

W. Nazaroff : Could you describe the method used for going into a home and taking a radon measurement? Do you close up the home prior to sampling?

R. McGregor : No, the surveyors approached the home in whatever state it happened to be in. We did take note of windows open or fans on. Most, and essentially all, measurements were taken in basement situations. We felt these areas approximated a closed air space.

-/2

W. Nazaroff : Did you contact people in advance?

R. McGregor : No, we just knocked at doors. We received very good response.

D. Morley : How was the groundwater survey done?

R. McGregor : Using the liquid scintillation counting techniques described by Prichard and Gesell in Health Physics.

R. Washington : Did you analyse ground water in Halifax for radium?

R. McGregor : No, we didn't do it specifically, but I understood from provincial measurements made that it is high in radium and uranium.

W. Whitehead : I notice that no results are given in your survey for centers in Saskatchewan and Manitoba. Was anything done in those two provinces?

R. McGregor : No, those are gaps in our program. This survey project was financed by the Dept. of Manpower and Immigration through their summer jobs work program. This program was designed to increase summer employment opportunities for students in areas of high unemployment. Due to the high employment rate of Manitoba and Sask. at the time, funds were not allotted for work in those provinces.

R. Morse : What is the geology of the Halifax county area?

R. McGregor : A granite pluton

D. Howchin : Have you taken any action because of high levels identified in housing?

R. McGregor : No, we have taken no action.

PRESENTED TO

THIRD WORKSHOP ON RADON AND RADON DAUGHTERS
IN URBAN COMMUNITIES ASSOCIATED WITH
URANIUM MINING AND PROCESSING
AT PORT HOPE, ONTARIO

MARCH 12-14, 1980

ELEVATED RADON AND THORON CONCENTRATIONS FROM NATURAL RADIOACTIVITY IN BUILDING MATERIALS

D. SMITH - DSMA (ACRES)
A. VIVYURKA - RIO ALGOM

DSMA/ACRES
ELLIOT LAKE

ELEVATED RADON AND THORON CONCENTRATIONS FROM NATURAL RADIOACTIVITY IN BUILDING MATERIALS

Rio Algom had measured working levels in excess of 20 mWL in ground floor units of one of their new apartment buildings under construction. Since the building was nearing completion Rio Algom requested DSMA-Acres' assistance in locating the routes of radon entry.

We made measurements in the ground floor apartments which gave radon concentrations as high as 6.9 pCi/l and apparent working levels of 100 mWL when the apartment doors were closed. (Table 1). Almost without exception the working level was much higher than would be expected from the observed radon levels even at equilibrium, as illustrated by the equilibrium fractions.

It was noticed that adjacent apartments had similar working levels. Was this because the transfer rate between apartments was so high that the entire ground floor behaved as one large room, or was each apartment unit independent of its neighbours? A transfer rate test was conducted to answer these questions.

Sulphur hexafluoride (SF_6), a tracer gas, was released in unit 105. Air samples were taken in unit 105 and the adjacent unit 106 over a period of 10 hours. The samples were analysed on a Gas Chromatograph equipped with an Electron Capture detector and results plotted. (Figure 1).

A numerical analysis of the changes in SF_6 concentration in units 105 and 106 gave an estimated transfer period of 70 hours or a rate of approximately 2cfm. This very small transfer rate told us that each apartment unit behaved independently of adjacent apartments and so the similar WL's in the apartments was the result of similar radon supply rates into each apartment.

The change in SF_6 concentration in unit 105 also gave an estimate of the ventilation period which was a surprisingly long 23 hours per airchange or a rate of approximately 8 cfm. This ventilation period was longer than any previously measured in houses by a factor of 2.

We repeated the ventilation test in a third floor apartment. (Figure 2). The ventilation period here was 29 hours per air-change. The main reasons for these long ventilation periods was that the apartment doors and windows all fitted tightly, and the weather was generally calm during the period of measurements.

The long ventilation periods suggested that very small radon supply rates would produce the observed working levels. It was strongly suspected that the natural radioactivity of the building materials contributed a major portion of the radon gas observed.

Working level and radon concentrations were measured in second and third floor apartments (Table 2) and found to be comparable to those found on the ground floor. This showed that the WL's measured in the ground floor apartments were not entirely due to the entry of soil gas containing radon. The only source possible in the upper floor apartments was the building materials.

To calculate if the observed radon concentrations in these apartments agree with what could be expected from the natural radioactivity of the concrete and other building materials, we carried out a mass balance calculation as shown in Figure 3.

We considered only the poured concrete floor and ceiling of an apartment unit as a significant radon source for the block walls were not of local materials. The measured radon flux rate from the concrete was 560 $pCi/hr/m^2$, the equilibrium radon concentration expected under these conditions was 7.8 pCi/l.

The equilibrium radon concentration was comparable with the levels we had observed in the apartments confirming that building materials were the source of the radon. It is important to note that the concrete itself had normal radio-activity. The radon flux rate of 560 pCi/hr/m^2 was slightly higher than average for local concrete but not unusual. The radon production rate of concrete dust was measured and found to contain the equivalent of 0.3 pg emRa/g, which is comparable to the level measured in local sands and aggregates.

The working levels expected from the observed radon concentration would normally be 30 to 40 mWL. The observed working levels, however, ranged from 50 to 100 mWL. (Table 1 and 2). This suggested that thoron daughters (^{220}Ra) were contributing to the alpha activity of the filters used to estimate working level.

Air filters used to measure working levels in the apartments were kept for at least 12 hours after counting, and were then recounted to estimate the contribution to the alpha activity on the filters from thoron daughters. (Table 4).

Thoron daughters interferences was as high as 23 mWL of the apparent working level. This contribution from thoron daughters was high compared to an average interference of less than 2 mWL seen in houses. The corrected working levels were all within the range expected from the measured radon concentrations.

The ventilation period in a similar apartment unit in a building where the mechanical ventilation system was operating was 4 hours. In this building radon and working levels were low, as would be expected from the mass balance.

Since the mechanical ventilation system was not yet operating in the new building, small fans were temporarily installed in

selected units to produce a ventilation period of a few hours. Working levels and radon gas concentrations were reduced significantly in these units. (Table 5). The working levels were below 20 mWL and the radon concentrations were below 3 pCi/l. It was concluded that as long as the mechanical ventilation system in apartment building was operating, elevated radon, thoron and working levels would not be observed.

The apartment building did not have a radon supply problem. It was the long ventilation periods in individual apartments combined with the natural radioactivity of the building materials that produced the high WL's observed.

TABLE 1

TYPICAL WL AND RADON MEASUREMENTS IN GROUND FLOOR APARTMENT UNITS

UNIT NO.	WORKING LEVEL (mWL)	RADON (pCi/L)	EQUILIBRIUM FRACTION
104	71	6.7	1.1
105	56	4.0	1.4
	95	6.9	1.4
	100	6.9	1.4
	70	3.8	1.8
	61	4.9	1.2
106	59	6.2	0.95
	74	4.8	1.5

TABLE 2

TYPICAL WL AND RADON MEASUREMENTS
IN UPPER FLOOR APARTMENT UNITS

	WORKING LEVEL (MWL)	RADON (PCI/L)
SECOND FLOOR	46	2.2
	43	3.8
THIRD FLOOR	57	1.8
	53	7.5

TABLE 3

MASS BALANCE

AT EQUILIBRIUM

$$C_E = \frac{\text{SUPPLY RATE}}{\text{LOSS RATE}} \text{ pCi/LITRE}$$

SUPPLY = SURFACE AREA X RADON FLUX RATE

= 200 M^2 X 560 pCi/H/M^2

= 112,000 pCi/H

LOSS RATE = VOLUME X (VENTILATION RATE + DECAY RATE)

= 300 M^3 X (1/25 H + 1/132 H) X 1000 LITRE/M^3

= 14,000 LITRE/H

C_E = 7.8 pCi/LITRE

TABLE 4

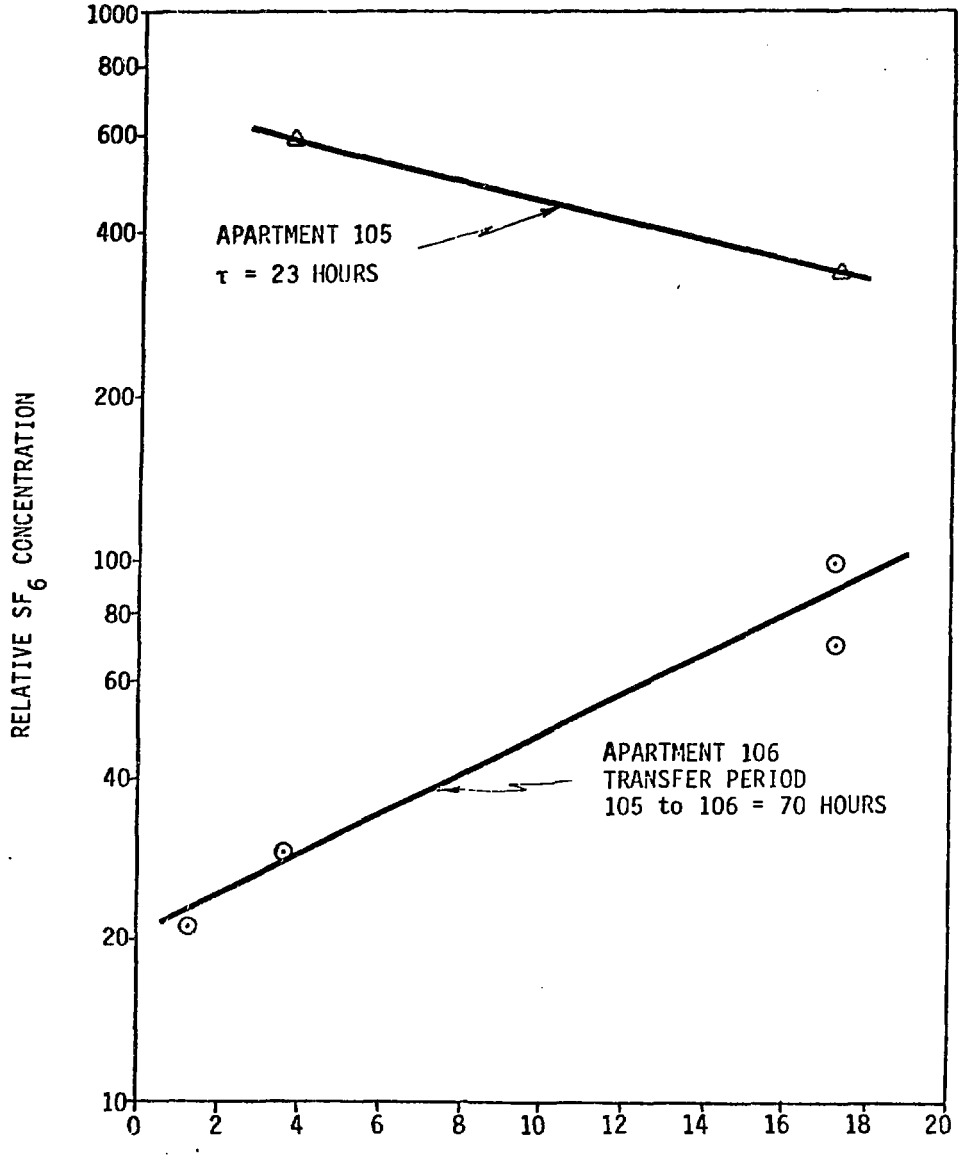
THORON INTERFERENCE WITH WL ESTIMATE

Apparent WL (mWL)	Thoron Contribution (mWL)	True WL (mWL)	% Over Estimate
38	11	27	40
46	17	29	60
25	7	18	40
34	12	22	55
34	23	11	210
43	9	34	25
53	20	33	60

TABLE 5

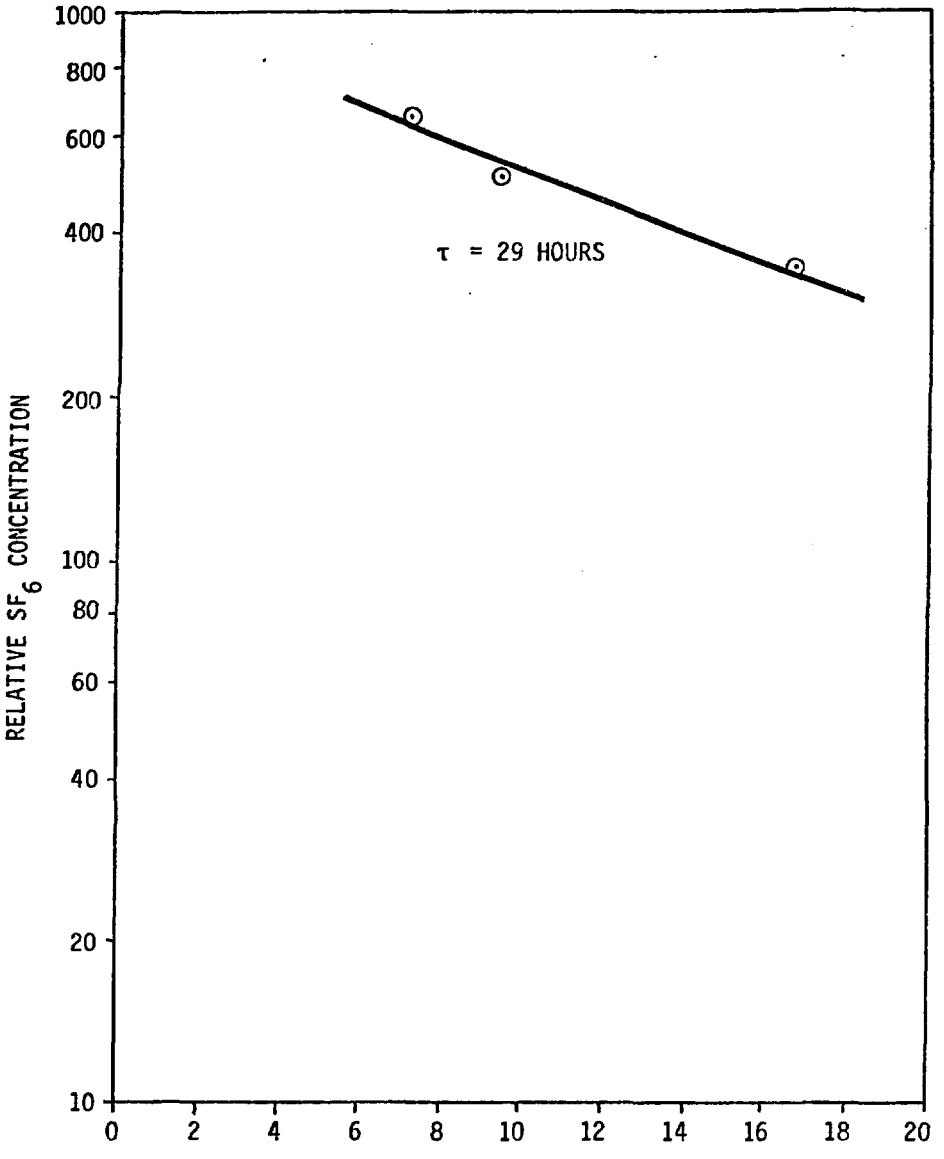
WL AND RADON MEASUREMENTS
IN GROUND FLOOR APARTMENT UNITS
AFTER INCREASING VENTILATION

UNIT NO.	WORKING LEVEL (mWL)	RADON (pCi/L)	EQUILIBRIUM FRACTION
105	16	1.9	0.8
	6	1.7	0.4
	11	2.2	0.5
	12	1.3	0.9
106	16	2.1	0.8
	4	1.5	0.3



TRANSFER PERIOD APARTMENT 105 to 106

FIGURE 1



VENTILATION PERIOD APARTMENT 308

TABLE 2

Elevated Radon and Thoron Concentrations From Natural Radioactivity in Building Materials

Questions/comments:

K. Cliff : The ventilation rates appear to be remarkably low.

In discussing ventilation rate measurements with our building research people, they indicated that they experienced problems with small leakages of SF_6 from sealed containers stored near the survey sites. They had to store the SF_6 containers about 3 miles downwind.

D. Smith : Our containers were stored about 5 miles away.

K. Cliff : Was the building occupied at the time of survey?

D. Smith : No, this was before the building was completed.

K. Cliff : It is unlikely that the occupants would be comfortable at these air exchange levels as odors etc. would be somewhat oppressive.

D. Smith : The building was not completed or occupied so the mechanical ventilation system that would normally pressurize the corridors was shut down.

K. Cliff : In talking with Arthur (Scott), he gives me the impression that he believes plate out is a major removal mechanism. Equilibrium fractions in excess of 1 would suggest that this isn't so.

A. Scott : Equilibrium fractions in excess of 1 were due to the presence of thoron daughters. If you correct for this, the equilibrium fractions become remarkably reasonable figures of .6, .7.

Since the building was recently constructed, the humidity was likely quite high due to water coming out of concrete. Also, plastering work was being done upstairs.

R. Eaton : How do you release your SF_6?

A. Scott : We fill two 5 ml. cells with SF_6 and pull the stops out to release it.

R. Washington : Did you check the half-life of thoron? Did you confirm that it is approximately 11 hrs.?

A. Scott : No, we waited 4 hours and counted.

R. Washington : Your results can be seriously affected if the second readings happen to be on alpha emitters of much longer activity such as uranium dust. I suspect that in most homes and buildings around uranium mining communities, there is a good deal of air-borne dust containing appreciable amounts of uranium.

A Scott : Some of the filters were left 48 hours by mistake and counted. The count rate was very low.

A. George : We did make measurements in uranium mines, and the question of uranium dust didn't seem to be a problem, so I don't expect it would be a problem indoors in houses.

D. Morley : We are doing SF_6 measurements also and are measuring air exchange rates of 29 hours.

A. Scott : We have measured some air exchange rates less than 29 hours.

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AT PORT HOPE, ONTARIO

MARCH 12-14, 1980

SAMPLING CONFIDENCE LIMITS -
A MONTE-CARLO ESTIMATE

ARTHUR G. SCOTT

DSMA/ACRES
ELLIOT LAKE

SAMPLING CONFIDENCE LIMITS - A MONTE-CARLO ESTIMATE

In a number of houses at Elliot Lake sufficient readings have been taken over a considerable period to demonstrate that the distribution of WL in a house is log-normal with a GSD of about 2. This is illustrated in Figure 1. As the distribution is not gaussian, traditional statistical methods based on the gaussian distribution will not give correct answers. However, theory does not tell us how incorrect these answers will be, and so to determine the differences between gaussian and log normal methods of analysis, a Monte-Carlo sampling simulation was carried out.

Figure 1 shows the theoretical C.D.F. for a log-normal distribution with mean 20 and GSD of 2.0 - a straight line on the graph paper used. The points adjacent to the line represent the actual CDF of 5500 numbers generated randomly from a log normal distribution with a mean of 20 and a GSD of 2.0. Figure 2 shows the differential distribution, with the theoretical distribution superimposed. It is a good fit to the theoretical.

The 5500 log-normal numbers were analysed in the usual manner which gave a mean of 19.7 and a standard deviation of 15.6. The gaussian with these parameters is shown in Figure 3, and can be seen to be a rather inadequate description of the actual distribution of numbers. Approximately 16% of the numbers would have to be negative for the gaussian to apply.

However, we do not make decisions based on a single reading, but only on the average of groups of readings. It is our practice to take at least 10 readings in a house before we make any decision and so in our case it is the frequency distribution of samples of 10 that is of interest. This distribution was obtained by taking 550 groups of 10 numbers from the 5500 log-normal numbers generated earlier. The arithmetic mean and the best estimate mean was calculated for each group of 10. The best

estimate mean is based on the logarithmic mean of the sample numbers, and is the theoretically correct method to estimate the average value of a log-normal distribution from a sample. Figure 4 shows the CDF of the 550 estimates. They are log-normally distributed as expected, with variability reduced close to the theoretical value of GSD = 1.25. The most interesting discovery is that the differences between the distribution of arithmetic means and the distribution of best estimate means is insignificant. The variability of the estimates is not set by the method of analysis, but by the variability of the measurements themselves. Given the relatively small GSD of 2.0, and the relatively high number of readings, there is no improvement in accuracy to be gained for the trouble of doing a best estimate mean rather than a simple arithmetic mean. So if any one has been using arthimetic means for convenience, they can now claim complete justification. However, if confidence limits are required on the estimate of the mean, the small asymetry in the distribution does require the confidence limits to be asymetric, and so confidence limits based on gaussian analysis will be incorrect. For example, based on gaussian analysis, the distribution of samples of 10 will have mean 19.7 and sigma 4.93. The 95% confidence limits of the mean are therefore 11.6 and 27.8.

Figure 4 enables the 95% confidence limits to be read directly. They are approximately 13 and 28.5, which are close to the gaussian values, but not exact. This may not be a significant problem, if one avoids the use of confidence limits as much as possible.

In practice, the use of confidence limits creates yet another problem - what to do in the case of those measurements that fall between the confidence limits. For example, if we wish to work to 90% two tailed confidence limits, and we make 10 measurements, Figure 4 shows us that we can make no decision if the mean of the measurements is more than 13 mWL and less than 28.5 mWL. Now, in

practice we cannot avoid making a decision, and although we could narrow the limits by taking more readings, the zone of indecision cannot be removed completely except by an arbitrary decision. We prefer to make our arbitrary decisions first, and so for our surveys we work at 50% confidence. At this level there is no zone of indecision, and it has the intuitively appealing feature that we apparently believe the average of our measurements when it comes to deciding if the annual average WL in a house is,or is not,greater than 20 mWL.

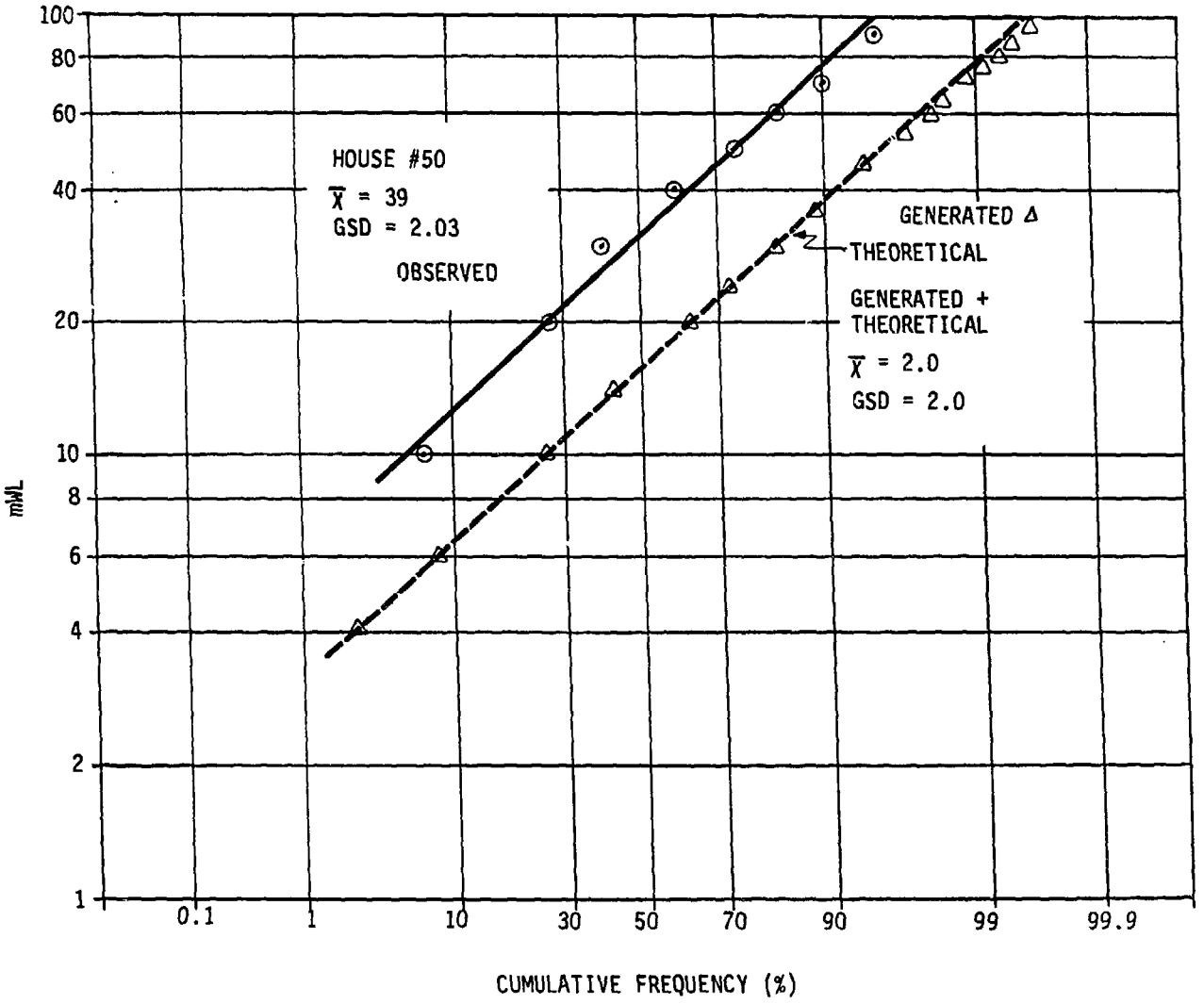
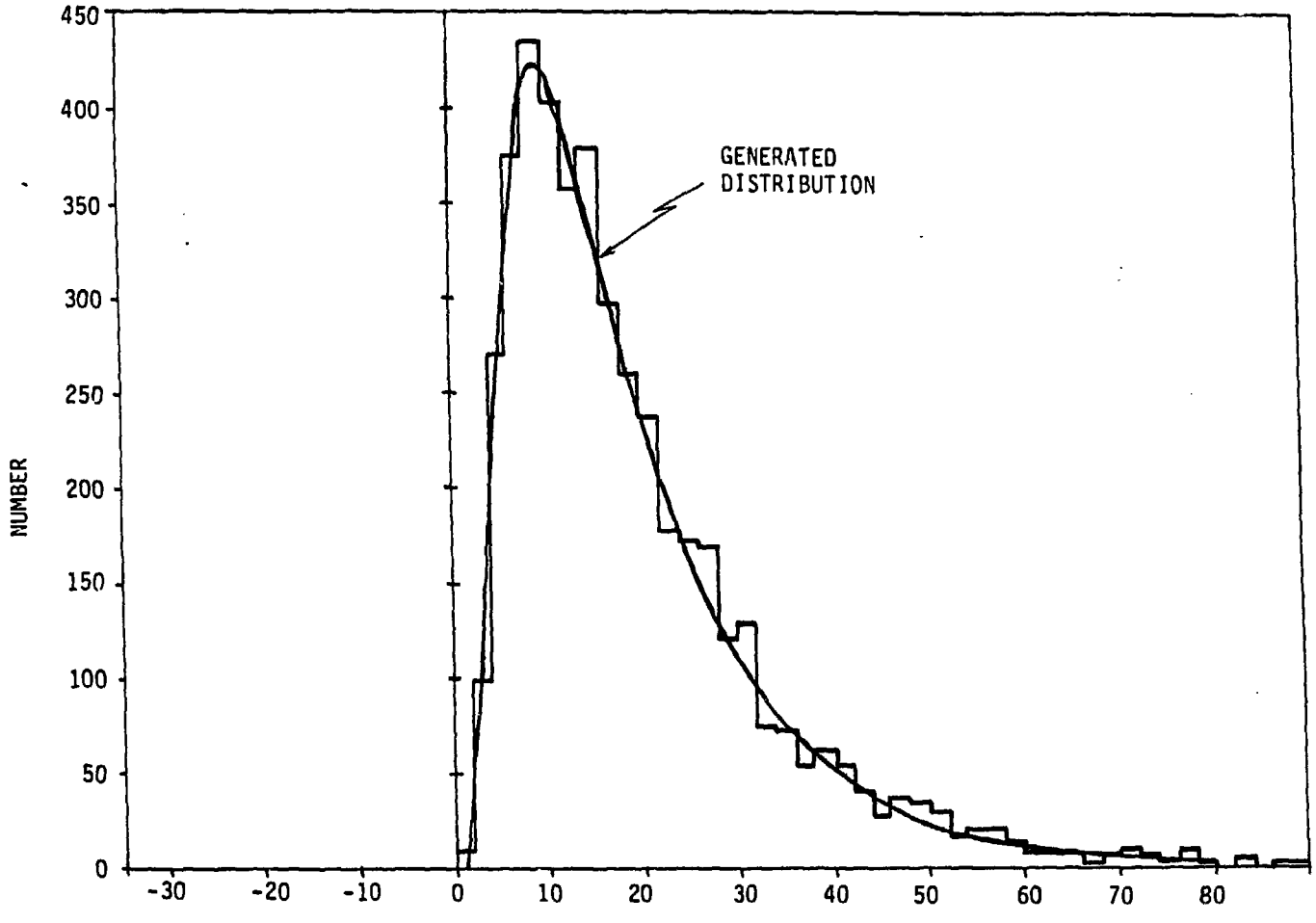

100
80
60
40
20
10
8
6
4
2
1
mWL
HOUSE #50
$\overline{X}$ = 39
GSD = 2.03
OBSERVED
GENERATED Δ
THEORETICAL
GENERATED +
THEORETICAL
$\overline{X}$ = 2.0
GSD = 2.0
0.1
1
10
30
50
70
90
99
99.9
CUMULATIVE FREQUENCY (%)

FIGURE I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100
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10
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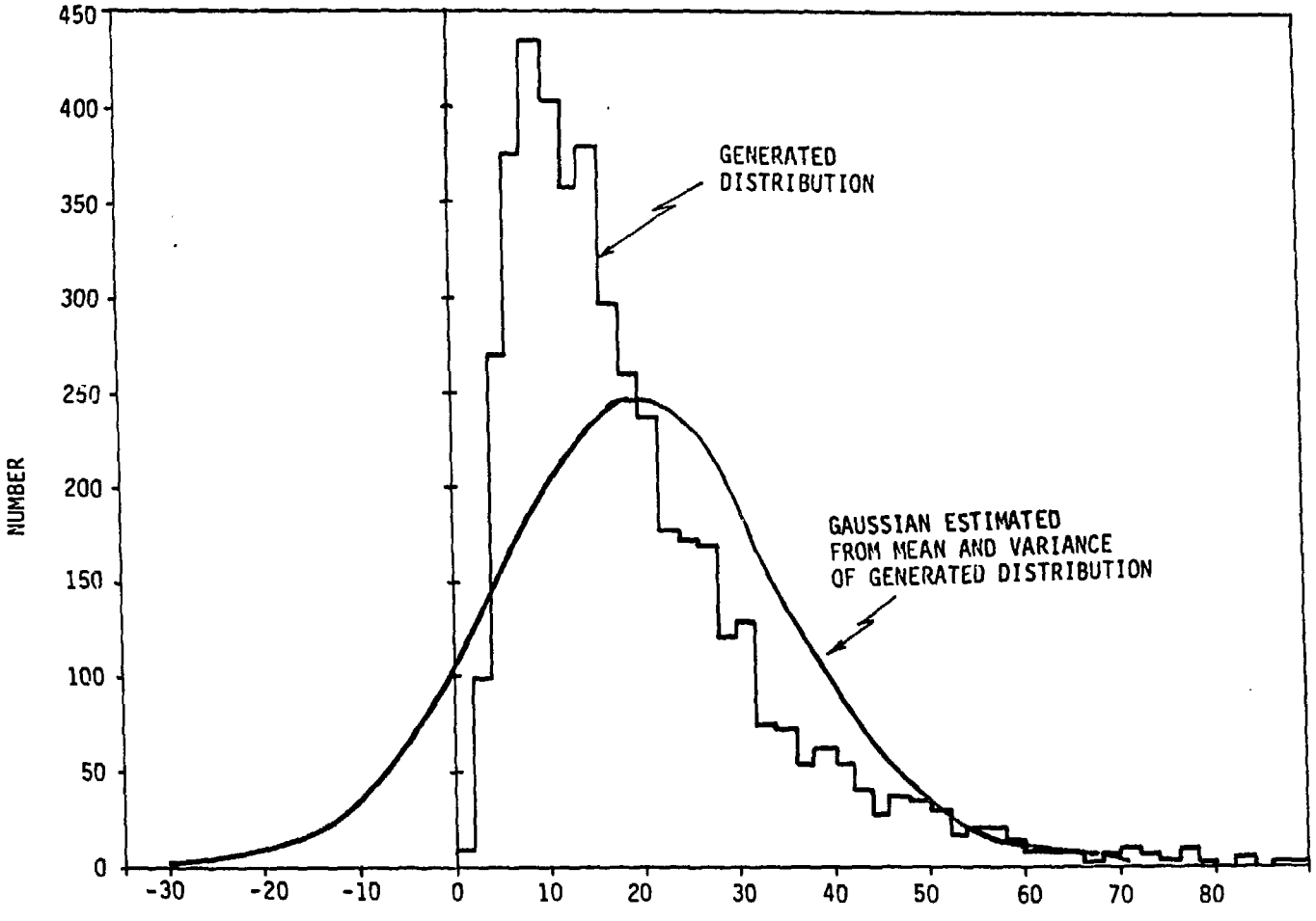
50
60
70
80
GENERATED
DISTRIBUTION

FIGURE 2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10
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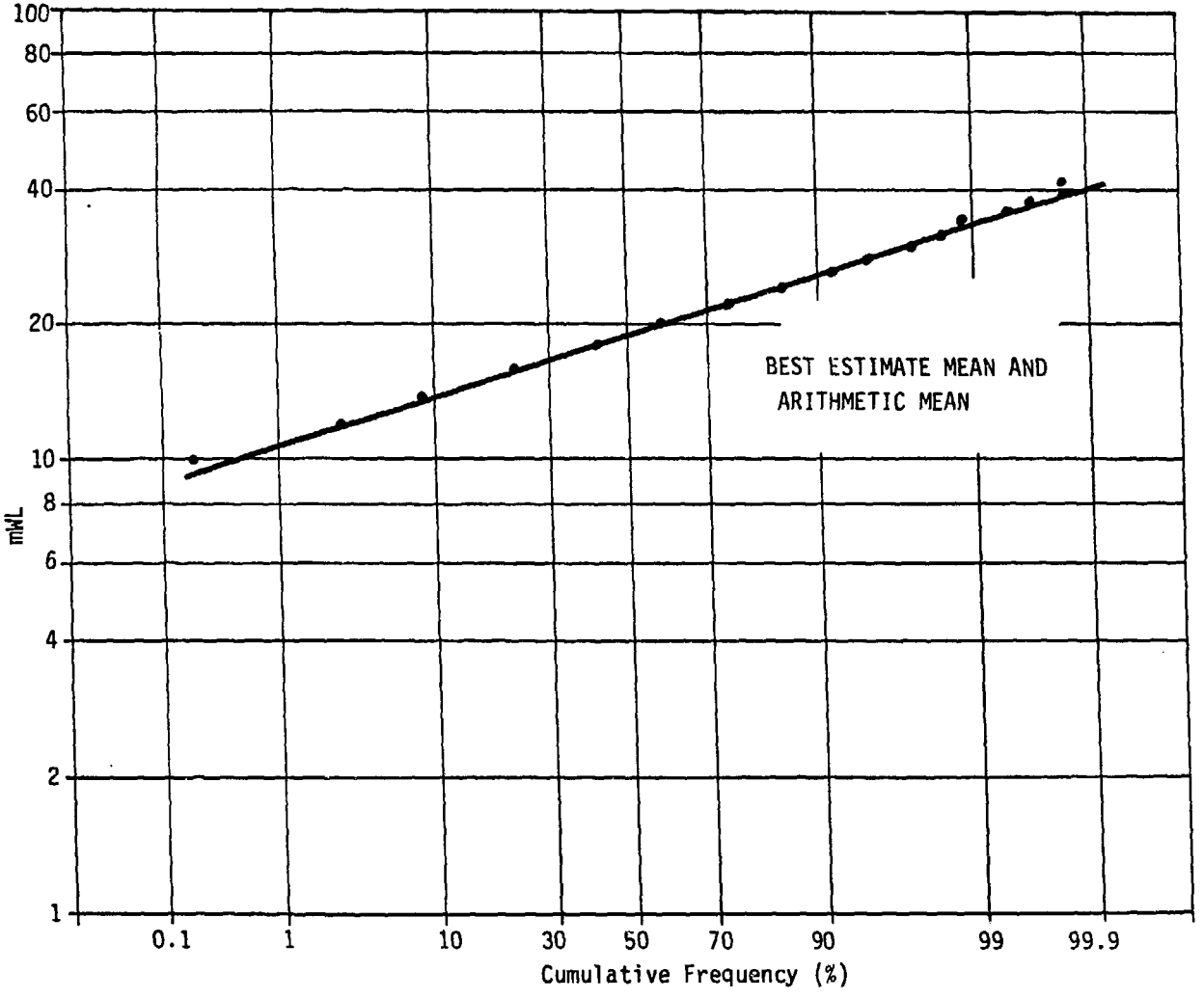
30
40
50
60
70
80
GENERATED
DISTRIBUTION
GAUSSIAN ESTIMATED
FROM MEAN AND VARIANCE
OF GENERATED DISTRIBUTION

FIGURE 3



DISTRIBUTION OF MEANS - GROUPS OF 10
FIGURE 4

Radon daughter exposure of the U.K. population:- Effects of energy conservation and possible action to reduce exposure

KEITH D. CLIFF

Workshop on radon daughters in urban communities associated with uranium mining and processing, Port Hope, Ontario, 12-14 March 1980

National Radiological Protection Board
Harwell
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Introduction

Although no recent extensive surveys of indoor γ-ray and cosmic-ray exposures have been undertaken in the United Kingdom the highest radiation dose to the body tissues from natural radioactivity is undoubtedly that to the bronchial epithelium. This arises predominantly from the short-lived daughters of ^{222}Rn with a lesser contribution from the daughters of ^{220}Rn. This paper will discuss the estimation of current United Kingdom population exposure to the short-lived daughters of ^{222}Rn and the daughters of ^{220}Rn (mainly ^{212}Pb).

Following common usage in the epidemiological studies of ^{222}Rn daughter exposures in miners the unit of exposure used will be the Working Level Month (WLM) and exposure rate the Working Level (WL). The WL is defined as any combination of the short-lived daughters of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) in one metre^3 of air which will result in the ultimate release of 1.3×10^8 MeV of alpha energy in decaying to ^{210}Pb. The Working Month is taken as 170 hours. Exposure is then found as $\frac{\text{WL x period of exposure in hours}}{170}$. Although the Working Level concept was introduced for the short-lived daughters of ^{222}Rn it can be extended to the daughter products of ^{220}Rn. However, the usefulness of the WL in the context of ^{220}Rn daughter exposure is questionable.

Method of measurement of radon daughters

In a survey of radon daughter concentrations in dwellings in England and Scotland an instrument based on the Radon Daughter Monitor (RDM) design of James and Strong[1] was used with the counting regime described by Cliff[2], [3] which permitted assessment of environmental ^{218}Po concentrations with adequate precision using readily portable equipment. In that survey measurements were made in living rooms of dwellings which had been closed for a period of at least 2½ hours. Measurements were made of ^{218}Po concentrations in the room air and in the open air outside the room and the ventilation rate of the room was measured using a tracer gas technique[4]. In this survey it was assumed that the production rate of ^{222}Rn into the room in terms of Bq per metre^3 of room air per hour is temporally invariant and hence the ^{222}Rn production rate could be determined from the measurements outlined above.

The ^{222}Rn production rate, K, of the room is given by[5]:-

$$K = j\,(1 + 0.073\lambda j)\,(C_A - C^1_A)\ \text{Bq m}^{-3}\ \text{h}^{-1}$$

UK Department of the Environment. (A limited survey of ventilation rates in closed living rooms by Warren[8] found a mean value of $0.8h^{-1}$ but when the smallest window in the room was opened to its first fixable position the ventilation rate increased typically by a factor of 4.) Assuming a ventilation rate of $1.0h^{-1}$, a mean ^{222}Rn production rate of 20.0 Bq $m^{-3}h^{-1}$ and that ^{222}Rn daughter products are lost from room air solely by radioactive decay and ventilation to outside air containing ^{222}Rn at the mean concentration found in the survey of 2.6 Bq m^{-3} then the mean Working Levels in living rooms is 0.0035 WL. Assuming an occupancy factor of 0.8 and including the exposure received in the 20% spent in outside air the average UK population exposure rate is 0.15 WLM y^{-1}.

To determine the ^{222}Rn output of the room tested, doors and windows of the room were shut after installation of the equipment. A period of 2½ hours was then allowed before measurements of ^{222}Rn daughter concentrations were taken that were used in the ^{222}Rn output assessment. However, measurements of ^{222}Rn daughter concentrations were made immediately following the installation of the equipment to give some indication of the concentrations likely to be measured later in the day. These measurements taken just after the equipment was installed might be taken as representative of actual conditions in dwellings in the early morning (these measurements were made between 0830 and 1030 hours). The distribution of Working Levels found in living rooms upon arrival (or shortly afterwards) is shown in Figure II. In this case the mean value of WL found was 0.00296 with a range of 1.9×10^{-5} to 0.0296 WL and the distribution again is approximately normal under a logarithmic transformation. It should be noted that the extreme value of these measurements (0.0296 WL) was not found in the same dwelling as the highest ^{222}Rn output of 204 Bq m^{-3} h^{-1}. Thus the mean WL found in the early morning is some 16% lower than that calculated from ^{222}Rn output assessment. This lower figure can be explained in part by the propensity of British housewives to open windows during the morning and that 50% of the measurements were made during the summer of 1976 which was an unusually dry and warm year. It is nevertheless gratifying that by either approach a similar mean WL value for living rooms is obtained. This leads to the conclusion that the assessed average population exposure to the short-lived daughters of ^{222}Rn of 0.15 WLM y^{-1} for the population of the UK is a reasonable working figure and agrees with theoretical predictions for single-family masonry houses[9].

In determining the representative exposure in single-family masonry dwellings a substantial contribution to the ^{222}Rn concentrations in dwell-

that 1 WL is given by 3.7 kBq m^{-3} of ^{222}Rn daughters in equilibrium compared with only 0.28 kBq m^{-3} of ^{220}Rn daughters (^{212}Pb, ^{212}Bi). Obviously more work is required to determine the ^{220}Rn daughter concentrations in rooms but if one assumes that the ^{220}Rn daughter WL is 20% of that due to ^{222}Rn then the mean annual exposure rate to ^{220}Rn daughters for the UK population is about 0.03 WLM/y. Various authors have derived conversion factors for dose per WLM from radon daughters [11,12,13,14,15]. The conversion factors so derived have varied by nearly two orders of magnitude for the daughters of ^{222}Rn depending upon the lung model used, assumed aerosol concentration in the atomosphere and assumed breathing rates. As the epidemiological data relating excess incidence of lung cancer to ^{222}Rn daughter exposures is based on cummulative exposures expressed in WLM it is preferable to give population exposures from environmental ^{222}Rn daughters in the same units. However, Jacobi[16] has calculated doses per WLM for both ^{222}Rn daughters and ^{220}Rn daughters. In the tracheo-bronchial region he finds the dose per WLM from ^{222}Rn daughters to be between 15 and 40 times that per WLM from ^{220}Rn daughters. The concentration of ^{222}Rn daughters in room air is more influenced by ventilation rate (increasing with decreasing rate) than is the concentration of ^{220}Rn daughters[17]. In view of these considerations it is apparent that the daughters of ^{222}Rn in the environment within buildings are the source of most concern with regard to the radiation dose to the bronchial epithelium of members of the general population.

Possible consequences of changes in ventilation rate

The dramatic increase in energy costs over the past few years has encouraged energy conservation in buildings and one effective measure is to reduce ventilation rates. The reduction of ventilation rate, in the absence of any compensating action, will increase the ^{222}Rn daughter concentration within buildings and hence increase the population exposure from this source. In the UK, energy conservation is unlikely to affect ventilation rates during the summer months and assuming that the mean ventilation rate during the five summer months is 2 air changes per hour and does not change it is possible to calculate the increased exposure rate as the mean winter (7 month) ventilation rate is reduced. Also in reviewing the epidemiological data from the uranium and fluorspar miner studies on excess lung cancer incidence and exposure to ^{222}Rn daughters Jacobi[18] has arrived at a risk estimate of 200 excess lung cancers per 10^6 miners per WLM. Hofman et al[19] and James[20] have indicated that the dose per

moved by plate-out to the chamber surfaces. The removal of radon daughters was probably enhanced by plate-out on the air fan blades (a recently reported removal mechanism [22]). In subsequent experiments with the environmental chamber similar measurements were made but the condensation nucleus concentration was periodically increased by allowing a cigarette to smoulder. Three air treatment devices were used; a humidifier, a dehumidifier and an electrostatic precipitator. Neither the humidifier nor the dehumidifier had any significant effect on the WL value. The electrostatic precipitator, however, produced a dramatic reduction in both WL and condensation nucleus concentration as is shown in Figure IV. Under favourable conditions the precipitator produced a reduction in WL by a factor of 20. This reduction was due to direct removal of ^{222}Rn daughters by the precipitator and by increased removal by plate-out as the condensation nucleus concentration was reduced resulting in a higher fraction of unattached ^{222}Rn daughters.

Discussion

At present the exposure to the short-lived daughters of ^{222}Rn for an average member of the population of the UK is 0.15 WLM y^{-1} for whom the winter ventilation rate is 0.8 h^{-1}. This will increase to 0.58 WLM y^{-1} if the winter ventilation rate is reduced to 0.2 h^{-1}. One possible method of effectively reducing the ^{222}Rn daughter concentration and hence the exposure is to use an electrostatic precipitator air treatment unit. However, the use of such a device would increase the unattached fraction of ^{222}Rn daughter products which might result in an increased absorbed dose per WLM. The alpha-dose to the tracheo-bronchial region has been shown to be dependent upon the total unattached fraction, f_p, of ^{222}Rn daughters according to the relationship Absorbed Dose $\alpha(1 + 6 f_p)$ [23].

If risk of lung cancer is proportional to absorbed dose then the use of the electrostatic precipitator would reduce population exposure in WLM y^{-1} but would also increase the risk per WLM compared with the risk derived from the miner studies. Further study is required before the balance of risk and benefit can be fully quantified.

In the light of present, admittedly scant, data on ^{220}Rn daughter products in room air these nuclides do not pose such a problem as the decay products of ^{222}Rn. Further work in this area is necessary to confirm this belief. Methods of reducing ^{222}Rn daughter concentration in buildings are being investigated. These methods include prevention of the ingress of ^{222}Rn from the subsoil and the coating of construction materials with

a "radon barrier" to prevent or reduce the emanation of radon from building materials, whether such practices could be justified by cost-benefit analysis remains to be seen. The reduction in emanation of radon from building materials would lead to a higher γ-ray exposure from retained daughters to the inhabitants of rooms and this effect needs to be studied.

Table I

Concentration of ^{222}Rn daughter products in similar rooms on different floors of a multi-storey residential building.

Floor*	WL X10^{-3}	Ventilation Rate, h^{-1}
Basement	14.3	0.23
1	0.98	0.79
2	1.13	0.58
3	2.13	-
4	3.70	0.43
5	3.58	0.40
6	7.41	0.41
8	3.58	0.36
9	4.67	0.21
10	2.47	0.58
12	3.09	0.40
14	5.70	0.65

*The floor number is for floors above ground level, i.e. ground level would be floor 0.

Table II

^{222}Rn daughter and ^{220}Rn daughter concentration, measured from the same sample, in different rooms.

WL x 10^{-3}		$\frac{^{222}Rn\text{-}WL}{^{220}Rn\text{-}WL}$
^{222}Rn	^{220}Rn	
3.79	1.20	3.16
0.20	0.30	0.67
11.1	4.38	2.53
3.61	0.45	8.02
14.7	1.20	12.3
24.5	1.50	16.3
24.0	1.60	15.0
1.73	1.55	1.12

CAPTIONS TO FIGURES

Figure I — Distribution of ^{222}Rn production rates in living rooms of dwellings in the UK.

Figure II — Distribution of WL values recorded in living rooms of dwellings in the UK under normal occupational conditions between 0830 and 1030 hours.

Figure III — Variation of WL and condensation nucleus concentrations in a sealed room without the operation of the electrostatic precipitator.

Figure IV — Variation of WL and condensation nucleus concentration in a sealed room demonstrating the effect of enhanced condensation nucleus concentrations by means of cigarette smoke and the effects of the electrostatic precipitator.

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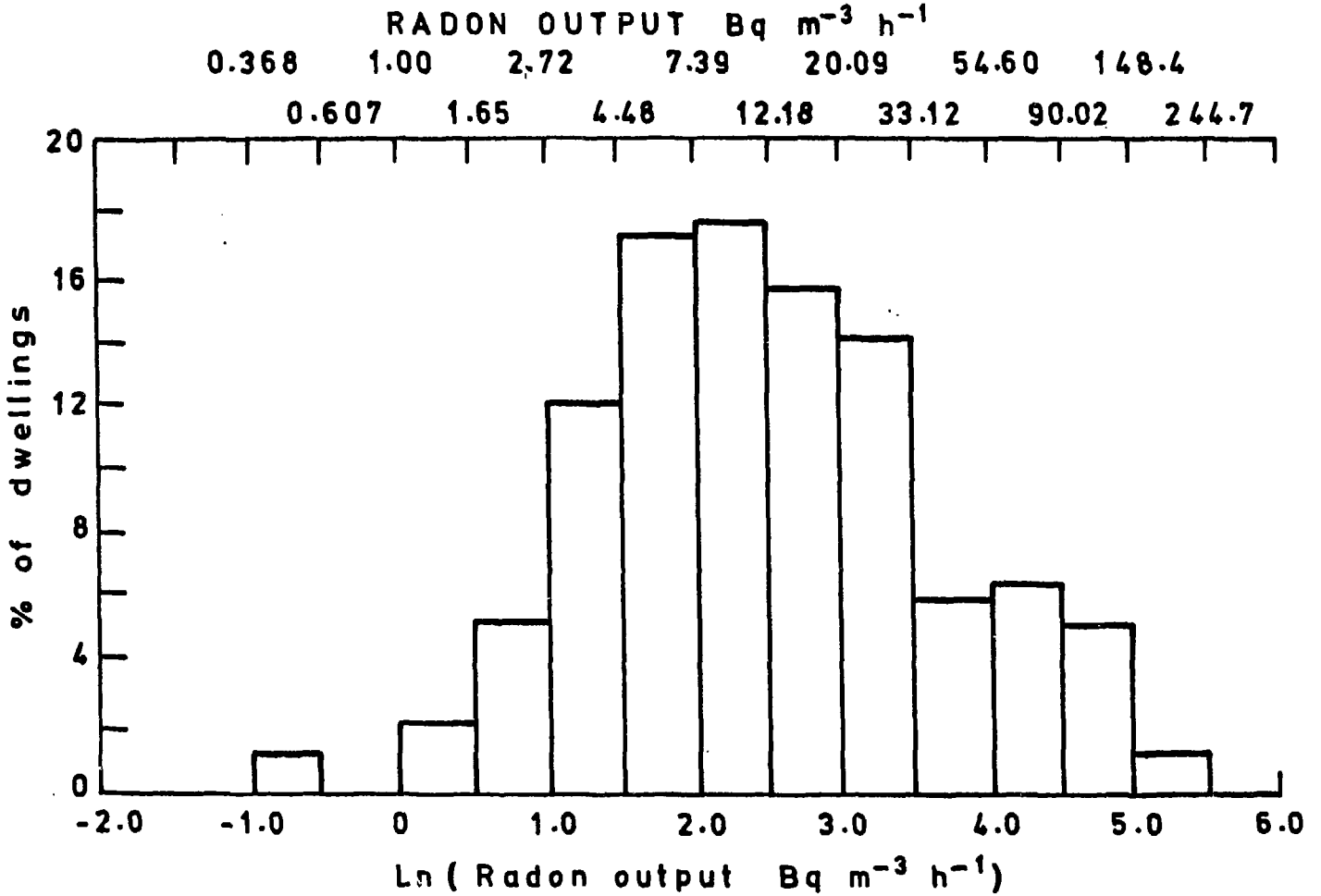

Figure I. Distribution of ^{222}Rn production rates in living rooms of dwellings in the UK.

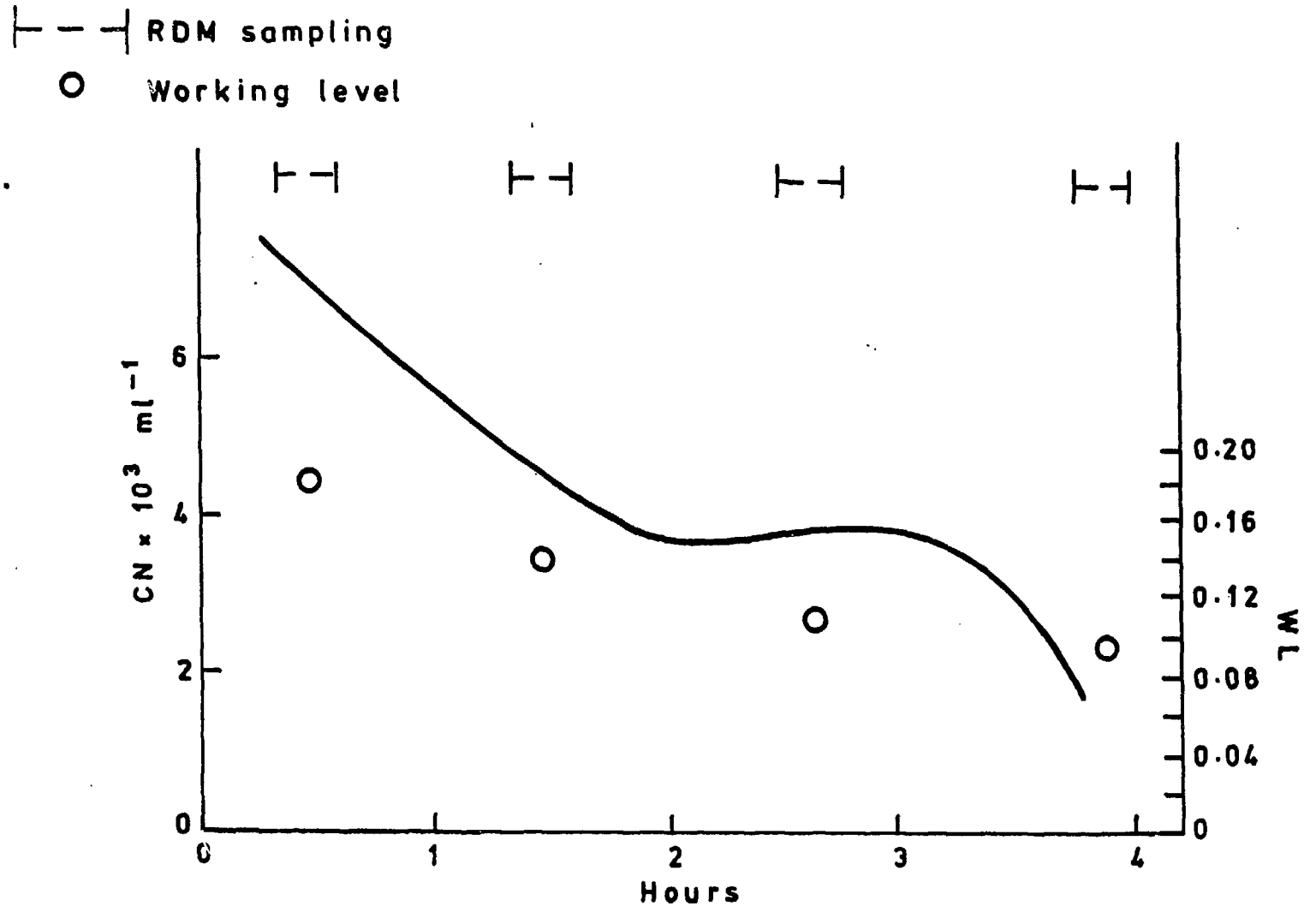

Figure III. Variation of WL and condensation nucleus concentrations in a sealed room without the operation of the electrostatic precipitator.

Radon Daughter Exposure of the U.K. Population - Effects of Energy Conservation and Possible Action to Reduce Exposure

Questions/Comments:

P. Manley : What percentage of the total number of lung cancer deaths would result from exposure to radon-radon daughters?

K. Cliff : If you accept the Medical Research Council advisory of 10^{-4}, then approx. 1 to 2 percent of the entire population. We still feel the overwhelming cause of lung cancer is due to cigarette smoking.

A. Scott : We tested the use of electrostatic precipitators in our office. The CN concentration went down but the ozone level rose more rapidly than the CN concentration went down.

K. Cliff : While the precipitators are effective for removal of cigarette smoke, the ozone may be a problem.

P. Manley : Is the ozone created a greater health hazard than the cigarette smoke?

K. Cliff : It may be. Another problem of concern to the building people is the build-up with low ventilation rates of toxic chemicals, (such as formaldehyde from chipboard), from building materials. This, in fact, may be the limiting factor in reducing air exchange rates in dwellings.

Since ozone does not migrate very far, the precipitator would be more acceptable for use in larger rooms.

R. Eaton : Did you identify the source of the radon measured in the high-rises?

K. Cliff : No, but on the basis of studies and measurements done, the working levels measured could not be totally supported on the basis of the expected emanation from the building materials used.

To be presented at the Third
Workshop on Radon and Radon Daughters
in Urban Communities Associated with
Uranium Mining and Processing,
Port Hope, Ontario, Canada,
March 12-14, 1980

LBL-10222
EEB-Vent 80-6

THE USE OF MECHANICAL VENTILATION WITH HEAT RECOVERY FOR CONTROLLING RADON AND RADON-DAUGHTER CONCENTRATIONS

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March 1980

The work described in this report was funded by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Energy of the U.S. Depatment of Energy under contract No. W-7405-ENG-48.

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ABSTRACT

An energy research house in Maryland was found to have radon concentrations far in excess of recommended guidelines. A mechanical ventilation system with heat recovery was installed in this house to test its effectiveness as an energy-efficient control technique for indoor radon. Radon concentration was monitored continuously for two weeks under varying ventilation conditions [0.07 to 0.8 air changes per hour (ach)] and radon daughter concentrations were measured by grab-sample techniques about nine times daily during this period. At ventilation rates of 0.6 ach and higher radon and radon daughter levels dropped below guidelines for indoor concentrations. Comparison with other studies indicates that indoor radon buildup may be a problem in a considerable portion of houses characterized by their low infiltration rates. The use of mechanical ventilation systems with air-to-air heat exchangers may offer a practical, cost-effective, and energy-efficient means of alleviating not only the radon problem specifically but also the general deterioration of indoor air quality in houses designed or retrofitted to achieve low infiltration.

Keywords: energy conservation, heat recovery, indoor air quality, mechanical ventilation, radon, residential buildings

features. Three specific energy-conseerving strategies are reducing heat loss through the building envelope, reducing infiltration, and reducing the amount of energy consumed by appliances. For our purposes, measures taken to reduce infiltration are of the greatest importance.

Infiltration Characteristics*

Measured infiltration rates in this house ranged from 0.05 to 0.15 air changes per hour (ach), in contrast to the typical range of 0.5 to 1.5 ach in conventional houses in the U.S.[6] This tenfold reduction was achieved by using a number of relatively inexpensive techniques for blocking air leakage. All cracks around doors, windows, and utility entrances had been sealed with caulking, all doors and windows had been weatherstripped, and a continuous plastic vapor barrier had been placed behind the drywall. All electric outlets and lighting fixtures were surface-mounted (avoiding penetration of the walls and consequent air leakage), and the exhaust fan ducts in the bathroom were dampered.

Other Design Features

The house is a single-story structure with a full basement. The basement walls are about 50% below grade, and are constructed of unfilled concrete block. The floating concrete slab rests on a 4-inch gravel base. The basement drain opens directly to the gravel base which is drained to a sump. The house is heated with a heat pump; air in both the main floor and the basement is conditioned. The air-distribution system takes air from the basement and blows it through registers into the main living space.

Indoor Air Quality

Air-quality problems were observed shortly after construction was completed. Excessive humidity, manifested by mildew and mold on the walls, was corrected by installing a dehumidifier. Spot measurements showed formaldehyde levels to be in excess of indoor formaldehyde standards.[7] The most serious problem we found, however, was the high concentrations of radon and radon daughters within the house. Spot measurements of radon consistently showed concentrations in excess of 20 picocuries per liter (pCi/l). Given typical indoor equilibrium factors** of

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*Infiltration in buildings arises from cracks and holes in the building envelope. The term refers specifically to uncontrolled air leakage, and is typically measured in air changes per hour (ach). One ach means that the amount of air entering the conditioned space of the structure in one hour equals the building volume. Infiltration rates vary with weather conditions: indoor-outdoor temperature differences and wind speed and direction.

**The equilibrium factor is defined as 100 times the radon-daughter working level divided by the radon concentration in pCi/l .

$$\eta(\text{efficiency}) = 0.75 = \frac{T_{sup} - 20F}{68F - 20F} \quad (1)$$

Ventilation rates were measured by means of tracer gas decay techniques. A tracer gas is injected into the house where it is mixed to a uniform concentration. The resulting gas concentration is then measured as a function of time and fitted to an exponential decay curve of the form

$$C = C_o e^{-\lambda_v t} \quad (2)$$

where t is time (hours), and λ_v is the air exchange rate (ach). The tracer gas used for this study was sulfur hexaflouride (SF_6), which is chemically inert and nontoxic. It was injected near the basement intake of the air-distribution system; the furnace fan (which operated continuously for all but one day of the experiment) mixed the SF_6 to a uniform concentration throughout the entire house. The SF_6 concentration sampled from the living room was measured with an infrared analyzer and recorded with a strip-chart recorder.

The mechanical ventilation system operating at low, medium and high fan speeds yielded air-exchange rates of 0.4, 0.6, and 0.8 ach, respectively. When the mechanical ventilation system was operated at low fan speed, with the intake and exhaust opening almost completely taped over, the air exchange rate was 0.13 ach. The fifth ventilation condition was infiltration with no mechanical ventilation (0.07 ach). The ventilation rate was measured several times under each of these ventilation conditions. Because the range of values obtained for a given condition was small (on the order of 10% or less) we considered the ventilation rate constant for any of the five conditions.

Pitot tubes were used to measure the rate of air flow through the ducts of the mechanical ventilation system. Measurements of total ventilation rate agreed well with the sum of the air flow through the heat exchanger and the natural infiltration rate of 0.07 ach.

RADON AND RADON-DAUGHTER INSTRUMENTATION

Radon concentrations were monitored constantly during the experiment with a continuous radon monitor (CRM), after a design by Thomas.[11] The CRM, designed and built by LBL, is shown in Figure 2. The CRM measurements were supplemented by analyses of approximately 50 grab samples taken at different times during the study. These samples were either counted in the field using the commercially available RDA-200 radon detector*, or sent to LBL for analysis. The grab-sampling apparatus was calibrated using a National Bureau of Standards radium solution. The use of grab sampling techniques provided a secondary standard for calibrating the continuous radon monitor. The uncertainty in this calibration is 10% (one standard deviation of the ratio of radon concentration measured by grab sampling to counts per interval in the CRM).

*EDA Instruments, Toronto, Ontario.

Thus if σ_{Rn} is constant, the plot of $\log(I_{Rn})$ versus $\log(\lambda_v)$ would result in a straight line with a slope of minus one. The data shown in Figure 5 are well fitted by such a line, given a source magnitude of 2.5 pCi/l/hr. The exception is the point corresponding to 0.8 ach. The calculated radon source at this ventilation rate was about half that computed for the rest of the experiment. The reason for this apparent source drop is not known.

As shown in Figure 6, the radon-daughter working level plotted as a function of time, reveals the same general dependence on ventilation as was seen for radon concentration. Within a given ventilation condition, however, the working level shows more variability than the radon concentration and indicates that radon daughter concentrations depend on factors other than radon concentration and ventilation rate. The working level drops below the 0.02 WL value (set as an indoor guideline[9] and adopted as a standard[8] for communities in Florida and Canada, respectively) only when ventilation rates exceeded 0.6 ach.

DISCUSSION

Before the results of this study can be applied on a broad scale, we must address the question of differing radon source magnitudes between this particular energy-efficient house and the general housing stock. The published data on this important question are limited. Histograms of the results of studies in England[13] and in the United States[14] are plotted in Figure 7, and compared with the range of values obtained for the EER in this study. As is evident, the source values span more than two orders of magnitude. The EER values rank from the 60th to the 93rd percentile against the U.S. study and from the 84th to the 95th percentile against the England study, suggesting that while the source magnitude at the EER is high, it is not unique.

Another way of looking at these data is to calculate the fraction of houses that might have radon problems if constructed tightly. Assuming that tight construction could lower infiltration rates to 0.1 ach, that all houses could be constructed this tightly, and that all had source magnitude distributions indicated in Figure 7, then 36% of the homes in England and 75% of the homes in the U.S. would have radon concentrations in excess of 5 pCi/l when closed. Assuming ventilation rates were raised to 0.6 ach, the corresponding percentages would be 5% in England, and 7% in the United States.

Mechanical ventilation systems with heat exchangers, in a size appropriate for residential use, are currently being manufactured in Europe, Japan, Canada and, to a much lesser extent, in the United States. Prices vary widely, from about $200 for a small window unit to $2,500 for a fully installed central mechanical ventilation system that takes exhaust air from the bathrooms and kitchen and supplies fresh air to the living room and bedrooms. The high cost of some units results from the necessity of installing ducts when central forced-air heating and cooling systems are not already in place. In the United States, where forced air-heating systems are the standard in most new housing, the ducts already exist, and the installation cost would be considerably less.

CONCLUSIONS

We have demonstrated the effectiveness of mechanical ventilation with heat recovery in reducing the concentrations of radon and radon daughters in a low-infiltration house. By a simple analysis, we were able to show that the strategy of building tight houses and installing mechanical ventilation systems with air-to-air heat exchangers may satisfy energy-conservation goals in a cost-effective manner without compromising indoor air quality.

This approach cannot, by itself, eliminate indoor air-quality problems in situations where source levels of pollutants are high. In the case of radon, for example, the ventilation rate in houses built on land where the radon source is characteristically high cannot be increased to the magnitude that would be necessary for effectively controlling indoor radon concentrations. In such cases, methods of eliminating or blocking the source must be adopted; however, mechanical ventilation with heat recovery may still be desirable to maintain low concentrations of other indoor air contaminants.

As more experience with air-to-air heat exchangers is gained, other important issues must be resolved--among them, the long-term reliability and efficiency of heat exchangers and public acceptance of maintaining an additional home appliance.

ACKNOWLEDGEMENTS

We acknowledge the efforts of several people who assisted in this work. A. Robb and J. Ingersoll designed and fabricated portions of the radon monitoring equipment. L. Davis constructed the heat exchanger. J. Koonce helped coordinate the project and install the mecanical ventilation system and the infiltration moitoring equipment. Special thanks to our editors L. Cook and C. Henderson, publications coordinator P. Bostelmann and UNIX operator J. McCreary, for their help in preparing the manuscript.

Finally, we acknowledge the cooperation of the National Association of Home Builders Research Foundation in providing the study site.

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Table 2. Annual Energy Cost Savings* (in Dollars).

	Mode #2			Mode #3		
	0.5 ach			0.75 ach		
City	Oil	Gas	Electricity	Oil	Gas	Electricity
Atlanta, Georgia	---	24.71	72.05	---	10.90	47.72
Washington, D.C.	79.34	52.04	158.86	56.50	32.93	125.18
Chicago, Illinois	113.18	72.64	283.28	82.33	47.14	230.02
Minneapolis, Minn.	166.26	109.80	332.36	130.82	81.82	275.10

*Savings of Modes #2 and #3 when compared to base case (Mode #1). [Fuel prices taken from "Consumer Price: Energy," Press Release, U.S. Department of Labor, Bureau of Labor Statistics, USDL-79-679 (August 1979)].

CONTINUOUS RADON MONITOR

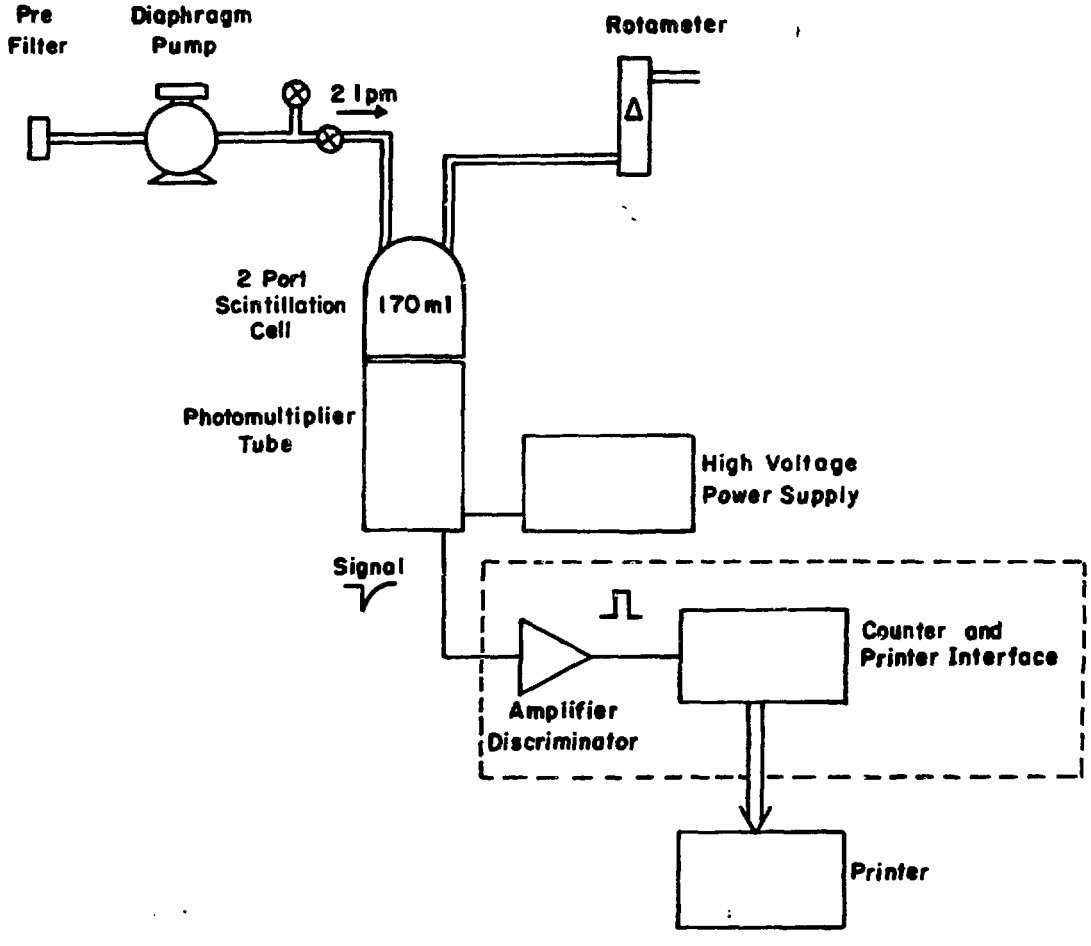

Figure 2

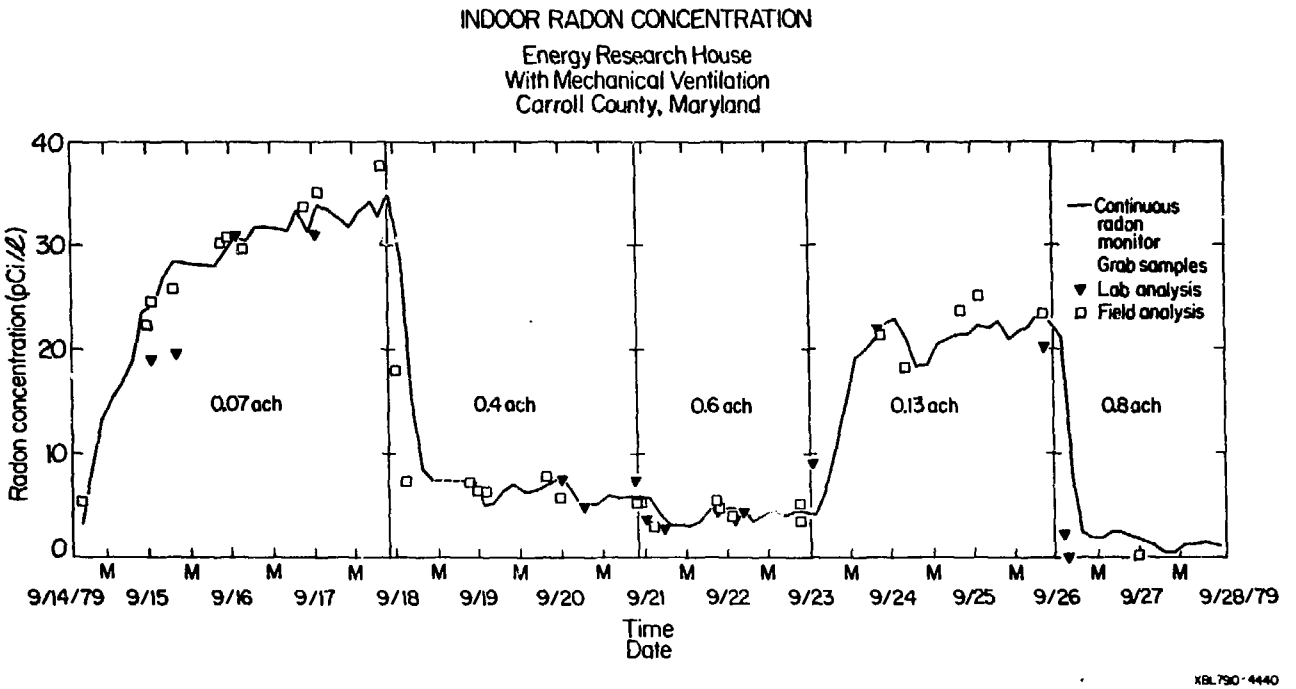
INDOOR RADON CONCENTRATION
Energy Research House
With Mechanical Ventilation
Carroll County, Maryland
Radon concentration (pCi/ℓ)
40
30
20
10
0
0.07 ach
0.4 ach
0.6 ach
0.13 ach
0.8 ach
Continuous radon monitor
Grab samples
Lab analysis
Field analysis
M
9/14/79
9/15
9/16
9/17
9/18
9/19
9/20
9/21
9/22
9/23
9/24
9/25
9/26
9/27
9/28/79
Time
Date
XBL 790-4440

Figure 4

RADON DAUGHTER WORKING LEVEL

Energy Research House
With Mechanical Ventilation
Carroll County, Maryland

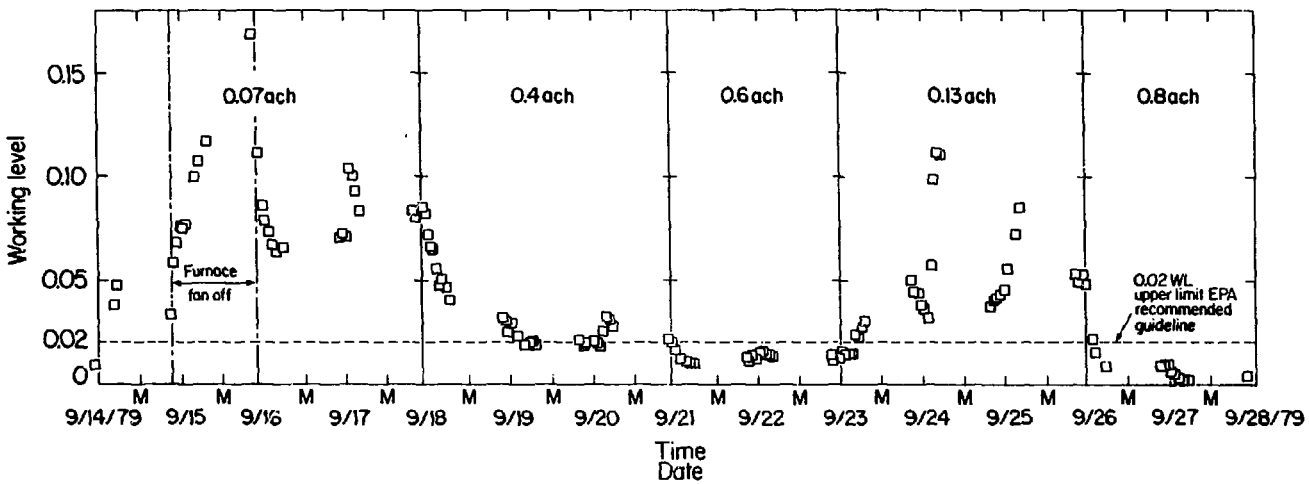

Figure 6

The Use of Mechanical Ventilation With Heat Recovery For Controlling Radon and Radon Daughter Concentrations

Questions/Comments

E. Haubrich : What is the floor area of the homes in which the heat exchanger has been used.

W. Nazaroff : These homes were approximately 2,000 ft.^{2} with 7.5 ft. ceilings, and we provided up to .75 of an air change per hour.

E. Haubrich : Are you assuming that provided the full air exchange?

W. Nazaroff : We measured the air-flow through the heat exchanger itself and it agreed closely with the k method that is adding .07 to the infiltration rate. We concluded that we didn't affect the natural infiltration rate significantly by using mechanical ventilation. We were providing approx. .73 air changes/hr. through the heat exchanger itself as verified by air-flow measurements.

L. Haywood : Has a cost/benefit analysis been done in this case?

W. Nazaroff : The energy load savings has been calculated which includes the operating cost.

C. Winzer : It appears from the figures given that the exchanger would pay for itself in about 2.5 years. Why has the concept not been adopted?

W. Nazaroff : What has happened to date is that many builders have gone only as far as the first stage - building more airtight structures.

A. Booth : You said that $450 was the cost of the heat exchanger?

W. Nazaroff : That is the cost that Besant has projected to install these units in homes. That cost would apply to new tightly sealed homes rather than existing, older housing.

Existing houses are very difficult to deal with because they cannot be more tightly sealed without a great deal of additional expense.

-/2

R. Eaton : A possible remedial technique for some of the difficult houses we are dealing with would be to seal up the homes tightly and install controlled ventilation, utilizing air to air heat exchangers. The fan size used would be optimized to effect appropriate reductions in radon and toxic chemical levels as well as achieve certain energy savings. The tight seal of the home would ensure that the occupants would maintain the fan in operational mode to protect their own comfort. That way, you could ensure the remedial work, ventilation, is maintained.

A. Scott : Existing techniques for tightening up old houses are reasonably standard in Canadian construction practice. There are new homes currently being built using these techniques which are electrically heated, have continuous vapor barriers and have the juncture of the wood frame and the concrete foundation walls sealed. These homes, when unoccupied, have ventilation periods exceeding 10 hours.

W. Nazaroff : Do you know of any people complaining about air quality problem in such homes?

A. Scott : I haven't heard of any.

A. Vivyurka : We are having moisture problems with those homes.

R. Eaton : Are the houses occupied?

A. Vivyurka : Yes.

TRACING AND DEALING WITH DWELLINGS WITH HIGH RADON AND RADON DAUGHTER CONCENTRATIONS

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Introduction

About a year ago the mass media gave publicity to the measurements being made by the National Institute of Radiation Protection in some single-family houses in a municipality in southern Sweden. The houses had been built on tailings from alum shale workings. Alum shale has been used as a raw material in Sweden since the sixteenth century. The radon and radon daughter concentrations found were considerable and for several months the fact that the carcinogenic gas radon was to be found in ordinary dwellings made headline news on the front pages of the newspapers and in radio and television programmes.

At about the same time that the matter became public, the Swedish government appointed a commission which was given the primary task of developing recommendations for tracing houses with unacceptable levels of radon daughters and developing a program for the investigations which were deemed necessary as a basis for the continued work on definite limiting levels.

The report issued by the commission proposes provisional limiting values for radon daughter exposures, for gamma radiation from the ground and for the concentrations of radioactive materials in building materials.

This report is largely based on the report issued by the Radon Commission. The proposals of the Commission and the provisional limiting values will be the subject of a debate in the Riksdag, the Swedish parliament, during the spring of 1980.

As early as in the 1950s an investigation was made into the radiation conditions in Swedish dwellings. It was found then that certain building materials, in particular aerated concrete based on alum shale, could give rise to higher radiation doses than did other materials. Thus there was at that time an awareness of the risks resulting from high radon levels although the risks were regarded as small since the ventilation in the dwellings was in general good. In connection with the energy crisis at the beginning of the 1970s, the National Institute of Radiation Protection pointed out the risks involved in excessive sealing of dwellings to save energy since this reduced the air circulation rate. This applied above all to dwellings built of alum shale based aerated concrete.

Alum shale occurs in many places in Sweden (Fig.1) and it has been exploited since the sixteenth century. The first application was for the dying of textiles and later it was used for lime-burning. It has also been used as a source of oil and it is at present the subject of an inquiry as a possible future source of uranium. Its uranium content is about 200 grams per tonne.

The tailings from the shale workings have been dumped in large heaps which exist here and there in many areas, mainly in Southern Sweden.

It was in connection with a housing area which had been planned on one of these tailings piles that this problem came to light and the National Institute of Radiation Protection advised that the plans should not be fulfilled in the manner proposed. However, it was then found that dwellings already existed on similar sites and it was therefore decided that some of these dwellings should be investigated.

In 1978 the National Institute of Radiation Protection asked the government to appoint a special commission to determine the extent of the problem of radon and radon daughters in dwellings. This commission was appointed in March 1979. The proposals of the commission were evolved in cooperation with the competent authority responsible and with other experts. The ingress to the memorandum issued by the commission includes the following passage:

> "Investigation into counter-measures against radiation risks in buildings etc. shall evolve, with the highest priority in accordance with our directives and in cooperation with the agencies concerned, a program for the investigations which are deemed necessary in order to determine the radiation levels in existing buildings."

It is also stated that:

> "In this memorandum a programme is proposed for tracing and reducing the risks for radiation from radioactive substances in the existing buildings."

In order to deal with unacceptably high health hazards as quickly as possible in certain Swedish dwellings and in the absence of further data, provisional limiting values intended to apply for a five-year period have been proposed. At the end of that period it is considered that there should be a sufficient basis of data concerning the extent of the radon problem and the consequences of lower limiting values in the future.

The main aims of the provisional limiting values are as follows:

a) To prevent the erection of buildings on ground containing large quantities of radioactive substances.

b) To prevent the use in new buildings of materials with unnecessarily high contents of radioactive substances.

c) To reduce the health hazards in existing buildings.

Provisional limiting values for the ground used for new building

With regard to gamma-radiation from the ground a provisional limiting value of 100 μR/h has been proposed. This value gives an effective dose equivalent of approximately 1 mSv/year for persons who spend 20 per cent of their time out-of-doors. The value was chosen in order to limit the risk from gamma radiation out-of-doors and also to limit the amount of radon exhaled from the ground which finds its way into buildings.

The proposal is to advise against the construction of any building when the gamma radiation exceeds 100 μR/h. This value, which includes the cosmic radiation, shall be measured above the ground surface. Further, a provisional investigatory range of 30 - 100 μR/h is proposed, the measurement in this case being made at the depth of the foundations. Within this range the radon exhalation shall be measured and recommendations regarding building work be issued.

Provisional limiting values for building materials for new buildings

For new buildings it is proposed that the quantities of radioactive substances in building materials be limited by means of limiting values for the gamma index and the radium index.

These are calculated as follows:

$$m_\gamma = C_K/10000 + C_{Ra}/1000 + C_{Th}/700$$

$$m_{Ra} = C_{Ra}/200$$

where C_K, C_{Ra} and C_{Th} are the concentrations of potassium, radium and thorium respectively in Bq/kg.

It is proposed that the provisional limiting values are that the gamma index and the radium index be less than 1.

These limiting values imply that the annual radiation dose is limited to approximately 2 mSv/year from gamma radiation and to approximately 10 mSv/year (70 Bq/m^3) from radon daughters for an air exchange rate of 0.5 per hour.

Figure 2 shows the gamma index and Figure 3 the radium index for various building materials.

Since aerated concrete based on alum shale is no longer manufactured in Sweden it is anticipated that all building materials on the market will be acceptable with these limiting values.

Provisional limiting action levels for existing buildings

For a long time the majority of Swedish dwellings will consist of buildings which already exist now.

The provisional limiting values proposed for these buildings only concern the radon daughter concentrations. It is true that high gamma radiation levels have been found, but the highest doses from gamma radiation known to exist during the course of the investigation (approaching 4 mSv/year) were not considered to involve such risks that any action was justified. Later measurements, however, have shown that gamma radiation dose-rates of up to about 6 mSv/year exist. In its forthcoming work the Radon Commission will have to decide what attitude to adopt with regard to these dose-rates.

However, the radon daughter concentrations in dwellings constitute a greater hazard than the gamma radiation and there are various methods which can be adopted to reduce them.

In making the choice of provisional limiting value, particular attention was paid to the risk involved in continuing with high radon daughter concentrations and thus to how quickly action should be taken.

As a provisional limiting value it is proposed that no-one should be exposed to more than 2000 Bq year/m^3 during the provisional period of five years. This implies, for instance, that action shall be taken to improve dwellings with radon daughter concentrations of 1000 Bq/m^3 (0.27 WL) within 2 years and dwellings with concentrations of 400 Bq/m^3 (0.10 WL) within 5 years.

It is estimated that the number of dwellings where the radon source is the building material and which would have to be improved in accordance with this scheme is between 3000 and 15000 and that the number of dwellings on radioactive ground is between 200 and 2000.

Principles established for the tracing and checking of houses with high radon daughter concentrations

One of the greatest problems is tracing the houses with excessive radon daughter concentrations. Since the radon daughter level is dependent on several factors, simple methods and rules of thumb can only be used for an initial rough identification of the houses likely to justify further investigation with more sophisticated methods of measurement combined with knowledge of the various sources of radon and the air exchange rates.

Radon in dwellings can originate from the building materials, from the ground and from the water supply. The radon from one, or possibly from several, of these sources gives rise to a definite radon daughter concentration indoors for a particular air exchange rate. This air exchange rate is determined by the ventilation system and by the meteorological conditions. Multi-family houses are usually fitted with fan ventilation systems and in such cases the meteorological conditions have little effect on the air exchange rate. Single-family houses, on the other hand, often have only natural draught ventilation and this is greatly affected by meteorological conditions. The air-tightness of the house is also a very significant factor.

The main principle in the tracing work is the successive elimination of houses in which the radon daughter concentrations are low. Tracing and checking must therefore be carried out in several stages in which the testing methods are suited to the accuracy requirements, the number of houses, available time and the costs involved. The local health authorities have the responsibility for organizing the tracing work.

In the first stage of the tracing work, information from municipal and general sources is used for a general assessment of buildings and of the ground in relevant areas. A large proportion of the dwellings can be eliminated in this stage of the tracing operation.

In the next stage, using active tracing with such methods as gamma radiation measurements from cars, questionnaires to households and study of the relevant geological conditions, the houses which in all probability have low radon daughter concentrations can be eliminated.

The next stage is to make a simple check on the houses which there is reason to believe may have higher than normal radon daughter concentrations. This can be done either with alpha sensitive track film or - in areas in which the ground and the water have not particularly high radon concentrations - with gamma measurements combined with inspection of the ventilation systems. If this first simple check indicates that there may be a risk for high radon daughter concentrations, more sophisticated methods can be used to determine the true exposures.

A summary of the methods which can be used is given below:

1. Measurement of gamma radiation from a car

   A measurement of the total gamma radiation determines whether the building materials is unusually radioactive. This measurement is made from a car at a distance of up to 20 - 25 meters from the house. All houses found to have enhanced gamma radiation are further checked with hand instruments to provide data on the proportions of radioactive building materials. This method is most suitable in densely populated areas.

2. Measurement of gamma radiation with hand instruments

   This method is most suitable in sparsely populated areas.

3. Integrated measurements of radon and radon daughter concentrations using alpha-sensitive film

   Alpha-sensitive film (track etch film) is exposed for three months in a dwelling. The measurements so far made with this method show large systematic uncertainties. The method can nevertheless be used as a basis for a decision concerning further checking.

4. Radon daughter measurements using filters

   One or more filter samples are taken in the dwelling and the radon daughter concentration is calculated - for example using Kusnetz's method. The disadvantage of this type of measurement is that it only provides an instantaneous value and it is therefore necessary to ensure that certain conditions are fulfilled with regard to the ventilation each time a measurement is made

5. Measurement of the radon concentration using a passive measuring device

The principle underlying these measurements is that radon diffuses into a measurement chamber in which there is a strong electrical field. The alpha decays are recorded by a thermoluminescent (TL) dosimeter. The National Institute of Radiation Protection has produced a number of radon measuring devices of this type for use in a research project. At present there are not enough of these devices available to allow them to be used in the dwelling-tracing work but there are proposals for producing larger numbers. These would be used principally in the cases in which it had been difficult to determine with other methods whether the mean exposure rate was above or below the proposed provisional limiting values.

Subsequent to the measurements, it is possible to judge whether the radon and radon daughter concentrations constitute a so-called sanitary nuisance, in other words whether a dwelling has radon daughter concentrations above the limiting value, in which case the local health authorities can recommend or prescribe various measures. As a rule these will consist of improvements in the ventilation system although other measures, for instance replacement of the filling material around a house, are conceivable depending on the source of the radon. The Radon Commission has proposed that the Swedish State should accept some responsibility for the costs involved, in the form of loans or grants.

Any corrective measures used should of course have the aim of reducing the radon daughter concentration as much as possible but in the case of major rebuilding operations requiring building permits the Radon Commission has proposed that an upper limit of 200 Bq/m^3 should be applied.

When corrective measures have been applied, the effectiveness of the measures should be checked by means of new measurements.

Figure 1. The occurrence of alum shale in Sweden.

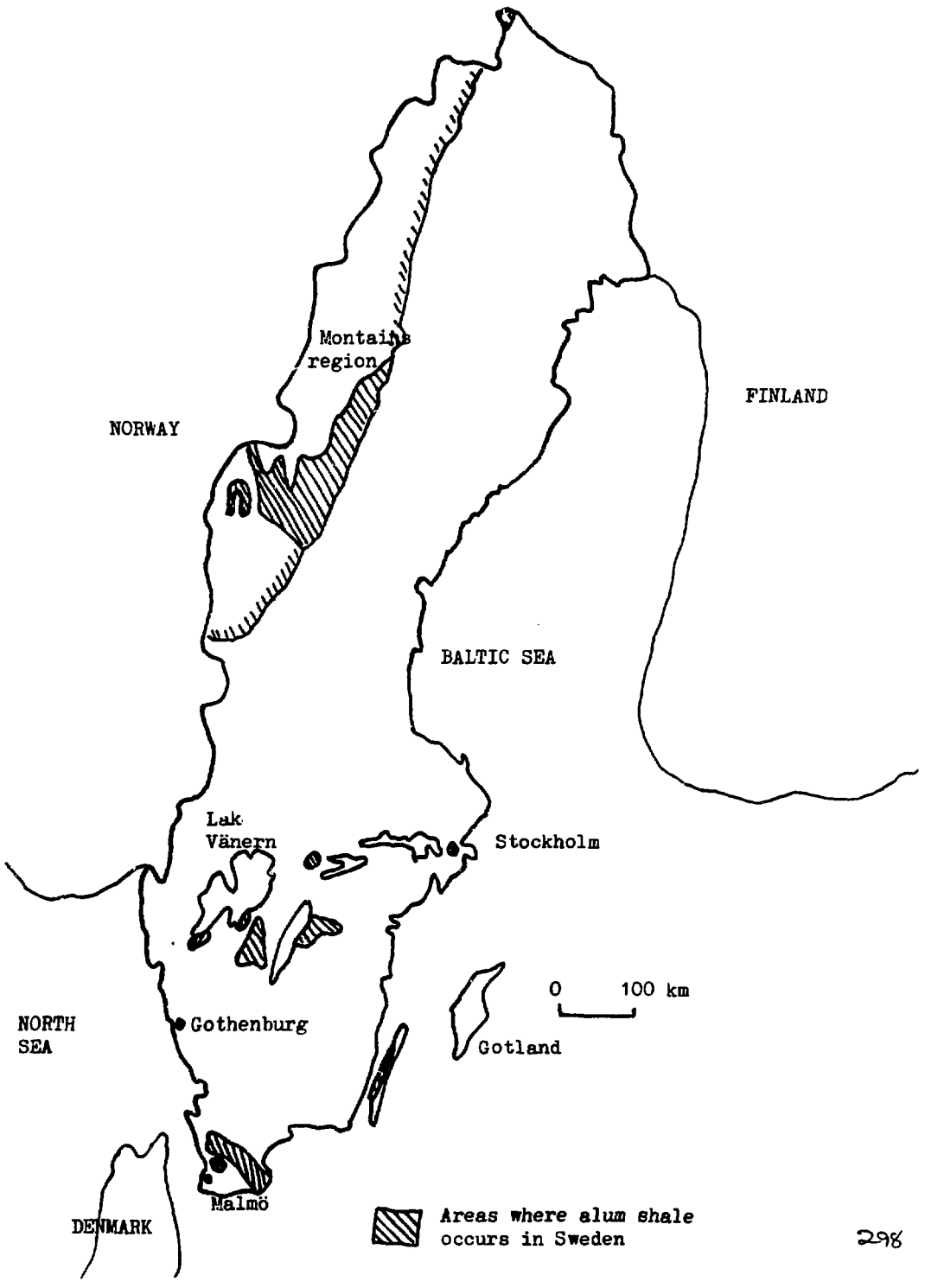


Figure 2. Gamma index for various building materials. The figure also shows the approximative value of the annual radiation dose to the gonads in the hypothetical case that all parts of a house were made of the building material in question.

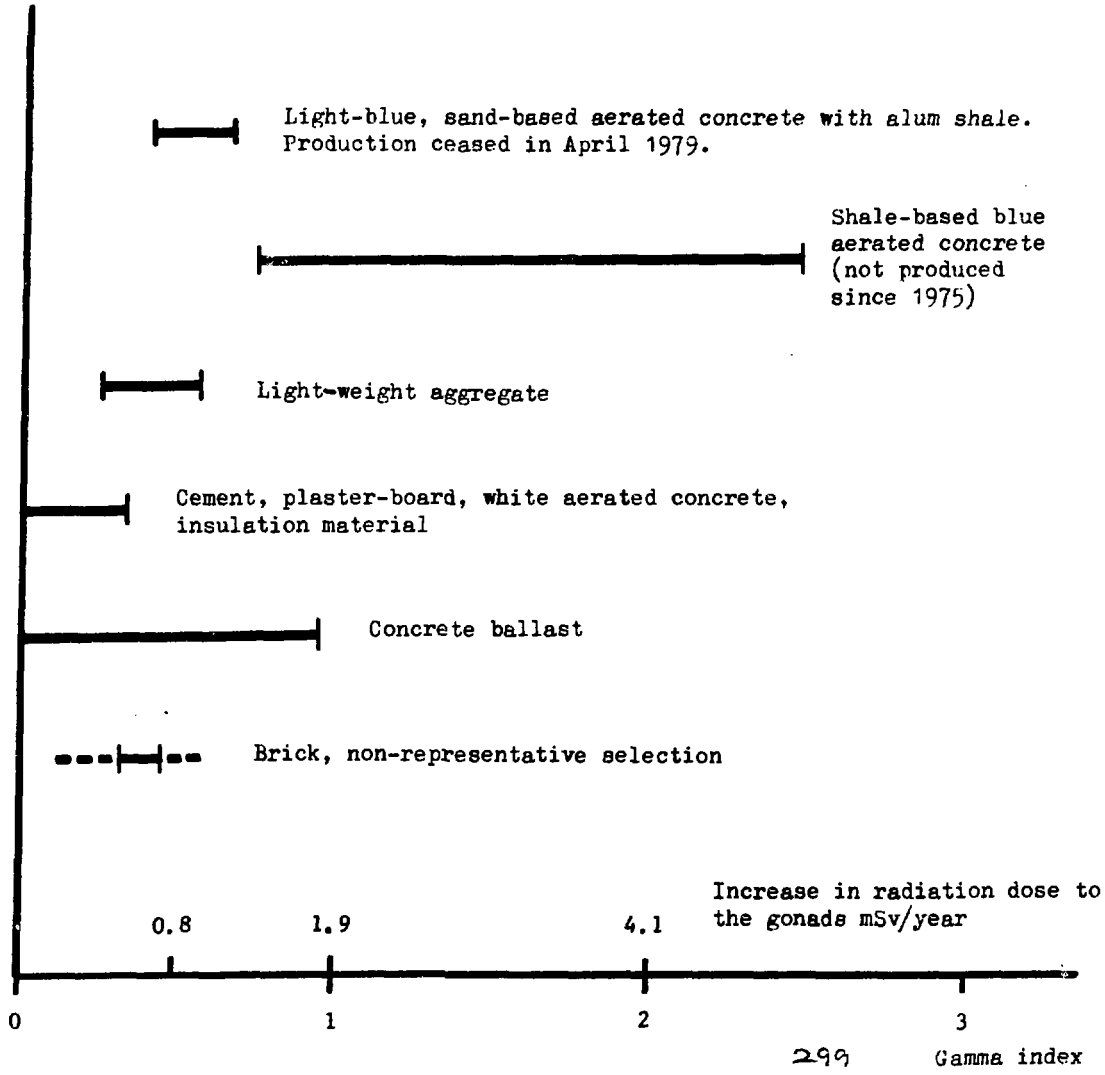
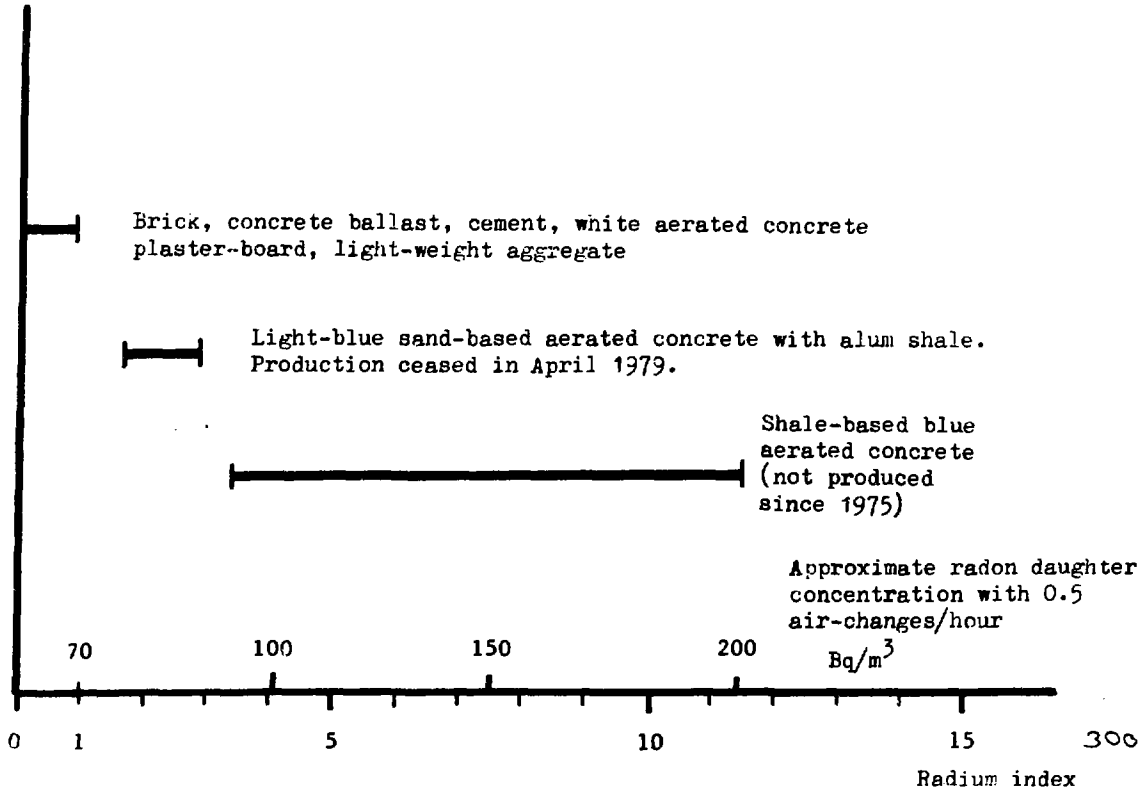


Figure 3. Radium index for various building materials. The figure shows the approximative values for the radon daughter concentration (working level ratio) corresponding to 0.5 air changes per hour. It is assumed that all parts of the house are made of the material in question.



NATIONAL BOARD OF PHYSICAL
PLANNING AND BUILDING
SWEDEN: Wilhelm Tell

March 6, 1980

Measures taken by the building authorities in order to reduce radiation risks in buildings

First I would like to give you a survey of authorities involved and their fields of action.

The Swedish Government is the authority primarily responsible for measures against radiation in buildings. The Parliament is informed accordingly and has the power to decide concerning certain matters, eg. housing loans.

Within the Government the Ministries of Housing and Physical Planning, of Health and Social Affairs and of Agriculture are responsible for questions concerning protection against radiation. For the handling of special matter the Ministries in Sweden have special boards. The National Board of Physical Planning and Building is responsible for the planning on radioactive ground and for the performance of buildings regarding radioactivity. The National Housing Board is responsible for housing loans. These two boards are subordinated to the Ministry of Housing and Physical Planning. The National Board of Health and Welfare is subordinated to the Ministry of Health and Social Affairs. The National Institute of Radiation Protection is attached to the Ministry of Agriculture.

Sweden is divided into 24 counties, each with its own county administration who among other things deals with questions of radiation within the county. The number of municipal districts in Sweden is 276. Within each of them there are a local building committee, a local public health committee and a local organization for housing loans. These three local authorities deal with the question of radiation locally.

A radon commission has been appointed in Sweden. The commission has proposed provisionary values for limiting gamma radiation and the content of radon daughters in buildings during a provisional period of five years. The commission has further suggested that house owners shall be granted state loans for measures in order to reduce the radiation risks. The commission has also proposed a programme for research and development. It has given the following main recommendations:

1. The risk of radiation and radon emission from the ground shall be considered when planning for new settlements.

2. Building materials with high radioactivity are not to be allowed for new buildings.

3. Existing buildings with great radiation risks shall be traced and measures taken accordingly.

I now want to describe our preparations for physical planning on ground with high radioactivity.

Considering the shortage of knowledge our board has not been able to propose directions for settlement on ground with radiation risks. The radon commission has proposed that settlement should be avoided within areas with a radiation exceeding 100 µR/h and that such areas with a radiation between 30 and 100 µR/h should be investigated regarding radon emission in order to clarify the necessary conditions for settlement. The Planning and Building Board, however, believes principally that one can build on all ground provided that the way of building is appropriate. A good example seems to be a house on plinths with the ground floor structure about 1/2 m above ground surface. Then the gamma radiation and the radon flow from the ground ought to be avoided.

The Board considers that it is vital that areas with dangerous gamma radiation and high radon emission are taken into consideration when planning for such areas. This can be done by the help of maps of gamma radiation from the ground in the scale 1 to 50,000. Such maps are now being worked out for topical areas in Sweden. The maps state areas within which the gamma radiation can be more than 30 µ/h. Within such areas one should consider the risk of high radioactivity and plan new settlements in such way that certain ultimate limits for new buildings shall not be exceeded. I will inform about the limits later on.

Many of our 24 County Administrations are now investigating areas with a gamma radiation of more than 30 µR/h. The investigations are based on the above mentioned maps and on other studies.

The intention also is that the local authority shall supplement their different plans in scales from 1 to 10,000 up to 1 to 400 with informations of radioactive areas and statements of the conditions for settlements and the performance of new buildings. The Board is likely to work out recommendations and direction for such planning probably in 1980.

I will now turn over to the suggestions concerning buildings.

A building permit according to our Building Act is necessary for new buildings and also for large changes of already existing buildings. This permit is granted by the local building committee. The technical performance of such buildings is stated in the Swedish Building Code which contains mandatory regulations as well as directions and recommendations. The Board has worked out proposals for new building and for rebuilding considering the suggested ultimate limit values for the content of radon daughters and for ghama radiation. These proposals will probably be in force from the 1st of January 1981. The ultimate limit value for the content of radon daughters indoors emanating from both the ground and the building materials as well as from drinking water is proposed to to be 70 Bq/m^3 and for the ghama radiation from building materials and ground to be about 30 µR/h. When changing a building the ultimate limit value for the content of radon daughters must be higher than for new buildings and is suggested to be 200 Bq/m^3.

The proposed values principally correspond with the recommendations given by the Swedish radon commission. The commission also recommends that buildings with a content of radon daughters exceeding 400 Bq/m^3 shall be traced and measures taken accordingly. Such high contents are considered to be of sanitary inconvenience according to the Ordinance for Hygiene and Public Health. Based on this Ordinance building owners can be either recommended or forced to take steps in already existing buildings.

The Building Ordinance gives no such possibility regarding existing buildings. Should the content of radon daughters exceed 400 Bq/m^3 the radon commission has recommended to reduce the content to below 200 Bq/m^3, which is the same value as is proposed for such rebuilding that requires building permit.

The values of 400 and 200 Bq/m^3 have been chosen on the basis of information about contents of radon daughters in existing buildings, given by the National Institute of Radiation Protection. By choosing these values extensive and expensive measures during at least a provisional period of five years may be avoided. After this period the radon commission considers that the knowledge has been enlarged to such an extent that more precise and probably lower ultimate limit value can be fixed. The proposed level of 200 Bq/m^3 is considered to be reached in all buildings by extended ventilation and if necessary even change of materials that are easily accessible such as fillings outside cellar walls and fillings in floor structures.

The Planning and Building Board now try to find out which control and testing methods that can be started and also which remedial measures that can be used in practice. I have learned much during these days here in Canada and we will follow up our contact with the delegates here. The big questions are of course the risks for the people and the limit values, which is handled primarily by other authorities. The Planning and Building Board is most interested in the testing methods and the remedial measures and how to administrate the radiation questions within the building field.

Some remarks about remedial actions and research program in Sweden

Sven-Olov Ericson

In the fall 1978 the National Institute for Radiation Protection measured high concentrations of radon in 6 one-family houses built on land where shale ash had been used as landfill. The mass-media gave this a great deal of publicity and politicians promised that the owners should be indemnified. It was decided that remedial actions should be taken in these houses and in some houses made of aerated concrete based on alum shale under a research project at the Swedish Council for Building Research.

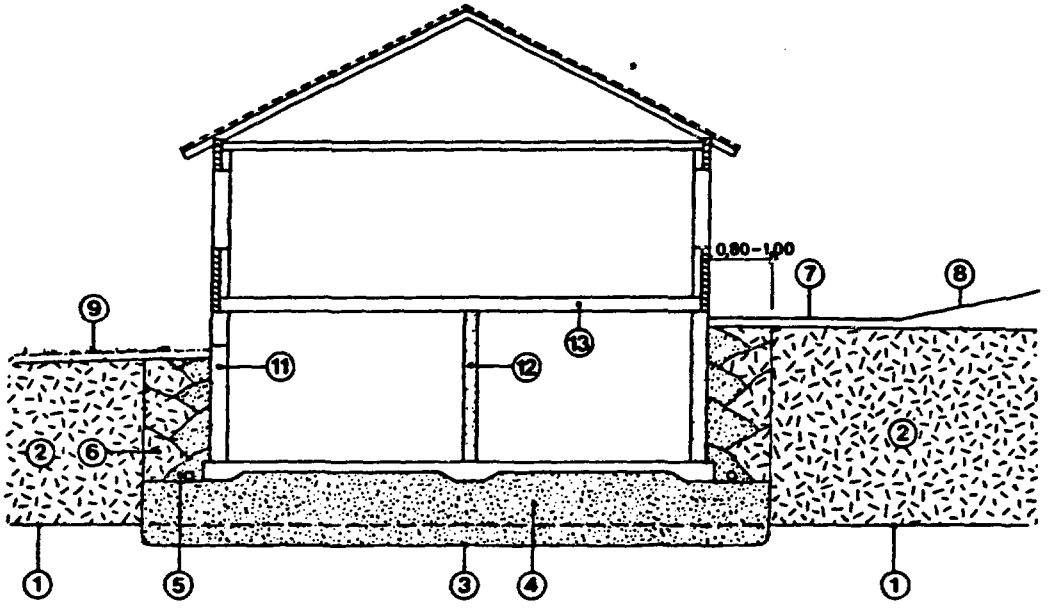
The houses are not very old and it was possible to get in contact with people who had seen the erection of the houses with their own eyes. By interviewing them we concluded that the land had been levelled with alum shale ash from an adjacent dump. This ash has a radium contents with a range from 900 to 3000 Bq/kg ^{226}Ra and 1500 Bq/kg as an average. Uncovered ash gave a gamma radiation of 60-170 μ R/h. In the gardens the ash is covered with soil which shields most of the radiation.

5 of the 6 houses have a full basement - one house was built with crawl space. We concluded from interviews that there was no ash under the basement slab - the local building authority had prescribed that the houses should be founded on natural solid ground and not on the ash. The situation is shown in figure 1.

In one of these houses we install a ventilation system which gives 0,5 air change/h in the living floor and up to 3 air changes/h in the basement. In order to prevent radon contaminated air to reach the living floor there is a flow of air down the stairs into the cellar. In order to limit the energy consumption the installation includes an efficient heat exchanger. The energy required to run the fans is not insignificant, but a great deal of it helps to heat the house. In order to prevent freezing in the heat exchanger there is an electric heater in the duct for supply air which automatically turns on when the outdoor temperature is too low. The cost of this sofisticated ventilation system was $16.000.

Fig 1.

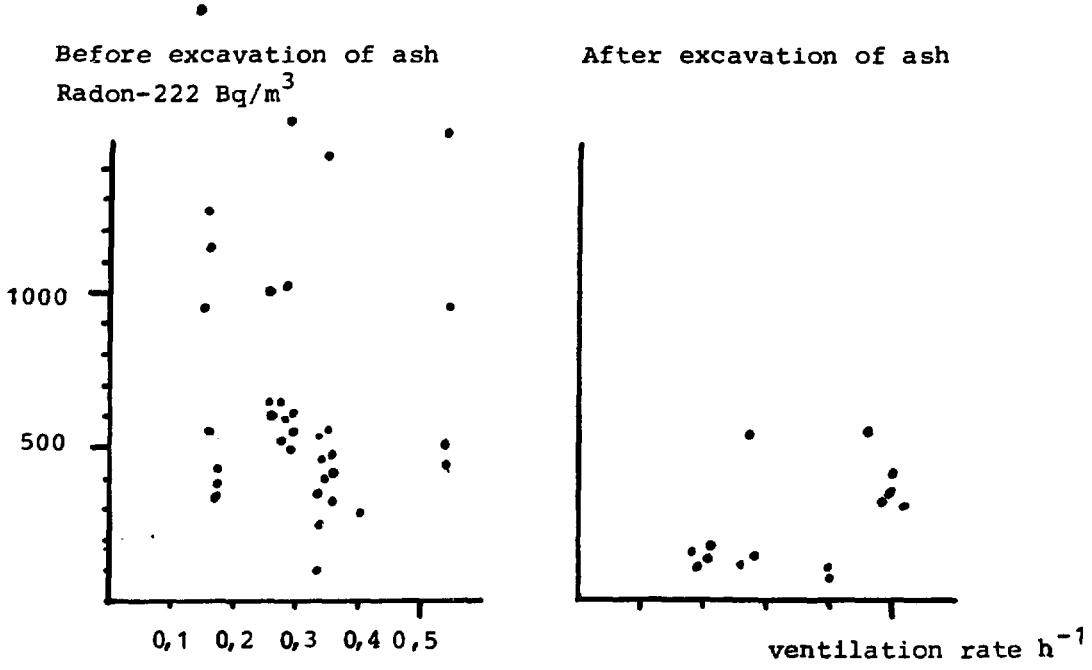
Skeleton drawing of house with full basement and landfill of shale ash.



1. Original ground level
2. Landfill with alum shale ash (filled before the house was built)
3. Bottom of excavation
4. Fill with normal gravel (1 metre thick)
5. Backfill with normal gravel
6. Probable backfill with shale ash
7. Terrace with concrete tiles
8. Soil covered with grass
9. Soil covered with grass
11. Coated twice with cold asphalt + slurry of cement mortar + 25 cm concrete block + plaster
12. Plaster + 7 or 20 cm concrete block + plaster
13. Framing of joists

The other four houses with full basement were remedied by the removal of all shale ash up to a distance of 4 metres from the house. The ash was replaced by normal fill with 40-60 Bq/kg of radium-226. The effect of this action has been preliminary evaluated. Figure 2 shows corresponding measurements of radon and ventilation rate in these houses before and after the removal of the ash. The cost of excavation and restoration of the gardens was $20.000 for each house.

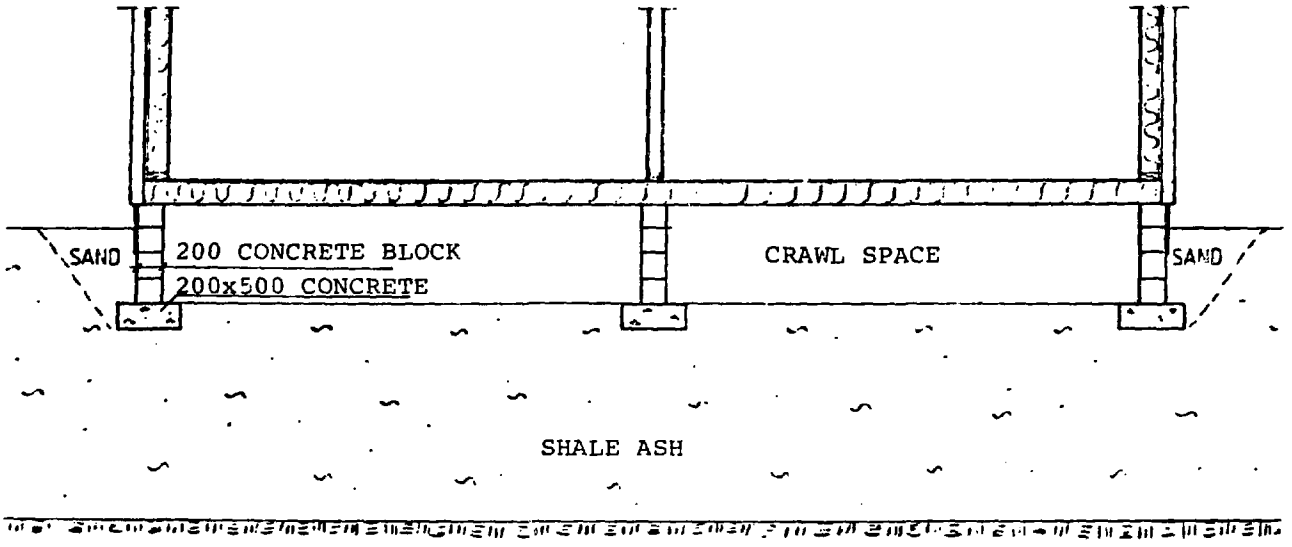
Fig 2. Corresponding measurements of radon-222 and ventilation rate in 5 houses with full basement in a ground where alum shale ash was used as fill.



Several measurements showed 3000-5000 Bq/m^3 radon-222 in closed rooms in the cellars.

One of the houses has a crawl space and is founded on 1,5 m of shale ash. We do not think it is feasible to remove this ash; figure 3.

Fig 3. House with crawl space on 1,5 m shale ash.



After the first measurements were made the occupants were recommended to increase the ventilation rate by the fan in the kitchen. This however resulted in an increase of radon concentration by an order of magnitude from 14 pCi/l (500 Bq/m^3) to 135 pCi/l (5000 Bq/m^3). The concentration of radon in the crawl space was 400 pCi/l (15.000 Bq/m^3). The reason for this increased radon concentration was that the fan caused an under-pressure in the house and suck heavily contaminated air from the crawl space through the floor. The walls were tight and the entrance to the crawl space was through the floor in the kitchen. As a temporary arrangement we then installed a fan sucking air out from the crawl space. This gave a slight underpressure in the crawl space and prevented contaminated air from entering the house. After that we measured less than 0,01 WL in the living area. The effect upon radon concentration in the crawl space was limited.

This arrangement cannot be used in wintertime - the foundation can be damaged if the ash freezes and the floor will be uncomfortably cold. As a final solution we intend to lead the exhaust air from the house down to the crawl space and further out. The crawl space will be kept at slightly lower pressure than the living floor. The foundation wall will be insulated in order to prevent condensation of moisture. One advantage with this technique is that it gives a warmer floor. We also consider to reduce the exhalation from the ash by pouring a 10-20 cm thick concrete slab into the crawl space.

In 5 houses built of aerated concrete based on alum shale we try to reduce the radon concentration by ventilation or by repapering the walls with aluminium foil.

The ventilation systems are designed to give 0,5-1,5 air change/h in every room and are equipped with heat exchanger. The cost for such a system is $4.500-5.000.

In laboratory experiments it has been proven that aluminimum foil can be radon tight. This is being tested as a remedial action in 3 houses, where all walls are repapered with 25 μm aluminium foil laminated with 25 μm polyethylene and paper on each side. In one of the houses 100 μm unlaminated aluminium is tested in part of the house. No results are yet available. Continuous aluminium foil on walls is considered to increase the probability that a malfunction in the electrical installation will cause a fire or accident with electrical shock. Such foils are banned in Sweden for occupational use, because of the risk for electrical shock during pasting.

In some houses with slab on grade we try to reduce the radon flow with a laminated aluminium foil on the slab. The test is carried out where the gamma radiation from the ground is up to 70 μR/h. No results are available yet.

The research program during the next 2 years will concentrate upon studies of

- the relation between elevated activity in rock and soil and indoor concentration of radon
- exhalation of radon from building materials.

We will measure radon indoors and the activity in the soil close to the house in order to find out what building technique that ought to be used on different types of ground to avoid a too high concentration of radon.

By the study of exhalation from building materials we want to establish how activity in the material, the texture and the surface treatment influence the exhalation from finished wall and floor.

The results from these and other studies are to be used when we evaluate the cost and benefits associated with different levels of permanent limit values for radon indoors in new and existing houses, radium contents in building materials and different guidelines for planning new buildings on land with elevated activity.

Methods and Instruments Available for the Measurement and Study of Radium, Radon and Other Alpha-Particle-Emitting Radioisotopes of the ^{238}U Radioactive Decay Chain in Soils, Rocks and Solutions.

Introduction, Theory and Fundamentals

In the section following this, the techniques and apparatus for making a particular type of measurement are described first. Examples of such measurements and of their value and interpretation follow this description, or sometimes follow the descriptions of a number of related methods. More space is devoted to new methods and apparatus than to those which have been used and described elsewhere. As used in these laboratories, some of the latter incorporate modifications which are described; others are well known and widely used methods which are mentioned only to indicate that they are in use here or to contrast them with others. Only the most essential aspects of theory and fundaments are described, and these chiefly in this introduction. However, the references cited provide a complete theoretical basis and justification for the methods described here.

Methods which are said to require further development have been tested sufficiently that there is no doubt that they would work as described. However, more tests are thought to be necessary to ascertain the ease with which such measurements may be made, their sensitivity and their advantages or disadvantages relative to other methods. They are described here because they are obvious extensions of other methods described, because they may offer important advantages, and to indicate the research and development we consider it valuable to undertake in extending the presently available methods.

In order to simplify these discussions it is assumed, unless otherwise stated, that the only significant radioisotopes present in the sample materials are those of the ^{238}U decay series. If this were not the case* adjustments in the procedures and the interpretations of the results would be needed in some cases, but these methods could still be used.

* This would usually be due to [Th] exceeding [U]; ^{235}U and its decay products would never contribute significantly to the alpha-activity of a sample and alpha-emitting trans-uranic isotopes would probably not be present even in cases of man-made contamination. For these isotopes and elements:

1ppm U = 2.64 pCi ^{238}U - alpha-activity per gram
= 0.106 " ^{235}U - " " " "
1ppm Th = 0.66 " ^{232}Th - " " " "

These values take into account both the parent isotope and its decay products. In the average material of the earth's crust the ratio [Th]/[U] is about 5; thus, in it, the alpha-activity of ^{238}U and ^{232}Th would be about equal. However in any material enriched in uranium, that of ^{238}U would exceed that of ^{232}Th.

Leaving out the unimportant branches and intermediate isotopes which do not concern us here, the ^{238}U decay chain is:

$$^{238}U \xrightarrow[(4.51)10^{9}y]{\alpha} {}^{234}Th \xrightarrow[25d]{2\beta} {}^{234}U \xrightarrow[(2.48)10^{5}y]{\alpha}$$

$$^{230}Th \xrightarrow[(7.52)10^{4}y]{\alpha} {}^{226}Ra \xrightarrow[1622y]{\alpha} {}^{222}Rn \xrightarrow[3.825d]{\alpha}$$

$$^{218}Po \xrightarrow[3.05m]{\alpha} {}^{214}Pb \xrightarrow[26.8m]{\beta} {}^{214}Bi \xrightarrow[19.7m]{\beta}$$

$$^{214}Po \xrightarrow[(1.6)10^{-4}s]{\alpha} {}^{210}Pb \xrightarrow[22y]{\beta} {}^{210}Bi \xrightarrow[5d]{\beta} {}^{210}Po \xrightarrow[138.4d]{\alpha} {}^{206}Pb$$

Most of the measurements described here are of the concentration of one or more of these radioisotopes in air, rock, soil, overburden or water samples. Uranium concentrations, which are practically ^{238}U concentrations, are usually determined by fluorimetric, X-ray fluorescence, or delayed neutron methods and are given in ppm or ppb. The radioisotopes are usually measured in picocuries per liter (pCi ℓ^{-1}) or picocuries per gram. A picocurie is a measure of radioactivity, 2.22 disintegrations per minute (dpm); the mass it represents varies with the isotope (2.99×10^{-6}g of ^{238}U, 10^{-12} g of ^{226}Ra and 6.40×10^{-18} g of ^{222}Rn e.g.).

In a system in which the atoms cannot move about or diffuse significantly, e.g., a rock at room temperature which is not undergoing weathering, a decay series such as $^{328}U \longrightarrow {}^{206}Pb$ reaches "radioactive equilibrium" or "secular equilibrium" in a time $\geq$10X the half life of the longest lived decay product. In a system in radioactive equilibrium there is an equal activity of each isotope, i.e., 1pCi of ^{238}U is accompanied by 1pCi of each of the other isotopes through ^{210}Po. In a system which began without decay products and in which equilibrium has not yet been achieved the concentrations of the decay products are lower than the equilibrium concentrations toward which they build up assymptotically with time. Several million years are required for equilibrium to be achieved in the $^{238}U \longrightarrow {}^{206}Pb$ system. However, in measuring the isotopes of the $^{226}Ra \longrightarrow {}^{210}Pb$ series the concentration of the ^{210}Pb is usually never allowed to grow significantly, and consequently equilibrium may be considered to be reached in the $^{226}Ra \longrightarrow {}^{210}Pb$ system in about 10 hours. For a number of reasons these are important considerations in measuring the concentrations of these isotopes. Radium is frequently measured by means of the radon produced from it, for example, and the degree of equilibrium in the sample at the time of measurement must be known in order to derive the [Ra] from the measured [Rn]. As the decay products of ^{222}Rn are solids at room

temperature, they precipitate out of air onto any solid particles or surfaces available. Hence they are normally not initially present in air pumped through tubing into a counter for measurement of radon and atmospheric radon is usually not accompanied by its equilibrium activities of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. The extent to which these isotopes do remain in radon-containing air until they decay is important in measurements of radon in radiation safety monitoring, as they are more serious health hazards than ^{222}Rn itself.

Most of the methods of measurement described here are of the alpha-particle-emitting members of the ^{238}U decay series, and measure their alpha-activity by one of the following processes:

(a) Scintillation Counting: Alpha particles from the sample material fall on a layer of zinc sulphide in which they produce "scintillations" of light which, in turn, produce pulses of current in a photo-multiplier tube. The current pulses are counted by an electronic circuit and the count is displayed on a scaler.

(b) Etched Track Counting: Nuclear particles such as alpha particles and fission fragments produce regions of radiation damage in solids such as plastics. These "particle tracks" can be enlarged to features visible through an optical microscope by exposing the solid to an etchant, which, for tracks in a plastic, is usually an aqueous solution of sodium hydroxide.

The number of tracks per unit area on the solid track detector surface is referred to as the "track density", ρ. The track density is proportional to the concentration of the particle-emitting isotope or isotopes, in the material which was in contact with the detector while the tracks were being formed. After etching, ρ is easily determined by counting the number of tracks in a measured area on the detector surface by means of a microscope. Similar track counting on a detector exposed to a material with a known concentration of the particle-emitting isotope or isotopes permits calibration.

Methods, Applications and Interpretations

(1) Measurement of Radon in Air and Soil Gas.

Several methods are available. Often only relative measures of the radon concentrations are needed (see below) but means of calibrating and obtaining absolute values are available for each method.

(a) Emanometry. This has been the most common method in the past. The air or soil gas is pumped into the ZnS-coated cell of a scintillation counter (or "emanometer"; Fig. 1) and the counting rate (c =counts per minute, c.p.m.) is read. Because of the rapid precipitation of the solid decay products of radon from air (Introduction; Fleischer and Mogro-Campero, 1978; McCorkell and Card, 1978) the air is nearly free of these when it enters the cell. The decay products begin to accumulate in the cell thereafter, so that both the total alpha activity and the energy spectrum of the alpha particles in the cell change for several hours after the air is introduced. Thus, for the most accurate results, the length of time that the air is circulated through the cell, the length of the count, and the length of time (if any) between introducing the air and counting, are standardized. Without further calculations the counting rates so obtained provide relative measures of the radon concentrations in the air samples. Counting rates measured for soil gas samples at different points over a terrane may, for example, be plotted on a map and contoured to show the variations in soil gas [Rn] without calculating the actual values of the latter. Calibration of the Bondar-Clegg RE 279 emanometer has been accomplished under standardized conditions by introducing air of known radon concentration R(pCi l^{-1}) and measuring the counting rate c (c.p.m. above background). The calibration factor C then is:

$$C = \frac{c}{R}$$

where C is in counts per minute per pCi of radon per liter. Subsequent readings of c, made under the same standardized conditions, may be converted to R using the known C value.

Similar methods of calibrating, involving the evaluation of a C factor, have been used for other methods of radon determination (see below) and hence it should be noted that C is also a measure of the sensitivity of the method; the larger is C, the lower is the minimum concentration of radon the method is capable of detecting. When a five minute-long count is made five minutes after radon containing air is introduced into the RE 279 calibration factors of about 0.4 are usually found. This and the background count rate of

about 4 c.p.m.* indicate a detection limit of about 20 pCi l^{-1} for this instrument and method (Porritt, 1979, pp 37-38). If the radon-containing air is left in a cell until the short-lived radon decay products have nearly reached their equilibrium concentrations (i.e. for about 3 hours) C values of about 0.70 are observed.

(b) Track Detector Method. In this method pieces of a plastic in which alpha particles produce etchable tracks are exposed to the air. Later they are etched and the numbers of tracks per unit area on their surfaces (ρ) are determined by counting with a microscope. The track detector usually used is cellulose nitrate and Kodak-Pathé LR 115 Type II (LR2 in the following) has proven highly satisfactory. Where the number of detectors is large, an image analyzer could probably be used to advantage in counting the tracks. It seems, however, that they have not, so far, been used in geochemical exploration utilizing radon-alpha-particle tracks in cellulose nitrate. They have been used frequently in counting etched tracks of various kinds in nuclear physics research and in radiation dosimetry, in which cases the tracks can be made to have very constant appearances. In the more uncontrolled and "natural" conditions in which geochemical exploration is done, etched tracks vary more in shape and size and in the contrast in image intensity between them and the surrounding surface of the track detector. Track counting with an image analyzer might, therefore, be more difficult. An image analyzer has been used to count fission tracks in Lexan in geochemical exploration. In this case the sample materials were the residues from water droplets and organic materials drawn off of plants with a suction tube and the analysis was for uranium. However, it seems that this technique should be described as a combined visual-and image analyzer-method of track counting; the tracks must be viewed and the counter adjusted before counting begins on each sample because of the varying appearances of the tracks, of the non-track features present, and of the etched plastic surface surrounding the tracks.

Kodak-Pathé LR2 consists of a 12μm thick layer of red cellulose nitrate on a 100 μm thick backing of clear, non-track-recording plastic. When it is exposed to radon-containing air most of the alpha particles reaching it pass through the red layer. The tracks produced, therefore, etch as holes through this layer. These are usually sharp-edged and round or slightly eliptical, and should be ideal for image analyzer counting. They are, of course, also easily recognized, counted, and distinguished from other features, by a technician using a microscope. They vary considerably in size but even if the image analyzer failed to count some of the largest and smallest tracks it would do so reproducibly and so produce no errors in the final results. The contrast

* In most laboratory measurements, B.G. values of less than 1 c.p.m. have been observed. The value of 4 c.p.m. used by Porritt in measurements of radon in a mine was the mean "observed during the survey" (Porritt, 1979, appendix B) and is, presumably, affected by radon decay products remaining in the cells from former uses.

in optical intensity between the track-hole image and the surrounding red layer is great and can be made still greater by viewing the detector with green light. In some types of etched track measurements the track density may vary greatly from point to point on the detector and hence errors may result in image-analyzer track counting due to varying degrees of track overlap. (A person viewing the tracks with a microscope, can distinguish the individual tracks in clusters much more easily than an image analyzer can. He can also vary his track counting procedures in ways to assure a random sampling of the track density which would be difficult to incorporate in an "automated" instrumental track counting process.) However, this difficulty would not arise in the counting of alpha particle tracks produced by atmospheric radon: an air-radon mixture is homogeneous and hence the track distribution produced by it is.

For the measurement of radon in soil gas track detectors are placed in plastic cups which are placed in covered holes or buried at the sites of interest. This procedure has been the subject of research and development here and some of the results of this are given below. Track detectors have also been used to measure soil-gas radon at greater depths. Several types of samplers have been developed which can be attached to rods and driven to depths of as much as 50 meters. They can then be opened by manipulating the rod at the surface, and a sample of about 30 ml of the overburden from that depth taken. To measure the soil-gas radon concentration at this depth a track detector is placed in the samplerwhich is then opened and left in place for three hours after being driven down. The overburden sample is then taken and the sampler drawn up. No other method exists for rapidly and routinely making measurements of radon at such depths, and many other types of measurements, some described below, can be made on the overburden sample taken at the same time. The cost of this service has been estimated at $90.00 per site if the average depth reached is 5 meters and the measurements are of soil gas radon and of uranium and radon in the sample retrieved. This compares favourably with $12.00-$25.00 per site for track detector measurements by the usual cup method at the surface, and only a single trip to the field is made in the case of overburden sampling. When greater depths are to be reached, it has been found that 45 site-meters can be drilled per day at about $18.00 per meter.

Only a simple microscope is needed for counting alpha-particle tracks in LR2 and methods have been devised for in-the-field etching of this detector. Track counting for the final mapping of radon concentrations would probably be done in the laboratory later, but field etching and counting would permit preliminary conclusions to be drawn from the results of each day's work before the next day's work began.

In most geochemical exploration using track detector measurements of radon concentrations track densities are plotted on maps and contoured. These, of course,show relative soil-gas-radon concentrations in the same way that counting rates do in emanometry.

To calibrate track detectors so that absolute radon concentrations can be calculated from their track densities, a track detector is exposed to air of known R for a measured length of time. Its track density then yields the track production rate ρ', tracks per cm^2 per hour per pCi per liter of radon. If the length of time a track detector is exposed in the field is then known, the radon concentration to which it was exposed can be calculated from its track density. However the calibration must be done in a container such as the track detector will be exposed in in the field; the track production rate varies with the size and shape of the container as well as with R (McCorkell and Card, 1978). This, however, is simply done: a track detector is placed in a cup, overburden sampler or other container such as will be used in the field and this is placed, for a measured length of time, in a tank in which a known concentration of radon is maintained.

(c) Collectors. These are strips of metal or plastic which are hung in the air whose radon concentration is to be measured. Later they are transferred to the cell of a scintillation counter and the concentrations of alpha-particle-emitting radon decay products (^{218}Po and ^{214}Po) precipitated or "collected" on them are measured (Fig. 2). The factors affecting the precipitation of radon decay products and the measurement of radon by means of collectors have been the subjects of a number of studies (McCorkell and Card, 1978; Bell and Card, 1979, Card and Bell 1979a, 1979b). For measuring radon in soil gas, a collector is hung in a cup which is buried in the soil as track-detector cups are.

It was found (McCorkell and Card, 1978; Card and Bell, 1979) that the material of which a collector is made has no effect on the activity it acquires in given conditions. However the activity a collector acquires increases roughly in proportion to its surface area. Also, in containers such as collectors are exposed in in the field or laboratory, the activity per unit area on a collector and, presumably, on the interior walls of the container, is roughly equal to the total decay product activity present in the container divided by the total internal surface area of the container (McCorkell and Card, 1978; Fleischer and Mogro-Campero, 1978).

In the simple collector-counter system shown in Fig. 2 the collector is a 3.5cm x 5.5cm strip of 0.125 μm thick Lexan. Half of the alpha particles emitted by radon decay products precipitated on this would be absorbed in the collector and hence the "counting geometry" is 2π and the maximum counting efficiency achievable would be 50%. The size of this collector relative to that of those used in other collector-radon-measuring systems (~5 cm^2) should be noted; an approximately threefold increase in sensitivity would be expected from this alone. If the collector is made of material thin enough that the alpha particles being counted pass through it, the counting efficiency would be further increased by about a factor of 2 (i.e. 4π counting geometry would be acheived).

For measuring radon in mines, dwellings and places of work collectors could be hung in the air and counted periodically. If they became dusty they could simply be wiped off. As long as they had hung undisturbed and untouched for about 3 or more hours before counting, the count would be accurate, and dust would not affect the count unless it contained a high concentration of alpha-emitting isotopes.

In some situations the highest possible sensitivity might be needed in radon measurements, and for these ribbon collectors have been developed. These are long strips of plastic so thin that the alpha particles being counted pass through many layers of it. These strips are hung in the air, and later rolled or folded for insertion in the counter.

Because the size of the container in which collectors are placed has a powerful effect on the activity acquired by them, methods of radon measurement utilizing collectors are more difficult to calibrate than emanometry or track detector methods. When the collectors are being exposed in standardized containers (as in cups for measuring soil gas radon) calibration can be carried out as it is for track detectors. However the problem of calibration when the collectors are being hung in large and variable-sized spaces, in which, and between which, air currents, ventillation, temperature, humidity and other factors vary is still being worked on. Collectors, of course, measure, not radon concentrations but the concentrations of radon decay products. However as explained above, in small containers such as the cups used for burying collectors in soil, the decay products precipitate rapidly and uniformly over all internal surfaces. In these, therefore, there is a constant relationship between the activity found on a collector and the concentration of radon. In these, also, the large ratio of the internal surface area to the volume (and hence to the total activity of decay products present) would be expected to lower the sensitivity of collector measurements. In volumes such as the rooms of houses the concentration of decay products maintained by a given radon concentration would probably be higher than in the small containers and the surface-to-total-decay-product-activity would be much lower. Consequently collector methods in such spaces would be much more sensitive (i.e. have larger C values) but the relationship between the radon concentration and the activity found on the collector may be variable and unpredictable. Such variation would reflect variation in the degree of equilibrium between the radon in the air and its decay products, which is certainly noted in measurements of "working levels" by means of filters (see below).

The results of some tests and calibrations of collectors given below show the effects mentioned above. Here C is in c.p.m. per pCi of radon per liter and the radon concentrations were either known (i.e. in tanks whose air had been circulated through radium solutions) or were measured by emanometry.

3.5 x 5.5 cm, 125 μm Lexan,	4ℓ tank	C = 0.39
	28ℓ "	= 0.65
	Room of house	= 1 - 4
25 μm Mylar {2 thicknesses}	28ℓ tank	= 0.90
		= 1.40
{25 μm Mylar }	" "	
27 x 5 cm ribbon of 5 μm Mylar, folded to 3.5 x 5 cm for counting	" "	= 2.20
Above ribbon	Room of house	= 13 - 24

The variations in C measured in rooms no doubt reflect the fact that the radon concentrations were probably varying in the few hours immediately prior to the measurements, whereas, in the 4ℓ and 28ℓ tanks they were not. The emanometry measurement gives the concentration of radon at the time of measurement; the collector measurement is affected by the radon concentrations (and probably by other factors such as air circulation) during several hours before the measurement. This problem is further discussed below.

No decay products are deposited in the scintillation cells during the counting of collectors, as they are in emanometry. Consequently the background count rate of the RE 279 could probably be kept below 0.4 c.p.m. during collector measurements. This fact and the above C values indicate that the concentration of radon in the normal atmosphere (about 0.1 pCi ℓ^{-1}) should be measureable by collector methods.

Recounting a collector about 10 hours after removal from the radon-containing air would show if thoron was also present: see footnote, section 3c.

(d) Filtration. In this system the air is drawn through a filter on which some or all of the solid decay products of radon are removed and the activity on the filter is then determined. Fig. 1 shows the apparatus used here. The membrane filters used have been shown to be practically 100% efficient in removing these decay products from air drawn through them, and it has also been shown that the alpha particles from decay products collected by them escape from the filters with practically their full energies (Porritt,1979). To measure the filtered activity the filter is laid on the ZnS-covered screen of the tray, and the tray is lowered over the window of the photomultiplier tube of the RE 279 counter.

Like collectors, filters measure, not radon itself, but its short lived, solid decay products. In health physics the concentrations of these in air are measured in "working levels" one working level being defined as: "The

potential alpha energy of any mixture of RaA(^{218}Po) RaB(^{214}Pb) RaC(^{214}Bi) and RaC'(^{214}Po) in 1 liter of air equivalent to that released by 100 pCi/ℓ of each of the same radon daughters; the amount of this energy is $(1.3)10^5$ MeV". That is, 1 working level is the concentration of these radon decay products which would exist in air which is 100 pCi ℓ^{-1} in radon if equilibrium existed in the radon decay chain from ^{222}Rn to ^{214}Po or the concentration of another combination of these isotopes which releases the same total energy in alpha particles. There are various standardized procedures for filtering and counting which permit working levels, or the actual concentrations of the various isotopes, to be calculated from the observed counting rates of the filters (Frank and Benton, 1977; IAEA, 1976). The concentration of radon decay products is not supposed to exceed 0.020 working levels in air in which people live and work.

(2) Examples, Comparison and Interpretation of Emanometry, Etched Track, Filter and Collector Methods. These, and a number of other methods to be mentioned later, were tested and compared on the South March uranium deposit near Ottawa. A complete compilation of the data obtained is in the paper McCorkell, Porritt and Brameld (sub. to JGE). Some of the most significant profiles are reproduced here (Fig. 3). All of these are along the baseline and the profiles found by emanometry and by fluorimetric uranium analysis of soil samples are essentially the same as found on this line by others (Charbonneau et al. 1975; Bell and Card 1979). Data not shown here but tabulated by McCorkell et al. show that analysis of the soils by a fission track method yields the same values for uranium, but the only advantage this technique has over fluorimetry is one not usually needed in geochemical exploration: greater sensitivity. The etched track method using LR2 shows a profile approximately the same as that of emanometry but the contrast between the anomalous and background regions is much greater on the former. Another track detector (CA 80-15) was also tested (McCorkell, Porritt and Brameld above). The same profile was found with it, but tracks in it are less easily counted. The sealed collector and the total alpha methods, whose results are shown in Fig. 2 are discussed below. Collectors (data in McCorkell, Porritt and Brameld) showed the same peaks as emanometry but the sensitivity with the small silver wire collectors used was poor. Flooding of the soil in some parts of this area and shallow overburden in others made emanometry measurements difficult, but track detector measurements were made at all points and collector measurements at enough to define the profile satisfactorily. Other conclusions drawn from this study were that the size of the cups in which the track detectors are buried does not affect the track density found significantly and that a number of track detector-cups buried at a given point give very reproducible track densities. Collectors integrate the radon concentration values over about 3 hours and need not be exposed longer; hence they could be installed and removed in the same day. If they are placed in track detector-type cups they could be used in water logged or shallow overburden, and if they are the 3cm x 5cm size they would give a sensitivity similar to or better than that achieved with emanometry.

Buildings at Elliot Lake, in which possible radon health hazards existed, were also used to test collector methods and to contrast them with filter and emanometry methods. Some of the results were shown above in the forms of C values found with different apparatus and procedures (section 1c). These results and others obtained in measuring radon with collectors in large spaces indicate the great sensitivity achievable with such apparatus, but also indicate the need for more research and development on them and especially on the interpretation of the measurements made with them. Measurement of the working levels present at the time of the collector measurement permitted a calibration factor W (counts per minute per working level) to be calculated. When the 3.5cm x 5.5cm collectors of 125 μm thick Lexan were used it was found that:

(1) A number of these hung in the same room 1 - 10 meters apart and counted at the same time gave, within the uncertainties, the same count rate.

(2) However W varied by much more than the uncertainties both with place and with time. Where the radon levels were near or at those constituting a health hazard (i.e. ~0.02 working levels) W values usually ranged from 130 to 400 counts per minute per working level. However, values of as much as 1000 were sometimes found, especially when the radon levels were lower i.e. ~0.001 working levels.

The ribbon collectors, as expected, had higher activities in given conditions. Where W for the Lexan collectors was 130 - 400 that for the ribbon collector was 1000 - 2000. As for the 3.5cm x 5.5cm Lexan Collectors, their W factors seemed dispropertionately high when the radon levels were considerably lower than the health hazard level,e.g. 40000 when 0.0006 working levels were present.

The variation in the W factor can usually be explained by the fact that it is calculated by comparing two measurements that are not really the same: the activity on a collector is a measure of the radon decay product concentrations in the air throughout a period of about 3 hours before the reading, while that on a filter is a measure of their concentrations in the air during the period of about 5 minutes during which filtration is carried out. In the situations where these measurements were made, the decay product concentrations had probably been changing during the 3 hour period prior to the measurements. From the point of view of radiation monitoring for health purposes, a measurement of working levels which integrates over several hours may be more useful than one which shows the instantaneous value at the time of measurement. However a suitable method of calculating the integrated working level value from the measured activity of the collector still has to be found and the anomalously high activities found on collectors exposed to low radon activities must be explained.

(3) Radon Emanation Rates. These are the rates at which radon is escaping from a solid, designated J (Thompkins and Cheng, 1969) or J_M and J_A:

J_A : emanation rate from the surfaces of solids of effectively infinite thickness for radon diffusion, in Curies cm^{-2} sec^{-1}.

J_M : emanation rate in Curies g^{-1} sec^{-1}, usually measured for powders.

Apparatus and methods available for making these measurements are:

(a) Emanation Chambers. These have volumes of about 4ℓ and have ZnS scintillation cells attached to them (Fig. 4). They are either radon tight or the leakage rate of radon from them is small, constant and known (McCorkell and Brameld, 1980). The sample (a hand specimen of a rock or about 50g of a powder usually) is sealed in one of these and the radon concentration in the chamber measured at intervals thereafter by inserting the scintillation cell into an RE 279 Counter (Fig. 4). This is the most precise and sensitive method of measuring J in use at present. With the present apparatus the detection limits are estimated to be 10^{-19} Ci cm^{-2} sec^{-1} or 5×10^{-19} Ci g^{-1} sec^{-1} with uncertainties of no more than ±10% at most levels. However the apparatus is somewhat large and complex and several days to a week are necessary for a measurement. Such measurements would probably be of most value in theoretical studies, in testing models of radon origin and diffusion in the earth or providing the parameters for such models, in the quantitative evaluation of possible sources of radon in overburden*, bedrock*, mines and mills (Porritt, 1979) and in the evaluation of radon emanation from building and insulating materials as possible health hazards. They could also serve to calibrate or check more rapid, less precise methods of measuring J.

Table I shows some results obtained with emanation chambers which illustrate the uses and value of such measurements. The uncertainties are mean deviations in at least 3, but usually 5-20 measurements. The fact that the same J_M is found for BL-3 regardless of the weight of sample used indicates that radon escapes readily from such powdered samples of such size and hence that J_M is a true measure of the escape rate of radon from the powder grains. This makes it somewhat puzzling that J_M is the same for the hand specimens from Beaverlodge as for powders of these rocks. Evidently these rocks are very porous. This fact helps to explain the observation of Porritt (1979) that the rate of emanation of radon into the Beaverlodge mine is much higher than would be expected from the areas of the walls and the laboratory-measured J_A values of the rocks of which these walls are composed: presumably radon is diffusing into the mine from considerable depths within the walls.

* For example: radon emanation from samples of soil, overburden, boulders from the overburden, or bedrock could be measured to learn if they are possible sources of a radon flux found in the overburden or at the surface.

(b) Track Detector Method. The specimen is placed in a radon-tight container with a track detector (LR2) in the air above it. A measured length of time later the track detector is removed and etched and its track density determined. From its track density, the exposure time and the rate at which radon produces alpha particle tracks in a detector in this container (ρ') J_A or J_M may be calculated. The container could be a bottle such as those of the Richards Glass Company. With this simple apparatus hundreds of measurements could be underway at once and the small size of these containers (0.125 or 0.25ℓ) compared to the emanation chambers (4ℓ) would greatly increase the sensitivity of the measurement.

This method has not been used frequently as yet. It is probable that, after suitable testing and calibration, it could be used for the same types of measurements as emanation chambers. However it is probable that its chief use will be for measuring emanation rates from soil and overburden samples. In geochemical exploration such measurements would serve:

(1) As a type of indirect measurement of Ra. These, in turn would help in locating uranium anomalies.

(2) In helping to interpret other measurements e.g. radon measured in soil gas by emanometry might be from Ra in the soil or might be diffusing from below. The radon emanation rate of the soil itself would permit a decision. If samples from several depths in the soil and overburden have been obtained and radon concentrations measured at these depths (see above, 1b) the source(s) and diffusion of the radon in the overburden could be studied in some detail.

(3) With other measurements (e.g. of uranium concentrations and total alpha activity: see later) in interpreting the history of the deposits and anomalous regions which have been found and the geochemical processes that are or have been active in them. This is discussed in more detail later (Section 4, Total Alpha and Related Methods).

As the track density increases continuously with exposure of the detector, the sensitivity of such a measurement of J as this is, in principle, limited only by the length of time available. The sensitivity achievable in practice has not yet been determined but it, and precision, are probably at least as good as that of emanation chambers. The chief disadvantage of this method relative to that of emanation chambers is that, by exposing a track detector to the radon emanated from a specimen and counting tracks one gets a single measurement of J; by placing a specimen in an emanation chamber one obtains a series of measurements. From the latter both J and its probable uncertainty may be evaluated, common errors in timing or reading count rates may be detected, and suspect values eliminated. In other words, with emanation chambers it is simple to make replicate measurements and to continue them until the results seem satisfactory.

(c) Collector Method. Like (b) but a collector rather than a track detector would be placed in the air above the sample. As the activity on a collector does not increase indefinitely with exposure, this method would be considerably less sensitive than the track detector method. However, like the track detector method, it is rapid and simple and requires only simple apparatus. As the collector would be counted as soon as removed from the bottle this method would be more rapid than the track detector method, and could easily be used in the field. Also, unlike the track detector method, it would permit the detection and measurement of thoron emanation*.

Data obtained in this way are described by McCorkell, Porritt and Brameld (sub. to J.G.E.) and there called "sealed collector measurements". The results obtained for the South March surface and near surface soil samples are contrasted with those of emanometry, and uranium analysis, in Fig. 3. The same anomalies are revealed by the sealed collectors as by the other methods.

(4) Total-Alpha Methods. These methods measure the sum of the concentrations of all alpha-particle-emitting radioisotopes in the sample. They are probably chiefly useful for soils and samples from overburden drilling. In such samples the alpha-emitters would usually be those of the ^{238}U decay chain, ^{238}U, ^{234}U, ^{230}Th ^{226}Ra ^{222}Rn, ^{218}Po, ^{214}Po and ^{210}Po. Total alpha measurements can be calibrated by means of the CANMET standard ore pulps whose concentrations of these isotopes have been measured. However, the state of equilibrium in the ^{238}U decay chain in soil and overburden samples is usually not known and, hence, the makeup of the mixture of alpha-emitting isotopes in such samples is usually unknown and variable. As the different isotopes emit alpha particles of different energies, both the alpha-activity per gram and the counting efficiency of the alpha particles emitted varies with the state of radioactive equilibrium in the uranium decay chain in the sample. Thus total-alpha measurements are usually only relative although, to provide a consistent and convenient system for expressing the results, they are usually expressed in terms of uranium concentrations - as is possible by means of the calibration with CANMET pulps and the assumption that

* The decay products of ^{222}Rn whose decay governs the activity on a collector are 3.05 min ^{218}Po, 26.8 min ^{214}Pb and 19.7 min ^{214}Bi. Hence 10 hours after exposure radon decay product activities on a collector have practically vanished, but any thoron decay products there (10.6^{h} ^{212}Pb and 60.6 min ^{212}Bi) would have decayed only ~50%. The emanation chain method would be free from thoron interference, but would not measure thoron emanation (McCorkell and Brameld, 1980).

the uranium decay chain in the samples is in the same state of (nearly complete) equilibrium as in the pulps.

Two methods are available for total-alpha measurements of samples and standards:

(a) Track Detector Method. Pieces of LR2 are covered with the powders and left for measured lengths of time.

(b) Scintillation Counter Method. The powder is placed in a vial, the lid of which has been replaced with an alpha-particle transmitting film of plastic and this is placed on the scintillation tray in an RE 279 counter. In a twenty minute count the activity in normal soil samples (i.e. that accompanying a few ppm of uranium) is detected.

In both cases the depth of the layer of sample placed on the detector or plastic film-cover of the vial need not be known or uniform as long as it is unbroken and more than about 1 mm thick i.e. of thickness greater than the ranges of the alpha particles. For this reason, samples need not be weighed for total alpha measurements.

(5) Total Alpha and Related Methods: Examples and Interpretations. These measurements can be grouped as follows:

(a) Simple total alpha measurement. A single measurement on each sample using either track detectors or the scintillation counter. At least 24 hours would be allowed to elapse between collecting the sample and making the measurement (see below).

Some results obtained by means of the scintillation counter are shown in Table II. Also shown here are the calibration by means of CANMET pulps (Table II and Fig. 6). The U-concentrations measured by the total alpha counts are contrasted with those measured by fluorimetry (HNO_3 - extracts) and by delayed neutron analysis on the same samples.

Simple total alpha measurements made with track detectors (again on the -80 mesh sieve fraction) were obtained for soils collected along the baseline of the South March grid (Section 2, p. 10, above; McCorkell, Porritt and Brameld, sub. to JGE). In this case [U] values were not calculated, but track densities were plotted, yielding a profile closely matching that obtained by fluorimetric uranium analysis and other methods (Fig. 3).

The total-alpha measurements made with the scintillation counter give [U] values considerably higher than obtained by other methods, both in the data shown in Table II and in other data not shown. In this case, the difference is fairly consistent and, as in the track-detector total alpha measurements (Fig. 3) the anomalies revealed by the total alpha method would

be the same as those revealed by other methods of uranium analysis. The difference between [U] (total alpha) and [U] (fluorimetric) can be explained only by disequilibrium in the ^{238}U chain in the samples*. In this case this disequilibrium has probably been brought about by a well known process: uranium has been oxidized and leached from these samples leaving behind the less soluble uranium decay products, chiefly ^{230}Th. If this is the explanation, the total-alpha [U] values probably indicate the lowest [U] values these samples can have had in the past (i.e. the uranium concentrations of these samples have probably been at least as high as the total alpha measurements indicate at some time in the past: the postulated process could lower the alpha activity but not raise it.). More likely the original [U] values were higher as the decay products have probably decayed somewhat themselves since the U was removed.

However, other ways in which [U] (total alpha) might exceed [U] (fluorimetric) can be imagined. If uranium in the UO_3^{+2} state, is migrating through overburden it could deposit decay products in it. Concentrations greatly exceeding those which the instantaneous uranium concentration would support might result. The migrating U might have its origin in some nearby U mineralization. Some such process may be taking place in the sandstones studied by autoradiography (McCorkell and Dyck EOS 60, 425, 1979 and below). On the other hand, recently deposited uranium (as in a region of low oxidation potential) would not be accompanied by its equilibrium concentration of decay products, and [U] (total alpha) would be found to be smaller than [U] (fluorimetric).

It can be seen from these results and these considerations that an area which is anomalous in the uranium concentrations of its soil or overburden would always be located by total alpha measurements. However, an area anomalous as shown by total alpha measurements might not be shown by uranium analysis; it might be anomalous only in U-decay products. The latter type of anomaly, however, would indicate uranium mineralization in its vicinity; some of the ways in which it could arise from the latter have been mentioned, and others probably exist. Simple total-alpha measurements, may, therefore, detect uranium mineralization that would be missed by uranium analysis of the same samples. They are also simpler and cheaper to carry out, and by using a scintillation counter, they could be made in the field.

* The samples might also be rich in ^{232}Th and its decay products. However, to explain the results this way it would have to be assumed that Th accomapnies U in these samples, as [U] (total-alpha) increases with [U] fluorimetric. This is unlikely: in the oxidizing overburden environment these elements are geochemically dissimilar.

(b) Two total-alpha measurements using the RE-279, one at the time of collection, the other at least 24 hours later. The difference between the first and the second readings would be a measure of the concentration of radon decay products (^{218}Po and ^{214}Po) deposited in the sample material by radon diffusing through it, and hence would provide a collector-type measurement of the radon in the soil gas. The second measurement would be as (a). These measurements, or at least the first, would have to be made in the field, and the apparatus and method could easily be used there. In the usual type of surface - soil survey the sample would be dug from the required depth, quickly shaken or pressed through a coarse-meshed sieve into the vial, a lid with 5 μm Kimfol window (previously prepared in the laboratory or field camp) would be placed on it, and the vial would be placed in the counter. The counting could proceed while the person was going to the next site and preparing the next sample. The samples so collected would be saved, for the second count the next day in camp and for other analyses. Both alpha-measurements would be available to the field crew soon enough to guide it in further exploration.

(c) Combination of measurements of uranium concentration, radon emanation and total-alpha activity. [U] would be determined by the usual fluorimetric or other technique. Radon emanation and total alpha measurements could be carried out by any of the techniques described above. A simple combination (now being tested on the samples of Table II and others from Cluff Lake and Guderham) is to place the soil or overburden sample in a Richards Glass bottle with a track detector buried under it and another in the air above it. Such a procedure would require several days. By using scintillation-total alpha measurements and a collector to measure radon emanation the results could be obtained within 24 hours, but samples with background levels of uranium, would probably show no detectable radon emanation by this technique.

It can be seen that total-alpha measurements on soil and overburden samples would permit the locating of areas anomalous with respect to uranium with a reliability at least equal to that of uranium analysis. If other measurements, some of them as simple as total-alpha measurements, are also made on these samples the histories of the anomalous areas and the geochemical processes involved in their formation and evolution may be elucidated, the manner in which uranium was deposited in the region, or is migrating in it may be learned, and indications of the source of the uranium may be obtained. The migration of uranium into and out of regions studied may be learned by measuring [U] (fluor.) and [U] (total-alpha). Variations in the difference between these two values from point to point in an area studied might be noted (the differences might be plotted on a map) and indicate directions or degrees of U migration, variations in migration with time, or the factors causing or influencing this migration. The measurements, and the apparatus needed for them, are in all cases simple and many can be used in the field.

Total-alpha measurements on soil or overburden samples would indicate if soil gas radon measured in the same soil was being generated by the soil or was diffusing from elsewhere*. In this connection, it has been pointed out that if radon is diffusing from uranium mineralization in bedrock into overlying, U-poor overburden this overburden might acquire a concentration of ^{210}Pb far in excess of that supported by the uranium in it. A measurement of this excess would provide a measurement of the radon flux from the bedrock integrated over approximately 100 years. A soil or overburden sample in which ^{210}Pb had accumulated would be indicated in (c) by low [U] (fluor.) and Rn-emission but high total-alpha activity. The discovery of such overburden would indicate probable U-mineralization in the underlying bedrock. These measurements could be made in the laboratory on samples taken much earlier - unlike methods for measuring soil gas radon.

(6) *Autoradiography.* Specimens to be studied by autoradiography are usually hand specimens of rocks or drill cores. Thin sections are prepared from these, or flat, polished surfaces are made on them, and these are placed on the autoradiograph film for the required length of time. Development of the film then produces a photograph-like image of the specimen surface in which the regions having the greatest concentrations of the radioisotopes (U and/or its decay products usually) have the greatest image intensity. Three types of autoradiographs can be produced:

(a) γ-autoradiographs. Produced by γ rays from the radioisotopes in the specimen. The specimen is placed on X-ray film for about 24 hours and the film then developed. The X-ray film is left in its paper envelope during exposure and consequently α and β particles do not contribute to the image.

(b) α-autoradiographs. Produced by the α particles which, in most specimens, are produced by the isotopes ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Po, and ^{210}Pb of the ^{238}U decay chain. The specimen surface is placed against a sheet of Kodak-Pathé LR 115 Type II for a time varying with the usually - approximately - known uranium concentration of the specimen from about 1 day to two weeks. Etching the LR2 then produces an image of the alpha-emitter-rich regions of the specimens.

* "Elsewhere" would usually be "below", but it is conceivable that radon could be horizontally channeled into a region along permeable layers, faults in bedrock, or in water. Boulders scattered through overburden might also be the source of radon observed in soil gas at the surface.

(c) Fission-Track Autoradiographs. The specimen surface is covered with a sheet of Lexan plastic. Irradiation with thermal neutrons in a nuclear reactor then causes some of the ^{235}U in the specimen to fission* and the fission fragments produced form fission tracks in the Lexan. Etching the Lexan then developes these tracks and produces an image like that on the alpha-autoradiograph.

(7) Calibration and Interpretation of Autoradiographs.

If the ^{238}U decay chain is in the same state of equilibrium in all parts of the specimen, the alpha-track and fission track autoradiographs of the specimen will be the same except, perhaps, for intensity. However, if there has been migration of uranium within the specimen (or migration of its decay products; but uranium is usually the more mobile) some regions may have little uranium but a high concentration of decay products, or vice versa. A region high in U but with a low [decay products] will show up intensely on the fission track autoradiograph but give a faint image on the alpha-autoradiograph. A region high in decay products but having little or no U will produce an intense image on the alpha-autoradiograph, but a faint image or none at all on the fission track autoradiograph (Fig. 7). The degree of such differences, of course, will depend on the degrees to which U and its decay products have separated in the specimen.

The number of fission tracks per unit area at a given point on a fission track autoradiograph is proportional to the concentration of uranium in the portion of the specimen facing the Lexan at that point during the irradiation. On the alpha-autoradiograph the number of tracks per unit area is proportional to the concentration of alpha emitters in the corresponding parts of the specimen. Both relationships can be calibrated so that measurements of track densities can be converted to [U] and [alpha-emitters] values. Fission track autoradiographs are calibrated by irradiating pieces of glass** of known [U] covered with Lexan at the same time that the specimens are irradiated and etching the resulting Lexan overlays of the glass. Counting tracks on these

* Only a small fraction of the ^{235}U in a specimen is destroyed in this process. A specimen could be autoradiographed hundreds of times, as some glasses of known uranium concentrations which serve as standards, are. Also neutron irradiation has no significant effect on the α-activity of specimen after about 1 week of cooling.

** The most convenient standard glasses are those available from the U.S. National Bureau of Standards, Washington, D.C. and numbered SRM 610 - SRM 616

overlays gives the relationship between the track density, ρ, and [U]. Calibration of alpha-autoradiographs is identical with calibration of total-alpha measurements; one must know, or assume, the state of equilibrium in the ^{238}U decay chain in the specimen in order to utilize the calibration obtained by exposing the LR2 film to a material such as the CANMET pulps for known lengths of time. As in the total-alpha measurements, these calibrations yield a relationship between ρ and [U] which applies if the ^{238}U decay chain is in equilibrium.

In alpha and fission-track autoradiography it is possible to find the point on an autoradiograph covered by a particular point of the specimen with great precision. This is done both by fiduciary marks and by outlining the specimen (usually the microscope slide of a thin section) on the autoradiograph film. The x and y coordinates of a point on the specimen can be measured from a fiduciary mark using a graduated mechanical stage and the corresponding point on the autoradiograph(s) found by measuring off the same distances from the same point. The same system can be used to compare track densities at corresponding points on f.t. and α-autoradiographs of the same specimen. Outlining the specimen on film aids in this work and makes comparisons between specimen and autoradiograph with the unaided eye easier.

Comparisons between [U] values obtained by track counting on fission track and alpha-track autoradiographs yields information similar to that obtained by comparison of total alpha and fluorimetric-[U] measurements. However the measurements are made in precisely defined regions of the specimen surface with areas of $\sim 10^{-4} cm^2$ and the migration of uranium between phases can be studied on this scale. Other measurements can be made, as with bulk chemical analysis of separated phases, microprobe traces across the specimen surface for major element concentrations, optical mineralogical identification of the phases in thin sections, etc., and compared with the patterns of [U] and [U-decay products] found. Often, of course, all that is needed is a naked-eye comparison of the thin section of the specimen and its autoradiograph to locate the phases which contain the uranium, which are then studied microscopically. A more detailed study was reported by McCorkell and Dyck (EOS 60, 425, 1979). In this case it was found that, in the light gray and yellow coloured parts of the sandstones studied, the concentrations of uranium calculated from alpha-track densities were about twice those found in the same areas from fission track densities. The small, dark coloured reduction centres scattered through these rocks often contained up to 0.1% uranium and in them others have found that the uranium is not accompanied by its equilibrium concentrations of decay products. The fission track-measured uranium concentrations are, of course, correct: where the alpha-track-measured values differ from them they indicate disequilibrium in the uranium decay chain. The light parts of the rock, therefore, contain about twice the concentration of decay products that would be maintained by the uranium there, while other evidence indicates that uranium is being, or has recently been, added to the darkest parts - presumably by reduction and precipitation by the organic matter there. Two possible explanations for this situation is possible: either

uranium is being mobilized in the light coloured parts, by oxidizing conditions and ground water there, and is diffusing from these parts into the dark centres leaving its less soluble decay products behind, or uranium is diffusing through the rock from other sources (perhaps nearby mineralization). In the latter case some of the uranium would be precipitated in the dark centres, and the much less soluble uranium decay products ^{230}Th and ^{236}Ra, would be left in the light parts from which uranium would be largely removed.

The microscopic locating of points and counting of tracks for such studies as this is tedious, although the outlining of the slide and the use of fiduciary marks facilitates it. Much more rapid and complete studies of this sort are possible by the "large print" technique. The autoradiographs may be treated as photographic negatives and prints prepared from them which greatly facilitate naked-eye comparisons between the autoradiographs and the specimens. If the prints are made with the correct enlargement and contrast the images of individual tracks can be seen and counted on them (Fig. 8 and Fig. 9). By counting the number of track images per unit area at different points on such prints, and comparing this with the number per unit area found on the autoradiograph of a standard of known [U] or [alpha emitter] the prints may be converted to maps of uranium or alpha-emitters-concentrations. This technique has not yet been developed in all its details but it appears quite feasible for alpha-autoradiographs. If a print to the same scale is prepared of the specimen - which would usually be a thin section - the map prepared on the autoradiograph print could easily be transferred to this. The method may not be so simply applied to fission track autoradiographs as fission tracks in Lexan are smaller than alpha tracks in LR2, contrast less with their surroundings, and are consequently more difficult to reproduce on prints.

As indicated, thin sections on microscope slides are the most useful forms for specimens to be prepared in for autoradiography. Soils and other powdered samples could be studied by autoradiography by spreading them in balsam on a slide and grinding this to thin section thickness. This would be a means, not only of identifying the uranium - bearing phases in the soil but of deciding if the uranium and/or decay products is within these grains or in a coatings on their surfaces.

Little has been said above about γ - autoradiographs, and they have been little used here. γ-rays penetrate much greater thicknesses of matter than do alpha particles and fission fragments, and, unlike the latter, they do not have fixed ranges; their flux from a given source is attenuated by matter, but never, theoretically, reduced to zero. The alpha particles and fission fragments which produce autoradiographs come from depths of no more than $20_{\mu}m$ beneath the surfaces of the specimens; γ-rays come from greater, and less well-defined depths. γ-autoradiographs therefore are less sharp and finely detailed and may show features which are not at the surface (Fig. 7). The degree of darkening of the film is proportional to the concentration of the radioisotopes at the corresponding point in the specimen. However to measure this darkening and to calibrate this relationship would be more difficult and less precise than to do the equivalent for fission track or alpha-autoradiographs.

(8) Radon and Radium Determination.

Radon in an aqueous solution may be measured by circulating the air of the scintillation cell of an RE 279 through the solution repeatedly using rubber tubing, a peristaltic pump and a drying tube (to remove water vapor from the air entering the cell). In the arrangements used here for this work, all of the radon in the solution does not enter the cell but attempts are made to ensure that the fraction which enters the cell is constant and reproducible. When this is so, the procedure may be calibrated with solutions of known radon concentration. To do this the volumes of all the parts of the apparatus are kept the same, the length of time and rate at which the air is circulated are always the same, and, for reasons mentioned in (1), the counting is always done for the same length of time and after the same interval, if any, after the circulation of the air.

Radium is determined by the radon it produces:

$$Ra \xrightarrow[1600y]{\alpha} {}^{222}Rn \xrightarrow[3.825d]{\alpha} {}^{218}Po$$

$$\lambda = 0.0075\ h^{-1}$$

If radium only is to be determined and the sample is aqueous, air is bubbled through the solution to drive off any radon already present and the sample is then sealed in a radon-tight container for a measured length of time. When greater sensitivity is desired, the sample may first be concentrated by evaporation. After sealing, the radon concentration increases with time. Its concentration is related to that of the parent radium by the relationship:

$$\frac{[Ra]}{[Rn]} = \frac{1}{1 - e^{-\lambda t}}$$

where λ = the decay constant of $^{222}Rn \equiv 0.0075\ h^{-1}$

t = length of time from sealing the sample to making the measurement of Rn (in hours if λ is in h^{-1})

After a measured length of time the radon is measured by circulating the air of a scintillation cell through the solution as described, and the measured $[Rn]$ is corrected by the above factor to obtain $[Ra]$.

Radium in solid samples is determined by dissolving weighed samples and treating the solution as above.

An aqueous sample may contain "unsupported" radon. This is radon which has diffused into the water (from soil, sediment or rocks with which the water existed) and is not being produced by radium in the water. If this is to be determined accurately the sample must be sealed in a radon-tight container as soon as it is taken, and the sampling time recorded. As soon as possible thereafter, the air of an RE 279 cell is circulated through it, and [Rn] measured. However this measurement does not indicate if the radon measured is supported, unsupported or partly supported by radium in the water. To complete the determination, the concentration of radium in the solution must be determined as above. The difference between the concentration of radon found in the first measurement and that which the radium present (if any) would have supported is the concentration of unsupported radon present in the solution at the time of measurement. This must be corrected for radioactive decay between the sampling time and the measuring time:

$$[Rn]_{\text{sampling time}} = \frac{Rn \text{ Measuring Time}}{e^{-\lambda t}}$$

where t = the length of time from sampling to measuring.

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SYMBOLS AND TERMS

c Counting rate of a radiation counter in counts per minute (c.p.m.) above the background count rate (B.G.).

C The calibration factor, relating c to the radon concentration being measured: c.p.m. per pCi of radon per liter.

LR2 The nuclear particle track detector LR 115 Type II cellulose nitrate manufactured by the Kodak - Pathé Company.

pCi Picocurie, a unit of radioactivity. 1 pCi = 2.22 disintegrations per minute (dpm) of a radioisotope.

R Radon concentration, pCi ℓ^{-1}

W The calibration factor relating c to the working level concentration of radon decay products, c.p.m. per working level.

ρ Track density, that is, the number of etchable nuclear particle tracks per unit area on a track detector. Here these are usually alpha particle tracks in cellulose nitrate.

ρ' Track production rate per unit of concentration of the track producing isotope, e.g., tracks per cm^2 per hour per pCi of Rn per liter.

Working Level A unit of concentration of radon decay products in air: see bottom, page 9.

[symbol of element or isotope] The concentration of the element or isotope whose symbol is enclosed. The units vary but are usually pCi per gram, pCi per liter or parts per million (ppm).

TABLE I

TABLE 1. Radon emanation rates for wall rocks and ores from the Beaverlodge Mine (as hand specimens and as powders), building materials, and CANMET standard ore pulps, measured with emanation chambers.

J_A = Curies $cm^{-2}sec^{-1}$

J_M = " g^{-1} " "

Hand specimens weighed 200 - 800g, powders, unless otherwise stated, 50g. Uncertainties are mean deviations.

Specimen or Pulp No.	Uranium (ppm)	Radon Emanation Rate $X10^{18}$			
		Hand Specimens and Pulps		Powders (J_M)	
		J_A	J_M	20-60 Mesh Fraction	<20 Mesh
BV 1	30	0.61 ± 0.12	0.286 ± 0.056	4.01 ± 0.26	4.87 ± 1.34
BV 2	2800	12.8 ± 1.2	6.31 ± 0.59	12.6 ± 2.4	10.5 ± 3.1
BV 3	1800	19.5 ± 1.4	6.12 ± 0.44	31.1 ± 0.5	29.5 ± 5.1
Bv 4	5700	120 ± 7	70.8 ± 4.1	62.4 ± 4.0	58.1 ± 11.9
BL-1 20g	220		12.3 ± 0.8		
BL-3 5g	10200		116 ± 5		
10g	"		116 ± 3		
20g	"		119 ± 6		
BL-4 20g	1740		52.9 ± 7.1		
ATHABASKA SANDSTONE		2.72 ± 0.31			
CONCRETE		0.30 ± 0.07			
* GYPSUM BOARD		<0.05			
(GYPROC		0.09 ± 0.027			
** (GYPROC FIREGUARD		0.056 ± 0.038			
(TUROC		0.096 ± 0.041			

* From an Ottawa lumber yard. No brand name.

** Samples of gypsum wallboards used in Uranium City, Saskatchewan from W. Whitehead, Atomic Energy Control Board, Ottawa.

TABLE II

Scintillation - Total Alpha Measurements
for Overburden Samples from Cluff Lake,
Minus 80 Sieve Fractions
from Various Depths

SAMPLE NO.	URANIUM CONCENTRATION (ppm)		
	FLUOR	DNA	Total - x
CLN 1A	1.5	2.1	15.7
2A	2.3	3.3	6.1
3	12.5	13.1	16.6
3A	5.6	5.9	15.7
3B	3.5	3.6	14.8
4A	6.2	7.7	9.6
4B	146.0	146.0	82.0
4C	30.0	27.5	INSUFF. SAMPLE
5A	7.4	8.0	17.5
5B	28.0	22.4	28.8
5C	53.0	53.7	129.1
6A	186.0	197.0	486.0
6B[1]	105.0	107.0	128.3
6B[2]	97.0	103.0	INSUFF. SAMPLE
6C	500.0	538.0	710.2
7A	56.0	52.4	INSUFF. SAMPLE
8A	8.7	9.6	42.8
9A	7.1	8.4	16.6
10A	5.6	7.1	20.9
11A	8.8	9.9	INSUFF. SAMPLE
12A	10.4	11.3	28.8
13A	6.2	8.0	44.5
13B	30.0	29.9	75.9
13C	27.0	24.4	16.6
14A	5.7	7.6	21.8
14B	4.5	6.1	INSUFF. SAMPLE
15A	7.9	8.9	22.7
16A	3.4	5.2	41.0
17A	4.1	6.1	11.3
18A	1.6	3.2	10.5
19A	4.1	5.9	61.1
20A	24.0	23.6	28.8
21A	4.5	5.9	24.4
21B	4.7	6.0	14.8
22A	13.1	14.9	33.2
22B	10.6	10.1	18.3
23A	8.0	8.2	19.2
23B	16.0	16.5	29.7

SAMPLE NO.	URANIUM CONCENTRATION (ppm)		
	FLUOR.	DNA	TOTAL - %
24A	25.0	21.8	63.7
24B	30.0	30.2	34.0
25A	26.0	28.1	INSUFF. SAMPLE
26A	5.3	6.8	14.8
27A	36.0	42.4	115.2

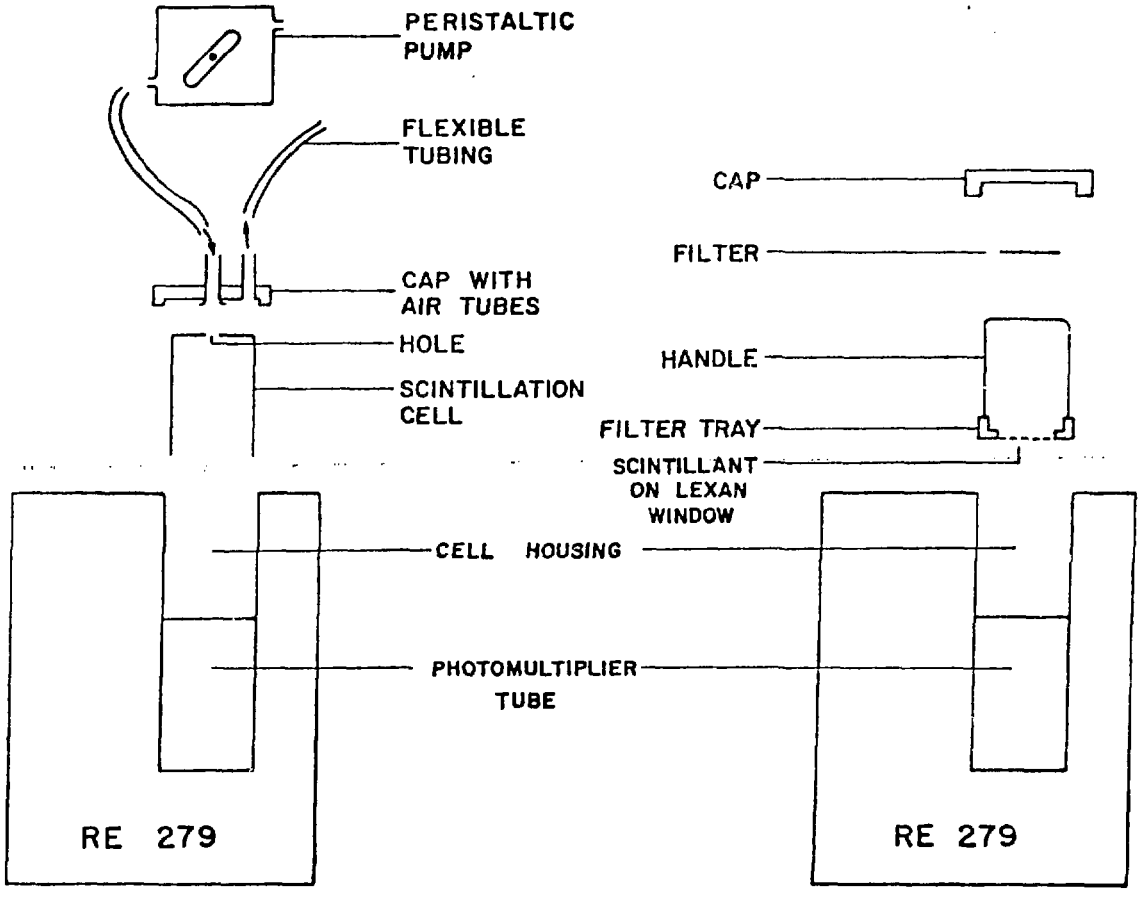


FIG. 1 RE-279 emanometer and

left: apparatus for measuring radon in air by pumping air into ZnS-lined scintillation cell.

right: apparatus for measuring alpha-activity on filter through which radon-containing air has been pumped.

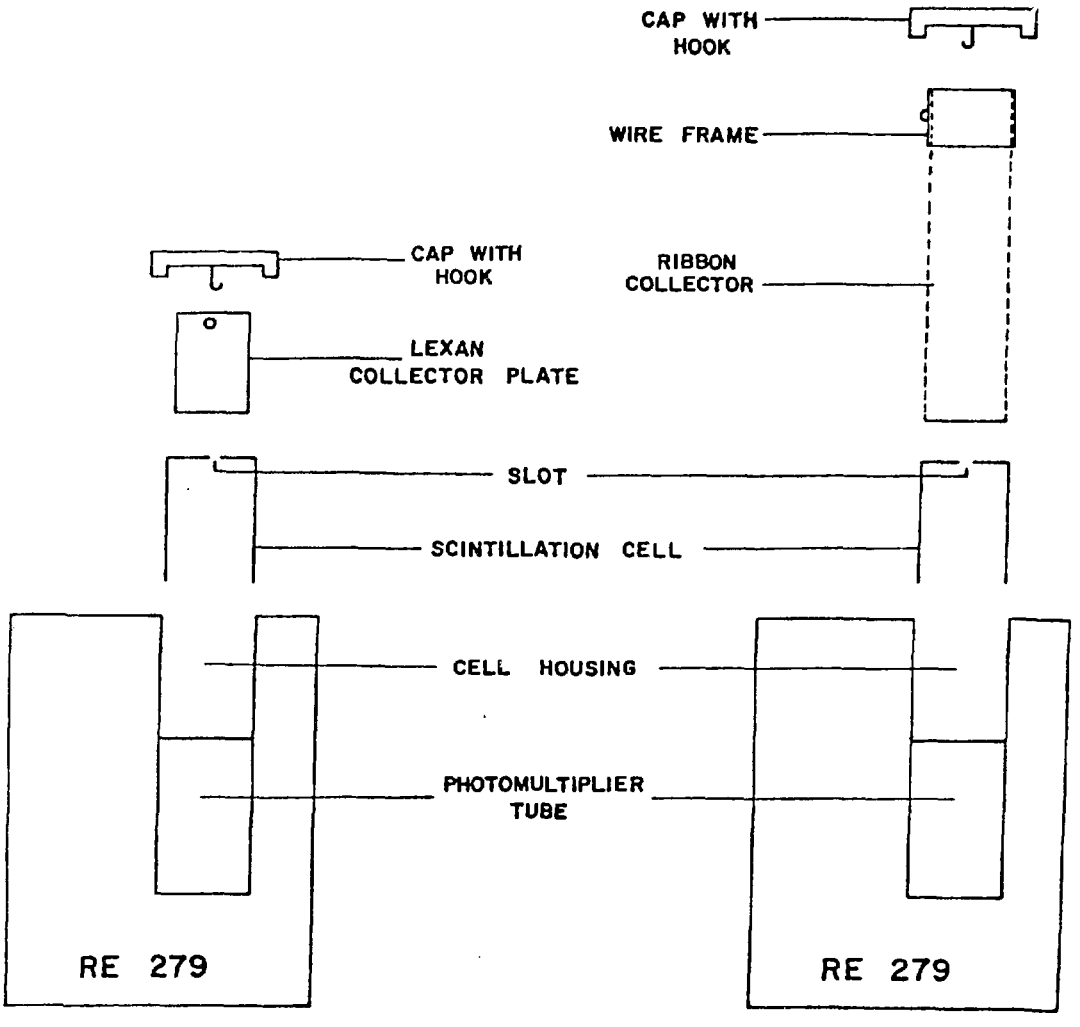


FIG. 2. RE 279 emanometer and apparatus for measuring radon-decay-product-activities on 3X5 cm Lexan (left) and ribbon (right) collectors. Collectors are exposed to radon-containing air and later hung in the scintillation cell for counting.

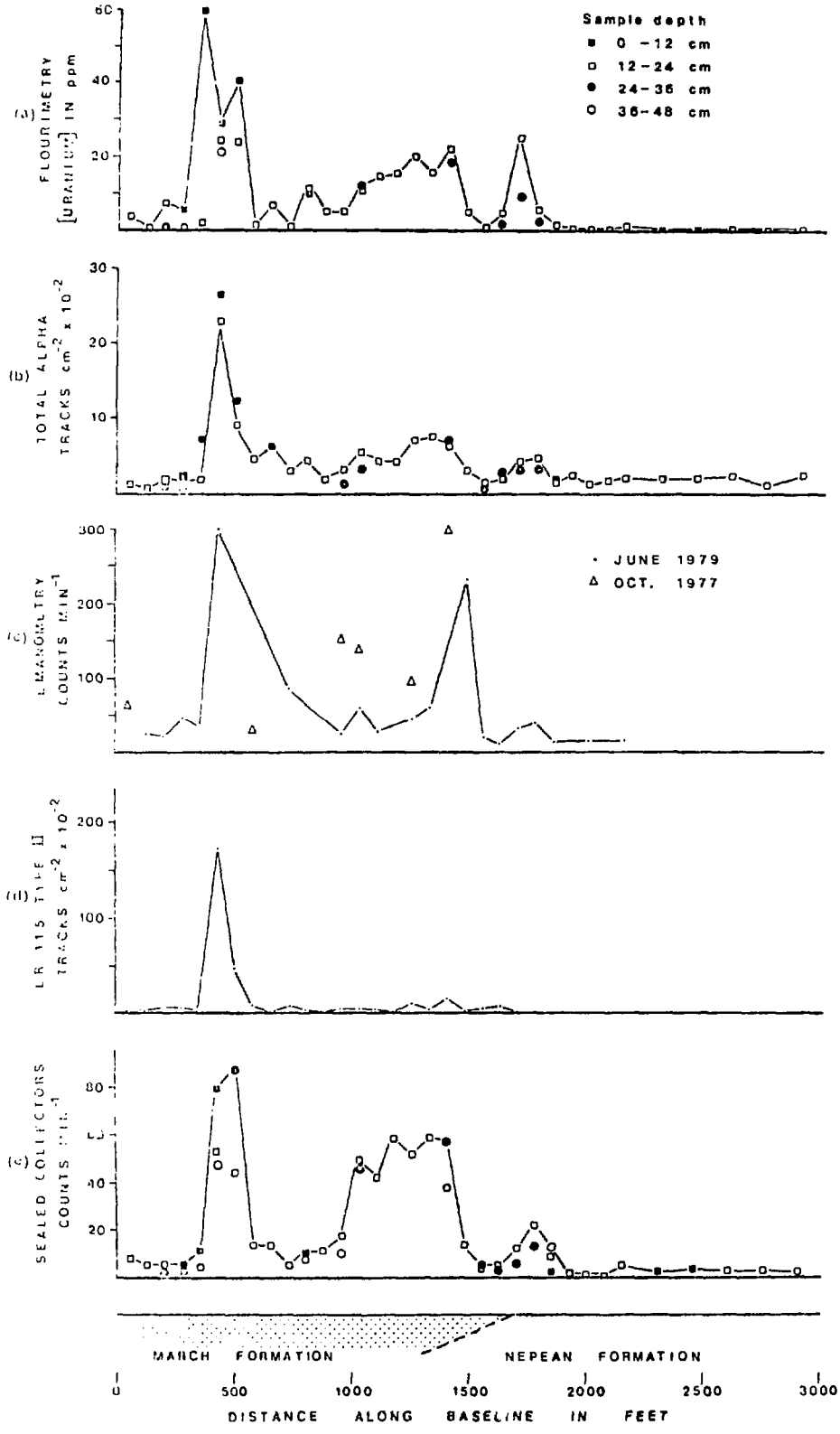


FIG. 3. Profiles along the baseline on the South March uranium occurrence. These were obtained in the different ways indicated, but all show the areas anomalous in uranium.

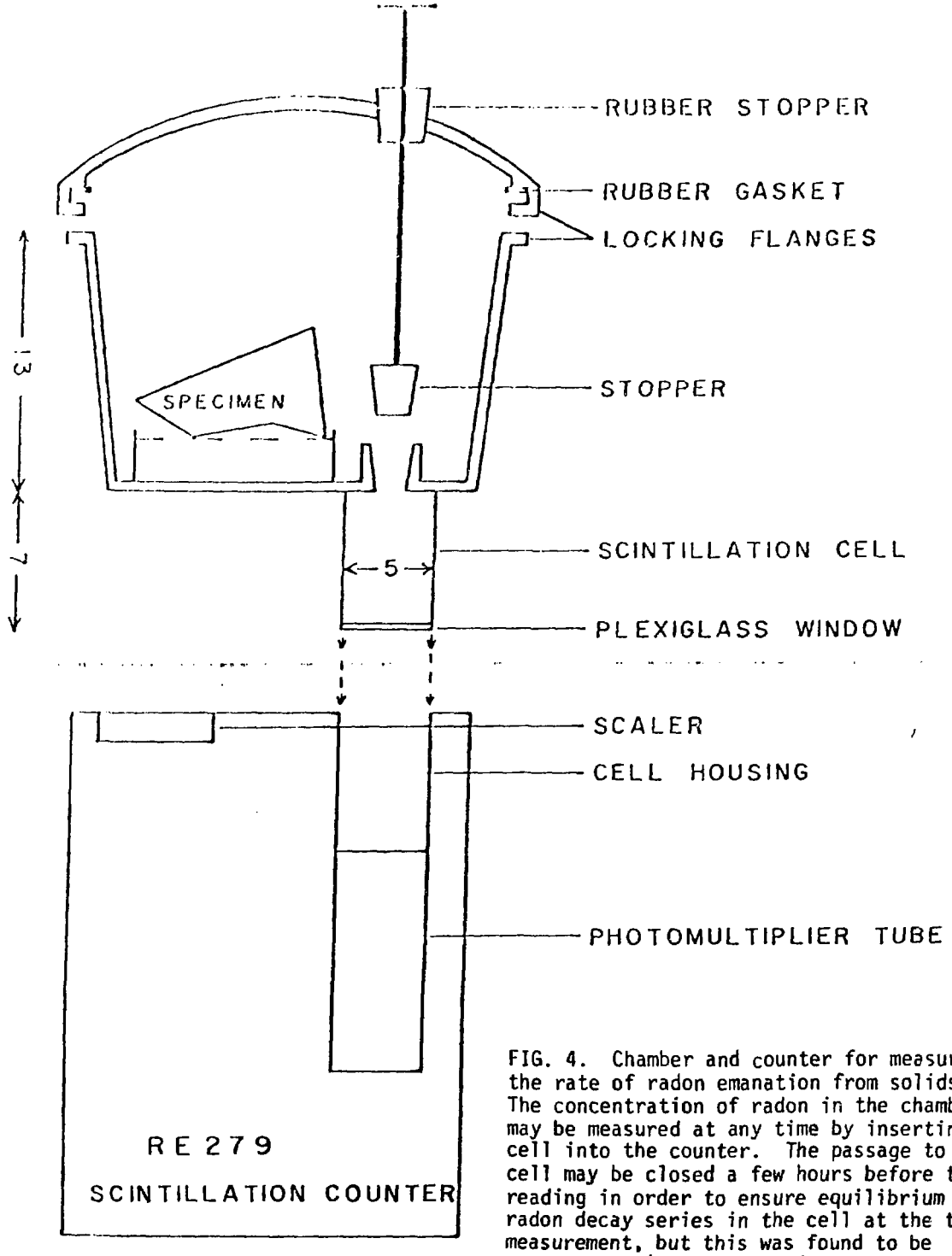


FIG. 4. Chamber and counter for measuring the rate of radon emanation from solids. The concentration of radon in the chamber may be measured at any time by inserting the cell into the counter. The passage to the cell may be closed a few hours before the reading in order to ensure equilibrium in the radon decay series in the cell at the time of measurement, but this was found to be unnecessary (McCorkell and Brameld, 1980).

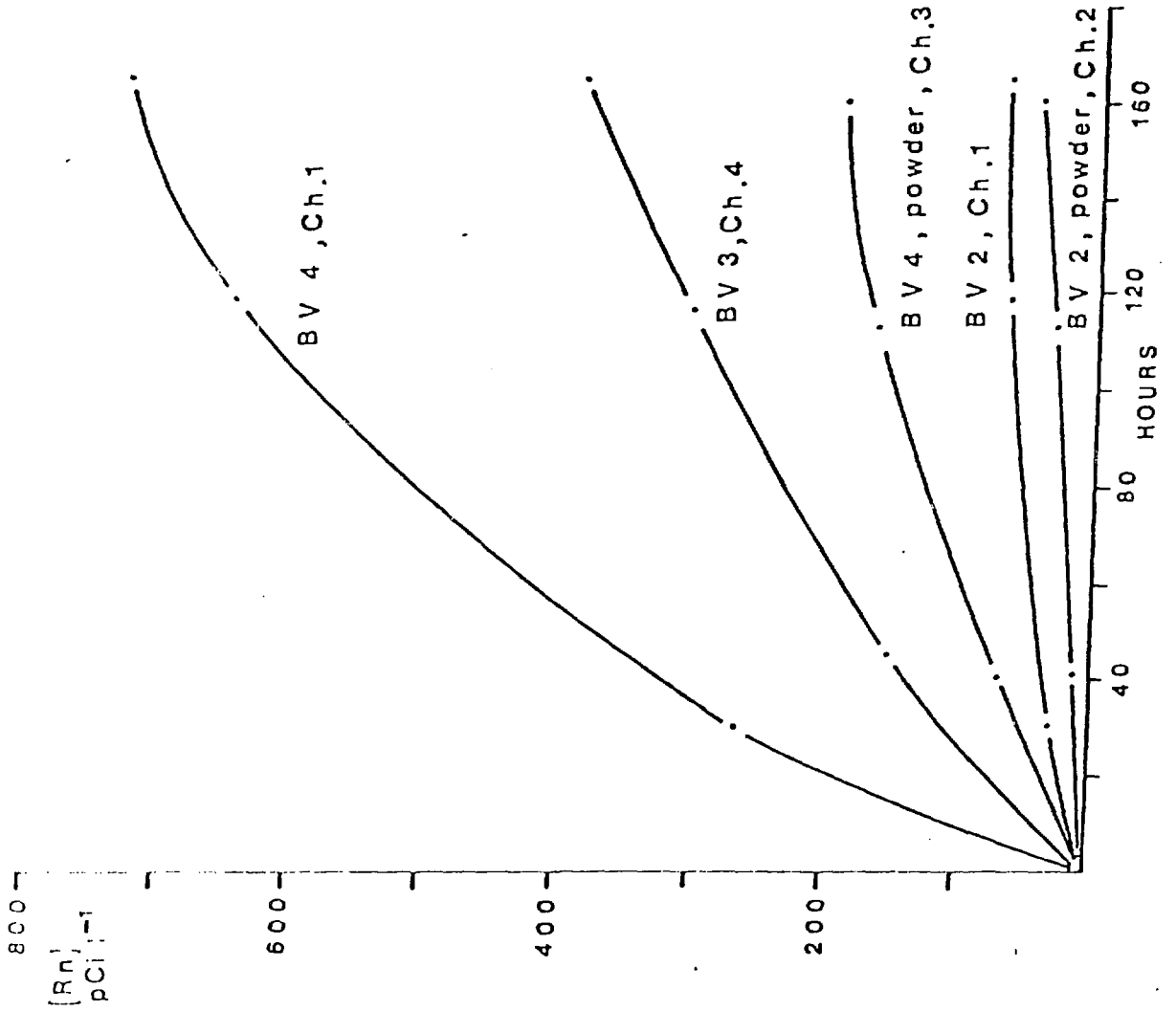


FIG. 5. Examples of the growth of radon concentration with time in emanation chambers such as shown in Fig. 4.

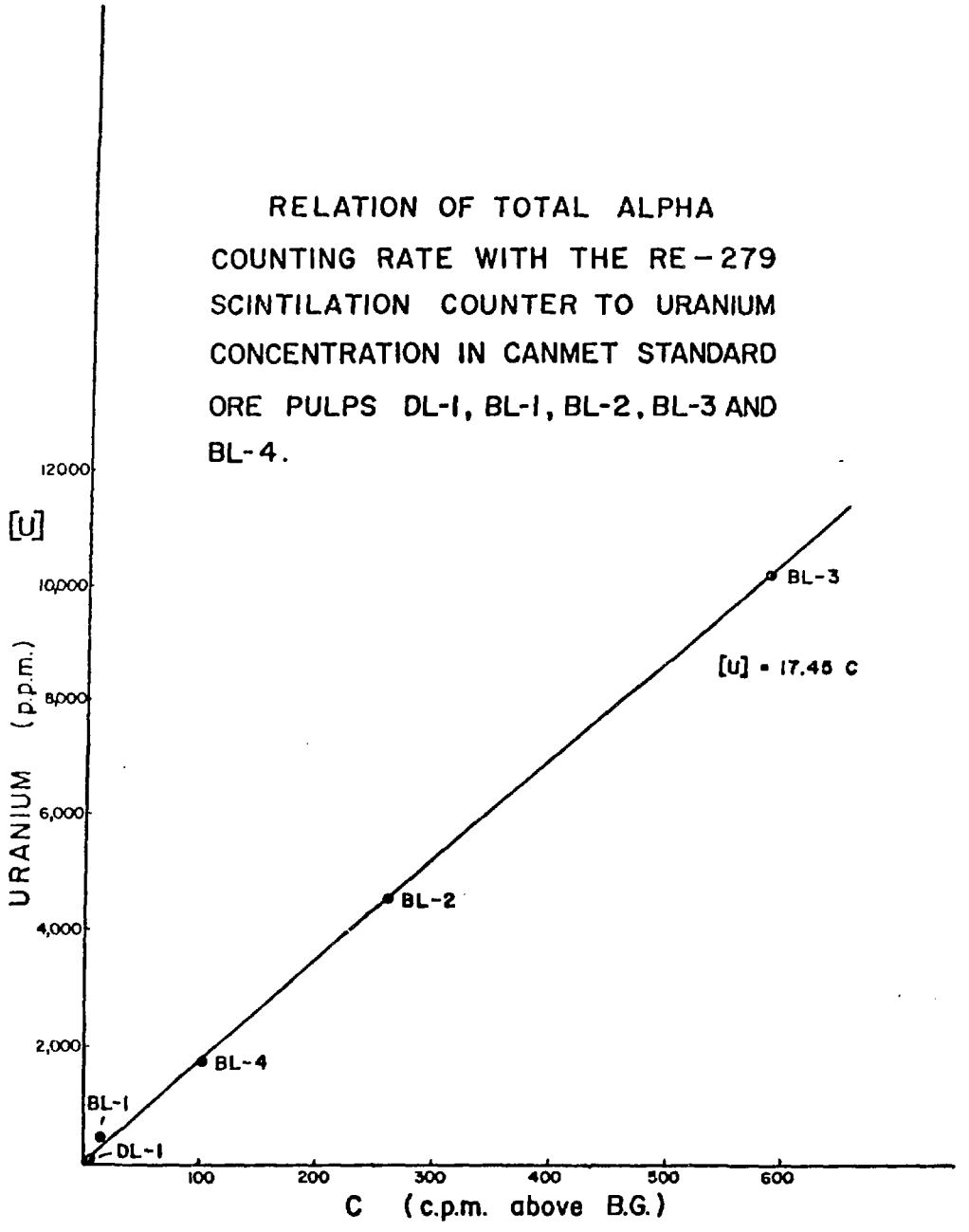
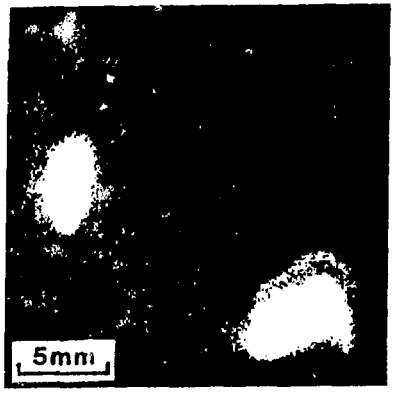


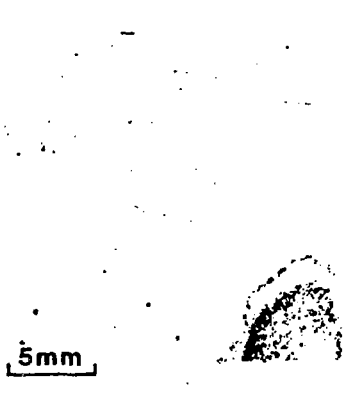
FIG. 6. Calibration of the scintillation - total-alpha method by means of CANMET standard ore pulps.

FIG. 7

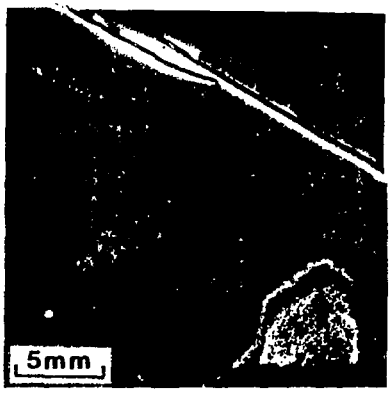
COMPARATIVE AUTORADIOGRAPHS



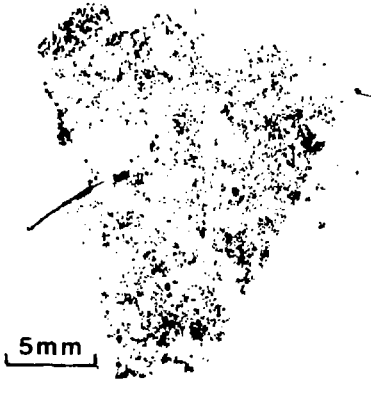
Gamma-radiograph of a sample showing 2 gamma emitting radioactive sources



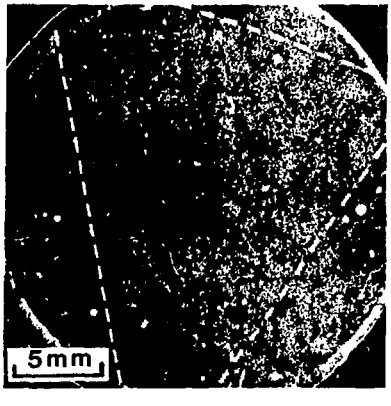
Alpha-radiograph of the same sample with a very well defined alpha-particle source shown in the lower right corner. The upper left source seen in figure 1 does not register on the alpha radiograph since it is beyond the alpha-particle range in rock.



Fission-track-radiograph of the same sample showing a high resolution pattern similar to figure 2.



Alpha-radiograph of a weathered sample showing an alpha-particle track pattern from residual uranium decay products



Fission-track-radiograph of the same weathered sample showing very weak uranium concentrations suggesting that the more mobile uranium has been leached out leaving its less mobile alpha-emitting decay products

ROCK SAMPLES FOR AUTORADIOGRAPHY USED WITH KIND PERMISSION OF W. DYCE (CGS)

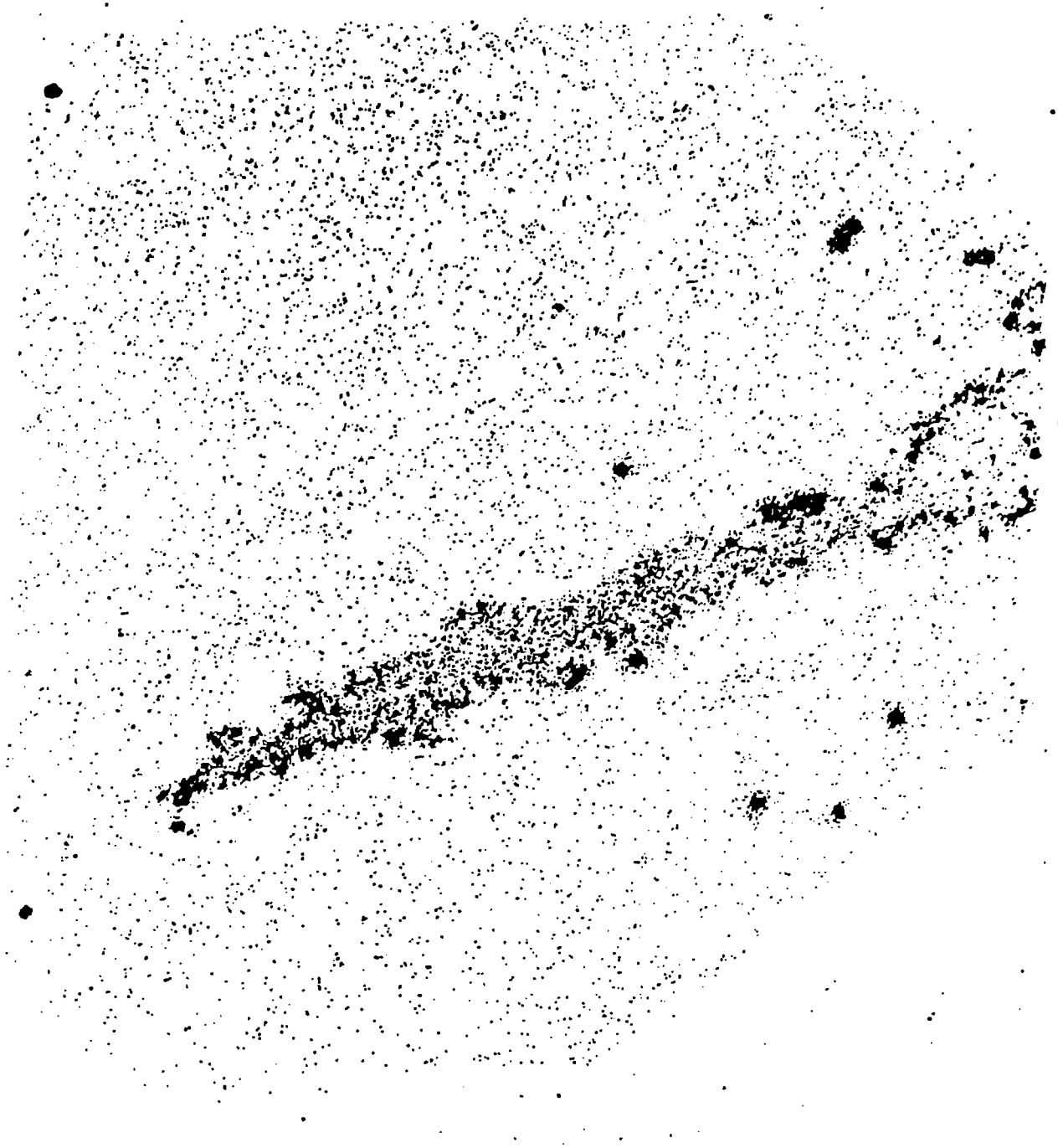


FIG. 8. Large print of an alpha-autoradiograph of a uranium-rich reduction centre in a sandstone. The print shows individual alpha-particle tracks.

FIG. 9 Large print of an alpha-autoradiograph of a uranium-rich reduction centre in a sandstone. The print shows individual alpha-particle tracks.

CONTENTS

Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

CANALPH-3
A PORTABLE ALPHA SPECTROMETER FOR RADIATION DOSIMETRY IN MINES AND HOMES

D.W. Carson
Chemical Laboratory

March 1980

(For presentation at the workshop on radon and radon daughters in urban communities associated with uranium mining and processing, Port Hope, Ontario, March 12-13-14, 1980.)

Project MRP-4.3.6.0.01
Underground Environment

MINERALS RESEARCH PROGRAM
MINERAL SCIENCES LABORATORIES
REPORT MRP/MSL 80-38 (OP)

CANALPH-3
A PORTABLE ALPHA SPECTROMETER FOR RADIATION DOSIMETRY IN MINES AND HOMES

D.W. Carson*

ABSTRACT

CANALPH-3 is a portable alpha spectrometer used in measuring the daughter products of radon and thoron to determine the health risk to personnel both underground in a mine environment and also in homes. This instrument developed at CANMET should become the standard instrument for determining the working level of both radon and thoron daughters in mines in Canada or beyond.

The instrument is described along with a discussion of the counting procedures for determining the working levels of radon and thoron.

The spectrometer, containing the latest microprocessor technology, will be produced commercially by Pylon Electronic Development Co. Ltd. of Ottawa, to be used throughout Canada and the world by mine personnel and scientists interested in the radiation field.

A previous report (1) describes the apparatus in detail.

[1] Carson, D.W. "A portable three-channel alpha spectrometer for measuring the daughter products of radon and thoron"; Division Report MRP/MSL 79-108 (TR); CANMET, Energy, Mines and Resources Canada; 1979.

*Electronic Technologist, Radiation and Mineral Physics Section, Chemical Laboratory, Mineral Sciences Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

PYLON INSTRUMENTS
Ottawa Canada

Pylon WL-1000 Working Level Meter

PYLON ELECTRONIC DEVELOPMENT company, ltd.
2011 Enterprise Avenue, Ottawa, Canada K2G 0A6 Tel: 613-226-1280, Telex PYLON OTT 053-4961

Pylon WL-1000 Working Level Meter

* A direct reading instrument for the quantitative determination of airborne radon and thoron daughters and working levels

- A portable, rugged, microprocessor based three channel α spectrometer
- Direct reading radon/thoron working levels
- Direct reading RaA, RaB, RaC, ThB, ThC concentrations
- Modified Kusnetz and α spectroscopic analysis
- Keyboard operation
- Fully automatic sampling, counting and calculation sequences
- Complete in-unit analysis of data
- An improved filter holder and detector geometry
- Large sample volume (80L @ 8L/min)
- Built-in charger/overnite charging

The WL-1000 working level meter determines radon and thoron working levels and daughter concentrations by both a modified Kusnetz and an α spectrometric method.

Sampling, counting and calculations are microprocessor controlled and access to results or input of program parameters such as counting efficiency is via a keyboard.

The large sample volume taken (80L), and the improved filter-detector geometry optimize the instrument's sensitivity and accuracy. The reliability of results is rechecked by the dual method of data analysis.

For ease of operation in difficult environments, the filters have been mounted in plastic holders and the sampling, counting and calculation sequences are automatic.

The pump is highly efficient and a large number of samples are possible before battery discharge. Overnite charging is possible and a charger is internally mounted.

Specifications

Sampling/Detector Head

• Mode of Operation	Automatic or manual sampling/counting sequence
• Sample Volume	0 to 80 L with 8L/minute pump
• Pump Flow Time	8 hours at 8L/minute between charging/overnite charging
• Batteries	Gel Cell/rechargeable
• Filters	0.8 μ Millipore sealed in individual plastic holder for handling simplicity
• Detector	457.3 mm^2 diffused junction silicon solid state detector; resolution better than 60 KeV for 5.47 MeV alpha
• Counting Efficiency	30 - 40%
• Mode of Calibration	Pylon Radon Daughter Standard

Electronics/Data Processing

- All solid state CMOS electronics, microprocessor controlled, fully automatic sampling, counting, calculation sequences
- Keyboard control/data input/output

Counting System

- Three channel discrimination RaA, RaC, ThC
- Variable count periods (programmable)
- Counts/channel $100 \times 10^6 - 1$
- Display LED

Calculations

- Calculations available/modified Kusnetz for WL Rn/WL Th; α-spectroscopic for WL Rn/WL Th and RaA, RaB, RaC, ThB, ThC concentrations/atoms/liter

Programmable Features

- Counting efficiency, sample volume, count periods
- Visual display of programming sequence

Output Features

- Keyboard control of output
- Led; display of daughter concentrations (Atoms/L), WL Rn/Th display counts (per counting period)

Optional Equipment

Type 102	Transit Case
Type 190	Radon Daughter Standard
Type 241-A	Am-241 Calibration Standard
Type 592-P	Glass Fiber Filters (0.8 μ)
Type 593-P	Millipore Filters (0.8 μ)

Other Pylon Products

RM-1003 Radon Detector
Type 109 Vacuum Scintillation Cell
Type 110 Vacuum Scintillation Cell
Type 300 Vacuum Scintillation Cell
RD-500 Air Sampling System
Type 1150 Radon Counter Calibration Standard
Type RN-1025-5 In-Line Source, Rn 222
Type TH-1025-5 In-Line Source, Rn 220
Type 150 Calibrated Radon Gas Source

Write For Additional Information

Pylon WL-1000 Working Level Meter

Questions/Comments:

W. Nazaroff : Is all the activity deposited on the filter?

G. Vandrish : It is deposited in proportion to the surface area.

W. Nazaroff: : Have you actually measured this property?

G. Vandrish : Yes

P. Pullen : With regard to practical application of this instrument underground, am I correct in assuming that for a 70 min. cycle to count both radon and thoron daughters, you can only get one sample, that is 4 or 5 samples per shift?

G. Vandrish : Yes, the limiting factor is thoron analysis. One could possibly use a multiple detector head to obtain more than one reading over a shorter time period.

A. Scott : Why is it that even with spectroscopy, no one seems to suggest a counting regime that can give estimated working levels faster than the Rolle method. With spectroscopy you can, in fact, take a sample, count immediately, estimate the working level, then count immediately following the sample. If you have three channel spectroscopy, you can also count thorium C' and estimate the thorium WL. If you modify the instrument so it is like the James and Strong instrument you can count at the time of sampling and immediately have an estimate of WL and thoron and radium A following the sample. Of course, you sacrifice some accuracy but the accuracy overall is more important than the accuracy of individual measurements.

L. Haywood : One should be careful in considering all methods of measurement, even the traditional ones. Most methods are based on mathematics where the assumptions are that the radon effectively exists in a vacuum, that the daughters are born in a vacuum and that there is nothing interfering or uncertain. There are mathematical relationships between each of the daughters and others of the radon. In reality, both free and attached daughters

exist. The relationship between the daughters and radon is further influenced by the condition of the air, and is of a very complex mathematical nature. We are merely using an idealistic method in any event for determining the working level by measurements of various kinds.

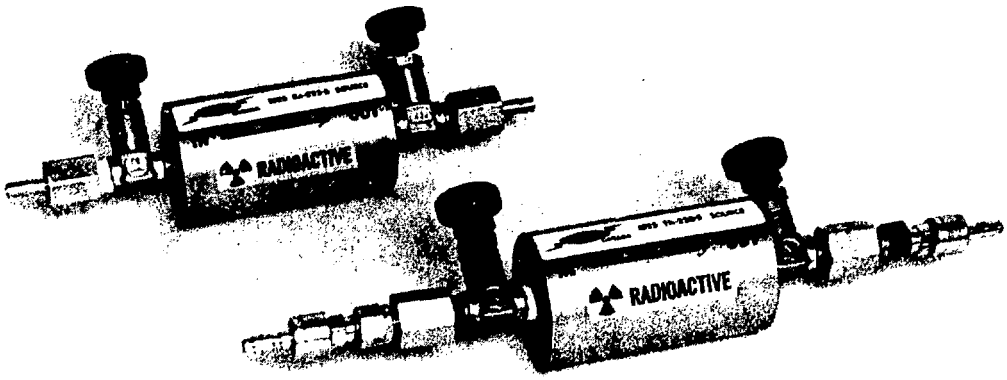
R. Washington : When you use the single measurement technique of alpha spectroscopy, you measure only the instantaneous amount of RaA. RaC' is removed before RaB which is the main contributor to the working level. At least two measurements with two alpha channels are required to solve the three equations for RaA, RaB and RaC.

A. Scott : That is only if you wish to measure the WL but if you wish to estimate the WL it is sufficient to measure RaC'. The Rolle method measures the RaC' and it is a satisfactory method for estimating WL. You can actually calculate an assumption on the ratio of the equilibrium with Ra, RaB and RaC the same as you have to do in the Kusnetz method. If you are prepared to accept a simplification for making estimates of the ratio of the daughters, you can have a genuinely instant working level meter. If you have spectroscopy to measure the concentrations of RaA and RaC' you can estimate the RaB concentration by assuming that it is the geometric mean of the two. While this admittedly would not be exact, you could have a meter that would give you instant estimated working levels with accuracy approximating that afforded by most of the present methods for estimating working levels based on gross alpha counts.

PYLON INSTRUMENTS
Ottawa Canada

1025
Radon–Thoron
Calibrated Gas Source

- An accessory for Radon and Thoron analysis



Pylon Type 1025 Flow Through Radon and Thoron Gas Sources

Applications:
- Environmental studies and research
- Uranium exploration
- Calibration of Radon & Thoron instrumentation

Featuring:
- Simple operation
- Reproducible results
- Certified against NBS standards

The Pylon Type 1025 In-Line generator and standard is a dry flow through source which provides calibrated quantities of radon or thoron gas for continuous or intermittent application.

The source was especially designed for use in conjunction with environmental chambers and for the calibration of radon and thoron instrumentation.

This series of Pylon radiation sources are designed for field or laboratory application. Since a dry radiation source is used there is no danger of spillage as with liquid standards.

PYLON ELECTRONIC DEVELOPMENT company, ltd.
2011 Enterprise Avenue, Ottawa, Canada K2G 0A6 Tel: 613-226-1280, Telex PYLON OTT 053-4961

PYLON TYPE 1025 FLOW THROUGH RADON AND THORON GAS SOURCE

Specifications for Radon Rn-222 or Thoron Th-220 Gas Source

Source Strength	5 μCi
Radon Continuously Available	100 pCi./Min/Litre Minimum
Thoron	.5 μCi/Min/Litre Minimum
Flow Rate	0 – 5 L/min
Precision (Traceable to NBS Standards)	± 4%
Gamma Field at Contact	50 uR/Hr

	Source Parameters (Rn-222)	Source Emanation Rate
Temperature	-30°C – +50°C	100%
Pressure	0 – 3 atmospheres	100%
Humidity	0 – 100% RH	100%
Time		Independent

Ordering Information	Part No.
Radon Rn222 Gas Source	Rn-1025-5
Thoron Rn220 Gas Source	Th-1025-5

Dimensions 9 cm L x 5 cm D
Weight 0.5 Kg

Other Pylon Products

Type 1150 Calibration Standard (Rn222)
Type 150 Calibrated Radon Gas Source (Rn 222)
Type 106 Scintillation Cell (Soil)
Type 109 Vacuum Scintillation Cell
Type 110 Vacuum Scintillation Cell
Type 300 Vacuum Scintillation Cell
RM-1003 Radon Detector
RM-1000 Radon Monitor Counter
WG-1001 Vacuum Water Degassing System

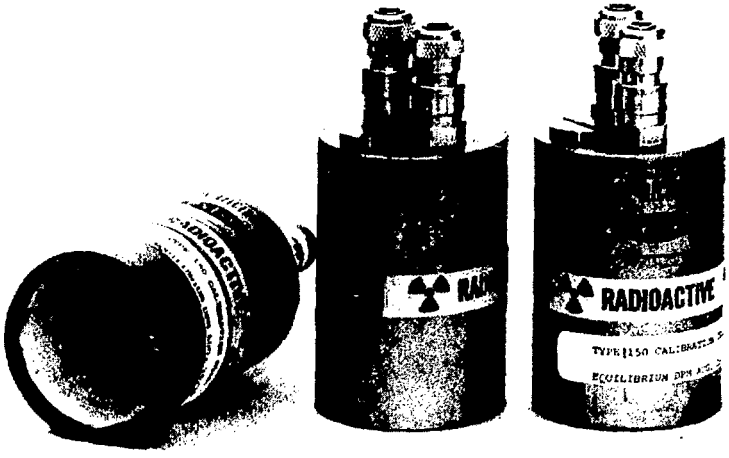
Additional information supplied on request.

Distributed by:

PYLON INSTRUMENTS
Ottawa Canada

1150
Calibration Standard

- An accessory for the Radon Gas Detector



Pylon Type 1150 Calibration Standard (Radon Gas Rn222)

- Reference source for calibration of Radon Detectors
- Measurements are accurate to within 2%
- Certified against NBS Standards

For the quantitative determination of radon gas in soils, water and sediments, radon gas detectors require calibration. Counting efficiencies must be frequently monitored to assess any changes in system parameters, otherwise field survey results may not be directly comparable.

The Pylon Type 1150 Calibration Standard (Rn222) is especially designed for the calibration of radon gas detectors, and will provide a reference radiation source with a certified number of disintegrations per minute of radon gas.

The 1150 calibration standard is composed of a radiation source sealed within a scintillation cell. The counting efficiency of the radon detector is easily determined by counting the 1150 calibration standard activity and comparing the results with the certified D.P.M.

20H Enterprise Avenue, Ottawa, Canada K2G 0A6 Tel: 613-226-1280, Telex PYLON OTT 053-4961

PYLON TYPE 1150 CALIBRATION STANDARD, RADON RN222

Specifications

Total Radium Content	300 - 500 ± 5 pCi
Total Radon Content	300 - 500 ± 5 pCi
System DPM	1500 - 3400 ± 30 dpm
Observed CPM (.740 Counting Efficiency)	2110 ± 30 cpm (example)
Cell Dimensions	5.9 cm Dia x 8.6 cm L
Cell Coating	Activated ZnS (Ag)

Source operating characteristics

		Count rate
Temperature	-30° — +50°C	100%
Pressure	76 ± 8 cm Hg	100% (System sealed)
Humidity	0—100%	100% (System sealed)
Time	Correction Half-Life Pb 210 - 22 years	100% (+ Small Half-Life Correction)

Other Pylon Products

Type 150 Calibrated Radon Gas Source (Rn222)
RM-1003 Radon Detector
RM-1000 Radon Monitor Counter
WG-1001 Vacuum Water Degassing System
154 Vacuum Soil Probe
RM-115 Aluminum Transit Case
RM-117 Leather Carrying Case (RM-1003)
106 Scintillation Cell (Soil)
109 Vacuum Scintillation Cell
110 Vacuum Scintillation Cell
300 Vacuum Scintillation Cell

Write for Additional Information

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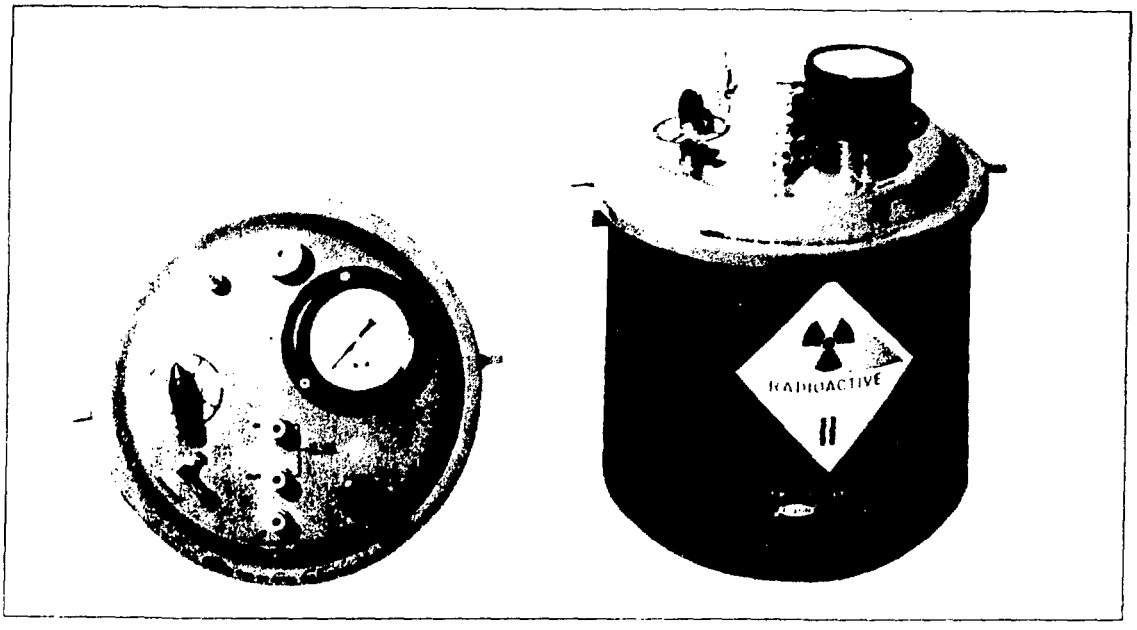
150
Radon Gas Source

- An accessory for the Radon Gas Analysis



Pylon Type 150 Calibrated Radon Gas Source (Rn222)

- Calibrations are accurate to 4%, certified against NBS Standards
- Two independent radon gas sources in one
- Designed for the calibration of radon counters and scintillation cells
- An in-line source for environmental studies of radon daughters
- Dispenses a calibrated amount of gas with minimum variation between gas samples
- Many samples per day are possible because of large supply of Radon gas
- Simple, rapid operation requiring minimal operator skill
- Sturdy and portable for field work with no danger of spillage or breakage (no liquids used)

Originally developed to meet the special requirements of the Atomic Energy Control Board of Canada, it is now commercially available.

PYLON ELECTRONIC DEVELOPMENT company, ltd.

20H Enterprise Avenue, Ottawa, Canada K2G 0A6 Tel: 613-226-1280, Telex PYLON OTT 053-4961

PYLON TYPE 150 CALIBRATED RADON GAS SOURCE (Rn222)

The type 150 Radon Gas System contains two independently operable calibrated radon gas sources - A and B.

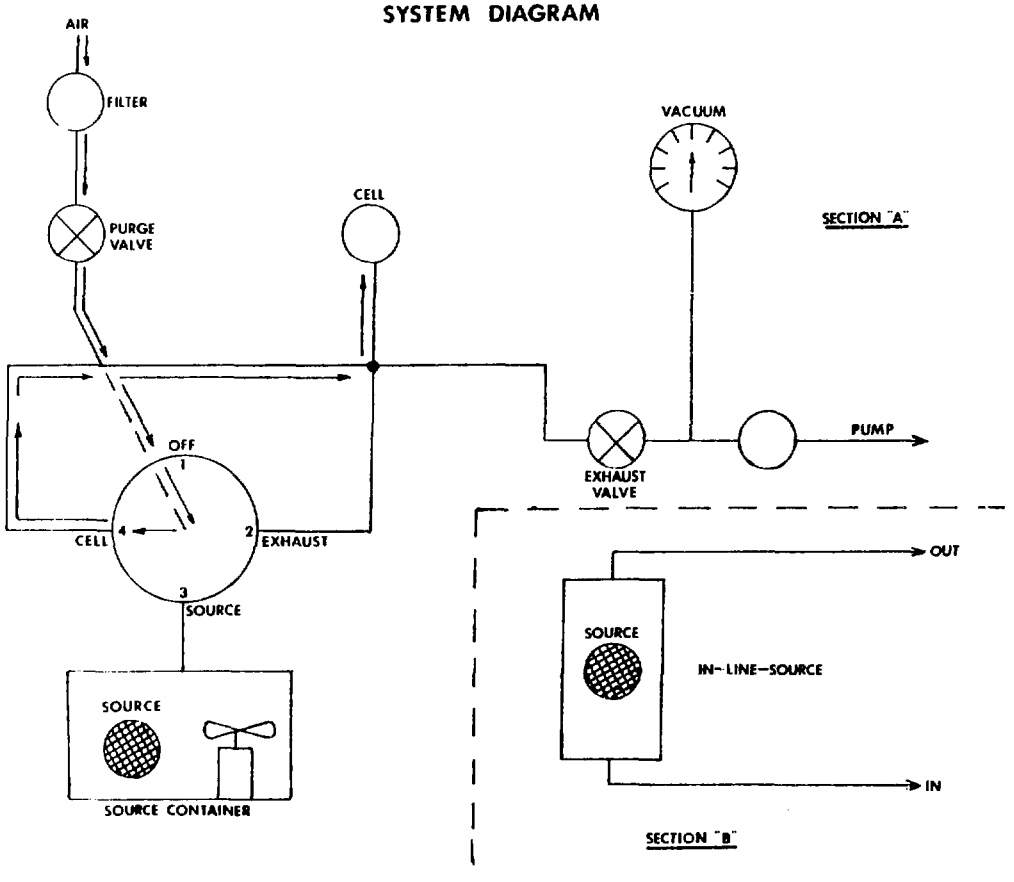
Section A is for calibration of Radon Detectors and scintillation cells. The calibrated radon gas system consists of a large volume source and a small volume gas dispenser. The radon gas available is constant under normal conditions of temperature, pressure and humidity with a calibration accuracy of 4%.

For the calibration of flow through monitors where a precise quantity of radon gas or radon daughters must be continuously available, section B of the system is equipped with an independent in-line radon gas source. This source is completely independent of the scintillation cell calibration system and the two may be operated simultaneously.

The in-line source was especially designed for use in conjunction with environmental chambers, flow through monitors and filter type detector systems.

The Pylon Type 150 system uses dry radon gas sources and can be utilized in both field and laboratory applications.

SYSTEM DIAGRAM



PYLON TYPE 150 CALIBRATED RADON GAS SOURCE (Rn222)

Specifications:

SECTION "A"

for the calibration of Radon Detectors, Scintillation Cells, etc.

Radon content (Rn222)	120,000 ± 1500 pCi nominal
Volume source	18.645 litres
Radon sample dispensed	120.9 ± 1.5 pCi.
Volume dispensed	18.8 cc
Sequential variation in radon between samples	Less than 1% per 10 samples
Max. number of samplings	50 per day
Gamma field at contact	4uR/Hr.
Accuracy of calibration	+4%
Method of calibration	NBS Standards

Source Stability

		Emanation rate
Temperature	-30°C — +50°C	100%
Humidity	0--100% RH	100%;
Time	Independent	100%

SECTION "B"

An in-line radon gas source used for calibration of flow through monitors and filter type radon daughter systems

Total radon continuously available	100 pCi/min/litre
Accuracy of calibration	± 4%

Source Stability

		Emanation rate
Temperature	-30°C — +50°C	100%
Humidity	0—100% RH	100%;
Time	Independent	100%

Dimensions (A + B)	36cmD × 30cmH
Weight (A + B)	2 kg

PYLON TYPE 150 CALIBRATED RADON GAS SOURCE (Rn222)

OPTIONAL EQUIPMENT

Type 119 Aluminium Transit Case

Type 109 Vacuum Scintillation Cell

Type 110 Vacuum Scintillation Cell

Type 300 Vacuum Scintillation Cell

Type 1150 Calibration Standard, Radon Rn222

Type RN-1025-5 in-line Gas Source, Rn222

Type TH-1025-5 in-line Gas Source Rn220

Type 190 Radon Daughter Calibration Standard

OTHER PYLON PRODUCTS

RM-1003 Radon Detector

W6-1001 Vacuum Water Degassing System

Type 154 Vacuum Soil Probe

RD-500 Air Sampling System

Write for additional information

Distributed by:

PYLON

with memory . . . .

U-Rn

Uranium/Radon

- PROSPECTING
- EXPLORATION
- WATER RECONNAISSANCE
- RADIATION PROTECTION

FEATURES

PORTABLE

Alpha Scintillation Counter

Specific For The Daughter of Uranium and Thorium

Measures Radon 220 and Radon 222 Independently

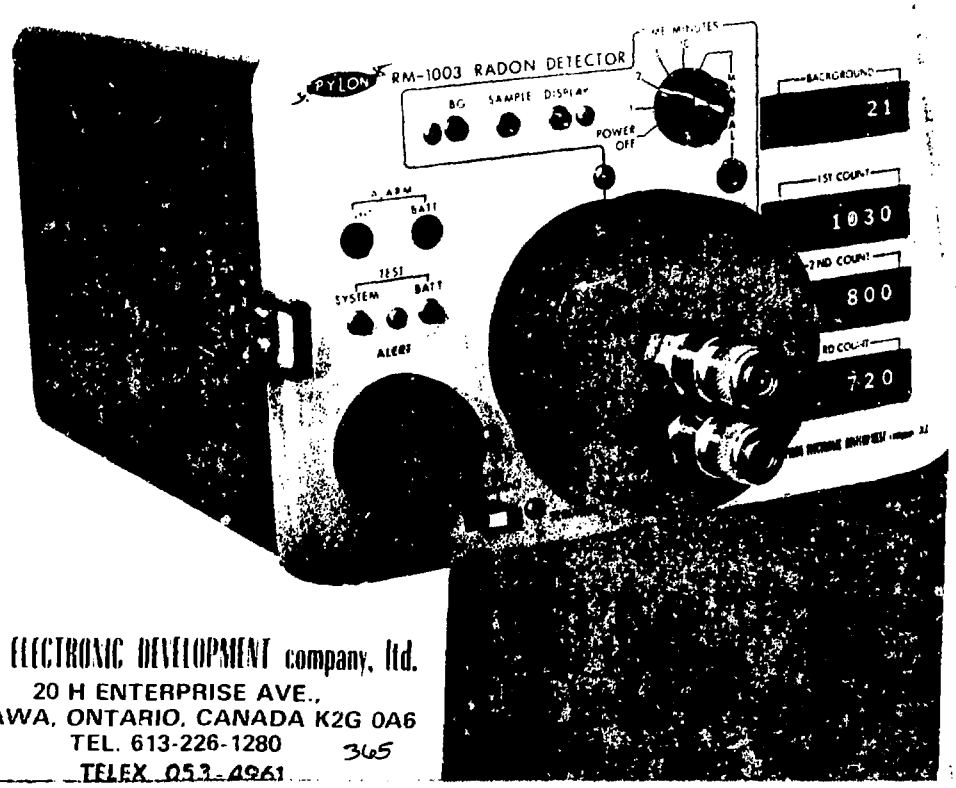
No Interference from Potassium and Cosmic Rays

Pollution and Radiation Protection.

Sensitivity:

Sub-Picocurie Levels of Radon Gas with Counting Time of 10 Minutes

Battery or Mains Operation



PYLON

PYLON ELECTRONIC DEVELOPMENT company, ltd.
20 H ENTERPRISE AVE.,
OTTAWA, ONTARIO, CANADA K2G 0A6
TEL. 613-226-1280
TELEX 053-4961

365

MODEL RM-1003 RADON DETECTOR WITH BUILT-IN MEMORY

The Pylon (R) Model RM-1003 Portable Radon Detector is an alpha scintillation counting instrument of unusual design. It incorporates the latest electronic technology in obtaining automatic readouts for the detection of Radon or Thorium gas.

- **PROSPECTING**
- **EXPLORATION**
- **WATER RECONNAISSANCE**
- **ENVIRONMENTAL STUDIES**

The Model RM-1003 is a highly sensitive instrument which gives accurate and fast results in the detection of Radon gas in:

Air	Soil	Rock
Water	Sediment	Ore
Snow	Organic Matter	

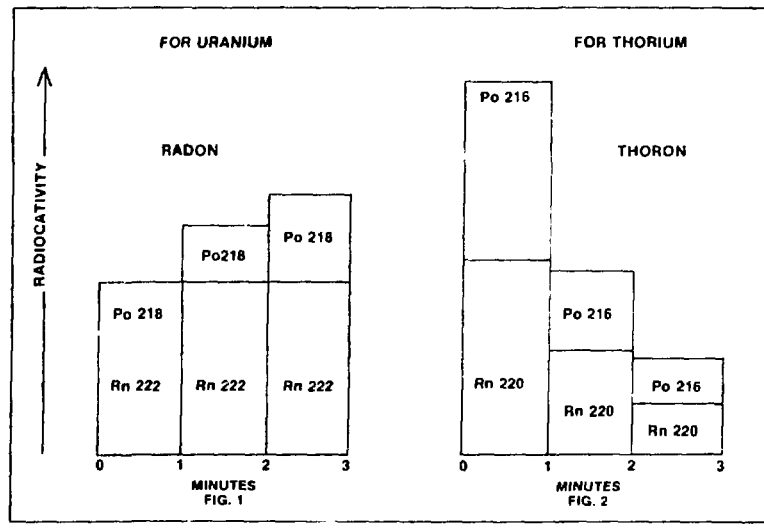
It has been designed specifically to save man hours in actual field operations and prevent errors in transcribing instrument data to a field note book.

URANIUM - THORIUM - RADIUM

Radioactivity from Uranium and Thorium when sampling with the Pylon RM-1003 Radon Detector.

The presence of radioactivity in gas samples is caused by small amounts of Radon and/or Thoron gas along with their solid daughter nuclides (Po 218 and Po 216 respectively).

Radon (Rn 222) evolves only from the Uranium 238 decay process. It has a half life of approximately 3.8 days. Subsequently, when Radon decays, it produces an alpha particle and a daughter Po 218 which also decays with the emission of another alpha particle in approximately three minutes. The result is that there is a growth in alpha radioactivity of Radon gas with time. This is illustrated in Figure 1.



Thoron (Rn 220) is specific to the Thorium decay chain. This gas has a half life of only 55 seconds and breaks down into an alpha particle and the Po 216 daughter. The latter has a half life of approximately 0.2 seconds and is an alpha emitter. In effect this means that there are effectively two alpha particles released at the same time. Hence, in the three minute period, the alpha radioactivity decreased rapidly as shown in Figure 2.

The three consecutive automatic counting cycles on the Pylon RM-1003 enables the operator to see at a glance if the material is Uranium or Thorium derived. If a count level is increasing or level, the ore body will be mainly Uranium. A falling activity indicates Thorium is downcount. Simple formulae can be applied to give more accurate information.

3666

Past experience has shown that during exploration, survey results may be inconclusive if data is recorded incorrectly. With this in mind, a Pylon research team came up with the proposal which led to the development of equipment which would greatly simplify field work and minimize the probability of human error.

The following features are considered essential:

1 Memory storage of background count of the scintillation cell available on demand.
2. Three consecutive radiation count periods, automatically taken and stored in memory for recall on demand.
3 An audible alarm to call the operator's attention to completion of the test cycle.
4 A built-in system test feature to ensure circuitry is performing correctly.
5 Incorporation of a digital voltmeter to monitor battery voltage.
6 Circuit minimization for low battery drain.

Examination of three consecutive count ratios quickly determines if the radiation source is from Uranium of Thorium. The RM-1003 performs all operations automatically. The operator is free to do other tasks away from the instrument.

In order to conserve power the digital display switches off after 5 seconds but the information is stored in the memory. It can be read again by depressing the display button.

The instrument, including long life batteries, weighs less than 4 KG.

Standard Pylon accessories are available for testing air, water, soil or sediment. The equipment is designed to accommodate accessories of other manufacturers and scintillation cells up to 5.85 cm in diameter and 8.90. in length.

MEASUREMENT TECHNIQUE

Soil

Solid measurements are made by punching a small hole in the ground and inserting a sampling probe. If the ground is covered with snow, punch a hole in the snow and sample in the same manner. Air is sucked from the hole and re-circulated via the instrument counting chamber back to the hole. A three minute measurement will normally suffice.

WATER ANALYSIS

Surface water is collected in one litre sample bottles and then "degassed". The resulting air is circulated through the instrument for counting. Providing the water remains liquid, the method is applicable to winter exploration.

The Standard Model RM-1003 Radon Detector is supplied with the necessary apparatus to make soil or water analysis.

STANDARD EQUIPMENT

The Model RM-1003 Radon Detector System is supplied with the following accessories:

Qty 1	Model RM-1003 Radon Detector Unit
Qty 1	Technical Manual
Qty 1	Type 105PT Test Source
Qty 6	No. 106 Scintillation Cell
Qty 6	No. 107 Water-Degassing Bottle
Qty 1	Soil Probe Assembly
Qty 1	Water Degassing Probe Assembly

SPECIFICATIONS

Detector Volume	- 150 c.c.
Scintillation Cell	- Alpha detecting type, 2.3 in. dia. x 3.4 in. long (5.9 x 8.6 cm)
Photomultiplier Tube	- 11 stage, 1.1 in. in diameter
Counter (Scaler)	- Four 4-decade counters, each providing 9,999 counts
Resolution	- Two counts per micro second.
Readout	- Four digital display indicators
Timer Ranges	- 1, 2, 5, 10 minutes and manual control. (other time ranges can be incorporated by simple changes in wiring)
Time Accuracy	- + 0.3%
Audio Alarm	- A panel-mounted speaker gives an audible alarm at the completion of the counting cycle.
Battery Test	- Built-in digital voltmeter
System Test	- Built-in digital simulator
Warning Lamps	- 1) Count condition - 2) Low battery voltage - 3) Photomultiplier tube exposed to light
Safety Features	- Automatic high voltage is switched off if the photomultiplier tube is exposed to light or if the battery - falls below the acceptable minimum for correct operation.
Power Conservation	- To conserve batteries, the digital display switches off automatically after a 5 second display of - counts. It can be read again by depressing a switch.
Operating Controls	- Background/Reset - Sample - Display - Time selector/power switch - Manual stop
Auxiliary Controls	- System Test - Battery Test - Internal/external power selector External power connector
Batteries	- 6 Type "D" battery cells - Mallory MN 1300 (recommended)
Battery Life	- Typical 60 hours at + 20°C (6 hours continuous use every 24 hours)
External Power Supply	- 8-9 volt 300 MA regulated
Ambient Temperature	- -10°C to + 50°C (with a special battery pack can be used down to -40°C
Overall Dimensions	- 14cm x 23cm x 29cm
Weight	- 4kg. including batteries
Carrying Mode	- Shoulder Strap

OPTIONAL EQUIPMENT

Type RM-115 Aluminum Transit Case.
This case is designed specifically for the transportation of Pylon's RM-1003 Radon Detection System. It insures maximum protection from shock, vibration and other hazards encountered in shipping and handling.

Type BP-112 Battery Pack
External battery pack for use when temperatures are below freezing.

Type RM-121 A.C. Power Supply
Portable Power Supply for base station operation or where A.C. mains are available, input 115/230 volts 50-60 HZ Output 9.0 V. 500MA D.C. regulated

Type 109 Vacuum Gas Cell
Complete with Swagelock Type 400-QC01 connector.

Type 110 Vacuum Circulating Gas Cell.
Similar in construction to Type 109 Vacuum Gas Cell but equipped with two Swagelock connectors, used mainly in the detection of air pollution. Room or mine air can be circulated through the Type 110 cell with a manual or power-operated vacuum pump. The alpha particle activity can be counted later using the Pylon RM-1003 Detector.

PYLON ELECTRONIC DEVELOPMENT company, ltd.
20 HENTERPRISE AVE.,
OTTAWA, ONTARIO, CANADA K2G 0A6
TEL. 613-226-1280

TELEX 053-4961

Time Integrating Radon Monitoring Devices

W.R. Thuma, EDA Instruments Inc., Toronto, Canada

Introduction

EDA Instruments has been developing and manufacturing radon and radon daughter detection and monitoring systems for a number of years. Included in these are several which evolved as a result of close co-operation between our staff and various government agencies and other end users.

Instruments such as the RDA-200 for grab sampling of radon and radon daughters, and the compatible RDU-200 for radon and radium measurements on water samples, the RDM-500 microprocessor controlled continuous radon monitor and the RDT-322 Passive Radon Monitor have been discussed before and are in common usage world wide. All have specific applications and each may be custom-tailored to fulfill customer-defined special needs. On-going research and development continually expands on their capabilities.

In mid-1979, EDA recognized through a technical marketing study the increasing need for simple standardized TLD-based monitors for use in and around areas where high levels of radium and its subsequent decay products presented health risks to substantially more people than had been previously recognized. This study revealed not only the design criteria which had to be met in order to satisfy the requirements of industry, government and public awareness groups.

Included in these applications are:

Residential and Industrial Monitoring both inside dwellings and out; and

Perimeter monitoring around known or suspected sources.

The design criteria as is typical for nearly every device such as those required included:

Simple Operation and Maintenance;

Rugged Construction;

Maximized Sensitivity;

The ability to operation unattended for long term monitoring;

Reliable performance;

And low cost.

To fill these demands, our research turned to two devices which were already in use on a limited scale. These devices, refered to in the literature as the "PERM" and "MOD" were designed by a team from the Environmental Measurements Laboratory (formerly Health and Safety Laboratories) of the U.S. Department of Energy in New York. Principle investigators included Andreas George, Al Breslin and Fred Gugginheim who together established the firm data base and designed many of the critical elements of the instruments we now refer to as the RDT-310 Passive Environmental Radon Monitor and the MOD-225 Time Integrating Radon Daughter Monitor.

RDT-310

The first instrument, the RDT-310, operates on the principle of the electrostatic collection of Po^{218} ions on an alpha sensitive TLD chip such as LiF. Decay to Radium "B" imparts alpha energy onto the chip which in affect stores this in a meta stable energy state which is later released as photons of light in a conventional TLD reader. The sensitivity is greatly enhanced by placing the chip at a high negative potential which in this case is 900 Volts. Enclosing a volume of space and creating this strong electrostatic field and desiccating the air diffusing into the space results in a high degree of sensitivity and a lessened variability of response for long term monitoring.

The RDT-310 finds many applications including monitoring programs around old tailings dumps and reclaimed phosphate lands. Also, uses around existing active facilities involved in the mining and processing of uranium, the burning of fossel fuels and storage of resulting low level wastes is increasing.

With these various uses in mind, and the firm design work previously conducted by EML, EDA embarked on what has to be properly called a commercialization of the "PERM". To the original design configuration we added several safety features including an electrical interlock to prevent accidental electrical shock; intrusion resistant components to prevent unauthorized entry which could result in loss of data, and an effective reconfigured rain

shield. Also, the upper desiccant chamber was improved by redesigning the viewing part assembly. The aesthetic appearance was slightly improved to be consistent with our design philosophy and to reduce resistance to emplacement in private homes.

The resulting device (Figure 1) retained all the elements of the original PERM's which are critical to its function. The desiccant bed consists of 1.6 kilograms of low radium indicator grade silica gel to a depth of 50 mm. This upper cannister is detachable and may be heated at 500°C to rejuvinate the silica gel without fear of component failure.

The sensitive volume of 1.5 litres is separated from the desiccant by special perforated brass screens and a Whitman #41 filter; this latter element is intended to prevent the in-flow of radon daughters. The TLD chip holder assembly is unchanged as is the high voltage supply.

The sensitivity of the unit is on the order of 0.03 pCi/l/week using LiF. Other TLD materials including CaF:Dy and $CaSO_4$ may be used. A second control chip is employed to correct for high gamma backgrounds and a third chip may be added for total gamma dose measurements.

MOD-225

The second instrument, designated by EDA as the MOD-225, is also a time integrating device. However, its application is in the collection and measurement of radon daughters, again using TLD's as the detecting mechanism.

The principle is simply to collect on a filter all daughters and airborne particulates over a long period of time to form a representative sample. A TLD chip, again either LiF or any other desired TLD material in chip form, is strategically placed to register the alpha and beta activity resulting from the decay of the collected particulates.

A low flow rate pump is used to draw in these particulates onto the filter, and an appropriate elapsed time indicator logs the time for volume calculations.

Applications for the MOD-225 include residential and industrial monitoring concurrent with or following either grab sampling or integrating passive detectors which have indicated the presence of radon concentrations at levels considered to be potentially hazardous. These may also be used to screen buildings for compliance to existing or projected codes and standards.

Original Design

The original design evolved a special sampling head which accomodated a 17mm 0.8 micron millipore filter 2mm in front of a TLD chip held firmly in place on a silastic pedistal. Air, drawn through three radially oriented ports by a solenoidal diaphragm pump, carried the particulates to the filter barrier. It's flow rate, although variable, was usually set at 100 ml/minute. Special attention was given to sound proofing the entire apparatus to make it more acceptable to building occupants.

In the EDA version (Figure 2), the EML sampling head design was unchanged except for a slight revision to the gamma control chip cavity. This sampling head was determined to be the critical component under our engineering criteria.

The pump however was felt to be too expensive for commercial manufacturing at the quantities forecast and an alternative was sought. Since low flow rate pumps are inherently unstable under filter loading, we devised a means to use an available dual piston pump.

The pump selected operates efficiently under our projected back pressures at a flow rate of 2 l/minutes, much to high for normal long term monitoring. However, by operating it at 2 litres per minute and splitting the in-flow through the sample head and a by-pass filter, we were able to achieve high stability and low flow

rate of 150 ml/minute. As well, we derived two other benefits, one being ease of adjustment from 0-750 ml/minute through the sample head, and the other being that the second filter or the by-pass filter which is proportionally larger than the sample filter, may be used to determine total particulate loading in the area mentioned. Chemical analysis of this collected residue may be of some peripheral importance for the sampling programme.

As with the EML design, an elapsed time meter was incorporated and acoustic baffels were designed into the unit to reduce noise to an acceptable minimum. A stable DC power supply was also added to retain overall flow rate stability.

The MOD-225 achieves sensitivities typically better than 0.005 WL using LiF chips. As with the RDT-310, other chips may be employed.

Both instruments meet the design restrictions mentioned earlier. They are cost effective sensitive instruments especially configured for the task of monitoring radon and radon daughters over long integrating time periods.

In closing I would like only to mention two points, one related to the above and somewhat redundant perhaps and the other not originally scheduled for this presentation. The first is to extend my personal thanks to the people at EML for their cooperation and assistance, and in fact my special thanks to Andy George. Their work provided the very basis for these instruments and we are grateful to have the opportunity of developing on that firm foundation.

The second is that I would like to draw your attention to the GRS-500 gamma ray spectrometer recently introduced by EDA (Figure 3). Although designed for use as a primary tool for uranium exploration, initial tests conducted in Port Hope pinpointed anomalous activity not only in the spots indicated by Roger Eaton (AECB), but also gave high readings at railroad grade crossings. This demonstrated resoundingly the enhanced sensitivity available in this unit. Present plans are to modify this unit to read out in conventional units rather than "cps", and to provide it with as many as 10 separate channels for individual radio isotope identification. In its present configuration however, it is a perfect survey tool to detect and quantify accidentally high concentration of gamma emitting isotopes.

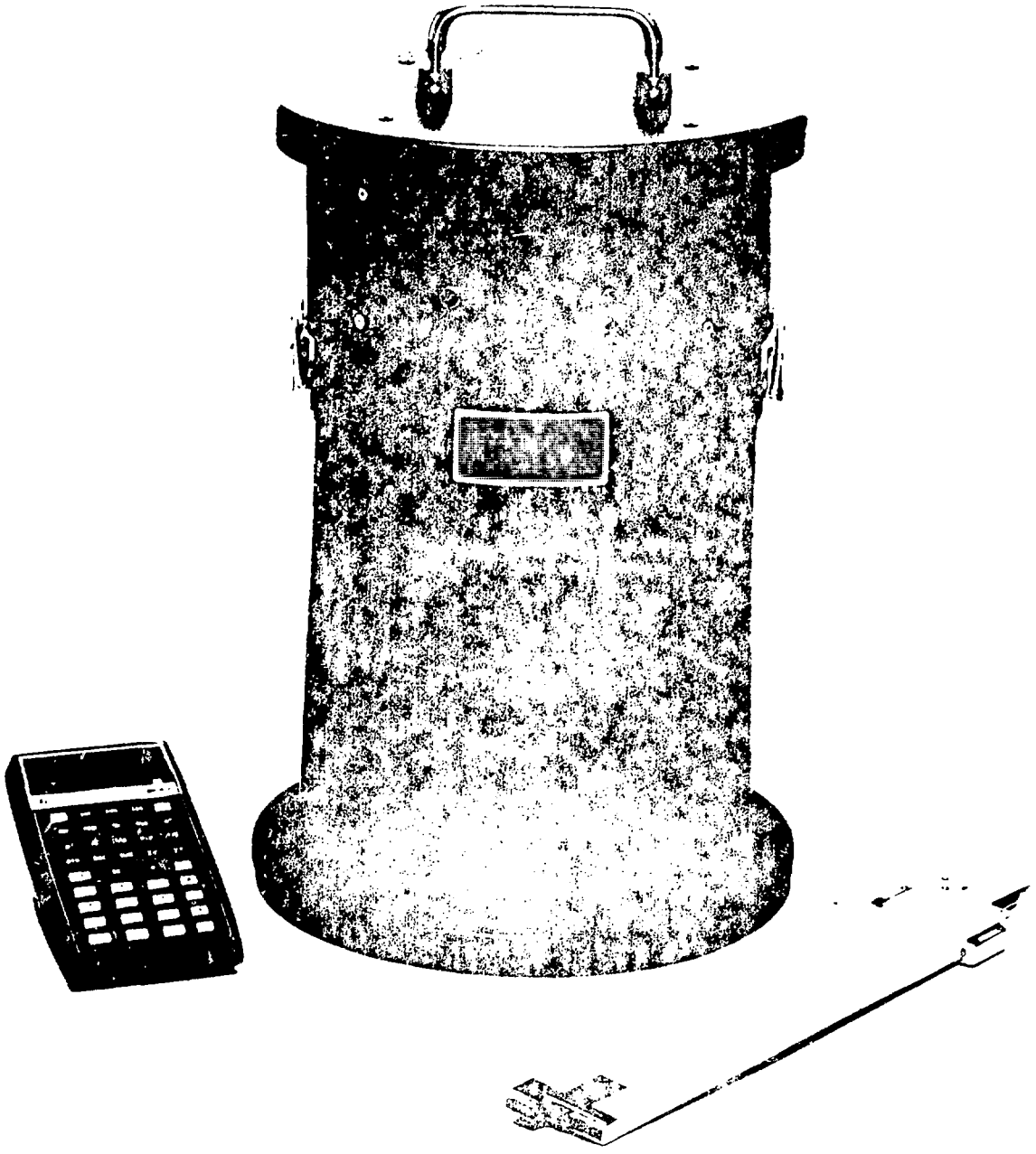


Figure 1

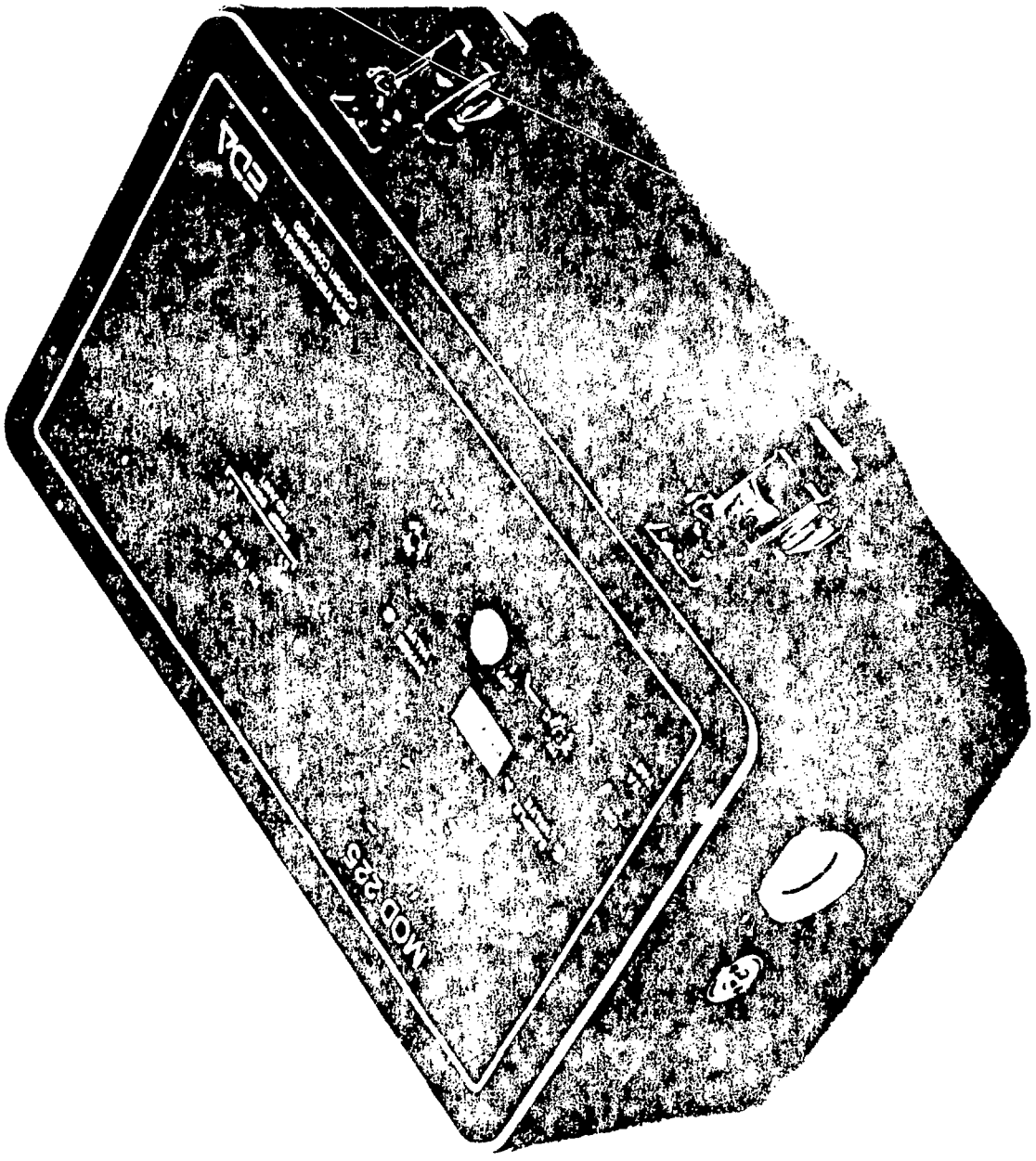


Figure 2

Figure 3

GRS-500 Differential Spectrometer / Scintillometer

EDA

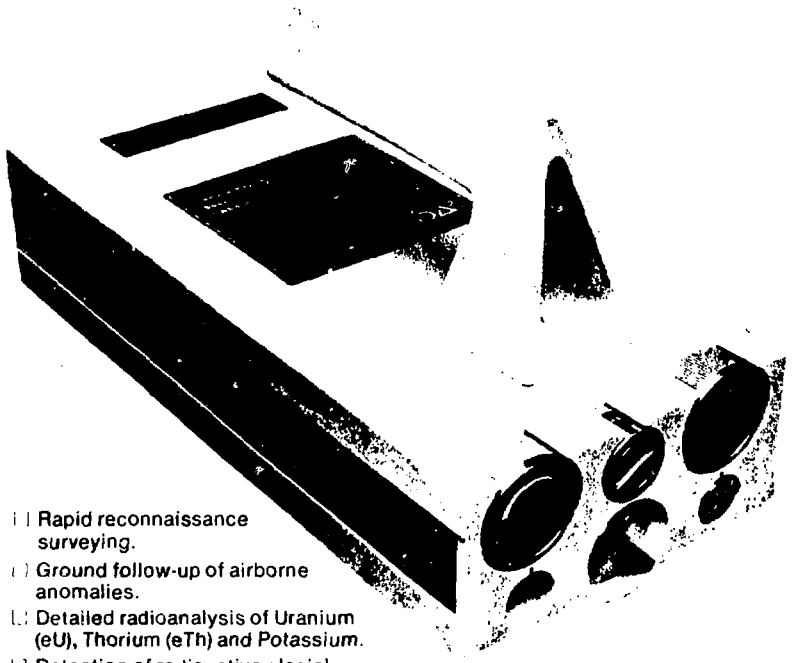
Applications

Effective Uranium exploration programmes require the use of several standard techniques and a variety of specialized tools, the selection of which depend on a number of factors. These include the nature of the target and its surrounding environment, the time and personnel available and the budget restraints.

Central to any programme however are the application of two devices which measure the gamma radiation emitted by various daughter isotopes in the Uranium decay series. The first of these for general reconnaissance is a sensitive scintillometer, or more correctly, a broadband spectrometer. This is a simple instrument which measures total gamma ray activity resulting from the Uranium series, as well as emitters from the naturally occurring Potassium and Thorium. It is an excellent tool for the rapid location of airborne anomalies, detection of local concentrations of radionuclides in outcrop, and the location of finite sources occurring in boulder trains and detritus.

The second instrument is more specific in its application and function, but is none the less fundamental to any project. It is a well calibrated stable sensitive spectrometer which detects gamma radiation originating from certain discrete isotopes. These include Bismuth-214, Thallium-208 and Potassium-40, isotopes with well defined energy peaks from the Uranium, Thorium and Potassium series respectively. Spectrometers are essential in any exploration programme for they quickly qualify the sources in terms of the parent element. These are therefore used for detailed examination, either of individual occurrances or as part of a systematic survey over a grid. Spectrometers also are used to provide rapid quantitative radio-assays of the three elements of interest, and find extensive use on outcrops and for the examination of drill cores or chip samples.

An instrument such as the GRS-500 Differential Spectrometer/Scintillometer combines the functions of both and will service in a variety of functions including:



- [ ] Rapid reconnaissance surveying.
- [ ] Ground follow-up of airborne anomalies.
- [ ] Detailed radioanalysis of Uranium (eU), Thorium (eTh) and Potassium.
- [ ] Detection of radioactive glacial float and detritus.
- [ ] Lithological and structural mapping.
- [ ] Systematic surveys and property evaluation.
- [ ] General prospecting.
- [ ] Grade control.
- [ ] Qualitative screening of drill core, chip samples and slurry for further more comprehensive lab analysis.
- [ ] Complements other geochemical surveys such as Radon, Helium and trace metals.

Description

In order to fulfill the above, an instrument must satisfy a number of rigid design and engineering criteria. The GRS-500 accomplishes the obvious but also because of our long experience in nuclear physics, geophysics and portable instrument design, it extends beyond other contemporary instruments. It is a high performance spectrometer employing the latest CMOS components and many custom engineered elements The result is a durable, sensitive instrument capable of withstanding typical field conditions yet exhibiting characteristics under tests normally reserved for only the best laboratory equipment.

From an operator point of view, the GRS-500 is a light weight five channel spectrometer. The first two channels TC_1 and TC_2 are lower thresholds set at 0.08 and 0.40 MeV respectively. These admit gamma energies originating from all natural terrestrial, cosmic and man-made sources above those levels, while blocking out lower energies which constitute noise and Compton scatter. These channels are used in reconnaissance surveys. The remaining three channels admit only gamma radiation within narrow bands. These are progressively centered on $K(K^{40})$ at 1.46 MeV, $U(Bi^{214})$ at 1.76 MeV and $Th(Tl^{208})$ at 2.62 MeV. Simple calculations may be applied to arrive at %K, eU and eTh is desired. An additional channel is provided specifically for rapid precise instrument calibration using a nuclear lab quality low activity Barium-133 isotope. Two sampling time periods of 1.0 and 10.0 are provided which satisfy the majority of applications. Greater statistical accuracy may be achieved if required

GRS-500
Differential Spectrometer/Scintillometer

EDA

by recording a series of 10 second readings, preferably displaced laterally to provide both time and area averages. This technique is superior for most surveys to a single long term measurement.

As a general exploration tool, the GRS-500 provides a loud fully adjustable anomaly alarm. A special electronic circuit accentuates small anomalies and with a fast response time of 0.5 seconds, results in clear positive hands-free anomaly identification.

Unlike other current designs, the GRS-500 uses a custom designed five digit liquid crystal display (LCD), built for low temperature conditions and including a continuous battery condition monitor. Each reading, normalized to cps, is clearly visible and updates automatically.

Central to the design if a custom designed ruggedized high resolution NaI(T1) detector coupled to photomultiplier tube. Found only in the EDA spectrometers, this special detector has 124cc (7.5 cu in) of geometrically optimized crystal volume, more than 30% greater than most units in the field today. The entire assembly is magnetically shielded and protected against thermal and mechanical shock.

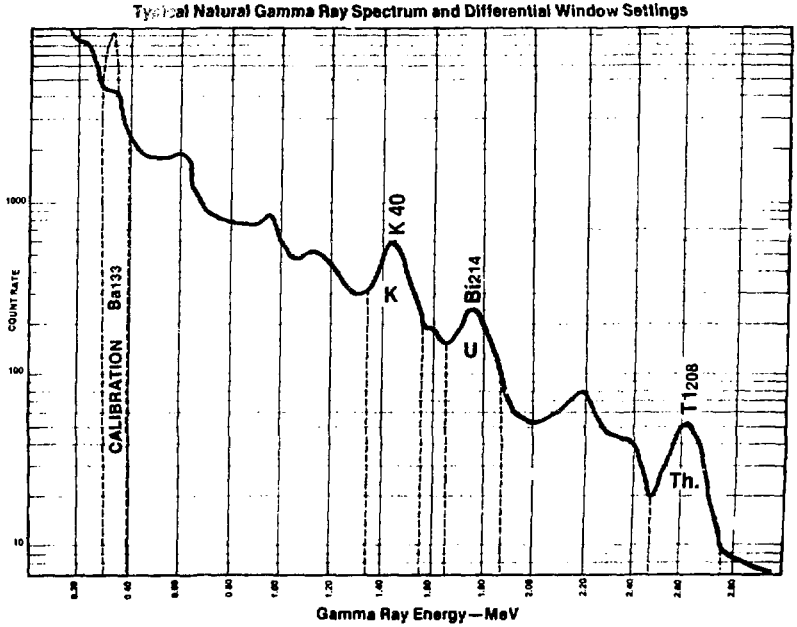
Following the detector are nuclear grade high voltage power supplies, amplifier discriminators, and scalers. All sections are stable and drift free, and are mounted in a light weight aluminum housing positively sealed against moisture and dust. All controls are designed for user convenience and are protected by recessing into the housing. Included in a separate lead shielded recess is the Barium-133 source which is taken out only to adjust the amplifier gain for accurate calibration of the spectrometer. All elements of the design are mounted in a lightweight weather-proof cast aluminum housing. The unit comes complete with a detachable handle and all standard accessories and is fully warranted.

Carried by hand, on the operators belt or in a pack sack, the GRS-500 provides the explorationist with a superior instrument without compromise in convenience, sensitivity or quality.

Features

- ☐ Large 124 cc ruggedized NaI(T1) detector.
- ☐ Five selectable energy thresholds included two for total count scintillometry.
- ☐ Custom five digit liquid crystal display (LCD) with count overflow indicator. Excellent visibility in direct sunlight.
- ☐ Continuous battery capacity indicator.
- ☐ Loud anomaly alarm.
- ☐ Simplified functions.
- ☐ Barium^{133} calibration source.
- ☐ Two sample rates 1 or 10 seconds, auto recycling.
- ☐ 60 hours continuous operation on one set of 4 "C" cells.
- ☐ Audio alarm and LCD display activates when batteries need replacement.
- ☐ Light weight cast aluminum case sealed against moisture.
- ☐ Ease of calibration and gain adjustment.
- ☐ Optional Rate meter output.

Typical Natural Gamma Ray Spectrum and Differential Window Settings



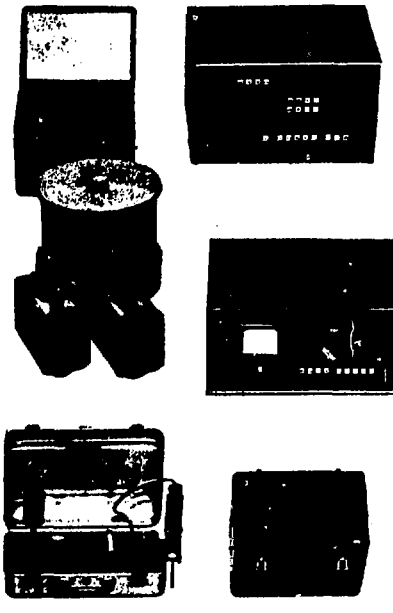
EDA

Specifications

Detector	NaI(T1) crystal and high stability photomultiplier tube with a mu-metal magnet shield. Volume 124cc (7.5 cu in). Mechanically ruggedized.
Resolution	Typically 8% FWHM in 2π Cs^{137} field.
Energy Thresholds	Switch selectable to:
TC_1	Total Count above 0.08 MeV.
TC_2	Total Count above 0.40 MeV.
K	All gamma energies between 1.35 and 1.59 MeV.
U	All gamma energies between 1.65 and 1.87 MeV.
T	All gamma energies between 2.45 and 2.79 MeV.
CAL	Measures Barium-133 photo peak at 0.352 MeV.
Energy Response Linearity	Less than 2% error from 0.3 to 3 MeV at 1000 cps.
Spectral Shift	Less than 2% from 1000 to 20,000 cps integrated over an energy interval from 80 keV to 1.5 MeV.
Deadtime	6 microsecond.
Display	Five digit ruggedized low temperature LCD. Displayed counts normalized to cps. Flashing count overflow and battery charge status indicators custom designed into display.
Sample Rate	1.0 or 10.0 seconds, auto recycle, for all energy levels, except for "CAL" position.
Calibration Source	Barium-133 (Ba^{133}) Isotope. Rated activity 0.5μ Ci.
Audio	
Type	High efficiency transducer coupled to an acoustic resonator.
Threshold	Continuous control. Audio activated when count rate exceeds preset level.
Response	0.5 seconds from 0 to 2500 cps.
Range	Frequency is 4 times actual displayed count rate. Range is from 0 to 5000 cps.
Power	Four alkaline "C" cells with an average continuous operation of 60 hours without audio at 23°C ambient temperature.
Battery Charge Monitor	Three bar indicators and charge status, linearly expressed in hours of operation remaining. When batteries are nearly discharged, a keyed audio alarm is activated, overriding the actual background count rate and a charge status triangle commences to flash.
Operating Temperature	−10°C to +60°C (+14°F to +140°F).
Relative Humidity	0 to 100%.
Weights and Dimensions	
Net	2.3kg (5.0lb), 235x115x640mm (9.25"x4.5"x2.5")
Shipping	3.2kg (7lb), 310x190x715mm (12.25"x7.5"x5.5").
Standard System Components	GRS-500 Differential Spectrometer/Scintillometer, Barium 133 Test Source (installed), 4 "C" Cell Batteries, Carrying Case, Instruction Manual.
Options and Accessories	GRS-435 Shipping/Storage Case GRS-407 Rate Meter Output

GRS-500
Differential Spectrometer/Scintillometer

- Portable Detectors
- Degassing Units
- Automatic Remote Networks with Central Recording
- Working Level Meters
- Passive TLD Monitors
- Direct Daughter Detectors
- Thoron and Radium Analysers
- Survey Assay Meters



- Uranium Exploration
- In-Mine and Plant Monitoring
- Residential Surveys
- Geothermal Prospecting
- Petroleum Reservoir Delineation
- Environmental Baseline Surveys
- Nuclear Power Plant Systems
- Earthquake Prediction Networks.

ıe GRS-500 Differential Spectrometer ɔmplements an expanding line of geo- ıemical and geophysical instru- ents. Included in this are Radium, adon and Radon Daughter Detectors, ranium Assayers and portable agnetometers. A complete series of ıvironmental Radon monitors serves e health physics market.

EDA Instruments Inc., Head Office: 1 Thorncliffe Park Drive, Toronto, Canada M4H 1G9
Telephone: (416) 425 7800, Telex: 06 23222 EDA TOR, Cables. INSTRUMENTS TORONTO

In USA, **EDA Instruments Inc.**, 5151 Ward Road, Wheat Ridge, Colorado 80033
Telephone (303) 422 9112

MOD-225
Integrating Radon
Daughter Monitor

EDA

Applications

The concern for the public and occupational health of individuals exposed to natural and man-made radiological hazards has centered primarily on Radon-222 and its respirable daughters. Many techniques have evolved to provide solid data to assess the degree of Radon intrusion in ambient, residential and work spaces. Important among these various techniques are those which integrate over long periods of time to simulate total exposure levels. This is important since Radon, being an inert soluble gas, is easily affected by a number of parameters including diurnal and seasonal atmospheric conditions, ventilation changes, occupancy and individuals activity and heating/cooling cycles. Single grab sample measurements may point to a problem in a space and under the influence of these variables, but only integrated measurements can substantiate them.

The MOD-225 operates unattended for up to four weeks under a variety of conditions. When calibrated, it provides a sensitive reliable means of quantitatively sampling the total Radon Daughter concentrations in acceptable terms such as Working Levels. As a further benefit, total respirable particulate load may be measured on two filters, and under certain circumstances, a program may use the collection filters to analyze relative concentrations of airborne constituents.

In summary, the applications include:

- Time Average of Radon Daughter concentrations around mines, mills, in homes, offices and public dwellings, and in open ambient spaces.
- Determination of public inhalation exposures.
  Complement integrated Radon-222 monitoring programs.
- Validate grab sampling data.
- Provides integrated gamma exposure levels.
- Sample total respirable particulates.

Description

The MOD-225 time Integrating Radon Daughter Monitor is a direct off shoot of a series of programs and research studies conducted by the scientists and engineers at the Environmental Measurements Laboratory (formerly HASL), U.S. DOE. The current design uses a standard sample head with a resilient silastic TLD chip holder which positions a chip 2mm from the surface of a 0.8 micron membrane filter. Also included but shielded from both beta and alpha activity is an identical TLD chip to register only penetrating gamma radiation.

Important to the design is a dual-piston diaphragm pump which is factory set at near its optimum flow rate. A two filter balanced by-pass technique achieves a low flow rate of between 0 - 750 ml / minute without loss of stability over extended sampling times and continued filter loading. Also adding to the overall stability is a well designed power supply which converts available AC to stable DC.

Elapsed time is recorded unfailingly on a 5 digit mechanical counter measuring to 0.1 hour increments. Unlike solid state clocks, time accumulation ceases when outages occur, and is restarted when power is restored.

The sample holder accepts any standard 3.2x3.2x0.38mm (0.125"x 0.125"x0.015") thermoluminescent dosimeter chip. These include LiF, CaF_2:Dy and $CaSO_4$:Dy. Calibration is usually conducted under laboratory conditions to equate TLD response to both Working Levels and for gamma exposure.

All elements of the design are contained in a small, well-sealed but

MOD-225
Integrating Radon Daughter Monitor

EDA

operator-accessible custom case. Visually attractive, it intrudes very little into the normal everyday activities of the people near it. Special attention to noise suppression and intrusion resistance satisfy the most demanding criteria.

A full line of options and accessories as well as a stock of spare parts for routine maintenance ensure maximum use, short down times and a rapid response to customer needs.

Features

- Standard EML (HASL) designed sample head.
- Low stable flow rate. Operator adjustable over 0-750 ml/minute range.
- Accepts any thin 3.2x3.2mm (0.125"x0.125") TLD chip including LiF, CaF_2:Dy and $CaSO_4$:Dy.
- Attractive appearance for indoor residential use yet rugged for harsh outdoor applications.
- Dual piston pump, mechanically balanced with long lasting mylar valves.
- Special noise suppression construction.
- Easily serviced and maintained.
- Accurate elapsed time meter.
- Unaffected by normal filter loading.
- Measures concentrations as low as 0.005 WL using LiF chip at a flow rate of 100 ml/h over one week.
- Sensitivity may be varied to suit application and conditions by changing flow rate, collection time and chip material.

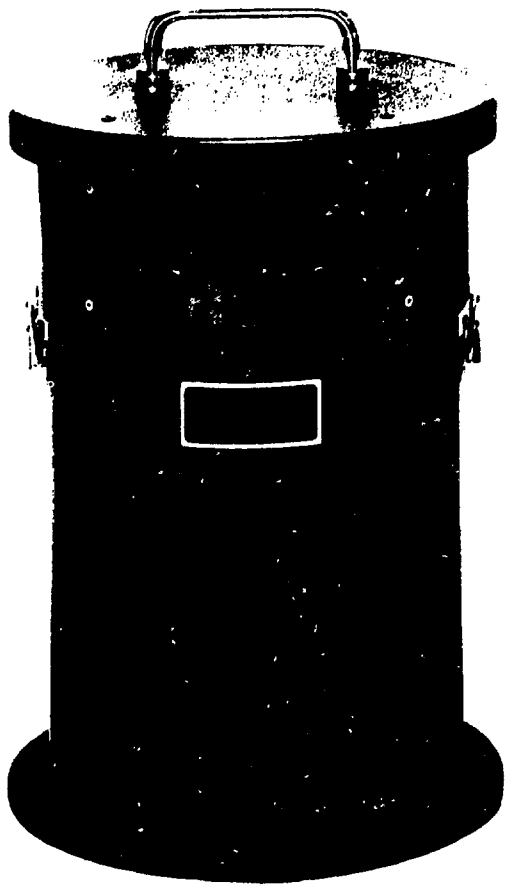
MOD-225
Integrating Radon Daughter Monitor

EDA

Specifications

Function	Time integrated Working Level monitor with secondary application of gamma exposure and total respirable dust measurement.
Technique	Filter collection of Radon Daughters and registration of alpha and beta activity on Thermoluminescent Dosimeter (TLD) chip.
Detector	Any 3.2x3.2x0.38mm (0.125"x0.125"x0.015") TLD material including LiF, CaF_2:Dy and $CaSO_4$:Dy.
Detector Assembly	Precision machined stainless steel sampling head with alpha/beta shielded gamma control chip well. Radial inlet ports for short travel paths and minimized plate-out. Designed by U.S. DOE Environmental Measurement Laboratory.
Flow Rate	0-750 ml/minute adjustable. Factory set at 150 ml/minute. Stable for long term sampling.
Filters Sample Head By-pass	Millipore 0.8μmembrane. 17.0mm diameter, effective area 67.50mm² (0.1046in²) 25.4mm diameter, effective area 426.1mm² (0.6604in²).
Sensitivity	Variable, depending on flow rate, TLD material and background gamma radiation. Typically 0.1 WL-h for LiF at 100 ml/minute in gamma field of 8-10μR/h.
Response	Typically 560 counts per WL-h at 100 ml/minute for LiF. External gamma response, 35 counts per mR.
Pump	Dual Piston "parel" diaphragm, mylar valves. Flow rate 0.5 - 10.0 l/minute. Vacuum 508mm Hg(20"). Nominal operational life 10,000 hours. Factory set at 7 V DC, current drain 165 mA for 2.0 l/minute flow rate. Shock mounted.
Power	115 V AC 60 Hz standard. 240 V AC 50 Hz available on request. DC operation optional. Power consumption 8 Watts.
Temperature Range	– 10°C to 40°C (7°F to 104°F).
Dimensions	203x406X203mm (8"x16"x8").
Weight	5.5kg (12 lbs).
Shipping Dimensions and Weight	355x355x610mm (14"x14"x24"), 6.8kg (15 lbs).
Standard System Components	Console with Detachable Lid, two Sampling Heads, one By-pass Filter Holder, 100 Sampling Head and By-pass Filters, Sample Head Spanner Wrench, Air Flow Test Adaptor, Spare 1 Amp Fast Blow Fuse, AC Line Cord, Instruction Manual.
Options and Accessories	Filter Cutter (17.0mm diameter). Spanner Wrench. Sample Head Assembly. Filters. Spare Parts Kit. DC Power Supply Option. Air Flow Meter, 0-1000 ml/minute. TLD Chips.

MOD-225
Integrating Radon Daughter Monitor



The MOD-225 Integrating Radon Daughter Monitor is but one of several instruments, systems and accessories developed and manufactured by EDA Instruments Inc. for radiological measurements. Also available are Passive TLD Monitors, Radon and Radon Daughter portable grab sampling devices, Radium analysis systems and Continuous Radon Monitors. Complementary to these instruments is a well equipped laboratory in Denver, Colorado to provide complete analytical services for environmental and geochemical sampling.

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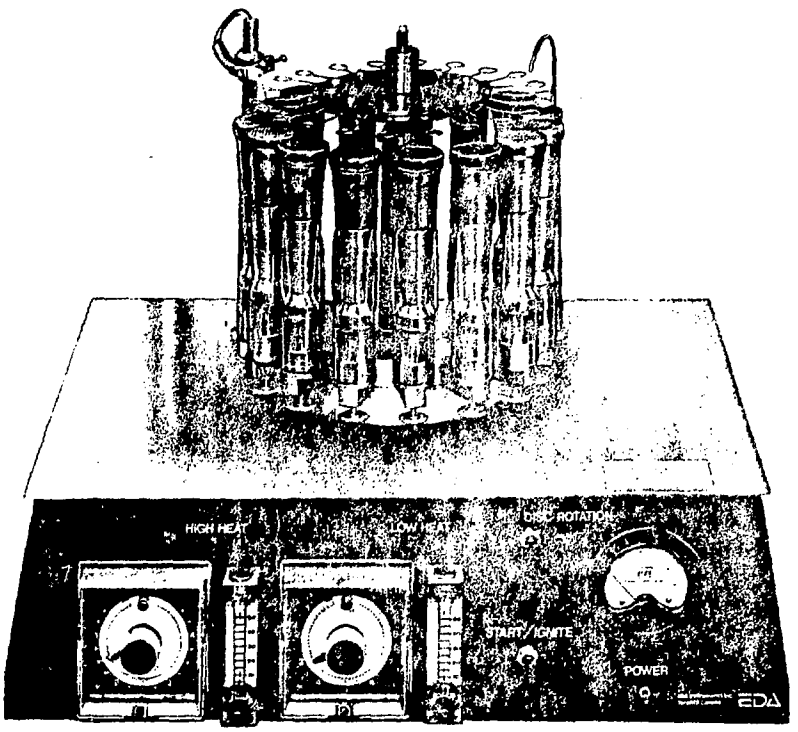
RFB-300 Rotary Fusion Burner

EDA

Applications

The RFB-300 is an important and essential laboratory device which simultaneously prepares 22 flux fusion beads within minutes for further analytical treatment. By automating and fully controlling the entire fusion process, it overcomes many of the disadvantages common to more cumbersome techniques. The RFB-300 is unmatched for high production rates, simplicity of operation, sample reproducibility and precision. Applications for beads produced by RFB-300 are many and include:

- Direct Uranium Analysis by Fluorimetry.
- Major Element Analysis in Coal Ash by X-Ray Fluorescence.
- Chemical and Atomic Absorption Analysis of Solutions.
- Ore and Mineral Analysis by Wet Chemistry, Atomic Absorption or Emission Spectroscopy.
- X-Ray Fluorescence Analysis of Bauxite, Iron Ore, Clay and Limestone.



Description

The RFB-300 Rotary Fusion Burner is a logic controlled heating device which prepares flux beads for further analysis. Operating over a fixed cycle of drying, fluxing and annealing with variable times and temperature, it results in exceptional reproducibility and speed. Precision is commonly ± 5%, better by a factor of as much as 3 over other techniques such as single element burners or muffle furnace fusing.

Once all functions are initially set, operation is simple thereby reducing technician induced errors and enhancing the safety of the unit.

Step-by-step, the operation is inherently simple. A lab technician prepares 22 dishes each with a weighed sample and a single 0.3 gram flux pellet. These are arranged on a circular sample holder and the entire assembly is set on the rotation table above 15 burner heads. Rotation is then initiated by a single toggle switch. Depressing the start/ignite button begins the automatic operation. The gas flow at the low heat setting begins and the "auto match" instantly ignites the 15 burners. The first phase is the drying/degassing cycle which lasts for 30 seconds. The flame temperature, adjustable by varying the gas flow rate, is usually set to 400°C for this cycle. After 30 seconds, the solenoid gas valve automatically opens further to produce the necessary fusion temperature for a period of normally between 1.5 to 2.5 minutes. Recommended fusion temperature for NaF-LiF fluxes is 950° - 1050°C. Following fusion, the gas valve resets to the lower temperature to maintain a non-oxidizing atmosphere during the change of state from liquid to solid. During this period, uniform crystal growth is ensured and transitional elements such as Fe are held at lower oxidation states. This reduces quenching or "brown bead" effects. Finally the gas valve closes, power turns off and all but the disc rotation ceases during the final cool-down.

Normally within 5 minutes 22 samples are ready for further analytical treatment resulting in fast efficient through-put.

Features

- Simple automatic operation.
- Variable preheat (drying), fusion and anneal times and temperatures.
- Prepares 22 beads in 3 minutes resulting in high production.
- Uniform reproducible fluxing conditions.
- Cooling (annealing) in non-oxidizing atmosphere prevents transition elements from reaching higher oxygen states.
- Automatic spark ignitor.
- Maintenance free.
- Stainless steel deck for ease of cleaning.
- Stepped rotation initialed by push button.

RFB-300
Rotary Fusion Burner

EDA

Specifications

Function	Production of fused beads for further analytical treatment.
Number of Samples per Cycle	22 0.75"(19mm) diameter fusion dishes for melt weight of 0.30gm. 11 dish sampling holder for larger samples optional.
Fusion Gas	L.P. (propane) for standard NaF-LiF flux. Natural Gas unit available on request at no extra charge.
Temperature	Operator variable. Standard settings 400°C and 1000°C.
Pyrometer	0-2400°C at ± 5°. Meter output on front panel.
Burner Heads	15 factory set for LP or Natural Gas.
Gas Flow	0-1416 l/hr (0-50cf/hr).
Timers	Separate master timer and fusion timer, adjustable to 10 minutes maximum.
Logic	Drying cycle factory set to 30 seconds, fusion cycle variable, annealing cycle (pre-cool). Automatic temperature step.
Heat Generated	5.27×10^7 J (50,000BTU).
Rotation Speed	10rpm.
Minimum Gas Pressure	103kPa (15psi).
Power Requirements	110 V AC 60Hz 1.5 amp. Optional 240 V AC 50Hz.
Weights and Dimensions	
Net	22kg (50 lbs), 483 × 584 × 495mm (19" × 23" × 19.5")
Shipping	41kg (90 lbs), 508 × 635 × 533 × mm (20" × 25" × 21").
Options and Accessories	Platinum/Rhodium Fusion Dishes Flux Pellet Press Flux (98% NaF — 2% LiF) Spare Rotating Sample Holder Support Stand for Rotary Sample Holder Dish Die — for reshaping dishes Spare Dish Ring Set Teflon Dish Cleaning Rack Spare Parts Kit Stainless Steel Fume Hood for 6" (15.4cm) duct work.

The RFB-300 is only one of many instruments and services available from EDA in the fields of mining exploration, development and production, environmental monitoring and geomagnetics.

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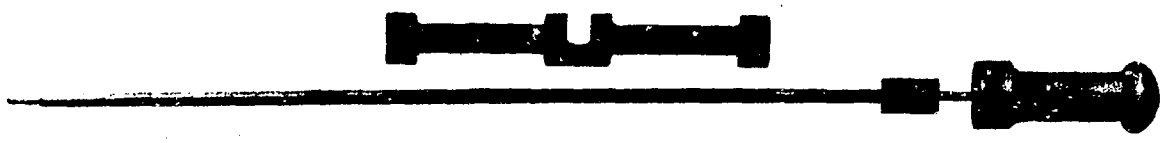
Radon Detector Systems Accessories

EDA

RDX-356 Heavy Duty Soil Probe

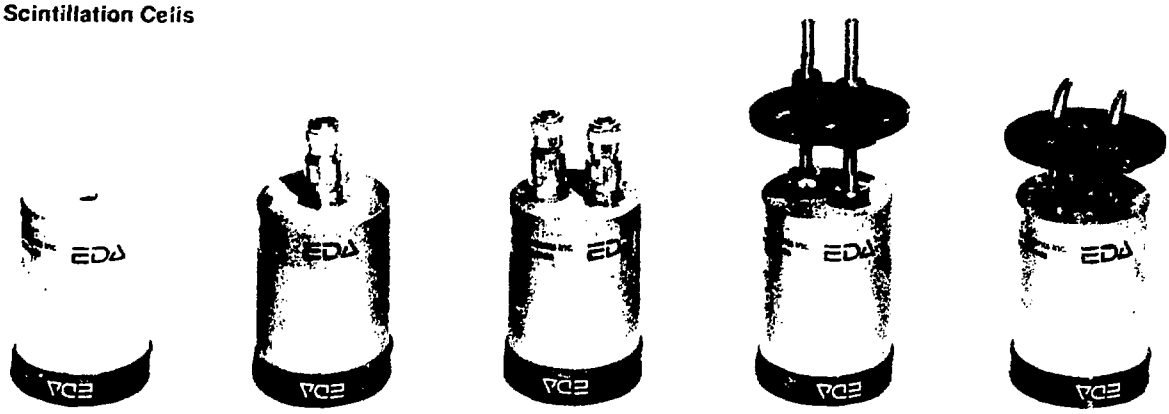


Soil-gas extracted from below the thick organic "A" horizon which preferentially adsorbs uranium complexed molecules is often more representative of the underlying bedrock. These deep samples also help in avoiding potential surface influence of atmospheric variables such as severe barometric changes and heavy precipitation.

The RDX-356 is a convenient probe consisting of a hollow steel tube, a solid inner rod and driver assembly, and a special wrench used to extract the probe if it becomes wedged.

Length	736mm (29").
Weight	3.6kg (8 lb)
Material	Steel.

Scintillation Cells



RDX-385 Soil Gas	RDX-386 Vacuum	RDX-388 Vacuum	RDX-387 Continuous Flow	RDX-389 Continuous Flow

One of the most important components of an alpha particle detection system is the scintillator cell. EDA offers a number of high efficiency large volume cylindrical chambers optimized for a variety of applications. Available in static, flow through or vacuum configurations.

Phosphor	ZnS(Ag) coating.
Efficiency	33-35%.
Volume	Up to 170cc (RDX-385).
Sensitive Area	14,350mm^2
Viewing Window	Plexiglass, 53mm diameter (RDX-385 are open ended).
Dimensions	58mm diameter x 79mm high O.D.
Connectors	Open, Swagelok or open tubing.

EDA

RDX-700 External Battery Pack

Snow cover provides an excellent homogeneous medium in which Radon sampling may be conducted. Since battery capacity is lessened in extreme cold, the RDX-700 is simply a convenient external source of power which is worn under the operator's coat. Used in this manner, standard "C" cells will last up to 30 days under average field conditions.

Capacity	8 "C" Cells.
Dimensions	39 x 127 x 177mm (1.5"x5.0"x7.0").
Weight	1.0kg (2.2 lb), less batteries.

RDX-706/707
Converter Power Supply

RDX-703/704
Battery Charger

RDX-700
External Battery Pack

RDX-703/704 Battery Charger

The RD-200 may be provided with standard rechargable NiCad batteries rather than the disposable "C" cells.

The RDX-703/704 is a completely solid state low power consumption charger which automatically switches off when a full charge is reached. Ths unit is protected against external shorting by a front panel mounted 1 amp fuse.

Input:	RDX-703	110V AC 60Hz 50ma.
	RDX-704	240V AC 50Hz 25ma.
Output		12V DC 100ma.
Dimensions		52 x 125 x 246mm (2.1"x4.9"x9.8").
Weight		1.5kg (3.3 lb).

RDX-706/707 Converter Power Supply

Field laboratories using the RD-200 and the RDU-200 to process large numbers of soil, sediment and water samples may have access to line power. In this case, the RDX-706/707 would eliminate the need for internal batteries in the RD-200 by providing a stable DC power supply.

Input:	RDX-706	110V AC 60 Hz 10ma.
	RDX-707	240V AC 50 Hz 5ma.
Dimensions		60 x 83 x 100mm (2.4"x3.4"x4.0").
Weight		1.2kg (2.6 lb).

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BGA-300 Uranium Ore Analyzer

EDA

Applications

The BGA-300 is a convenient and dependable uranium analyzer which yields laboratory grade uranium assays. It operates exceptionally well under adverse conditions, saving time and money over other techniques. Uses include:

- Grade Control at Mine and Mill Heads.
- Geochemical Analysis in Laboratories.
- Mobile Laboratories.

Description

The BGA-300 is a simple to operate Beta/Gamma detector system which uses a unique yet proven technique to analyze % U_3O_8 rapidly and effectively.

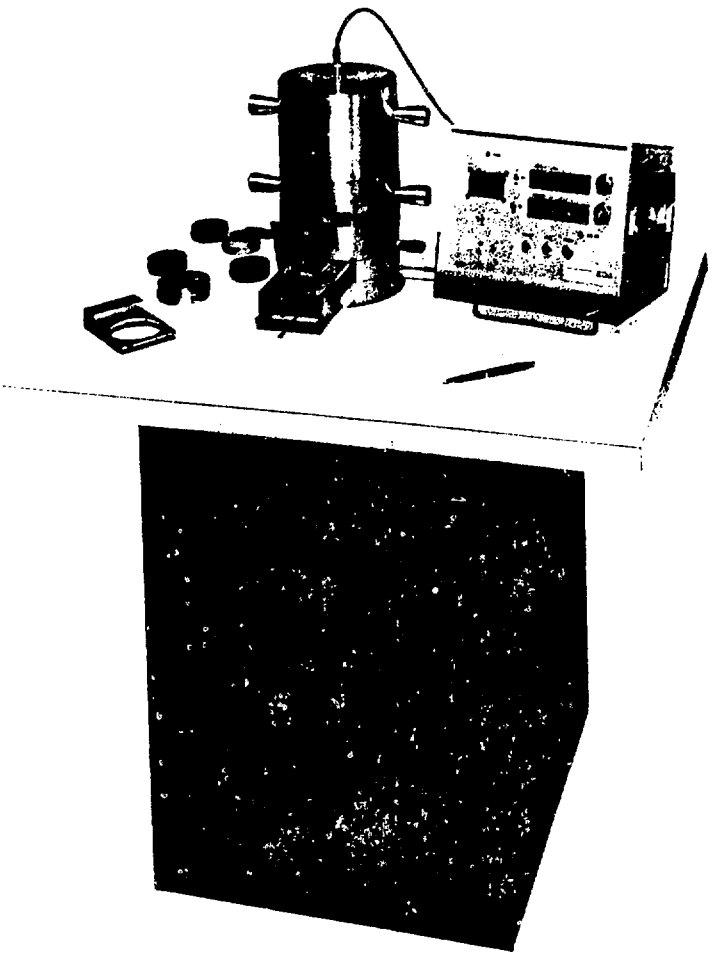
This system is comprised of a shield and detector assembly, and a small electronics console with front panel controls, switches, indicators and digital readouts.

Central to the design are two separate detectors. The NaI(Tl) crystal below the sample chamber measures only gamma radiation while a high efficiency plastic scintillator positioned above the open sample measures only beta. Calibration using sets of accurately measured samples spanning the entire range of conditions from extreme disequilibrium to secular equilibrium, is rapid. Results are output on the light emitting diode (LED) display in % U_3O_8, beta and gamma counts. gamma counts.

The unit is self supporting and shipped ready to begin production sampling. Power may be either 110 or 240V AC, or 12V DC for truly mobile applications.

Sample preparation involves crushing to - 10 mesh or finer, homogenizing and packing the required amount into either 35, 70 or 140 gram metal tins. Once samples are prepared, they are analyzed at a rate dependent upon accuracy desired. Run-of-mill assaying can be accomplished with a high degree of confidence in 20 seconds.

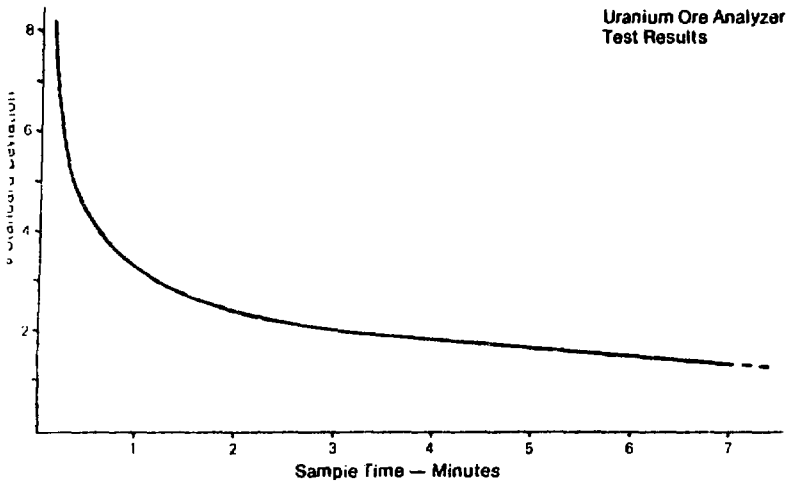
Full instructions accompany each system and a well maintained spare parts inventory ensures limited downtime should breakdowns occur.



Features

- Rapid, non-destructive analysis.
- Dual detectors and separate beta and gamma displays.
- Shielded to eliminate external radiation.
- Direct read-out in % U_3O_8.
- Unaffected by natural disequilibrium.
- Greatly superior to simple gamma devices which measure Radium group isotopes.
- Measures %e U_3O_8 and %eU_3O_8.
- Measures % Radon loss and % e U_3O_8 (closed can technique).
- Easily calibrated using Standards provided.
- % expressed in 1.0, 1.00 or 1.000, switch selectable.
- AC and DC operation.
- Simple to operate and highly reliable.
- Variable counting times up to 15.99 minutes.
- Accurate to 0.001%.

GA-300
ranium Ore Analyzer

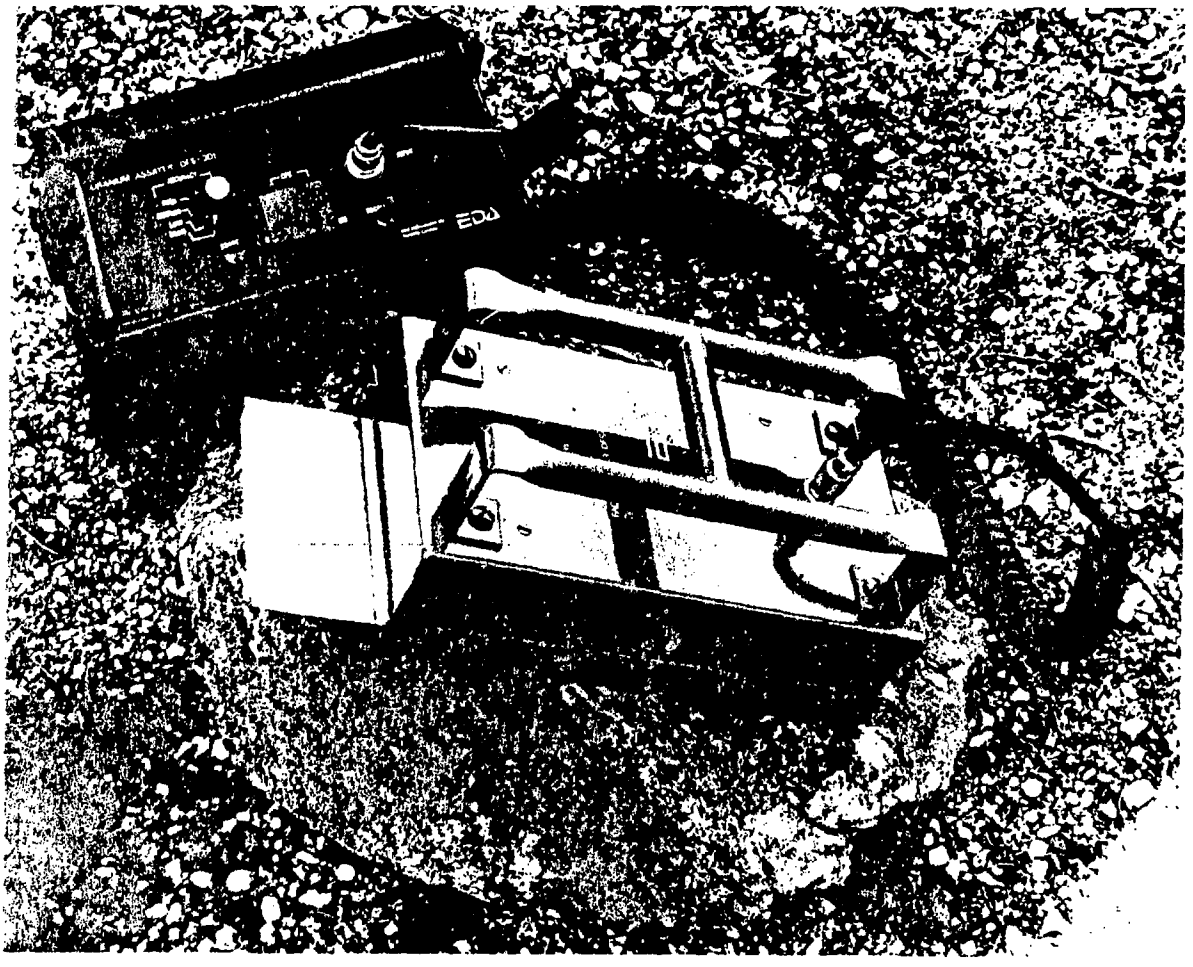


ımple Data:

eight	140gm
ze	—100 mesh
ade	0.28% U_3O_8

BGA-300
Uranium Ore Analyzer

EDA



The BGA-300 is only one of several instruments, systems and services designed for use in all phases of uranium exploration, development mining, milling and associated environmental monitoring. Also available are laboratory devices for sample preparation, radium, radon and radon daughter detectors, gamma ray spectrometers, various portable assaying devices and magnetometers.

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BGA-300 0290

BGA-300
Uranium Ore Analyzer

EDA

Specifications

Function	Rapid non-destructive analysis of Uranium ore, concentrates and rock samples.
Technique	Beta-gamma equivalent.
Output	Digital display of % U_3O_8, gamma and beta in gross counts.
Sensitivity	.005% U_3O_8 for count times of less than one minutes and sample size of 140 gm.
Accuracy	At 1% U_3O_8 ±0.02 At 0.1% U_3O_8 ±0.004 At 0.01% U_3O_8 ± 0.001
Range	0.001% to high grade.
Detectors	
Beta	Thin 102mm(2.0") diameter planer convex plastic scintillator. Efficiency 67% of anthracene standard. 120mm(2.0") diameter PMT operating at nominal 1200V DC.
Gamma	102.5 diameter × 19mm (2" diameter × 0.75") NaI (Tl). 38ml(2.4 cu.in.) volume. 102mm(2.0") diameter PMT operating at nominal 1000V DC.
Controls	On-off, high voltage adjust, count time, time multiplier, range, reset, count, subtract.
Time Base	Crystal controlled, variable from 0.01 to 15.99 minutes. Multipliers for 0.2, 0.5 and 1.0 interconnected with displays.
Sample Size	70 and 140gm standard. 35gm optional.
Sample Preparation	Maximum size fraction -- 10 mesh, -- 100 mesh preferred. Samples dried to less than 15% moisture content.
Calibration	Using standards provided. 1% U_3O_8 (refined yellow cake), 1% U_3O_8 (typical equilibrium ore), 6.4 μCi/kg Radium-226, and silica blank.
Background Shield	Low background lead-antimony. Minimum thickness 50.8mm(2.0").
Power Requirements	110V AC or 240V AC 50-60Hz, stable to ± 10%, and 12V DC. Consumption 24 Watts DC or 75 Watts AC.
Weights and Dimensions	
Console	5.6kg(12.3 lb) 235 × 292 × 279mm(9.25" × 11.5" × 11.0").
Detector Assembly	122.0kg(268 lb) 187mm diameter × 508mm(7.38" diameter × 20.0").
Cabinet	44.5kg(97.9 lb) 775 × 533 × 648mm(30.5" × 21.0" × 25.5").
Top	17.5kg(38.5 lb) 914 × 711 × 38mm(36.0" × 28.0" × 1.5").
Miscellaneous	6kg(13.2 lb).
Shipping	261kg(575 lb) 1130 × 660 × 762mm(44.5" × 26.0" × 30.0").
Standard System Components	Console, Detector Assembly and Lead Shield, 70gram and 140gram Sample Insertion Assemblies, Cabinet, Trip Balance, Standards Set, Packing Plate, 72 70 gram and 36 140gram Sample Cans, and Instruction Manual.
Options and Accessories	35gram Sampling Kit including Insertion Assembly, Standards Set and 144 Sample Cans. Digital Printer Automatic Sample Packer Minor Spare Parts Kit Major Spare Parts Kit Shock Mounts for Mobile Installation

R. H. Morse & Associates Ltd.

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INTERLABORATORY COMPARISONS OF EDA PORTABLE RADON DETECTORS

This paper summarizes the results of calibration of EDA's radon scintillation cells and portable radon detectors at four different labs over the past three years. Customer feedback of this type has always been a major contributor to EDA's research and development, engineering and quality control. The information is provided to give an idea of the variations in efficiency to be expected from cell to cell. It also may be of interest to the labs responsible for the tests, whose cooperation and permission to release the data we gratefully acknowledge.

The data is presented as an information base, mainly, with little or no attempt to reach conclusions. Probably other calibration studies have been carried out in addition to the four described here. Readers are urged to forward copies of any of these to EDA.

In the tables presented, efficiency factors are given as counts per disintegration.

Tables I and II present calibration efficiencies for eight different portable radon Detectors and for 48 cells by the Canada Radiation Protection Bureau (Vasudev and Taniguchi, 1978). Table II shows an intercalibration of 9 cells with 8 detectors. The variation in efficiency shown in Tables I and II was of concern to EDA and to the RPB. In response,

EDA initiated improved quality control in the manufacture of the cells. In particular, a more consistent mix in the zinc-sulfide preparation was maintained. Also the detectors themselves are now subject to a more rigorous series of tests. As the later studies indicate, variations in efficiency have been substantially reduced.

Calibrations by G. Smithson at the Saskatchewan Research Council are presented in Table III. Each involves the average of at least two determinations.

In a study commissioned by EDA, C. R. Phillips of the University of Toronto calibrated 14 cells three times each. Table IV shows the variation from run-to-run for each cell as well as the cell-to-cell variations.

Results in Table V were obtained by R. F. Droullard of the U.S. Bureau of Mines. After seeing the variability in the first column, four cells with standard plexiglass windows, the customer requested special cells with quartz windows. Four were tested in June, 1979, and 5 in September with much more consistent results. It is especially encouraging to note the good reproducibility with the batches.

Reference:

Vasudev, P. and H. Taniguchi, Plateau Characteristics and Calibration of Flow-Through Radon Cells. Presented at the Workshop on Radon and Radon Daughters in Urban Communities associated with Uranium Mining and Processing, Atomic Energy Control Board, Elliot Lake, Ont., March, 1978.

TABLE I

Efficiency of Cells with Reference to Individual Radon Detectors

Radon detector number:	1198	1192	1212	1191	1178
	.53	.56	.42	.44	.32
	.48	.56	.42	.45	.26
	.44	.58	.45	.48	.24
	.50	.59	.45	.55	.27
	.50	.59	.50	.53	.24
	.48	.62	.42	.42	.36
	.50	.55	.44	.45	.39
	.52	.55	.45	.53	.36
	.53	.58	.48	.53	.41
	$\bar{x}$ = .50	$\bar{x}$ = .57	$\bar{x}$ = .45	$\bar{x}$ = .49	$\bar{x}$ = .32

From Vasudev and Taniguchi.

TABLE II

Intercalibration Efficiency

Cell No.	Radon Detector Number 0987	1027	1170	1178	1191	1192	1198	1212	$\bar{x}$
21	.24	.26	.26	.32	.26	.29	.26	.26	.27
29	.70	.56	.32	.39	.50	.61	.48	.45	.50
32	.68	.55	.36	.44	.30	.62	.53	.48	.50
59	.68	.56	.35	.33	.53	.59	.53	.48	.51
73	.61	.50	.26	.32	.45	.53	.44	.42	.44
96	.71	.55	.30	.35	.48	.62	.52	.44	.50
99	.65	.50	.26	.53	.42	.58	.48	.42	.48
196	.70	.56	.32	.39	.53	.61	.47	.48	.51
199	.38	.33	.38	.38	.33	.36	.35	.30	.35
$\bar{x}$	.59	.48	.31	.38	.42	.53	.45	.42	.45

TABLE III

1979		1977
.74	.72	.81
.72	.60	.78
.71	.59	.72
.54	.65	.72
.75	.75	
.55	.76	$\bar{x}$ = .76
.63	.56	
.75		
$\bar{x}$ = .67		

From G. Smithson, Saskatchewan Research Council.

TABLE IV

Test #1	Test #2	Test #3	$\bar{x}$
.472	.513	.470	.468
.455	.468	.482	.468
.440	.450	.412	.434
.414	.406	.407	.409
.483	.482	.492	.486
.470	.432	.450	.452
.478	.490	.477	.481
.493	.514	.449	.485
.507	.519	.475	.500
.459	.475	.509	.481
.439	.469	.490	.466
.459	.495	.492	.482
.453	.380	.319	.384
.454	.442	.314	.404

From C. R. Phillips, University of Toronto.

TABLE V

Standard Window	Quartz Window	
Jan. 79	June 79	Sept. 79
.58	.71	.67
.57	.72	.67
.61	.72	.67
.62	.72	.67
$\bar{x}$ = .60	$\bar{x}$ = .72	.65
		$\bar{x}$ = .67

From R. F. Droullard, U.S. Bureau of Mines.

CALIBRATION OF MOBILE RADON-RADIUM LAB

In addition to standard checks of internal consistency, the mobile radon-radium lab of R. H. Morse & Associates Ltd. was calibrated against outside standards to add confidence to absolute values and to enable comparisons with other workers. These calibrations agreed with estimates based on known efficiencies.

Estimate

Efficiency of transfer of radon from solution in the water sample to the scintillation cell was established by degassing a sample of high but unknown radon concentration into a cell and then degassing the same sample once more into a clean evacuated cell without pumping or flushing the degassing system. Degassing efficiency is equal to

$$\frac{C_1 - C_2}{C_2}$$

where C_1 and C_2 are the net counts per minute of the first and second degassing respectively. A series of nine tests gave an average efficiency of about 50%.

The counting efficiency of the EDA cells is known from various labs to be about 45%. A few hours after degassing, radon is in equilibrium with its two alpha-emitting daughters and gives by definition an event rate of 6.66 disintegrations per minute (dpm). Samples are normally counted in the period from 4 to 10 minutes after degassing at which time the event rate is 3.58 dpm (the daughters are not yet in equilibrium). Multiplying the degassing efficiency (50%) by the counting efficiency (45%) by 3.58 dpm by the sample volume (.130 liter) gives an estimated response of .105 cpm/pCi/l. For example, a water sample containing 1000 pCi/l of radon would be expected to give 105 cpm when degassed and counted in the usual manner.

W. Dyck reports a degassing efficiency of close to 100%. A series of experiments were run in our lab to determine what happened to the missing 50% of the radon. Scrubbing efficiency was tested by degassing a sample into a cell, flushing the degassing system and then degassing the sample once more into another cell. Efficiency was calculated as above. A series of 4 pairs gave an average efficiency of 75%; in other words 25% of the radon is left in solution. The amount of radon left in the degassing system was assessed by degassing a sample into a cell, disconnecting the sample and then flushing the system into another cell. The amount left in the cell is

$$\frac{C_2}{C_1 + C_2}$$

A series of 6 tests gave an average of 25% left in the degassing system. Thus the missing 50% is equally divided between the degassing system and the solution. The difference in degassing efficiency between our lab and Dyck's cannot be explained without further studies. Limited experiments with different bubbling rates have not resulted in any increase in bubbling efficiency. The dead volume of the degassing system is only 5% of the total volume available to the radon.

Check with W. Dyck's lab

A standard provided by W. Dyck of the Geological Survey of Canada, reported to contain 1000 pCi/l, was run several times in our lab. Cross checking with different cells, different degassing systems and different counters gave an average count rate of 114 cpm, corrected to 4 to 10 minutes after sampling. The response, in other words, is .114 cpm/pCi/l.

Check with Radiation Protection Lab

Standard sample number 276 is a clastic stream-sediment sample collected at Kipawa, Quebec, in 1971, and used in our lab as an internal calibration source of radon ever since. About 35 cc of sediment has been

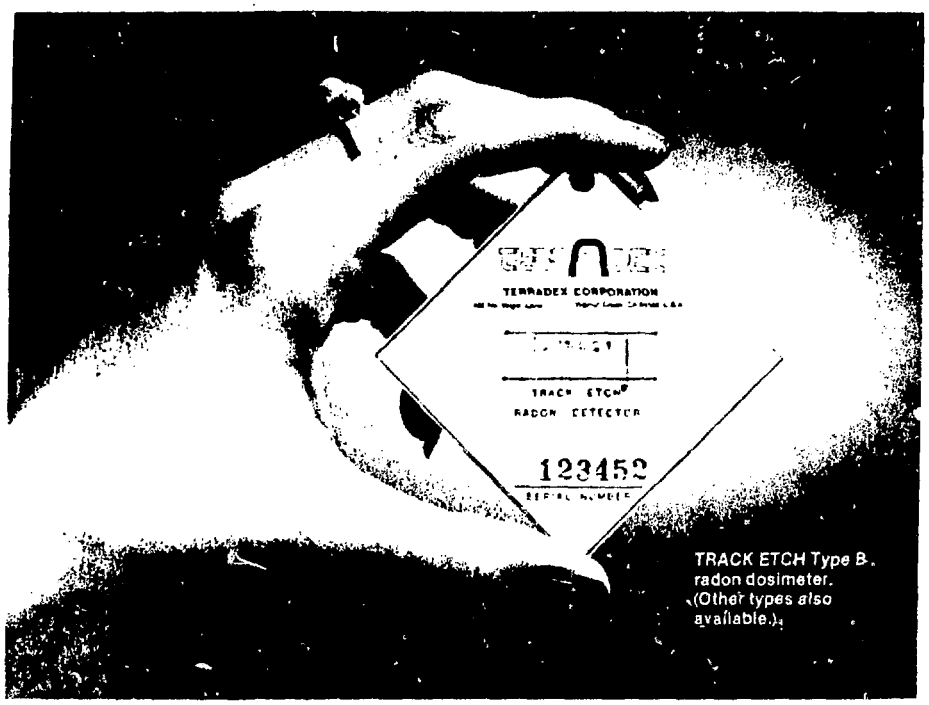
placed in an 8-ounce glass jar which is filled with water and sealed with a steel cap and left to equilibrate for a week or more. To generate a radon-bearing water solution, the jar is turned over several times to transfer the radon into the water. After a few minutes to allow the mud to settle out, the water is decanted into the bubbling tube and degassed and counted as usual. After the test the water is returned to the jar which is again filled and sealed and left to equilibrate for the next test.

The standard sample was decanted in the above manner at the Ontario Radiation Laboratory and analysed for radon by their usual method. They reported a result of 820 pCi/l. The average value for this standard obtained in our lab during the course of 1978 and 1979 was 82 cpm. Dividing this 82 cpm by 820 pCi/l gives a response of .100 cpm/pCi/l.

Discussion

The estimated response of .105 cpm/pCi/l agrees well with that obtained from cross checks with Dyck's lab (.114 cpm/pCi/l) and the Radiation Protection Lab (.100 cpm/pCi/l). This variation is well within the experimental error and the average (.106 cpm/pCi/l) should be used to convert our values of counts per minute into picocuries per liter. The same factor should be used to calculate results for radium in sediment and soil with suitable adjustments made for weight or volume of sample and volume of water into which the radon is transferred.

The factor used in our lab should not be used in other labs without checking. The large difference in degassing efficiency between Dyck's lab and our lab (100% versus 50%) demonstrates the need to calibrate each facility separately. Bubbling efficiency varies from lab to lab, and different degassing systems have different dead volumes and radon retention characteristics.



TRACK ETCH Type B, radon dosimeter. (Other types also available.)

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This advertisement will appear in technical journals such as Health Physics, Nuclear News, and Environmental Science & Technology.

TRACK ETCH* FOR ENVIRONMENTAL MONITORING*

Terradex Corporation's TRACK ETCH technology to measure radon levels has been widely used for years as an effective tool in uranium exploration. Many hundreds of thousands of radon soil gas measurements have been made using TRACK ETCH in a wide variety of rough field environments. In the course of this work, Terradex has developed several new and important improvements to the basic TRACK ETCH process.

A few tests have also been made over the past few years with TRACK ETCH to measure radon levels in homes and other buildings and to support the safety and environmental needs of the uranium industry. These tests, using earlier TRACK ETCH materials and techniques, have demonstrated the value of a completely passive device that can integrate the highly variable radon values over periods of months to a year.

New developments by Terradex have greatly increased the sensitivity of the TRACK ETCH detector and permit radon-only measurements using membrane and filter technology. Processing and reading improvements have also reduced costs. In addition, major calibration programs have now defined sensitivity and statistics so that TRACK ETCH can be reliably applied. Development is in progress on devices to measure only radon-daughters (working level values).

*TRACK ETCH techniques are covered by worldwide patents of the Terradex Corporation.

DEVELOPMENTS IMPORTANT TO ENVIRONMENTAL WORK

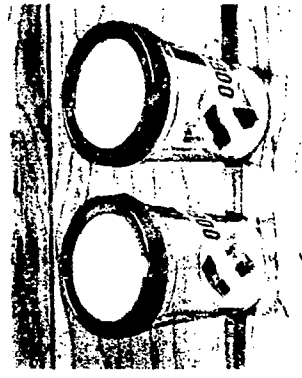
Recent enhancements of the TRACK ETCH system add greatly to its value in environmental monitoring. Compared to older systems, improved TRACK ETCH detectors are 5 to 10 times more sensitive to alpha particles and have superior resistance to hot and humid environments. Their optical properties permit automated counting, hence lower processing costs and higher accuracy. They are able to overcome the major problems of variability in radon levels as measured by conventional sampling or short-integrating-time devices; thus, new TRACK ETCH detectors can easily integrate the radon dose over a period of a few days to a year or more if necessary.

A variety of configurations are now available for detector mounting (see photos).

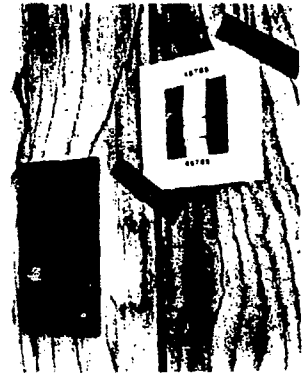
Other configurations, now under development, measure radon daughters only (working level) and are adaptable to area monitoring and personnel dosimetry. Detectors and configurations are calibrated in standard U.S. Government radon chambers so that results can be reported in terms of picocuries/litre and working level values. This work also yields sensitivity limits and error statistics. For example, a dose of 2 pci/l-months (roughly equivalent to .01WL-month) can be measured to a standard deviation of 30%.

SOME ENVIRONMENTAL APPLICATIONS

- Time-integrating passive area monitoring in mines or processing plants.
- Personnel dosimetry for the miner by means of a rugged, small, light and passive device having no electrical or moving parts.
- Monitoring of homes and buildings under abnormal conditions; for example, mining towns or construction over radioactive ground or with radioactive materials.
- Monitoring of homes and buildings under normal conditions to locate abnormally high indoor radon levels resulting from poor ventilation or local soil or water conditions.



"Filtered detectors" for indoor or outdoor use, measuring radon only.



"Bare detectors" for indoor monitoring with the detector mounted flat on an object.

"Open cup detector" for indoor or outdoor use, measuring both radon and daughters.

Paul Carrière : How is the sensitivity of the detector affected by dust or water film deposited on the surface?

J. Gingrich : If the dust deposit had alpha particle contamination this would be sensed by the detector. We would suggest using a detector cup with a vapor filter over it so as to eliminate any dust containing problem materials.

There are different approaches that can be employed when making measurements in areas where excessive moisture might be a problem. The container can be baffled in such a way as to restrict the entry of water. In areas of high humidity, a type of desiccant is available for insertion in the cup behind the membrane and acts as a drying agent to reduce the moisture levels so that they will not affect the film.

International radon workshop on ...international radon meeting in Port Hope

By JAMES CUTTING

The third Canadian international scientific workshop studying radon gas and its decay or daughter products bosted by the Atomic Energy Control Board began today and will run for three days at the legion hall in Port Hope with over 60 scientist and government agency representatives from North America and Europe.

The Canadian government through the AECB has spent well over $3 million in the past four years removing radioactive contaminated soils around 300 homes and buildings in Port Hope where evidence of radon gas was detected in a town-wide survey conducted by James F. MacLaren Ltd. in 1975.

Roger Eaton, chairman of the radioactive remedial actions group of the Atomic Energy Control Board, said in an interview at the start of the conference that this was the third radon workshop held in Canada, but the first workshop at which representatives from Sweden and Great Britain were in attendance.

Also in attendance are scientific and government agency officials from across Canada and the United States from as far away as California, Ohio and New York.

RADON WORKSHOP NOT OPEN TO THE GENERAL PUBLIC

Two previous radon workshops hosted by the AECB have been held at Elliott Lake in 1978 and at Bancroft in 1979. The workshops which are highly technical in nature are not open to the general public.

Sweden, whose government in 10 days will vote on a moratorium on nuclear energy, has sent three representatives including Hans Ehdwall from the National Institute of Radiation Protection from Stockholm, Sweden; Sven-Olive Ericson and Win Helm Tell from the Scandanavian Engineering Corporation, also in Stockholm, Sweden.

BRITISH AND UNITED STATES REPRESENTATIVES WILL ADDRESS WORKSHOP ON THURSDAY ABOUT OTHER RADON GAS RESEARCH

Dr. Keith Cliff from Britain's national Radiological Protection Board from Oxsfordshire, England, will discuss radon daughter exposure of the United Kingdom population, and the effects of energy conservation and possible action to reduce exposure.

William Nazaroff of the Lawrence Berkeley Laboratory in Berkeley, California will discuss the control of radon and radon daughters in a low infiltratrion house using mechanical ventilation with heat recovery.

The Monsanto Research Corporation of Ohio is represented at the conference by G. R. Hagee while A.C.George of United States Department of Energy is attending the workshop from New York.

RADON GAS IS A RADIOACTIVE GAS

The AECB defines Radon (Rn-222) as a radioactive gas that results from the radioactive decay of radium, which in turn results from the decay of uranium.

Since traces of uranium occur naturally in most soil and rock, and in building materials such as bricks and concrete, traces of radium and radon are also present in these materials, as well as in waste from uranium mining , milling and refining operations.

There is concern that modern energy efficient air tight homes may pose as problem in the future if some building materials used in the construction contained naturally occurring radon gas.

Since radon is radioactive, it spontaneously changes into a different substance and at the same time gives off radiation. This spontaneous change is called "radioactive decay" or simply "decay".

Half of the radon atoms present at any time undergo radioactive decay in 3.8 days. Although radon is produced continuously by the radioactive decay of radium, it also decays continuously and therefore tends to remain at a more-or-less constant concentration in the natural environment.

Although radon is a gas, it doesn't burn (it is chemically inert) and it has no odor. It can only be detected by special radiation. It is nearly 8 times as heavy as air, which gives it some tendency to settle in hot areas, however, radon is found in such low concentration (of the order of 1 atom for every billion billion molecules of air) that it readily diffuss out of low areas inspite on high density.

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