REPORT ON

INVESTIGATION AND IMPLEMENTATION
OF REMEDIAL MEASURES

FOR

THE REDUCTION OF RADIOACTIVITY FOUND IN BANCROFT ONTARIO AND ITS ENVIRONS

TO

THE ATOMIC ENERGY CONTROL BOARD

FEBRUARY 1979

JAMES F. MacLAREN LIMITED
CONSULTING ENGINEERS, PLANNERS AND SCIENTISTS

Acknowledgements

James F. MacLaren Limited would like to thank members of the Atomic Energy Control Board who have provided direction and guidance throughout this preliminary stage of the program.

We would also like to acknowledge the co-operation and assistance of the following groups in providing us with background information and/or use of laboratory facilities.

- Ontario Ministry of Environment
- Ontario Ministry of Natural Resources
- Ontario Ministry of Labour
- Ontario Ministry of Health
- Madawaska Mines Limited
- DSMA/Acres Project Staff - Elliot Lake, Ontario
- Chalk River Nuclear Laboratories
- Representatives of Project Area Municipalities

In addition we would like to express our appreciation to individual homeowners for the continued co-operation and patience extended to members of the project team.

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12 February 1979

Dr. R. S. Eaton
Chief
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Atomic Energy Control Board
270 Albert Street
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Dear Dr. Eaton:

In accordance with the requirements of the agreement dated February 1978 between Supply and Services Canada and James F. MacLaren Limited, we are pleased to submit this Report on Investigation and Implementation of Remedial Measures for the Reduction of Radioactivity Found in Bancroft Ontario and Its Environs.

The report contains the evaluation of compiled radiological and engineering data obtained from detailed investigations at a cross-section of sites in the project area. As required by the Terms of Reference an overall program including schedules and cost estimates is included to assist the Atomic Energy Control Board in determining the nature and extent of further work remaining to be completed.

All of which is respectfully submitted,

Yours very truly,

JAMES F. MacLAREN LIMITED

E. J. Chart, P.Eng.
Project Director

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Summary

A program for the investigation and implementation of remedial measures to accomplish the decontamination and control of radioactivity in Bancroft, Ontario and its environs, is currently being carried out for the Atomic Energy Control Board. As a follow-up to the preliminary survey conducted by the Federal-Provincial Task Force on Radioactivity in 1977, the ongoing project has identified natural radioactivity and contamination of cultural (man-introduced) origins as the sources responsible for elevated radiation levels in a number of buildings in the project area.

The natural radioactive sources are uranium-bearing mineralizations within the bedrock (generally in localized and sporadic dikes) and, in some instances, boulders of glacial drift.

Contamination of cultural origins has resulted from the uncontrolled spread of waste rock originating from past uranium mining activities. The disposal of mill tailings has been controlled and this source has not been identified as a problem at sites surveyed to date.

Based on detailed investigations at 129 of the 1,167 sites originally surveyed by the Federal-Provincial Task Force, approximately 55 sites were found to have levels in excess of the established criteria for gamma exposure or radon daughter concentrations. From this survey it is projected that in total, 512 sites within the project area will require detailed investigations, and 126 of these will require

remedial work.

It is anticipated that the entire program, can be completed by March of 1981. The total program management and site investigation costs, including costs incurred to date, are estimated at $1,270,000. The total cost for remedial work at the 126 sites is estimated at $673,200. Remedial work at 16 of these sites is currently underway.

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Project Description

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Concern of governmental agencies for the effect of elevated levels of radioactivity on the general public has led to programs of remedial measures for the decontamination of areas throughout North America. Originally centred in Canada on contamination of cultural or man-made origin in Port Hope - Ontario, concern has spread to uranium mining areas where natural radioactive in situ materials are known to be present (Uranium City - Saskatchewan, Elliot Lake and Bancroft - Ontario).

In recognition of the potential for cultural as well as natural sources of radioactivity, a preliminary radiation survey of residences, institutions and commercial buildings in Bancroft and its environs (Fig. 1.1) was carried out between April and September of 1977 by survey personnel provided by the member agencies of the Federal-Provincial Task Force on Radioactivity under the leadership of the Atomic Energy Control Board (AECB). Of the 1167 sites surveyed by the Task Force, 412 or 35% were identified as requiring further detailed investigations to determine the radiation levels in relation to established criteria.

On the basis of the compiled results of the preliminary Task Force survey, proposals for a remedial measures program were solicited by Supply and Services Canada in November, 1977, and a contract was awarded to James F. MacLaren Limited in March, 1978. The requirements of the program, as summarized in the Terms of Reference were:

1) to undertake radiation surveys and investigation of the source of radon gas in built-up areas of Bancroft and its environs;*
2) to prepare a report suitable for public dissemination and as an aid for future program planning based on such investigation;
3) to undertake remedial measures for radiation reduction and radioactive decontamination of Bancroft, Ontario and its environs.

The program initiated in mid-March 1978 and scheduled to be completed by 31 March, 1979, consists of a detailed radiological survey of a cross-section of the 412 original sites identified by the Task Force as requiring further investigations. To date, 129 sites have been investigated and the information compiled at these sites has been used as a data base for: identifying sites where immediate priority remedial action should be taken; identifying the source and magnitude of the radiation problem in structures; developing remedial techniques appropriate to the study area; and developing a program for continued investigations and projection of the total number of sites requiring remedial action and the associated costs.

The investigation involves the measurement of gaseous and particulate airborne radioactivity and ambient gamma radiation in order to estimate mean annual levels for comparison to established criteria. Further studies including soil and water analysis are carried out to determine the source and entry mechanism of radon at the identified problem locations.

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*The environs of Bancroft are defined as including the communities located at Dyno Estates, Paudash, Lower Faraday Road, Coe Hill, Ormsby, McArthurs Mills, Lakeview Road, L'Amable, Gunter, Gilmour, Birds Creek, Maynooth, Bentley Lake Area, Bicroft Heights and Cardiff.

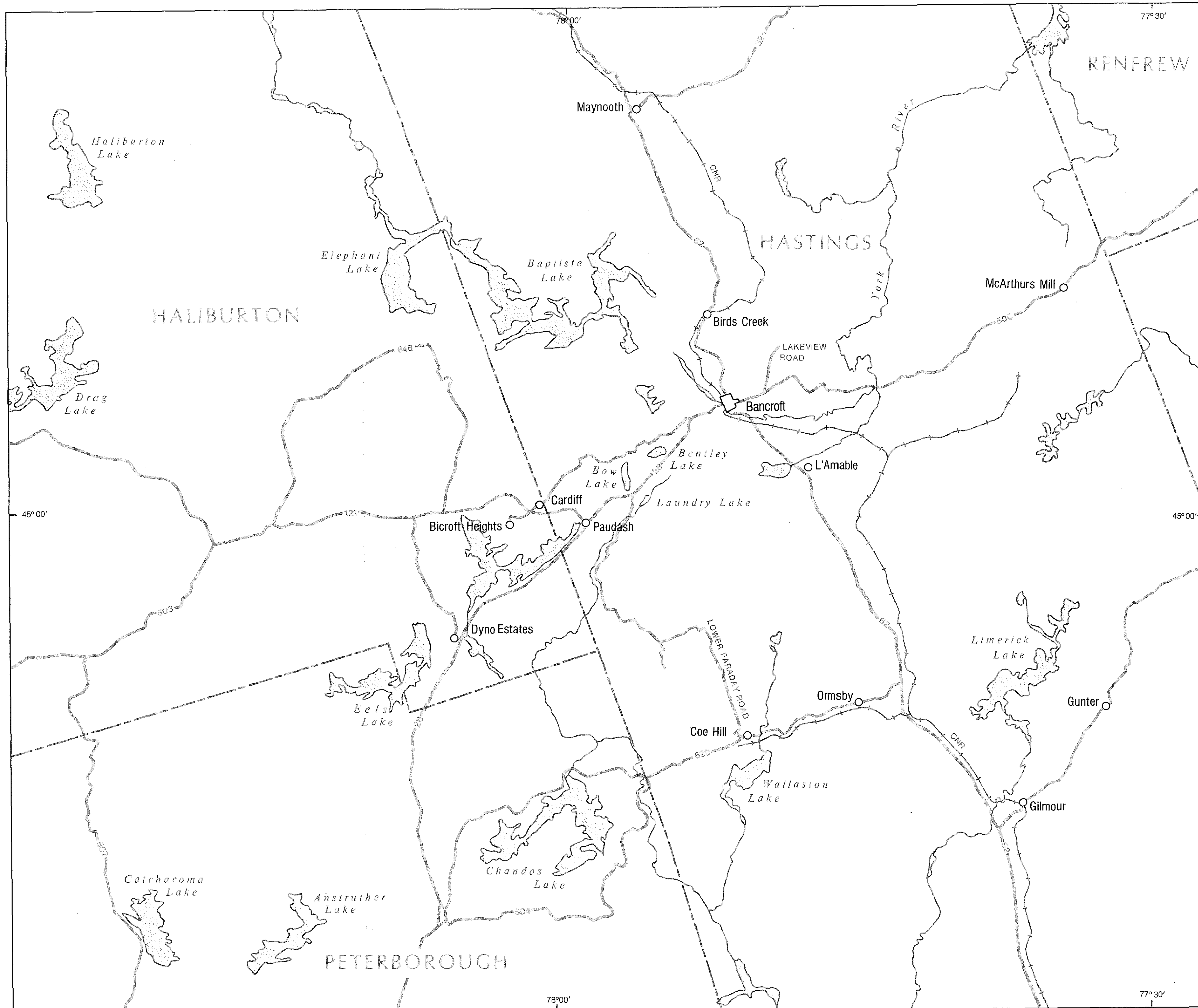


Figure 1.1

Project Area

0 5 10
Kilometres

At sites found to be clearly above the criteria, remedial action is undertaken following the identification of the radioactive source. Where practical, radioactive source materials are removed to an approved waste storage site, or if removal is not practical, other remedial measures such as sealing radon entry routes or improving ventilation are carried out.

Results of investigations to date are presented in this report. A historical and geological review as related to radioactivity is presented in Chapter 2 in terms of published data, field observations, and discussions held with members of various organizations, agencies, and individuals associated with past and present mining activities and geological studies. Information on the health significance of exposure to radiation and details on the Task Force criteria is provided in Chapter 3. Radiological aspects and actual observations of compiled data including details of surface and subsurface gamma measurements, soil and water analyses and radon/radon daughter concentrations are presented in Chapter 4.

Recommended remedial techniques are presented in Chapter 5. A projection of the total number of sites requiring remedial action, estimated costs, and a schedule for execution of further surveys and remedial work are presented in Chapter 6. Basic measurement procedures are presented in the Appendix Section.

Geological Background 2

2.1 General

The purpose of this chapter is to highlight the geological features as well as the mining activities that have combined and led to the current program to reduce radioactive contamination at a number of locations in the project area.

Before discussing these factors, it is important at the outset to bring into focus the relationship of uranium and the radioactive contamination problem.

Most natural occurring uranium decays into certain gamma radiation-emitting elements and ultimately into radon-222 gas. Since gamma radiation levels and radon gas concentrations form the basis for the remedial measures program, uranium is the origin of radioactivity associated with problem sites. Chapter 3 of the report discusses radiation and radioactive decay, and the health aspects in more detail.

2.2 History of Mining

The first European settlement in the area occurred in the mid-nineteenth century (Ref. 1,2) following the development of colonization roads and the issuing of land grants to settlers. Later, as initial mining and lumbering industries declined, and farming proved difficult, most settlers abandoned the area and roads fell into disrepair. Bancroft, however, continued to grow, and with the introduction of rail service (1907) and new highways (1930) became an important centre for mining, lumbering, farming and tourism.

Radioactive minerals have been known to occur in the project area for many years. In 1922 uraninite was discovered in what became the Fission property at Wilberforce in Cardiff Township. An attempt was made to develop this deposit as a source of radium from 1929 to 1931. The property was re-opened in 1947 by Fission Mines, and exploration was carried out periodically until 1955.

From 1932 to 1942, Canadian Radium Mines carried on underground exploration and development on a property at Cheddar in Cardiff Township. In 1939 and 1940, a 90 t/day mill was built on this property, but this was closed after unsatisfactory test runs.

Although prospecting activity was continuous in the area, it was not until 1953, when underground development was started by Centre Lake Uranium Mines (Bicroft Uranium Mines), and important diamond drilling results on the Faraday Uranium property were obtained, that the greatest period of exploration took place. In the period 1953-6 a large number of uranium prospects were opened up in the area. Satterly's 1956 report (Ref. 3) describes the operations at 125 of these prospects.

Of these 125 prospects, four became productive; however, only Bicroft Uranium Mines and Faraday Uranium Mines produced significant amounts of uranium oxide. The two minor producers were Canadian Dyno Mines, in production from 1958 to 1960, and Greyhawk Uranium Mines from 1957 to 1959.

Production at Bicroft Uranium Mines began in 1953 and continued until 1963, when lack of markets for uranium caused its closure.

Underground workings at Faraday Uranium Mines were started in 1954, and production began in April, 1957. This company later became Consolidated Canadian Faraday Limited. Production continued until mid-1964 when termination of the contract for the sale of uranium forced its shutdown.

Total production of uranium oxide in the Bancroft area from 1956 to 1964 was approximately 500,000 kg valued at about $105,000,000. The ore milled to achieve this production totalled some 5,380,000 tonnes.

These mining companies provided housing for their personnel and new communities such as Cardiff, Bicroft Heights, Dyno Estates, Faraday Heights in Bancroft, Greyhawk area (Highway 28), Bow Lake area on the Faraday Mine site and additional housing in Paudash, were developed during this period. These developments naturally, but unfortunately, were located close to the mining activity in areas prone to uranium mineralization.

In 1975 a new company, Madawaska Mines Limited was formed out of the Faraday holdings and production resumed in August, 1976. At the present time the mine is milling 1,400 t/day and producing approximately 23,000 kg of uranium oxide a month.

2.3 General and Structural Geology of the Project Area

The project area is located in the southern part of the Grenville geological province of the Precambrian Canadian Shield.

The two main groups of rock present are the Grenville type, highly metamorphosed sediments, and the plutonic (igneous) rocks (Ref. 3,4).

The oldest rocks in the area are the marble, paragneiss, quartzite and amphibolite of the Grenville series. These rocks were laid down as limestones, sandy and shaly limestones, and sandstones in early precambrian seas.

The rocks of the Bancroft district have been highly metamorphosed (greatly changed by intense heat and pressure). It is believed that the area was once buried to a depth of at least 16 km and that this overlying strata has since been stripped away by erosion, and the once deeply buried rocks are now exposed at the surface. Structurally the area is divided into two contrasting metamorphic terrains: the Haliburton-Hastings Highlands gneiss complex to the north and the Hastings Basin to the south (Ref.4). These two areas are shown in Figure 2.1.

In the Highland gneiss complex three areas of plutonic activity encompass the four original producing uranium mines. These are shown in Figure 2.1. Hewitt (Ref. 1,4,5,6) named the more westerly of these the Cheddar granite, the central one the Cardiff plutonic complex, and the most easterly one the Faraday granite. The Hastings Basin portion of the area to the south according to Hewitt (Ref. 4); "was folded during or after the Grenville orogeny (mountain building period) but was not affected by the granitic centres of intrusion that formed the Highlands area during the orogeny. It may have formed a foreland flanking the mountain-built belt."

A series of south-dipping faults divides the Hastings Highland complex from the Hastings Basin. The south-dipping McArthurs Mills fault (Fig. 2.1) zone can be traced along from Paudash Lake in Cardiff Township, northeasterly along Highway 28, passing just south of the Village of Bancroft.

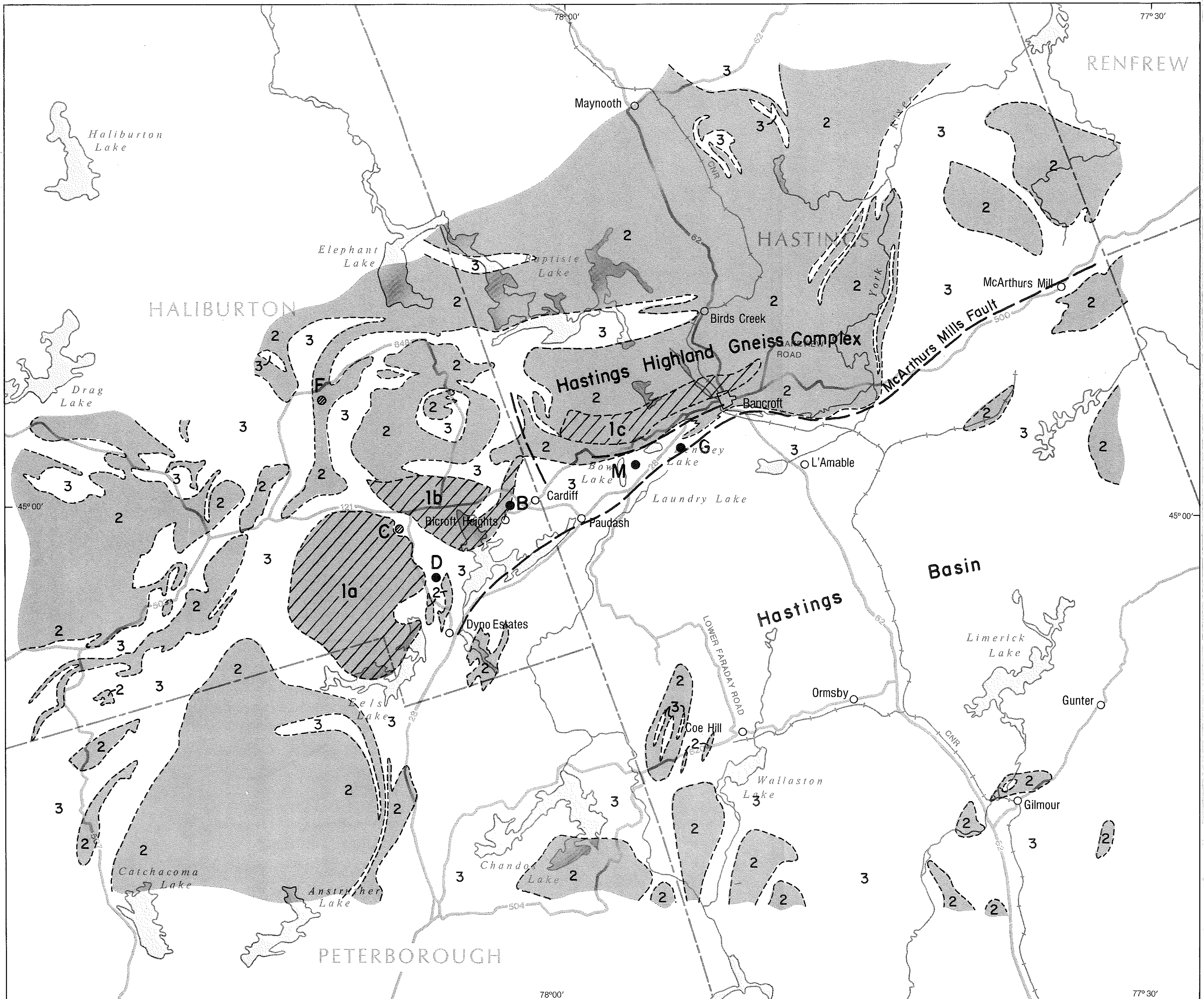


Figure 2.1

Generalised Geology

0 5 10
Kilometres

LEGEND

1 Granite
a. Cheddar Granite
b. Cardiff Plutonic Complex
c. Faraday Granite

2 Granitic and Syenitic Rocks

3 Metasediments, Metavolcanics Basic Intrusive Rocks

Assumed faults

● B - Bicroft D - Canadian Dyno
G - Greyhawk M - Madawaska

◍ C - Canadian Radium
F - Fission Mines

Geology from volume LXVI, Part 3, 1957 and Map 1957-1, and from Map 1957-b, all by D.F. Hewitt, Ontario Department of Mines.

It continues to the east boundary of Faraday Township and eastward through Dungannon and Mayo Townships. This fault was picked up and definitely identified by diamond drilling on the property of Greyhawk Uranium Mines. It is interesting to note that the Greyhawk ore deposits were all north of this fault. No ore was ever found south of the fault on the Greyhawk property.

The youngest rocks in the area are dikes of granite pegmatite, syenite pegmatite and diabase.

During Pleistocene times the area was glaciated. The last advance by the Wisconsin glacier took place about 27,000 years ago and the glacial features of the Bancroft area were formed during this period. The surficial geology is therefore mainly comprised of glacial drift with rock outcroppings occupying a relatively small proportion of the project area.

It is certain that the glaciers would have removed and transported material from any radioactive deposits which were exposed to the surface. Consequently radioactive boulders and gravels can be found in many of the glacial drift deposits.

2.4 Radioactive Occurrences and Their Significance

The previous section described the formation of the natural radioactive occurrences, specifically uranium-bearing deposits, in the project area. It is significant in relation to study findings thus far that these original deposits are believed to have occurred mainly in the area adjacent to one of the three granite bodies and north of the McArthurs Mills Fault, and that the majority of structures in the project area are located in this region. It is interesting to note that in the project area these deposits, unlike those occurring in Elliot Lake and Uranium City, are found in numerous small localized dikes and veins often exposed at the surface.

The following section, which describes the local geology in specific problem areas, illustrates the scattered nature of these numerous natural deposits.

2.4.1 Natural Radioactive Occurrences in Areas North of the McArthurs Mills Fault

Bancroft Village

Bancroft Village is located to the south of the south contact of the Faraday granite sheet. Ninety-five percent of the village is within 1.5 km of this contact. It also lies north of the McArthurs Mills Fault and must therefore be considered to be located well within the zone favourable for the occurrence of uranium bearing deposits.

Consequently, it is not surprising that rock outcrops, showing significant radioactivity in some cases, are found in the gardens and basements of some of the Bancroft homes and buildings.

There are several areas where this is very evident. Several homes on Sherbourne Street North showing elevated radon gas concentrations have radioactive outcrops in the gardens behind the houses. In two cases these are replacement deposits on crystalline limestone, which show high gamma radioactivity. The third is a pegmatite dike which gives moderate gamma readings (Fig. 2.2).

Thus with several radioactive deposits in the immediate area and the reasonable assumption that non-visible deposits lie beneath the houses, the problems in this area can be attributed to these natural geological features.

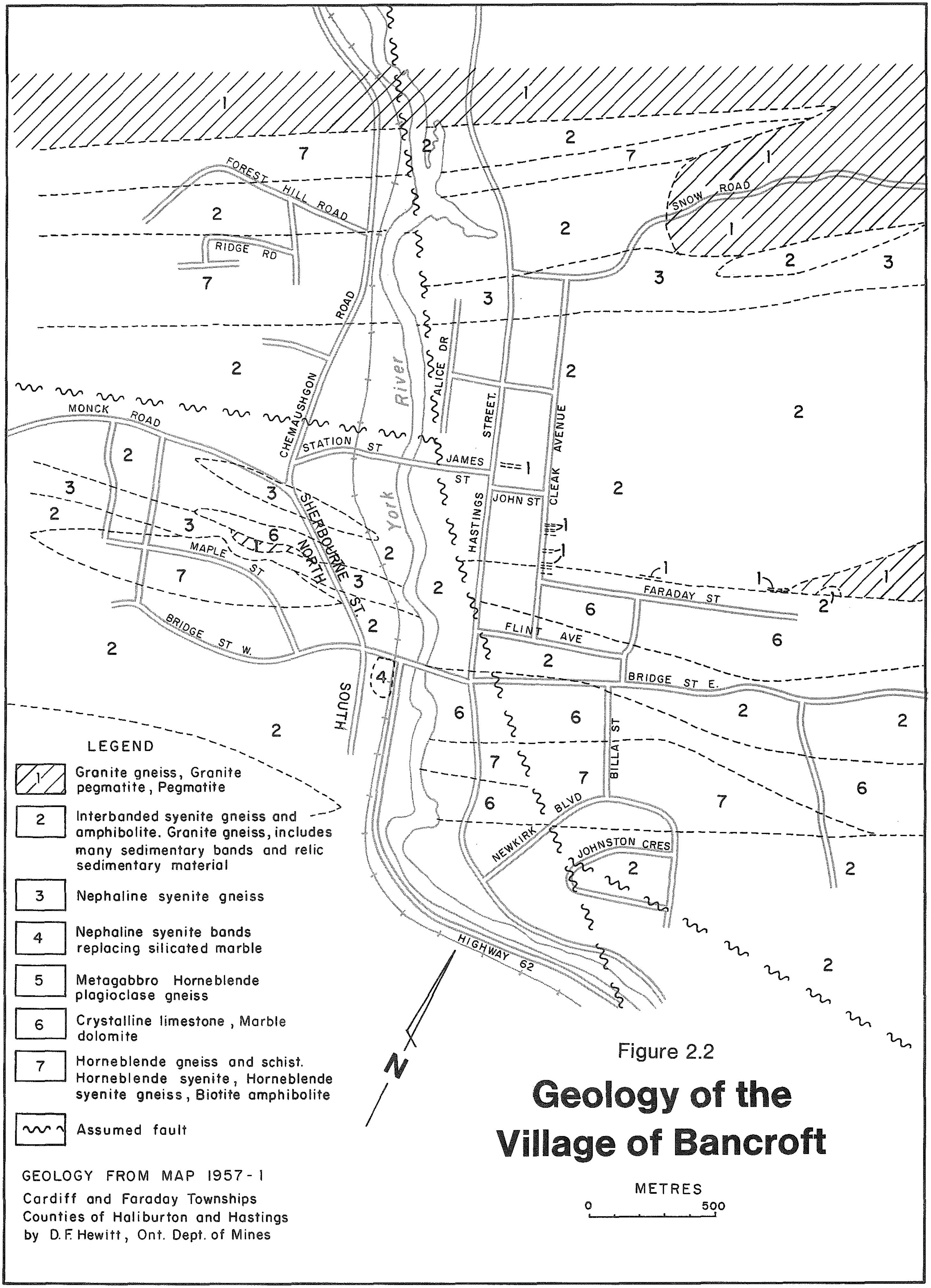


Figure 2.2

Geology of the Village of Bancroft

Another problem area is along the north side of Faraday Street. At the junction of this street and Cleak Street, (Fig. 2.2) a series of pegmatite dikes occur to the north of Faraday Street. Two of these dikes show moderate to high gamma activity. The dikes dip 55-65 degrees to the south and strike approximately 70 degrees northeast, roughly parallel to Faraday Street.

One property in this area has a large outcrop of coarse-grained pegmatite located some 6 m behind the house. At the southwest end of this outcrop, an area of several square metres shows gamma activity some 25 to 30 times background.

At another site in the same area, a large rock outcrop composed entirely of coarse and fine grained pegmatite was found about 3 m behind the house. One small area of this pegmatite also gave readings 20 to 30 times background. This pegmatite dips south under the basement.

At a third site, on Faraday Street, outcroppings were not visible near the house; however, several boreholes behind the house showed significantly increasing radioactivity with depth. Since this location is 60 m east and on strike of the pegmatite outcropping on Cleak Street, it may be assumed that this radioactivity is caused by a buried dike or dikes.

The conclusion, based on these findings, is that these dikes extend eastward through all the gardens behind the houses on the north side of Faraday Street.

At another problem site, in the vicinity of Hastings Street North, John Street and Cleak Street, a one metre coarse-grained pegmatite dike was found running parallel to John

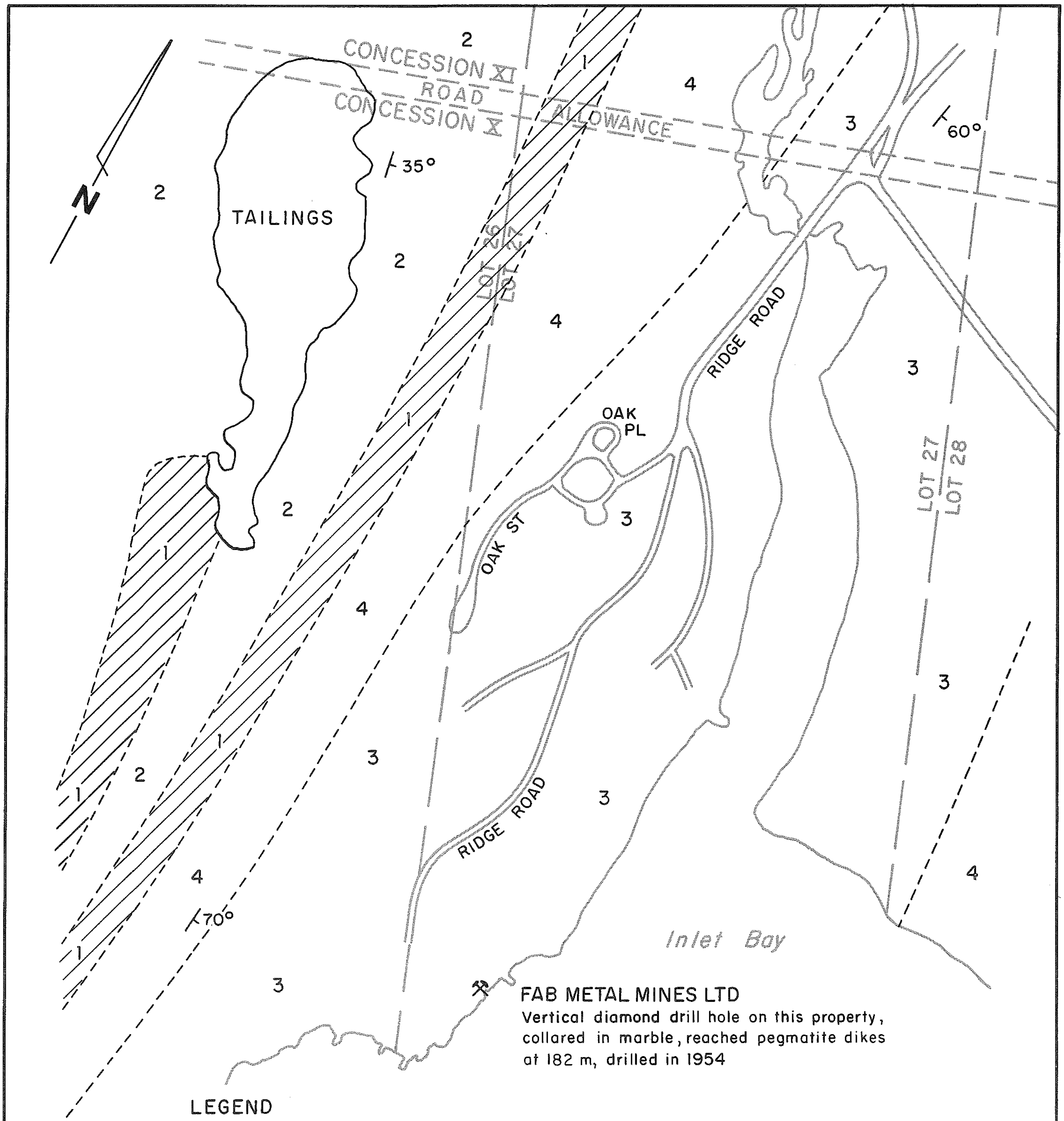
Street on the north side. It is exposed for some 20 m in an east-west direction and shows significant radioactivity. This dike dips to the south and in one case forms part of a basement wall.

On Cleak Street, a problem structure is located directly on strike of this dike and several other narrow dikes. A very narrow pegmatite dike, with only minor radioactivity was found in the garden of this site. However, it seems reasonable to assume that some or all of the pegmatite dikes found in the Hastings Street outcrops could extend eastward into this property on Cleak Street, a distance of only 60 m.

In summary, it is concluded that the significant source of radioactivity in the Village of Bancroft is the natural geology. It is also significant that the problem structures surveyed so far in the Village of Bancroft have exhibited some of the highest radon concentrations found in the project area. These findings are discussed further in Chapter 4.

Bicroft Heights

Homes in this area are situated on an area completely underlain by marble (crystalline limestone). The nearest rock which might be radioactive, is a wide pegmatitic granite dike outcropping some 200 metres to the west of the houses. This dike dips 60-70 degrees to the east, and would pass beneath the Bicroft Heights residences at a vertical depth of 90-120 metres below surface. This has been definitely established by a vertical diamond drill hole, located on the shore of Inlet Bay, approximately 200 metres east of Bicroft Heights. This hole cut some pegmatite dikes at a vertical depth of 182 metres (see Fig. 2.3).



LEGEND

1	Granitic rocks. granitic pegmatites
2	Syenitic rocks. syenite gneiss
3	Marble. silicated marble
4	Paragneiss. amphibolite

GEOLOGY FROM MAP 1957-1
Cardiff and Faraday Townships
Counties of Haliburton and Hastings
by D.F. Hewitt, Ont. Dept. of Mines.

Figure 2.3

Geology of Bicroft Heights

METRES
0 500

While there are some conflicting opinions in the literature about the migration of radon from deposits at great depth, the possibility that such a deposit could contribute to the problem in this particular area cannot be ruled out. Other definite sources of radioactivity in this area are discussed in a later section.

Cardiff Townsite

This area is completely underlain by marble. There are no known radioactive deposits within 2.5 km of the townsite. One rock outcrop was found at the back of a house in this area but it consisted entirely of marble and gave only background gamma readings. The source of the problem in this area is discussed in later sections.

The Bentley Lake Development, 5 km west of Bancroft is located within 1.5 km south of the south contact of the Faraday granite. It is underlain by metagabbro and amphibolite. It is thus in the favourable zone for the occurrence of uranium deposits.

Dyno Estates, 22 km southwest of Bancroft is located within 1.5 km of the Cheddar Granite batholith. It covers an area of paragneiss and marble with small bodies of granite gneiss and granite pegmatite. This location is definitely within an area favourable for the occurrence of uranium deposits.

Birds Creek and Maynooth, 6 and 24 km respectively north of Bancroft, are located well north of the Faraday granite. They are underlain by granite gneiss and granite pegmatite. Very few radioactive occurrences have been found in these formations and none are near Birds Creek or Maynooth.

Paudash, 11 km southwest of Bancroft is underlain by marble which is the extension to the southeast of the same marble formation found at Cardiff Townsite 3 km away. It is very unlikely that uranium deposits occur in this area.

2.4.2 Natural Radioactive Occurrences in Areas South of the McArthurs Mills Fault

McArthurs Mills, 22 km east of Bancroft, lies just south of the eastern extension of the McArthurs Mills Fault. It is underlain by amphibolite and a small granite intrusion lying just to the south which might show minor radioactivity. There are no known uranium deposits in this area.

L'Amable, 6 km south, Ormsby, 24 km south, Gilmour, 32 km south, and Gunter, 30 km southeast of Bancroft, are all underlain by marble. With the exception of L'Amable, all are located many kilometres from any known uranium occurrences.

Coe Hill, 22 km south of Bancroft, is underlain by syenite, amphibolite and paragneiss. To date no evidence of unusual radioactivity within the village has been found. There are several outcrops and areas of granite, granite gneiss and granite pegmatite within 2.5 to 5 km west and southwest of Coe Hill. Two of these along Highway 620 (Fig. 2.1), show appreciable radioactivity.

Lower Faraday Road, 8 km southwest of Bancroft, is approximately 3 km south of the Faraday granite contact. It is underlain by paragneiss and marble and is on the south side of the McArthurs Mills Fault. It is thus not in the area favourable for uranium deposits.

2.4.3 Other Factors Related to Radioactive Occurrences

While the natural geological formations described in the previous sections are a major contribution in formulating remedial action, other factors affecting the spread of radioactivity in the study area must also be considered. The discussion in Section 2.3 of glacial transport of radioactive materials may in part explain the presence of abnormal levels of radon in the soil gas in areas of known glacial drift and where rock formations favourable to uranium deposits do not exist. Unfortunately, detailed mapping of the surficial geology of the project area does not exist and therefore, it was not possible to relate this factor directly to specific problem areas. However, Lower Faraday Road which is essentially in an area of glacial drift, runs roughly parallel to the direction of glacial movements, and thus radioactive material from the area of Madawaska Mines could be deposited along the area of Lower Faraday road.

The transport of radon from uranium deposits in ground and surface waters has been documented in many scientific papers. While there is no question that this mechanism of transport is important in dealing with radon problems in mines, a direct relationship between radon problems in surface structures and radon levels in groundwater moving beneath these structures has not been demonstrated. Further discussions on this subject related to specific problem areas are considered in Chapter 4.

Another factor of equal importance to the known uranium deposits as a source of specific problems in the project area has been the transport of mine waste rock through cultural or man-related activities.

The most common source of this material has been rock produced in the development of shafts, drifts, etc., to gain access to ore bodies. Often included in this waste rock is ore of too low a grade to process. The segregation of ore from waste mine rock was usually lax until an electronic separation technique was developed around 1959-60. In the early stages, the Bicroft Mine waste rock was produced in a coarse size (8 cm). However, later all waste rock, from this source and the Faraday Mine, was crushed to a 2 cm maximum size.

Disposal of development waste rock was not controlled and no records were kept of production or subsequent distribution. However, the many thousands of tons of waste rock produced at several mine sites has virtually disappeared. The large size (8 cm) has been observed as backfill around structures, while finely crushed material has been used in road and driveway construction, trench backfill, subgrade material beneath basement slabs and filter material for basement window wells and domestic weeping tile systems.

The presence of biotite in this waste rock is reported to have made it unsuitable for use as concrete aggregate. As discussed in Chapter 4, investigations to date do not dispute this theory.

Development mine waste rock has been observed in most areas of the Bancroft environs. In particular, its use has been observed in Bancroft, Bicroft Heights, Cardiff, Dyno Estates, Paudash and in several intermediate areas. Most deployment of mine waste rock has been within a radius of less than 15-30 km of a mine. Consistent with this observation, no mine waste rock has been observed in more remote areas such as Maynooth or Coe Hill.

Mill tailings contain higher concentrations of radioactive materials than the waste rock but this material has in most cases been held in controlled tailings areas. No mill tailings have been found at sites surveyed in the project area to date.

Another possible cultural source of radioactive contamination that was considered in the program was the uncontrolled distribution of contaminated building materials from the mines and mills during the early period after the shutdown in the 1960's.

At Faraday, there have been at least two structural collapses in the mill area. Reclaimed scrap lumber was placed outside the site and eventually removed by the general public. Contamination of this type thus far has only been observed in one isolated case.

References - Geological Background

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Ref. 4. D.F. Hewitt, "Geology of Cardiff and Faraday Townships, Haliburton and Hastings Counties", Annual Reports and Accompanyings Maps, Vol. LXVI, part III, Toronto, Ontario Department of Mines, 1957.

Ref. 5. D.F. Hewitt, "Uranium and Thorium Deposits of Southern Ontario", Mineral Resources Circular No. 4, Toronto, Ontario Department of Mines, 1967.

Ref. 6. D.F. Hewitt, "Cardiff and Faraday Townships, Haliburton and Hastings Counties, Ontario", Annual Reports and Accompanying Maps, Map No. 1957-1, Toronto, Ontario Department of Mines, 1957.

Remedial Action Criteria and Related Health Significance

3

3.1 General

The biological effects of radiation have been studied since their initial discovery in the early twentieth century. Extremely high radiation exposure can produce obvious symptoms within a few hours, whereas the effects of low level radiation exposure may take many years to become apparent. The radiation exposure from radon daughters in the extremely large concentrations once allowed in uranium mines induced lung cancer many years after the fact. Extrapolation of these radon daughter exposures to relatively small concentrations has resulted in establishing concentrations below which there are no noticeable increases in the lung cancer rate of the general population. A discussion of established radiation exposure criteria must first consider the various forms of radiation and the resulting biological effects.

3.2 Radiation

Radiation is simply the emission of energy through space or through a material medium. Radiation has been present in man's environment since the beginning of time. For instance, electromagnetic and sound waves are forms of radiation. Radiation may also appear in the form of corpuscular emissions such as alpha radiation, or rays of mixed or unknown type such as cosmic radiation. Radiation is emitted by many naturally occurring elements contained in the earth's crust such as potassium, thorium, uranium and radium.

3.2.1 Gamma Radiation

A gamma ray is short wavelength electromagnetic radiation of nuclear origin. Its characteristics are the same as an x-ray except the x-ray is of extranuclear origin and usually of long wavelength. Gamma rays are emitted from natural elements in the earth's crust and from the sun in association with cosmic rays.

One consideration in the established criteria (discussed in Section 3.3) is the gamma radiation exposure resulting from naturally occurring elements. The reason for the limiting criteria is to avoid undue risk of biological damage known to result from exposure to gamma radiation. The primary biological considerations associated with this low level gamma radiation exposure are the disruption of white blood cells which can induce leukemia, and the translocation and breaking of genetic cells or chromosomes which can result in latent birth defects.

Gamma rays are measured in terms of the units called Roentgens (R). One Roentgen is a quantity of gamma radiation that produces a given amount of electrical charge (2.58×10^{-4} coloumb) in a kilogram of air; this unit of measurement is thus related to the biological damage caused by producing electrical charges in cells of the body. The criteria refers to gamma radiation measured in milli-Roentgen per hour (mR/h); this is simply one-thousandth of a Roentgen exposure in a one-hour time period. Instruments used in this study measure gamma radiation in units of micro-Roentgen per hour (uR/h): one-millionth of a Roentgen exposure in a one-hour time period.

3.2.2 Radon and Its Daughters

Through decay (radioactive disintegration) of certain elements (nuclides) contained in the earth's crust, spontaneous transformation into one or more different nuclides results in the emission of certain types of radiation. The original nuclide is commonly called the parent and the decay nuclides are referred to as the daughters. For example, where the parent uranium-238 is present so will its daughter radium-226 be found.

Radon-222 gas (radon) is a decay product of the naturally occurring nuclide radium-226; hence, radium is the parent of radon. Radon is a noble gas, i.e., it does not readily combine chemically with other materials and as such will readily migrate or diffuse through air, soil and various structural materials. It can enter a structure through various influx routes and develop large concentrations within that structure in much the same manner as would a small natural gas or propane leak.

Radon gas, in turn, decays into nuclides that are radioactive particles and are commonly referred to as radon daughters. These daughters are electrically charged and attach themselves to dust, smoke, etc., in the atmosphere. The radon decays into the first daughter, which is also radioactive and this daughter then decays into the second daughter, and so on. Decay occurs primarily through the emission of alpha radiation. Being in the air the daughters can be inhaled and locate themselves next to live body cells in the lung. On decay the alpha particles will be absorbed and may impart their energy to the cell in such a way as to destroy or damage the cell control mechanisms. Hence, inhalation of these radon daughters can produce biological damage and possibly induce lung cancer over the long term.

Therefore, the other consideration of the limiting criteria discussed in Section 3.3 is the avoidance of undue risk of biological damage known to result from exposure to radon daughters. Radon daughters are measured in units called working levels (WL). The WL unit was adopted in 1957 following recognition that the air-borne radiation exposure to the human lung is predominantly due to the radon daughters filtered out of the respired air by the lung, and not to the gaseous radon component in the air. The WL is concerned with the alpha radiation only and relates directly to energy of the alpha particle which can be absorbed by body cells. One WL is defined as any combination of the short-lived decay products (daughters) of radon-222 in one litre of air that will result in the emission of 1.3×10^5 million electron volts (MeV) of alpha energy. Thus, this is a measure of the potential biological damage. Accumulated exposure is expressed in terms of working level month (WLM) which is based on a 173 hour work month.

3.3 Criteria

Criteria for acceptable levels of radiation exposure were established by the Federal-Provincial Task Force on Radioactivity in April, 1977. Acceptable levels of radiation exposure to the general public are generally set at 1/10 the maximum permissable occupational exposure i.e., exposure to people working in controlled radiation environments.

3.3.1 Gamma Radiation

The gamma radiation exposure limit for radiation workers is 5 R/yr, and the limit for the general public is 0.5 R/yr from which a maximum exposure rate of 0.050 mR/h may be derived. The risk associated with the general public limit would be an expected additional cancer rate of 0.1 cases per year per 10,000 people, and the additional genetic risk for lifetime would be 0.04 cases per year per 10,000 people. Comparing these risks to natural risks (those expected without regard to radiation exposure), 15 fatal cancer cases per year per 10,000 people in Ontario, and 17 genetically-related cases per year per 10,000 people for lifetime are current statistics (Ref. 1,2).

The following summarizes the gamma exposure criteria for radioactive cleanup in Canada (Ref. 2):

<u>Gamma Radiation Inside Buildings</u>

Prompt Interim Action	-	greater than 0.10 mR/h (100 uR/h) at 1 m above floor in centre of room
Primary Criterion	-	greater than 0.05 mR/h (50 uR/h) at 1 m above floor in centre of room
	-	greater than 0.05 mR/h (50 uR/h) at 0.5 m above a localized area

<u>Gamma Radiation Outside Buildings</u>

Primary Criterion	-	greater than 0.10 mR/h (100 uR/h) at 1 m above bare ground*
	-	greater than 0.25 mR/h (250 uR/h) at 1 m above the surface of an existing road averaged over a distance of 1 km**

* The outdoor level takes into account the fact that people spend no more than half their time outdoors during the course of a year.

** Level based upon the maximum likely exposure of regular road users, for roads that are constructed of naturally radioactive materials.

The values summarized above are intended for use in actual or potential living or occupied areas and apply to the average gamma exposure rate over the course of one year. All values are based on conservative assumptions to ensure that no member of the general public will receive exposure in excess of the annual limit.

3.3.2 Radon Daughters

As previously stated acceptable levels of radiation exposure for the general public are set at one tenth of that permitted for radiation workers. To obtain the general public exposure limit for radon daughters from occupational limit for radiation workers, an additional correction is made for breathing rate and time of exposure. From this the Federal-Provincial Task Force has derived a radon daughter concentration limit of 0.02 WL for inhabited structures (Ref. 2). Normally, radiation protection regulations limit only those exposures that are in addition to natural background radiation but criteria for radiation cleanup include the background radiation since many areas under investigation have radon daughter levels exclusively due to natural background; hence, an added safety factor is included in this exposure limit.

The risk due to continuous exposure to a concentration of 0.02 WL exposure rate is estimated to be 0.15 cases of lung cancer per year per 10,000 people. This risk may be compared to the normal incidence of lung cancer in Ontario which is 3 cases per year per 10,000 people (Ref. 2).

The following summarizes radon daughter exposure criteria for radioactive cleanup in Canada (Ref. 2).

Radon Daughter Levels Inside Buildings

Prompt Interim Action	- greater than 0.15 WL*
Primary Criterion	- greater than 0.02 WL*
Investigation Level	- greater than 0.01 WL*

*Using an average value of 0.3 for the Equilibrium Factor results in radon concentration equivalents as follows:

Prompt Interim Action	- greater than 50 pCi/L
Primary Criterion	- greater than 7 pCi/L
Investigation Level	- greater than 3 pCi/L

The above values are intended for use in actual or potential living or occupied areas of homes and other buildings and they apply to the average concentration over the course of one year.

References-Remedial Action Criteria and Related Health Significance

Ref. 1. International Commission on Radiological Protection, ICRP Publication No. 26.

Ref. 2. Federal-Provincial Task Force on Radioactivity, Working Party on "Radiation Criteria; Recommendations", December, 1976.

Radiological Aspects 4

4.1 General

The radiological aspects of the project are intended to accumulate measurements and data for comparison with the criteria discussed in Chapter 3 of this report. Stringent instrument calibrations and operational checks have been routinely performed to maintain the accuracy of radiological measurements. Additionally, measurements have been taken by qualified physicists and trained technicians to ensure that proper techniques and data interpretation were employed.

A sample group of 129 sites was selected, for detailed radiological investigation, from the Task Force list of 412 sites, to form a basis for the following project requirements:

- identifying the source and nature of the radioactive contamination in the project area;
- defining the number of sites and costs for the total remedial program;
- formulating remedial techniques suitable for eliminating the problems in the project area;
- selecting sites for priority remedial works.

It was recognized at the outset that these requirements would dictate concentrating the survey effort at those sites classified by the Task Force survey to be above the remedial action criteria level (0.02 WL). However, it was also recognized that if sites falling below this criteria were not included in the sample, an unbiased projection of the total magnitude of the problem could result since a large proportion of the 412 assigned sites were in the investigative range, i.e., between 0.01 and 0.02 WL. In order to eliminate this bias in the application of the detailed survey results, the Task Force data was subdivided into three categories or ranges:

- low range (sites between 0.010 and 0.015 WL);
- middle range (sites between 0.016 and 0.025 WL);
- upper range (sites above 0.025 WL)

The logic behind the choice of these ranges is based on previous experience which indicates a low probability of finding remedial action sites (above 0.02 WL over a long sampling period) from a group originally classified in the lower range on the basis of preliminary screening surveys. On the other hand, long term sampling at sites initially grouped in the upper range exhibit a high probability of requiring remedial work.

Those sites falling in the middle range are the most difficult to judge on the basis of preliminary surveys and therefore a sampling of these sites was included in the sample selection.

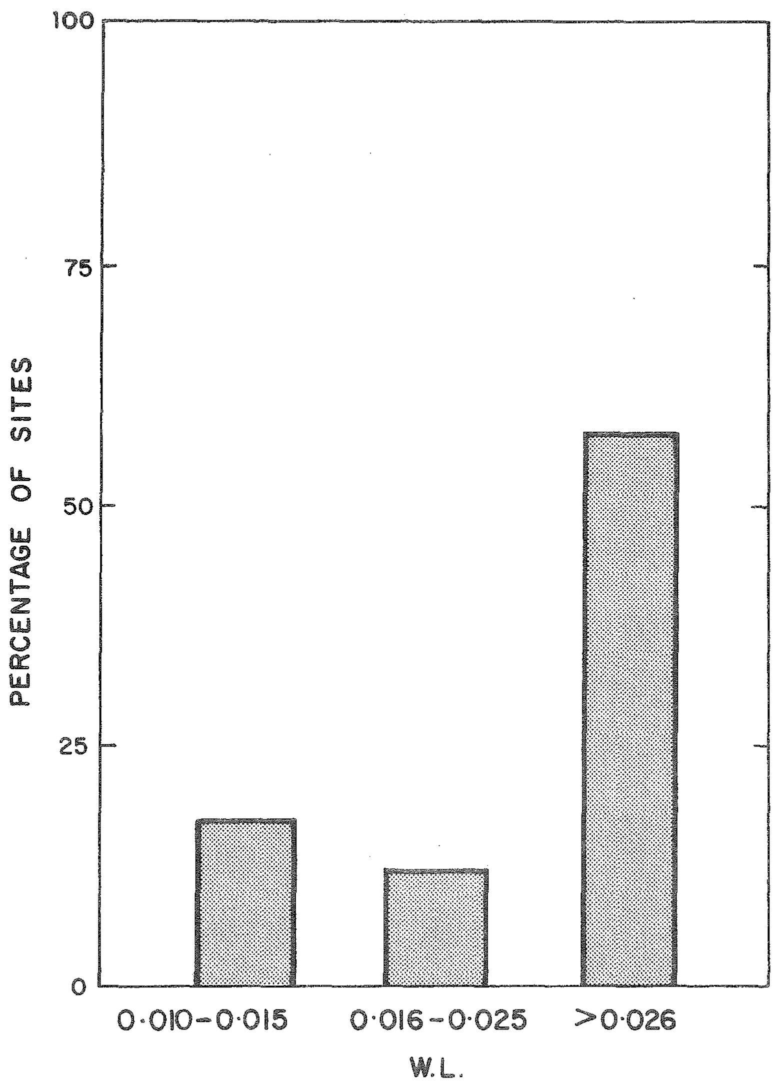
The percentage of selected sites falling into each range or category are shown in Figure 4.1.

4.2 Gamma Radiation

The potential biological effects of low-level gamma radiation have led to the requirement of detailed gamma surveys being carried out on all structures and areas under investigation. Previous studies in Grand Junction, Colorado and Port Hope, Ontario have shown that such surveys were necessary primarily due to the presence of radioactive source materials which when measured were in excess of established criteria.

Figure 4.1

Distribution of Task Force Working Levels



CATEGORIES OF TASK FORCE WORKING LEVEL MEASUREMENTS AT 129 SITES

Experience on the Bancroft study has demonstrated that radioactive sources at problem sites do not generally exceed established gamma exposure criteria. However, the diagnostic value of these surveys for verifying the gamma criteria has suggested the maintenance of a curtailed gamma survey program. Gamma radiation surveys conducted on the selected sites involved surface examination using grid surveys over interior and exterior areas and subsurface inspection employing borehole loggings around the exterior and under basement floor slabs of existing structures.

4.2.1 Surface Investigations

Surface grid surveys (see Appendix) were performed for the interior and exterior of each site.

a) Exterior Surveys

Results of exterior gamma surveys conducted on 129 sites in the study established a one metre background level ranging from 0.004 to 0.007 mR/h (4 to 7 uR/h) with a mean of 6 uR/h. At sites where gamma levels are above this normal background (anomalies) the measured radioactivity can generally be traced to its origin, i.e. a natural or cultural source. Naturally occurring sources are in the form of minerals within bedrock or glacial drift. Sources of radioactivity from cultural origins are generally in the form of low concentrations of mineralization in waste mine rock. This crushed waste rock is prevalent throughout localities in Bancroft and environs, where it has been used extensively as granular base on roads, driveways, and as a backfill material around or under foundations, building services and lawns. Figure 4.2 shows details of measured background gamma levels and anomalies of various locations in the project area.

Details of the measured background gamma levels are shown along the left ordinate axis (Column A) and the percentage of total sites with specific anomalies is shown along the right ordinate axis (Columns B-E). A summary for the entire project area is incorporated in the legend. Of the 129 sites investigated only 3 were observed to have gamma radiation levels exceeding criteria while anomalies were identified at 58 individual sites.

b) Interior Surveys

Interior grid and contamination surveys were performed at the selected sites. The interior gamma one metre background level was established at a mean of 6 uR/h with a range of 4-9 uR/h.

Sources of abnormal radioactivity inside structures can be attributed to mineralization in field stone foundations, natural rock outcroppings, sub-floor radioactive occurrences (both natural and cultural), and occasionally to radioactive stones used in fireplaces. A total of 14 sites were found to have interior gamma radiation levels in excess of background but only one of these sites (rock in fireplace) actually exceeded criteria. The interiors of these sites were also scanned for possible surface contamination using beta-gamma and alpha radiation detection equipment. No contamination was observed at any of the interior sites investigated.

4.2.2 Subsurface Investigations

Subsurface investigations by borehole logging (see Appendix) at exterior and interior structure areas were used with considerable success to determine subsurface radiation anomalies. Typical borehole log profiles are shown in Figure 4.3.

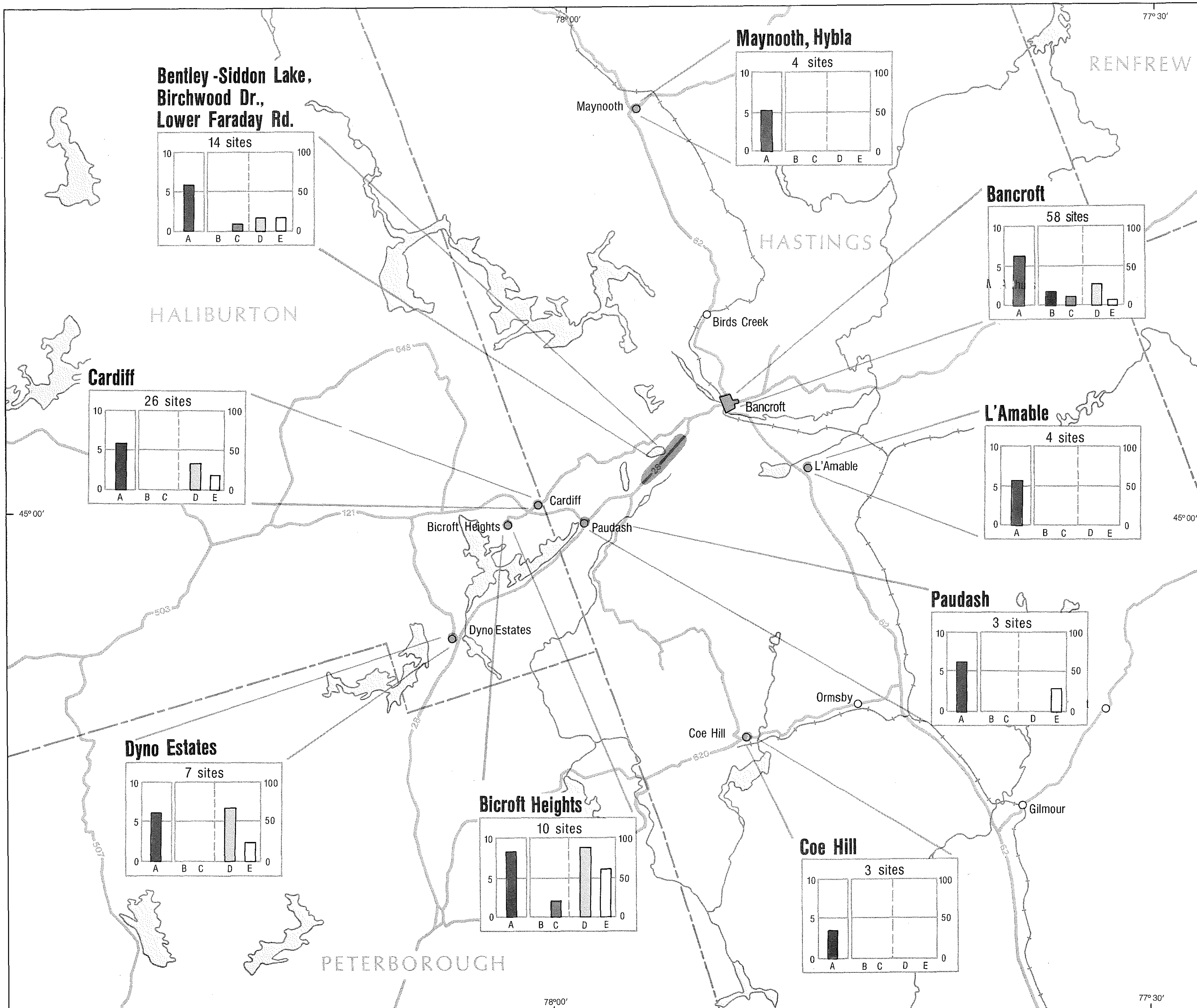
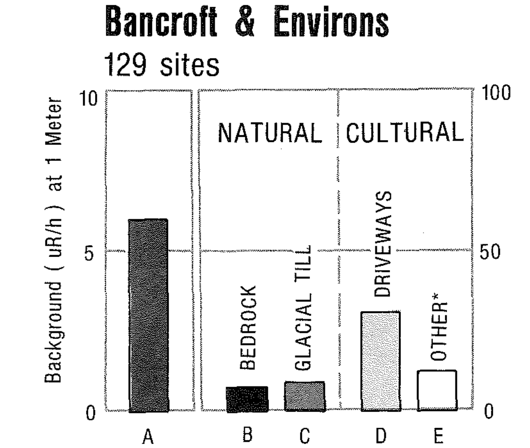


Figure 4.2

Exterior Background Gamma Levels and Anomalies

0 5 10
Kilometres



*OTHER : Backfill, Lawns, Window wells

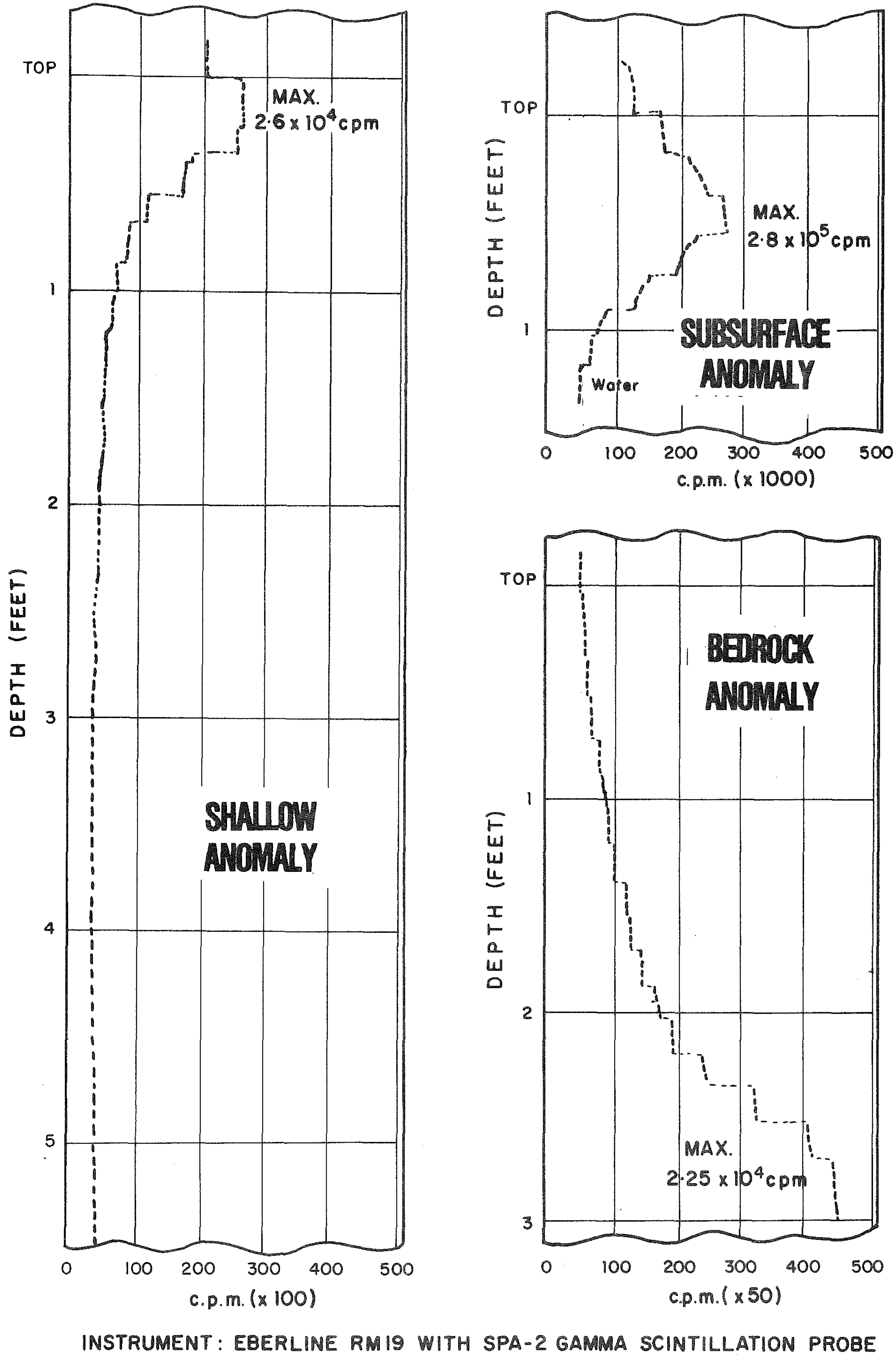


Figure 4.3

Typical Borehole Log Profiles

a) Exterior Boreholes

A total of 382 exploratory boreholes were logged at 82 sites. Subsurface anomalies include bedrock at 6 sites and waste rock at 28 sites. Since all anomalies were observed at sites with elevated interior radon levels, future subsurface exploration will be limited to those sites with abnormal radon concentrations.

b) Interior Boreholes

A total of 31 interior boreholes were logged at 12 sites. Interior borehole logging was normally performed at sites with abnormal radon concentrations where gamma surveys indicated possible sub-floor source material or where source material was not identified from the exterior surveys. Of the 12 sites, radioactive occurrences attributed to bedrock were noted at six and waste mine rock was identified at three. At the remaining three sites no radioactive sources were observed beneath the floor.

4.3 Radioactivity in Soil

Radioactivity in soil has been studied with regard to the soil radium concentrations and radon concentrations in the soil gas. Although radium concentrations in soil appear comparable to Elliot Lake, this study indicates that more specific sources can be identified in the majority of cases. Analysis for thorium content has also been performed to assess the potential of radon-220 (thoron) interference (Sect. 4.5.3. d).

4.3.1 Soils

Soil samples were analysed for radium-226 and thorium-228 by the Chalk River Nuclear Laboratories using a germanium-lithium (Ge-Li) detector as a gamma spectrometer. A field laboratory procedure was employed to analyse the emanating radium-226 in the soil (see Appendix). The emanating radium content (the radium free to emanate radon) is significantly lower than the total radium content since much of the radium is sealed within the crystalline structure of the mineralization. A comparison of the two techniques indicated a correlation between total radium and emanating radium content in soils but a poor correlation in mine rock depending on the degree of fragmentation.

a) Laboratory Analysis (Ge-Li)

A total of 12 samples were analysed for radium-226 (^{226}Ra) and thorium-228 (^{228}Th) with the results shown in Table 4.1.

TABLE 4.1

Radium and Thorium Content of Soils

Identification	Concentration Range (pCi/g) ^{226}Ra	^{228}Th
Natural overburden	0.2 - 0.9	0.4 - 1.0
Mine waste rock	34.0 - 183.0	17.0 - 25.0
Comparable Data from Other Locales (Ref. 1,2)		
Elliot Lake overburden	0.7 - 1.0	N.A.
Uranium City overburden	0.1 - 1.1	N.A.
World-wide overburden	0.3 - 4.0	N.A.
Uranium City waste rock	21.0 - 22.0	N.A.

b) Emanating Radium Analysis

This field laboratory procedure facilitated the analysis of 67 samples resulting in the categorical observations shown in Table 4.2.

TABLE 4.2

Emanating Radium-226 Content of Soils

Identification	Concentration Range (pCi/g) Emanating ^{226}Ra
Background (13 sites)	0.06 - 0.2
Overburden problem sites	0.06 - 0.8
Mine waste rock	0.2 - 6.3
Bedrock deposits	4.1 - 1,500
Concrete core (from basements)	0.06 - 0.2

Background samples listed (13 sites) were collected at locations where no radiological problems were identified. Other samples were collected inside or adjacent to problem structures and confirm the significance of mine waste rock and bedrock deposits as sources of radon.

4.3.2 Soil Gas

Since it is believed that a radon "cloud" can extend hundreds of metres around a significant source when soils are porous, measurements of radon concentrations in soil gas are routinely used for uranium prospecting. Similarly, concentrations of radon in soil gas can be used to aid in isolating possible emanating sources associated with problem sites. Samples of soil gas were collected by two methods, one incorporating the use of perforated PVC collection tubes and the other a metal soil gas probe (see Appendix). A combination of the porosity of local soils and the facility of sampling made the metal probe the more frequently employed technique.

A total of 63 soil gas samples (9 samples by the perforated tube method) at 14 sites were analysed for radon gas concentrations.

Background radon concentrations in soil gas were found to be in a range of 30-900 pCi/L. In areas known to contain abnormal amounts of radioactive material, soil gas tests have shown 4 to 10 times (700-7000 pCi/L) more radon near source material than was observed in areas remote from the source but on the same site. Soil gas studies in Elliot Lake indicate comparable concentrations ranging from 30-6000 pCi/L (Ref. 1) around structures with high interior radon concentrations.

The broad range of background soil gas concentrations found in the project area limits the usefulness of this technique as an absolute method of determining potential problem areas. However, this method has proven useful in locating source material at individual problem sites.

4.4 Radioactivity in Water

Concentrations of radioactivity in water is an important aspect of the diagnostic procedure with respect to transport of radon. Although a direct relationship between radon problems in surface structures and radon concentrations in ground water moving adjacent to or beneath the structure has not been demonstrated, the possibility of this phenomenon affecting a structure cannot be ignored. One studied structure has shown that its domestic water supply contains relatively high radon concentrations which have produced elevated radon daughter levels inside the structure through de-emanation of the water when it is used within the structure.

A total of 19 water samples were collected from wells, lakes, creeks and ground deposits. These samples were analysed using the water de-emanation technique (see Appendix) for radon (^{222}Rn) and radium (^{226} Ra). The results are shown in Table 4.3.

TABLE 4.3

Concentrations of Radon and Radium in Water

Identification	Concentrations (pCi/L) ^{222}Rn	^{226}Ra
Background, potable water (wells & lakes)	11 - 540	0.8 - 7.4
Background, lakes and streams	62 - 450	1.7 - 3.7
Background, groundwater	90	3.7
Waste rock deposits, groundwater	3,000	140
Potable well, one observation (Sect. 4.5.3 c)	51,000	18
Comparison from Previous Bancroft Area Study (Ref. 3)		
Streams	23	0.9
Lakes	3	0.9
Swamps	20	0.9
Springs	120	0.4

With the exceptions of the waste rock groundwater and the single potable well samples listed above, concentrations compare favourably to those reported throughout the western hemisphere.

Previous data compiled by the Ministry of the Environment involving 15 wells in the project area (Cardiff Township), indicated that 60% of the radon concentrations were in excess of 2,000 pCi/L. A similar study in the United States, conducted in an area of elevated natural radioactivity, indicated that 44% of groundwater samples exceeded 2,000 pCi/L (Ref. 4).

4.5 Radioactivity in Air

Radon and radon daughter concentrations in air are of primary concern in the Bancroft project area. Since significant gamma levels are uncommon, these air concentrations are the primary limiting factor with regard to criteria. Data collected during this study includes outdoor ambient sampling as well as interior sampling, since outdoor levels constitute the lowest possible concentration inside a structure.

4.5.1 Exterior Sampling

Ambient air samples were collected using grab sampling techniques and integrated samplers (see Appendix). Grab samples taken in the Bancroft environs, (at 0600 hours and 1600 hours on days of relatively minimal wind velocity), indicated background ambient radon levels from 0.1 - 1.0 pCi/L. Ambient radon concentrations exceeding this background range were measured in only one area: a development adjacent to Madawaska Mines Mill Tailings Area #2, where the range was 0.5 - 6.3 pCi/L (Sect. 4.6).

Figure 4.4 shows details of measured ambient levels at various locations throughout the project area. Average morning and evening levels are indicated along the left ordinate axis (Columns A & B). A summary for the entire project area is incorporated in the legend. Similar ambient levels were observed in Elliot Lake (Ref. 5).

4.5.2 Interior Sampling

Enclosed structures normally accommodate a build-up of radon, since they inhibit the natural disbursement of soil gases

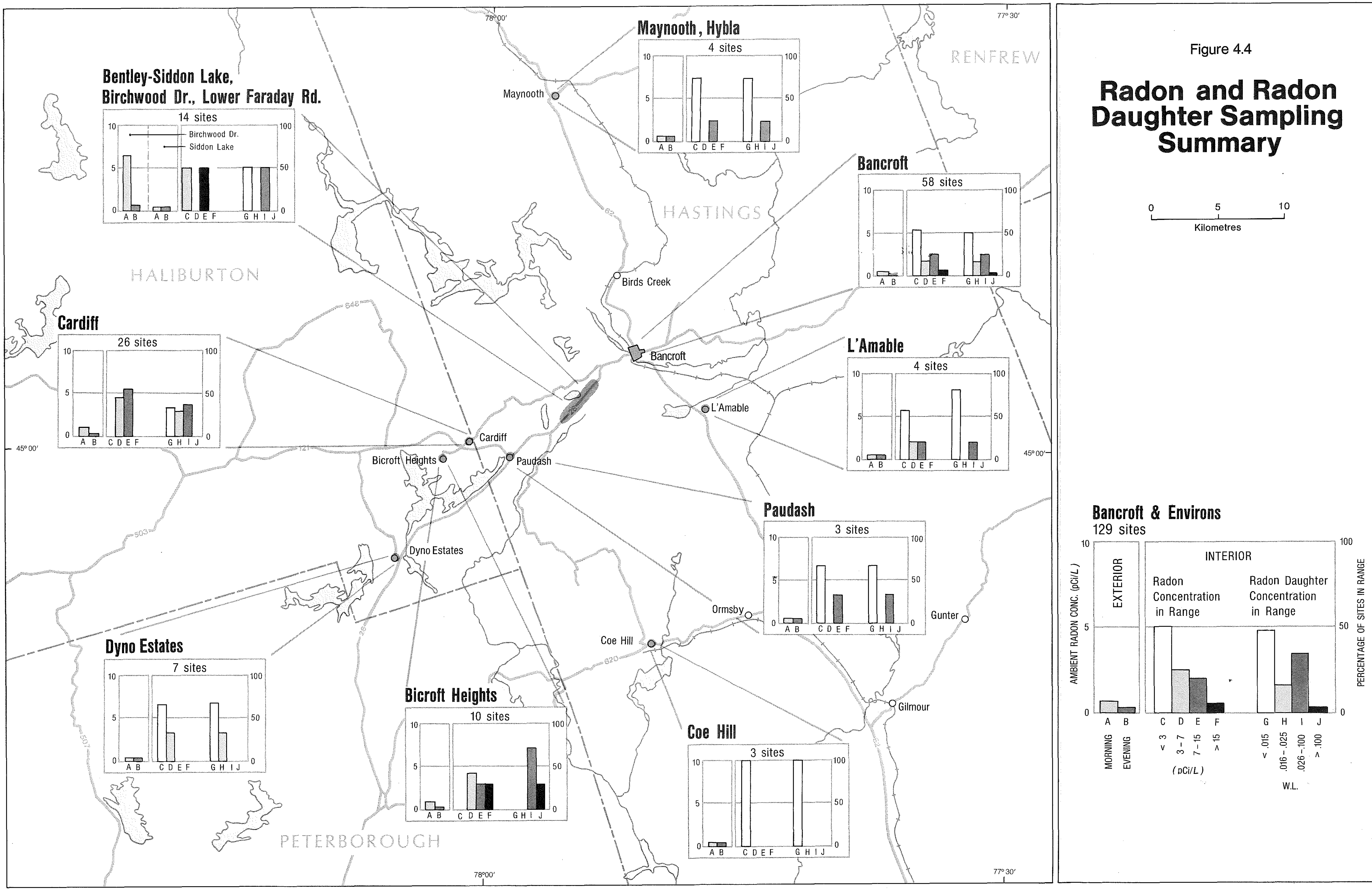


Figure 4.4

Radon and Radon Daughter Sampling Summary

into the open atmosphere. If a structure happens to be placed over or near a natural deposit of radioactive minerals, or if radioactive materials are placed near or against the structure during construction, the radon emanation rate is increased which can result in unacceptable concentrations inside the structure.

Investigation involving detailed study of interior concentrations and influx routes revealed several additional considerations which are discussed in Section 4.5.3.

a) Radon and Radon Daughters

Radon concentrations in air have been measured by employing scintillation cell "grab" samples (see Appendix). Radon daughter samples were collected simultaneously with the radon samples and the concentrations were calculated using the modified Kusnetz Method (see Appendix). Although radon concentrations are not a rigid part of the criteria, measurements are necessary to evaluate entry routes and to provide a better understanding of sampling conditions by observing the ratio of radon to radon daughters. Over 800 air samples from the 129 individual sites were analysed for radon and radon daughters. The distribution of radon and radon daughter concentrations in each area is shown in Figure 4.4 along the right ordinate axis (Columns C-J) of each individual graph. The summary for the total Bancroft and environs area is incorporated in the legend for definition. Figure 4.4 shows distinct variations throughout the project area with higher concentrations evident in Bancroft and Bicroft Heights. The higher concentrations in Bancroft can be attributed to natural occurrences and the concentrations in Bicroft Heights to extensive use of waste mine rock.

b) Radon Influx

Radon can enter a structure through several routes; it can pass through cracks and openings in concrete walls and floors and weeping tile connections to sumps or floor drains. A comprehensive survey for influx routes of radon involved 171 flux measurements (see Appendix) made in and around sites exceeding remedial criteria. Results are shown in Table 4.4.

TABLE 4.4

Radon Flux Measurements

Description	Radon Flux
Surface of waste rock deposit	6.4 $pCi \cdot m^{-2} \cdot s^{-1}$
Earthen floor	0.03-44.0 $pCi \cdot m^{-2} \cdot s^{-1}$
Concrete floor (cracked)	0 - 1.3 $pCi \cdot (m\ crack)^{-1*} \cdot s^{-1}$
Concrete floor (sound)	0 - 0.83 $pCi \cdot m^{-2} \cdot s^{-1}$
Concrete walls (sound)	0 - 0.92 $pCi \cdot m^{-2} \cdot s^{-1}$
Floor/wall joints	0 - 4.2 $pCi \cdot (m\ Crack)^{-1*} \cdot s^{-1}$
Floor drains, sumps & holes	0 - 5.8 $pCi \cdot s^{-1}$
Elliot Lake Comparison (Ref. 1,6)	
Concrete floor (sound)	0 - 0.28 $pCi \cdot m^{-2} \cdot s^{-1}$
Concrete floor (cracked)	0.56 $pCi \cdot (m\ crack)^{-1*} \cdot s^{-1}$

* Per metre of floor crack

Various studies and published data reveal considerable discussion with regard to the passage of radon gas through poured concrete structures. A report on studies performed in Colorado, using uranium mill tailings adjacent to a concrete slab, indicated a flux of 0.26 $pCi \cdot m^{-2} \cdot s^{-1}$ through sound concrete from a 40,000 pCi/L concentration source (Ref. 7). Studies in Elliot Lake noted fluxes ranging from 0 to 0.28 $pCi \cdot m^{-2} \cdot s^{-1}$ through sound concrete from source concentrations ranging from 50-1,000 pCi/L (Ref. 6). These fluxes were partially attributed to the radium content of the concrete aggregate in the wall. Unpublished studies conducted in Uranium City, have shown that mine waste rock source material similar to that found in the Bancroft area, below a 10 cm thick concrete (approximately 34% porosity) slab with no visible defects, produces a flux of about 1.1 $pCi \cdot m^{-2} \cdot s^{-1}$ (Ref. 8).

There are, of course, many factors that influence the ability of radon to enter a structure and it is difficult to be simplistic and generalize on the subject. However, two factors that interact and seem to play an important role in the matter are:

- the design, material quality and placement methods used in the construction of poured concrete foundation systems;
- the magnitude and location of the source material producing radon adjacent to the structure.

The manufacture and placement of concrete in housing construction is not normally a well-controlled process and therefore the quality and soundness of the final in-place product is extremely variable. An excess of water or cement added to the mix during manufacture or placement causes abnormal shrinkage during the curing process inducing a multitude of cracks, many of which are invisible under normal inspection.

These conditions, along with other variables, such as actual in-place density and thickness all combine to make evaluation of the radon barrier qualities of <u>existing</u> concrete structures more of an art than a science.

It has been found, however, that when the radon source is remote and the soil gas concentrations around the structure not excessive, a reasonably competent concrete floor and wall system, with all obvious migration routes sealed, will limit the influx of radon to a rate that can be handled by normal structure ventilation.

On the other hand, when a large radon producing source is close to a structure, experience has shown that the barrier provided by the concrete may not reduce the flux rate enough to prevent an unacceptable radon buildup inside the structure. Under these conditions, other techniques must be employed to either reduce the radon concentration adjacent to the structure or enhance the capabilities of the foundation system as a radon barrier. Foundations constructed of concrete block have special problems and these are discussed in Chapter 5.

4.5.3 Special Considerations

a) Equilibrium Factors

When radon daughters are in equilibrium with the parent radon, a concentration of 1 working level (WL) is approximately equivalent to 100 pCi/L. Since 4-6 hours decay time is required for radon daughters to essentially establish secular equilibrium, the ventilation and/or leak rate of a structure causes dilution of the daughters which creates a situation where there is more radon present than daughters. An additional consideration in this disequilibrium situation is the plate-out of radon daughter particles on interior surfaces, i.e., the charged daughter particles are attracted and attached to other charged surfaces.

The percent of radon daughters present in the air compared with the amount of radon is known as the equilibrium factor (F) which is calculated by:

$$F = \frac{WL \times 100}{pCi/L} \times 100$$

An annual average value for F of about 30% has been speculated from previous studies as typical. However, average equilibrium factors established in the Bancroft area for the months of April through December 1978, indicate a probable mean annual equilibrium in excess of this value with the highest averages in the summer months (Fig. 4.5). Only data obtained from basements containing radon concentrations greater that 2 pCi/L were used to calculate mean monthly equilibrium factors.

Concentrations of condensation nuclei (particles in the air) appears to be a significant consideration with regard to variation in the equilibrium factor. Variations in monthly relative humidity and absolute humidity distributions (Fig. 4.5) measured in sampled structures indicate a seasonable variation similar to that observed for equilibrium factors.

Studies of the radon-220 (thoron) daughters present in the air have indicated they contribute about 8% to the Kusnetz working level alpha count rate (Sect. 4.5.3 d). This thoron contribution tends to slightly bias WL measurements resulting in a proportional equilibrium increase. Additionally, seasonal variation in structure ventilation rates affect the radon daughter equilibrium factor (Sect. 4.5.3 b).

b) Structure Ventilation

Radon concentrations inside a structure are related to the dilution provided by exterior air. The ventilation (dilu-ion) rates of individual structures are related to many factors, e.g., cross ventilation from open windows and/or doors, temperature gradients between inside and outside air, structure occupancy, and heating system operation. A study performed on two houses in Ottawa (Ref. 9) closely parallels conditions observed in the Bancroft area: leakage during the winter depended primarily on the stack effect of the house, furnace operation and surface winds whereas summer leakage depended on the surface winds alone. The average rate of closed structure air changes decreased in the summer to 39% and 32% of winter rates respectively. Summer closed ventilation rates were found to approximate an average 0.15 air changes per hour while winter closed ventilation rates averaged 0.35 air changes per hour.

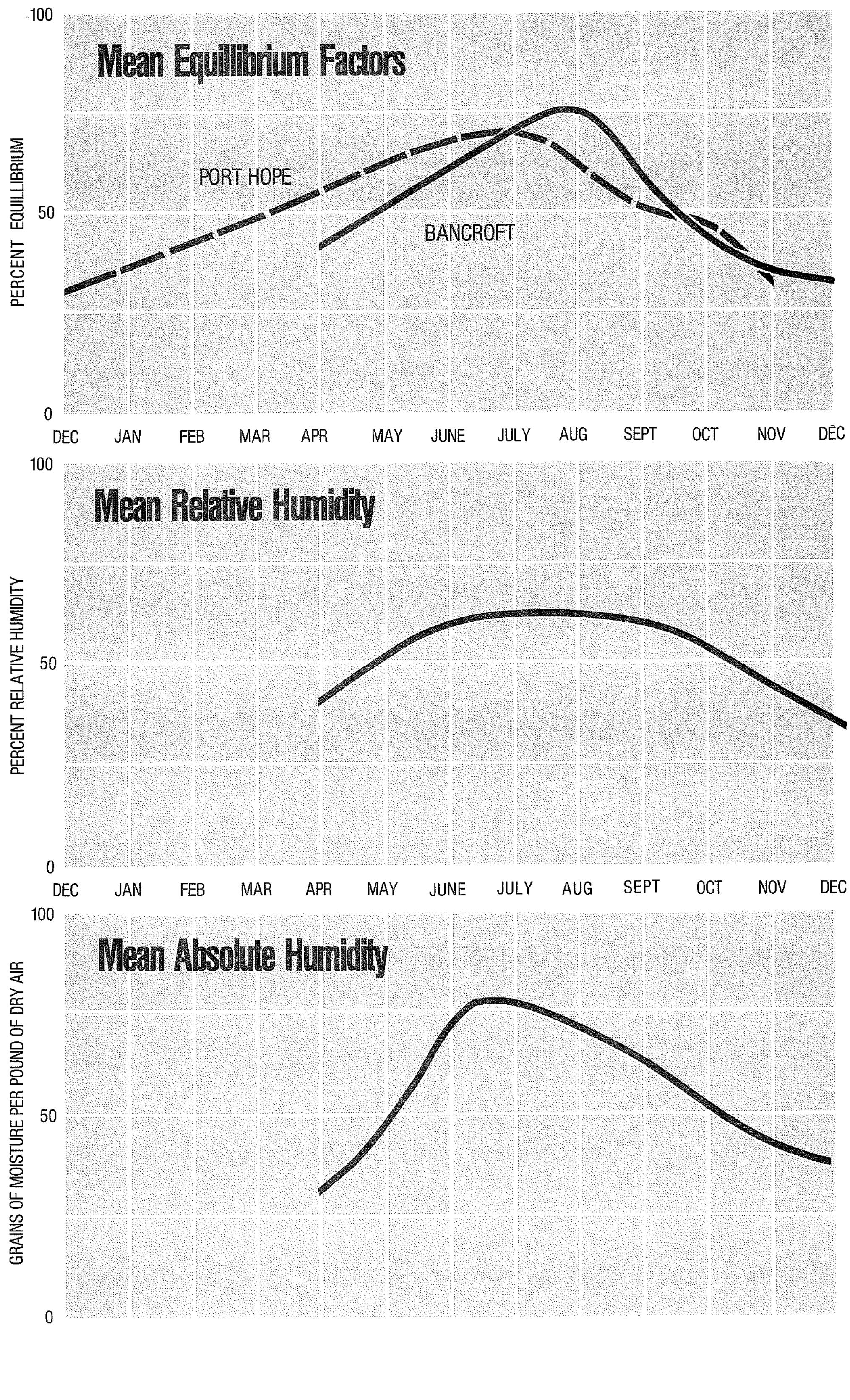
Structure ventilation conditions are of prime importance to the radon/radon daughter sampling program. Using the "fail safe" philosophy that data biased high will result in appropriate decisions regarding need for remedial measures, an attempt is made to sample structures under closed conditions. Samples collected under these conditions are considered to represent maximum potential concentrations and resulting data are used for comparison with established "annual average" criteria.

c) Shower De-emanation of Radon

Previous studies in the United States by the Environmental Protection Agency has indicated that radon in potable water will cause an increase in indoor radon levels (Ref. 4).

Figure 4.5

Mean Monthly Equillibrium and Humidity Factors (1978)



Experiments in Houston using a shower with a flow rate of 13.4 L/min of water containing 634 pCi/L radon increased interior concentrations in a 6.7 m^3 bathroom from 0.5 pCi/L to 13.4 pCi/L over a 12 minute period.

One structure in the project area has an average basement radon concentration of 11.6 pCi/L. The potable water supply to the structure is from a drilled well near an area suspected of containing uranium deposits. Water samples from this well have shown radon concentrations up to 51,000 pCi/L. The basement shower, two baths, and several water faucets are used regularly by the six occupants of the structure.

To test the possible effect of the water supply on the radon levels in the structure, an air sample measuring 6.3 pCi/L was taken in the basement shower stall before turning on the water. After turning the water on at a typical flow rate for two minutes with the shower curtain closed, a further air sample indicated a radon concentration of 193 pCi/L; this converts to a total radon release of about 4×10^5 pCi. Assuming normal shower usage and an air change rate of 0.15 h^{-1} and thorough air mixing in the entire structure, an average structure radon concentration of 8 pCi/L could result from this shower alone.

Radon sampling in the structure at the end of a two-day unoccupied period indicated an average concentration of 4.6 pCi/L in the basement.

d) Radon-220 Contribution

Radon-220, commonly called thoron, is a relatively short-lived isotope ($T_{\frac{1}{2}}$ = 54 s) in the thorium-232 (natural thorium) decay series. Thoron and radon are identical chemically, but differ in their nuclear composition. Thoron decays through one very short-lived daughter to ThB which subsequently beta decays to two other alpha decaying short-lived daughters.

Studies on the concentration of thoron and its progeny have been performed in mines where the abundance of natural thorium is greater than normally observed. A study in 1971 in an Alaskan uranium mine containing an uranium/thorium ratio of 3:1 indicated that radon daughter working levels were generally twice as high as thoron daughter working levels (Ref. 10). Similar ratios were observed in Elliot Lake (U:Th=4:1)(Ref. 5). However, in the Bancroft area the thorium content of one of the most common radioactive minerals (uranothorite) is far higher with an average U:Th ratio of 1:4.4 (Ref. 11). This high content of natural thorium has led to investigating possible thoron daughter interference with radon daughter working level measurements and consideration of health effects related to thoron daughters.

The thoron daughter interference with radon daughter filtered samples was established by observing filter decay for five to ten hours after sampling. This indicated a decay in the counting rate that approximated the half life of ThB (10.6 h). Counts due to thoron daughters observed at some time later than five hours after sampling (i.e. after the radon daughters have decayed) can be extrapolated back to the Kusnetz counting time using a decay constant equal to that of ThB. By subtracting the back extrapolated counts from the earlier count, a corrected radon daughter working level can be obtained. In general, the correction required when the thoron daughter counts are considered results in an 8% reduction of the radon daughter working level. The resultant discrepancy is generally not considered significant relative to sampling variables and other errors inherent in working level measurements.

The biological effect of thoron daughters has not been rigourously assessed and hence examination is limited to a concentration measurement. By definition, one working level is any combination of short-lived radon daughters in one litre of air which will result in the ultimate emission by them of 1.3×10^5 MeV of alpha particle energy. This definition can be extended to thoron daughters of which ThB is most abundant. The thoron daughter working level is probably an overestimate of the radiological hazard compared with the radon daughter working level because an appreciable portion of ThB ($T_{1/2}$ =10.6 h) will have been cleared from the respiratory system before alpha emission occurs (Ref. 12).

Thoron daughter working levels have been calculated at a number of sites in the project area employing a method developed by the U.S. Public Health Service (Ref. 13) in which filter counting occurs five hours after sampling. Table 4.5 shows simultaneously measured concentrations of radon and thoron daughters at a number of sites. Measured and corrected radon daughter and thoron daughter levels are shown with the associated radon concentration. Generally the ratio indicates radon daughter working levels were found to be about twice those of thoron daughters.

TABLE 4.5

Simultaneous Thoron and Radon Daughter Measurements in the Bancroft Area

Location	Radon (pCi/L)	Radon Daughter (WL) Initial	Radon Daughter (WL) Corrected	Thoron Daughter (WL)	Ratio Radon Daughter/ Thoron Daughter
1	15.6	.149	.136	.097	1.4:1
2	2.4	.015	.014	.008	1.8:1
3	15.2	.108	.097	.092	1.1:1
4	10.6	.078	.072	.023	3.1:1
5	7.2	.066	.061	.041	1.5:1
6	18.7	.166	.154	.023	6.7:1
7	4.9	.031	.029	.011	2.6:1
8	8.1	.078	.076	.008	9.5:1
9	1.3	.011	.010	.008	1.3:1

4.6 Summary of Radiological Aspects by Locality

Studies to date indicate that the radiological problems in each of the project area localities can be related to specific causes. These observations are briefly summarized as follows:

Bancroft Village is located in an area very prevalent to concentrated uranium-bearing mineralization with outcrop rock in some cases emitting up to 1,000 uR/h gamma radiation on contact. Although limited use of waste mine rock can be observed in the community, most structures with relatively high radon concentrations are associated with adjacent radioactive mineralizations. Subfloor excavations at one such structure confirms the presence of parallel deposits directly beneath the structure.

Paudash is in an area where natural radioactive occurrences are neither expected nor observed. Radioactive waste mine rock (up to 300 uR/h gamma radiation on contact) has been observed to have been used as land fill.

Cardiff is in an area where natural radioactive occurrences have not been observed, however, extensive use of radioactive waste mine rock on roads, driveways (up to 100 uR/h gamma on contact), and as backfill material, is evident throughout the townsite. Low level radon concentrations (below 7 pCi/L) prevalent in most problem sites appear to be related to the entry of soil gas through weeping tile systems and cracks in structure foundations.

Bicroft Heights is in a location not expected to contain natural activity, although a possible subsurface source exists (Sect. 2.4.1). Extensive use of radioactive waste mine rock has been observed on all roads and driveways (up to 200 uR/h gamma on contact) and as backfill around and under structures, on lawns, in window wells (up to 300 uR/h gamma on contact) and as retaining walls. It would appear that waste mine rock is the significant source of radioactivity at problem sites in this community.

Dyno Estates is in an area considered geologically favourable to natural radioactive occurrences although such occurrences have not been observed. Waste mine rock of low activity (up to 30 uR/h gamma on contact) has been used to a limited extent. Although investigations to date have not been sufficient to specifically identify all sources of radioactivity at problem sites it is probable that waste mine rock is the predominant contributor.

L'Amable-Detlor area is not favourable to natural radioactive occurrences and has not had any observed deployment of waste mine rock. Generally structures do not exceed remedial criteria.

Coe Hill-Ormsby area to the southwest, Gunter-Gilmour area to the southeast, McArthurs Mills area to the east and Maynooth-Birds Creek-Hybla area to the north all have generally unfavourable geological forms for natural radioactive occurrences and no observed use of waste mine rock. Interior concentrations have not exceeded remedial criteria at any of the investigated sites.

Birchwood Drive, a residential development located within close proximity of Madawaska Mines Mill Tailings Area #2, has been found to experience tailings-related effects which concern this study. Area #2 is an inactive tailings pond covering 34 hectares of land directly opposite Birchwood Drive.

Gamma measurement contours, related to "shine" from the tailings area (Fig. 4.6), indicated elevated background levels. Thermoluminescent dosimeters (TLD) within structures on Birchwood Drive established exposure rates in a range 12 - 17 (±5) uR/h.

Ambient air grab samples indicated radon concentrations as high as 13.4 pCi/L on days of negligible wind in the yards facing the tailings area. Adjacent to structures, concentrations from grab samples have been observed to range from 6.3 pCi/L on days of negligible wind to less than 1.0 pCi/L with a wind from the north at 20 km/h. A 24 hour integrated sample taken adjacent to these same structures measured 4.3 pCi/L with the wind from the north-west at 9 km/h. The generally high baseline data observed in this area requires further detailed study to differentiate the effects of local source material and those of the tailings area. The results of these tests will be used to establish the requirements for remedial action.

Figure 4.6

Birchwood Drive Gamma Level Contours

READINGS (μR/hr, at 1m) FROM TAILINGS DISPOSAL AREA No. 2 MADAWASKA MINES

Bicroft Mines Waste Rock Disposal and Tailings Area

At the non-operating Bicroft Mine, a swamp adjacent to the mill has been used as a disposal site for development waste rock and mill tailings. Gamma measurements at one metre above the surface of the area filled with waste rock ranged from 100 - 290 uR/h, and radon exhalation rates measured approximately 8.3 $pCi \cdot m^{-2} \cdot s^{-1}$; this data indicates the waste rock is a significant radon gas source. Gamma measurements at one metre above the tailings pond area, immediately adjacent to the west side of the access road, range from 100 - 500 uR/h, at one metre. In both cases, access is unrestricted and there are indications that materials are being removed from these sites.

References – Radiological Aspects

Ref. 1. Dilworth, Secord, Meagher and Associates Limited, and Acres Consulting Services Limited, "Investigation and Implementation of Remedial Measures for the Radiation Reduction and Radioactive Decontamination of Elliot Lake, Ontario", report to the Atomic Energy Control Board, January, 1978.

Ref. 2. Keith Consulting, "Investigative and Remedial Measures for the Radiation Reduction and Radioactive Decontamination in Uranium City, Saskatchewan", report to the Atomic Energy Control Board, March, 1978.

Ref. 3. R.J. Morse, "The Surficial Geochemistry of Radium, Radon and Uranium near Bancroft, Ontario, with Applications to Prospecting for Uranium", Ph. D. Thesis, Kingston, Ontario, Queen's University, 1970.

Ref. 4. Kurt L. Feldman (ed.), "Radiological Quality of the Environment in the United States", EPA 520/1-77-009, Washington, D.C., U.S. EPA, 1977.

Ref. 5. James F. MacLaren Limited, "Environmental Assessment of the Proposed Elliot Lake Uranium Mines Expansion, Vol. 2 - Background Information Update, Vol. 4 - Environmental Assessment", report to Denison Mines Limited and Rio Algom Limited, 1978.

Ref. 6. Dilworth, Secord, Meagher and Associates Limited, and Acres Consulting Services Limited, "Radon Diffusion Through Concrete", Elliot Lake Technical Note No. 2, February, 1978.

Ref. 7. M.J.V. Culot et al, "Radon Progeny Control in Buildings", Fort Collins, CO., Colorado State University, 1973.

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Ref. 9. G.T. Tamura and A.G. Wilson, "Air Leakage and Pressure Measurements on Two Occupied Houses", ASHRAE Journal, Vol. 5., 1963.

Ref. 10. R.L. Rock, "Sampling Mines Atmosphere for Potential Alpha Energy Due to the Presence of Radon-220 (Thoron) Daughters", MESA Information Report 1015, Washington, D.C., U.S. Department of the Interior, 1975.

Ref. 11. J. Satterly, "Radioactive Mineral Occurrences in the Bancroft Area, Hastings, Haliburton, and Peterborough Counties", Annual Reports and Accompanying Maps, Vol. LXV, part VI, Toronto, Ontario Department of Mines, 1956.

Ref. 12. T.L. Odgen, "A Method for Measuring the Working Level Values of Mixed Radon and Thoron Daughters in Coal Mine Air", Ann. Occup. Hyp., Vol. 17, 1974.

Ref. 13. R.L. Blanchard and D.A. Holaday, "Evaluation of Radiation Hazards Created by Thoron and Thoron Daughters", Amer. Industrial Hygiene Assoc. Journal, Vol. 21, 1960.

Remedial Techniques 5

5.1 General

Due to the varying nature of the radiation problems and the different types of construction encountered in the project area, no simple remedial action has a potential for universal success. The solution, therefore, must be based on a detailed evaluation of the radiological problems, discussed in Chapter 4, combined with structural modifications suitable to particular site conditions. Such structural modifications, designed to remove or seal out sources of radiation, have been based on established engineering and construction principles and the technology and procedures developed at other locations associated with radiation reduction programs.

The Atomic Energy Control Board is currently funding a Remedial Demonstration Program in Elliot Lake, Ontario. Data supplied by the Board's consultant on this project (DSMA/Acres) and elements from related projects in Port Hope - Ontario, Uranium City - Saskatchewan, and Grand Junction - Colorado, have all been incorporated into the development of remedial techniques for use in the Bancroft and environs program.

The selection of a remedial technique for a specific site is dictated by radiological aspects (the source of radiation), the type of construction, the quality of workmanship originally employed and the structural condition of the foundation and/or basement floor.

5.2 Local Construction Practices

Construction practices which are unique to the project area and must be considered in the design of any remedial action are discussed in the subsections that follow.

5.2.1 Housing Construction

Detailed investigations performed to date indicate that there is no particular emphasis on a preferred type of house construction in the study area. The structural designs have included field stone foundations - with and without concrete floors, poured concrete foundation walls, block foundation walls, slab-on-grade construction, buildings with combined basements and crawl spaces, buildings with full crawl spaces, and mobile homes set on block foundations. Exceptions to the general observations are in the townsites of Cardiff and Bicroft Heights, where homes have generally been built on poured concrete foundation walls.

Construction details and structural conditions of buildings over or adjacent to radiation sources are very important as each has its peculiarities in terms of providing an influx route for radon gas. Field stone foundations at older structures provide a limited barrier to the influx of radon due to the effects of differential settlement and to deterioration of mortared stonework. Migration of radon through earth floors and open sumps has been well demonstrated both in this study and in related projects.

Structural and shrinkage cracks in poured concrete as well as the normal perimeter crack at the floor/wall construction joint are all known entry routes for radon gas. These structural deficiencies are generally most pronounced in concrete floors which have been poured to substandard thickness, without the benefit of reinforcing steel and without proper bedding. The deterioration of snap-ties left in formed concrete is another possible influx route.

Block foundation construction has its own set of unique conditions that favour radon entry. Radon migrating to the structure can readily enter the wall cavity through the mortar joints or indeed through the web of the block itself (3 to 4 cm thickness). Once in the wall cavity the radon will concentrate to levels several times those measured in the ambient air of the basement. Experience has shown that the prime entry route of radon from the cavity to the interior of the structure is not through the web of the block, the mortar joint or the floor/wall joint but rather over the top of the wall through gaps between the timber plate and the final block coursing. When this entry point is sealed radon levels will be reduced; however, only temporarily as the increased gradient creates new influx routes (block web and mortar joints), and depending on the magnitude of the source, the interior radon levels can again increase to unacceptable levels.

Many of the homes, particularly older ones in the village of Bancroft, have been built either without basements or only with partial basements due generally to the presence of outcrop rock. Floors of these buildings have invariably been built over poorly ventilated or inaccessible crawl spaces permitting the exhaled radon from the soil to develop sufficient concentrations and subsequently migrate through the floor structure to habitable areas.

Varying expanses of rock outcrop have been encountered in the basements of a number of sites. Radiation problems at these sites have been attributed to the radioactive sources in the rock itself, migration of radon through fissures in the rocks and through structural cracks in floors and walls caused by differential settlement of buildings erected on partial rock and soil areas.

5.2.2 Building Services

The majority of buildings in the project area are heated by oil-fired forced air systems; however, a few structures are heated by electrical and hot water radiant heating and by wood burning stoves and furnaces. While it has not been demonstrated that the type of heating system has a significant effect on the radiation levels in a structure the operation of forced air systems, particularly with cold air returns in crawl spaces, can cause the movement of unacceptable radon concentrations from non-inhabitable to inhabitable areas of the structure.

Potable water is supplied by municipal systems in Bancroft and in the larger hamlets; however, rural locations are generally served by dug or drilled wells. While municipal water supplies have not proved to be a problem, well water supplies can be a source of radon entry into a structure when radon is transported in sufficiently high concentrations from a subsurface source.

Sewage disposal varies throughout the area with the majority of buildings in Bancroft and the large hamlets being serviced by municipal sewage systems. At other locations conventional septic tank systems are typical. Although not generally a contributor to the radiation problem of a structure, septic tank systems in a few isolated cases were built on a bedding of waste mine rock. Emanating radon from this source can cause abnormal concentrations in a structure should a suitable route of entry be available.

The connection of footing drains to the building sewer can invariably produce a radon influx route primarily through floor drains if these fixtures are not adequately trapped and kept primed. This particular mode of transport for radon gas is most prevalent in Cardiff where footing drains are used extensively due to a high water table. With exceptions there have been limited use of footing drains at other locations due in part to the free draining nature of the soil and the lack of suitable disposal facilities.

Openings around service conduits entering a structure below grade provide ready access routes for the entry of radon gas into a structure. This entry mechanism can become quite significant if services such as sewer and water lines have been bedded on waste mine rock.

5.3 Remedial Designs

In view of the variable nature of the radiation problem and site conditions encountered in the project area, a number of alternative techniques have been standardized for incorporation into the site specific remedial designs. The following philosophy has been adopted in the selection of techniques and the development of specific remedial designs for sites in the project area.

(i) The techniques should be as "fail safe" as possible and not be dependent on mechanical or electrical systems that require rigourous maintenance.

(ii) The techniques should have a proven success record.

(iii) The techniques selected for any specific site design should be conservative and offer a high probability of initial success and avoid the "piecemeal" approach that is not only costly to the overall program but annoying to the homeowner.

(iv) Such designs should take full account of the magnitude and location of the source, the potential mechanisms of gas transport and the problem of secondary influx routes.

The preferred "fail safe" remedial technique is of course the removal of the source causing the problem. However, experience indicates that source removal is only practical in perhaps 15% of the cases investigated in the project area to date. Other techniques to seal out radon and/or improve natural ventilation of the structure must therefore be employed.

A brief outline of the techniques and designs developed for the remedial program to date are described in the subsections that follow. It should be noted that these techniques and designs listed here are the ones currently being implemented. The list, however, is constantly being reviewed and updated as results of new methods and feedback from installations already in place are evaluated.

a) Interior Source Removal

This work involves removal of waste mine rock used as fill under basement floor slabs. Removal of individual rock in field stone foundation walls or fireplaces is included when appropriate.

b) Exterior Source Removal

Waste mine rock used on driveways and as fill material a-around structures is removed where such material is identified as a significant radon emanating source or where gamma levels exceed criteria.

c) Crawl Space Sealing and Ventilation

Spray application of a close-celled urethane foam material with high thermal insulation properties, in combination with increasing natural ventilation (providing additional outside openings), is used to dilute radon gas emanating from sub-floor areas as well as providing a partial radon barrier.

d) Trap Floor Drains and Sumps

When structural design includes weeping tile connections to sumps or floor drains, air transport of radon from the tile into the house must be considered. This problem may be resolved by rebuilding floor drains and sumps to include a positive primed trap that provides a gas barrier.

e) Seal Cracks and Floor/Wall Joints

The sealing of structural and shrinkage cracks in poured concrete floors and walls, sealing of openings around conduits entering the structure below grade, and the sealing of the perimeter crack at the floor/wall construction joint can lead to a substantial reduction in the influx of radon gas under certain conditions. Sealing of these openings is readily achieved by opening the cracks (routing) to accommodate subsequent application of bonding agents or sealants. Limited long term reduction of radiation levels will be obtained, however, if secondary routes such as provided by invisible temperature cracks and mortar joints in block and field stone walls are present.

f) Install Sub-Floor Venting System

A sub-floor venting system is generally installed where earth floors or badly cracked concrete dictates the installation of a new reinforced concrete floor. This system in conjunction with the new floor is designed not only to provide a barrier to radon entry but also to provide a passive escape route for radon gas (originating from a subsurface natural source) through a stack to the atmosphere, thus minimizing the accumulation of high radon gas concentrations under the floor.

g) Seal Exposed Bedrock

In buildings where bedrock containing radioactive mineralization of fissured rock is exposed, radon emanation is reduced by application of an appropriate sealant or by the installation of a sub-floor venting system over the rock followed by a reinforced concrete cap.

h) Interior Sealant Application

As previously discussed, large radon concentration gradients created by high intensity source material against a structure can accommodate radon passage through walls and floors. This problem generally exists in buildings with concrete block foundation walls, relatively thin concrete floors, and floors with normal shrinkage cracks that are not readily visible. The installation of a continuous barrier on floors and walls using a suitable epoxy sealant has been successfully demonstrated in work accomplished at the Colorado State University (Ref. 1), and in remedial work accomplished at structures built over source material in Grand Junction, Colorado and in Uranium City, Saskatchewan.

i) Exterior Sealant Application

The application of an appropriate liquid polymer sealant to exterior foundation walls decreases the ability of radon gas to pass through foundation walls. This technique has its most common application in conjunction with source removal from areas adjacent to a structure.

j) Mechanical Ventilation

In certain confined areas such as crawl spaces or generally inaccessible locations when natural ventilation or other remedial techniques are not feasible, dilution of inside air by mechanical ventilation must be considered as a possible solution by the remedial designer and evaluated as to its cost-effectiveness. Heating of associated dilution air may be necessary.

k) High Efficiency Filtration or Electrostatic Precipitation

In cases where the ambient outside air contains elevated concentrations of radon gas, filtration and electrostatic precipitation of the inside air must be considered as alternatives by the remedial designer. Such systems continuously remove particulates from the air and have been shown to reduce the working levels in demonstration and permanent installations (Ref. 2). Properly maintained, these systems are reported to be capable of reducing the working level in a structure by 90%.

l) Potable Water Aeration

When radon rich potable water is suspected to be a contributor to elevated radon concentrations in a structure, the most direct solution is of course to connect the structure to an alternate low radon source of supply. However, in some cases this is not always possible. Studies are currently underway to develop methods of aerating potable water supplies and venting the gas before entry into the structure.

The last three methods described (Items j,k,l) all rely on mechanical/electrical systems to reduce concentrations to acceptable levels. Such systems require maintenance and also have associated with them certain operating costs, and as such there is some resistance among the general public to accept these as remedial measures. It should be pointed out, however, that in some circumstances, these systems when properly maintained, offer the only practical alternative to solving the problem. It is also interesting to note that mechanical ventilation systems have been used for years and are continuing to be employed to reduce the hazard of methane gas accumulation in structures built adjacent to or in the proximity of either man made or natural organic waste deposits.

At the majority of sites where radiation measurements exceed the criteria, experience has shown that a single remedial technique is sufficient to reduce radiation to acceptable levels. At a few sites, however, a combination of remedial actions may be necessary to achieve satisfactory radiation reduction.

When conditions encountered indicate that more than one remedial technique may be appropriate, alternatives are evaluated on the basis of cost-effectiveness. At sites where particular remedial solutions are difficult to establish or evaluate, a detailed review is made by the project's technical advisory staff, which is made up of engineering specialists and health physicists. This technical review ensures that each problem site receives complete and careful consideration and that remedial measures which have a high probability of initial success are chosen.

5.4 Waste Management

At sites where radioactive materials such as waste mine rock and debris created by disturbing natural occurring bedrock are found against or below a structure, it may be necessary as part of the remedial work to remove and transport this material to a controlled radioactive waste storage area. For this purpose such an area has been established at the Madawaska Mines Limited Tailings Area No. 2. Total storage requirements for this low level source is not expected to exceed 15,000 tonnes.

Since these materials are solid rock form, it is very unlikely that airborne radioactivity or contamination of equipment and personnel could result through handling. However, in the event handling of source material with different consistency or higher radioactivity than that observed to date becomes necessary, control and decontamination techniques have been established in a Health Physics Manual prepared and submitted to the AECB.

5.5 Remedial Work Contracting and Management

Local construction firms have been pre-qualified for participation in the remedial action program on the basis of financial responsibility and related experience and performance. Pre-qualified contractors are invited to submit competitive quotations on remedial measures contracts assembled for groups of sites with similar remedial requirements. All sites are carefully inspected during the progress of work to ensure that design specificiations are met and that the highest quality of workmanship is maintained.

At the completion of the remedial work at a site, a program of radiological monitoring is initiated to evaluate the effectiveness of the work to insure that the radiation levels have been reduced to an acceptable level. The results of the post-remedial monitoring, description of the remedial measures, and the pre-remedial data, form the basis of the compliance file that is sent to the AECB for evaluation once the program manager is satisfied that the site meets the established criteria in all respects.

References-Remedial Techniques

Ref. 1. H.G. Olson, "Sealant Demonstration Program", Fort Collins, CO., Colorado State University, 1974.

Ref. 2. G. Carr and J. Tappan, "Phase I Demonstration and Study of Ventilation/Filtration Techniques as a Uranium Mill Tailings Remedial Action", September, 1976.

Cost Estimates Program Schedule and Forecasts 6

6.1 General

Previous preliminary investigations co-ordinated by the Federal-Provincial Task Force on Radioactivity at 1,167 sites in the Bancroft and environs project area estimated that 412 sites had radiation levels sufficiently high as to require further investigations in order to establish the need for remedial action. The detailed investigations discussed in Chapter 4, conducted at 129 sites provided the basis for projecting the total number of sites which are expected to exceed the established criteria and require remedial action. An overall program cost estimate and a suggested program schedule has been prepared based on this projection and on the requirement for completing detailed investigations at the remaining Task Force sites.

6.2 Remedial Costs

Representative costs for each type of remedial action discussed in Chapter 5 were estimated on the basis of average unit prices tendered for work currently underway at 16 remedial sites. These costs include influx route sealing, removal and disposal of materials as necessary and the complete restoration and reinstatement of properties. Cost estimates for each type of remedial action are listed in Table 6.1.

TABLE 6.1

REMEDIAL TECHNIQUE COSTS

	Remedial Technique	Cost/Application
1.	Interior Source Removal	$2,500.00
2.	Exterior Source Removal	3,500.00
3.	Trap Floor Drains	500.00
4.	Trap Floor Drains & Modify Sump	1,500.00
5.	Seal Cracks, Floor/Wall Joints	2,000.00
6.	Sub-Floor Venting System (including removal and reconstruction of floor slab and installation of gravity stack)	8,000.00
7.	Seal Exposed Bedrock	3,000.00
8.	Exterior Sealant Application (including excavation and reinstatement)	5,500.00
9.	Interior Sealant Application (finished basement)	9,200.00
10.	Interior Sealant Application (unfinished basement)	6,500.00
11.	Crawl Space Sealing and Passive Ventilation	4,500.00
12.	Mechanical Ventilation	2,000.00

6.3 Remedial Measures Projection

The detailed investigations indicated that approximately 55 (43%) of the 129 sites studied have levels in excess of the established criteria for either gamma levels or radon daughter concentrations. The remaining 74 (57%) sites were found to require no remedial work.

As discussed in Chapter 4 (Sec. 1.1) the sites investigated for this report were subdivided into various WL categories. The percentage of sites requiring or not requiring remedial work within each category are shown in Table 6.2. Applying these percentages to the 412 Task Force sites, a projection indicated a total of 109 sites will require remedial work (Fig. 6.1).

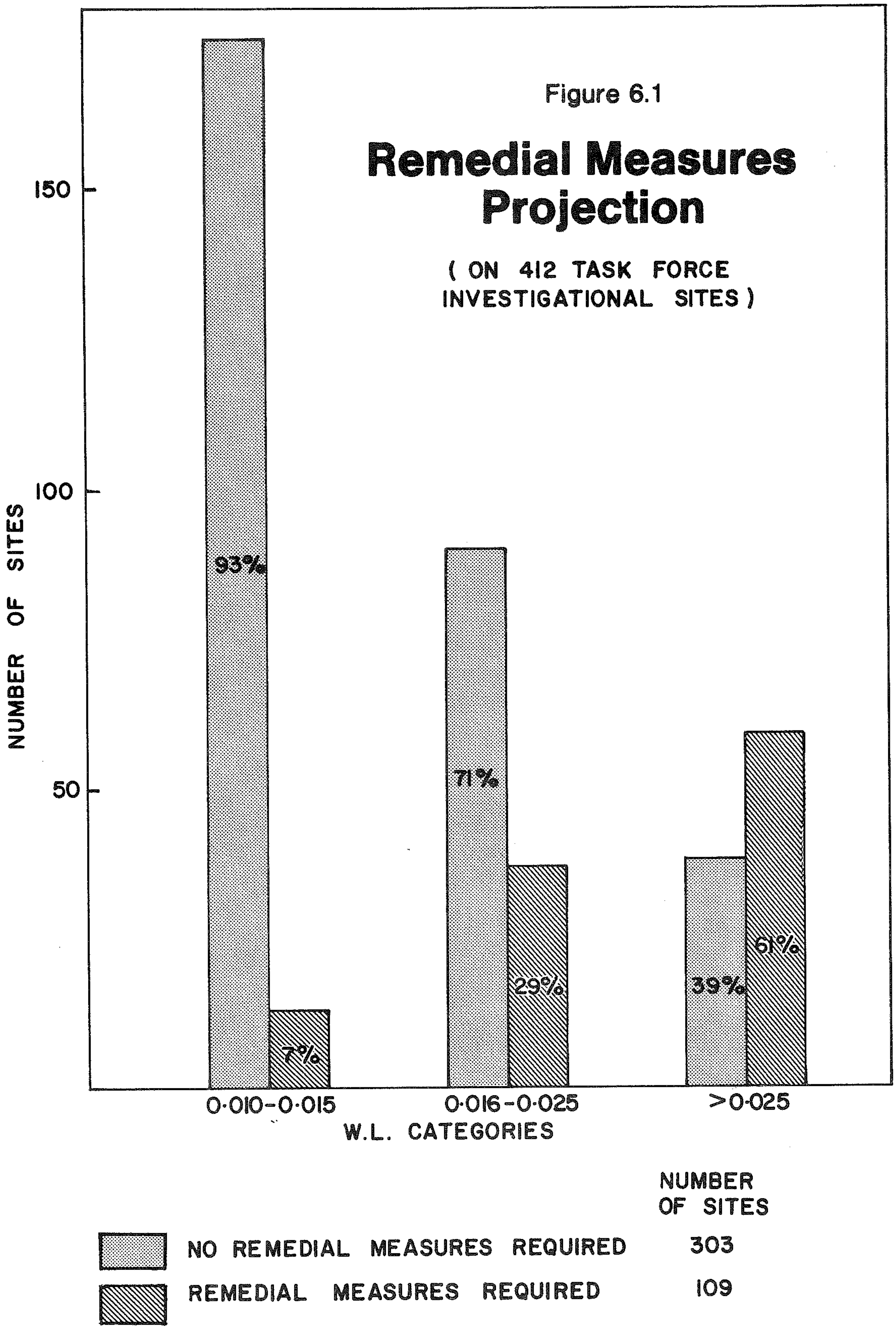
Figure 6.1
Remedial Measures Projection
(ON 412 TASK FORCE INVESTIGATIONAL SITES)
150
100
50
NUMBER OF SITES
93%
7%
71%
29%
39%
61%
0·010–0·015
0·016–0·025
>0·025
W.L. CATEGORIES
NUMBER OF SITES
NO REMEDIAL MEASURES REQUIRED 303
REMEDIAL MEASURES REQUIRED 109

TABLE 6.2

PERCENTAGE COMPARISON OF DETAILED AND PRELIMINARY SURVEY RESULTS (129 SITES)

Preliminary Task Force Survey	Detailed Project Survey % Requiring Remedial Work > .02 WL	% Not Requiring Remedial Work < .02 WL
.010 - .015 WL (30)	7 (2)	93 (28)
.016 - .025 WL (24)	29 (7)	71 (17)
> .025 WL (75)	61 (46)	39 (29)

( ) Denotes Number of Sites

Sites not previously surveyed by the Task Force will require testing from time to time during the duration of the remedial program. These special request sites are generally investigated on the basis of requests by property owners whose homes and businesses were not included in the original Task Force survey. For estimating purposes, it has been assumed that requests to survey an additional 100 such sites will be received throughout the duration of the program. Since 17% of special request sites surveyed to date were a-above criteria, it is estimated that 17 additional sites will require some form of remedial action.

In summary, a total of 512 sites, including those investigated to date, will require detailed investigation, and a total of 126 sites will require remedial work.

6.4 Program Schedule and Project Costs

Using data from the 129 sites studied to date, the overall timing and costs required to complete the entire program has been estimated. These provide for:

- the investigation of all remaining Task Force and special request sites;

- the preparation of design and contract documents;
- the implementation and administration of construction contracts; and
- the carrying out of the post-remedial radiation monitoring program and preparing site compliance reports.

It is anticipated that the entire program, including the detailed investigation of the estimated 512 sites and remedial work at the projected 126 sites, can be completed by the end of Fiscal Year 1980-81.

The program management and site investigation costs for Fiscal 1979-80 are estimated at $442,000 and for Fiscal 1980-81 at $376,000. The total costs for this aspect of the program including the current 1978-79 fiscal year is therefore estimated at $1,270,000.

A total remedial cost of $673,200 has been established on the basis of projecting results obtained from detailed investigations at the 55 sites referred to in Section 6.3. Consideration for the level of effort and related costs associated with the degree of radiation reduction necessary at remedial sites has been taken into account in this estimate. The total cost includes remedial work contracted to date. A cost estimate summary is shown in Table 6.3. A contingency allowance of 20% is provided for unforeseen work requirements and miscellaneous expenses associated with remedial contracts.

A summary of the overall estimate of costs and the number of sites that can be accommodated within the proposed budget in each of the fiscal years of the program, are presented in Table 6.4. The suggestion of a three year schedule to complete the entire program takes into account the optimum sizing of the program management staff, the dependence on seasonal constraints and the availability of local qualified contractors to undertake the remedial work.

The level of effort required in each fiscal year is discussed in the following subsections.

6.4.1 1978-79 Fiscal Year

An estimated total of 160 sites will be investigated and available funding will permit 20 sites to undergo remedial work. However, should additional funding be made available, work at an additional 15 sites can be completed in the fiscal year. Additional contracts are under preparation to permit a full utilization of the 1979-80 construction season. Investigation at 129 sites and remedial work at 16 sites has been undertaken to date. Additionally, site compliance reports for 44 sites not requiring remedial work have been turned over to the AECB.

6.4.2 1979-80 Fiscal Year

During the 1979-80 period an estimated total of 200 sites will be scheduled for investigation and remedial work completed at 65 sites.

6.4.3 1980-81 Fiscal Year

It is anticipated that the testing of the remaining 152 investigational sites and work at the remaining remedial sites, will be completed in this final year.

TABLE 6.3

REMEDIAL MEASURES COSTS ESTIMATE
(Based on projected requirements at 126 sites)

	Remedial Technique	Cost/Application	Estimated Number of Applications	Total Cost
1.	Interior Source Removal	$2,500.00	5	$ 12,500.00
2.	Exterior Source Removal	3,500.00	21	73,500.00
3.	Trap Floor Drains	500.00	23	11,500.00
4.	Trap Floor Drains & Modify Sump	1,500.00	31	46,500.00
5.	Seal Cracks, Floor/Wall Joints	2,000.00	47	94,000.00
6.	Sub-Floor Venting System (including removal and reconstruction of floor slab and installation of gravity stack)	8,000.00	13	104,000.00
7.	Seal Exposed Bedrock	3,000.00	3	9,000.00
8.	Exterior Sealant Application (including excavation and reinstatement)	5,500.00	5	27,500.00
9.	Interior Sealant Application (finished basement)	9,200.00	10	92,000.00
10.	Interior Sealant Application (unfinished basement)	6,500.00	8	52,000.00
11.	Crawl Space Sealing and Passive Ventilation	4,500.00	5	22,500.00
12.	Mechanical Ventilation	2,000.00	8	16,000.00
			SUB TOTAL	$561,000.00
			20% CONTINGENCY	$112,200.00
			TOTAL COST	$673,200.00

TABLE 6.4

PROGRAM SCHEDULE AND COST SUMMARY

Program Function	1978-79 Fiscal Year Number of Sites	1978-79 Fiscal Year Cost $	1979-80 Fiscal Year Number of Sites	1979-80 Fiscal Year Cost $	1980-81 Fiscal Year Number of Sites	1980-81 Fiscal Year Cost $	Total Costs $
Program Management and Site Investigations	160	452,000	200	442,000	152	376,000	1,270,000
Remedial Work	20*	100,000	65	350,000	41	223,200	673,200
Total Costs $		552,000		792,000		599,200	1,943,200

* Remedial work currently underway at 16 sites.

Appendix

Basic Radiation Measurement Equipment and Techniques

Equipment and methods used for the Bancroft project are adopted from similar Canadian projects and generally established practices. This Appendix presents a brief description of the equipment and techniques used to facilitate the radiological measurements discussed in Chapter 4. Completely detailed individual procedures are maintained in the Bancroft field office for review by interested parties.

I Gamma Radiation

A. Equipment

Portable survey instruments, equipped with a gamma scintillation detector probe, are used for interior and exterior grid surveys. Periodic calibration is performed on each unit using a certified radium-226 needle source.

A portable augering machine powered by a 7 hp gasoline engine is used to bore holes in soil to accommodate gamma logging.

A portable instrument, incorporating an extension gamma scintillation detector probe and a strip chart recorder, is used to accomplish the borehole logging.

B. Technique

Grid surveys are accomplised at 3 m increments on exterior areas and at 1.5 m increments on interior areas. Measurements are recorded near contact with the surface and at 1 metre above the surface. Interior surveys include all floors of each structure. Borehole logging is accomplished by lowering the detector probe down holes at 5 cm intervals. The recorded incremental gamma level is related to source depth and intensity.

II Radioactivity in Air

A. Equipment

Zinc sulphide coated flow-through scintillation cells are used to collect radon-222 gas samples. These cells are calibrated using the radium-226 de-emanation technique. A battery operated portable pump is used to draw air through a pre-filter and into the scintillation cell.

A special Tedlar bag and pulsating air pump (battery operated) is used to accommodate collection of air samples integrated over a period of time.

A high volume air pump (30 L/min) incorporating glass fibre filters is used to collect radon daughter air samples (filtered "grab" samples). Flow calibration is routinely performed on this air pump.

A portable scaler incorporating a photomultiplier tube detector and a zinc sulphide coated mylar disc, is used to count alpha disintegrations from the glass filter samples. Detector efficiency and high voltage are routinely determined using a calibrated thorium-230 source.

A scaler, incorporating a photomultiplier tube, is used to count alpha disintegrations resulting from scintillation cell radon samples. Calibration of the scalers is performed on a routine basis using cross-calibrations with similar equipment in Port Hope and with cells of known concentration obtained from the Chalk River Nuclear Laboratories.

B. Technique

Radon gas samples are collected from interior locations inside inhabited structures as well as from certain exterior areas of interest. Air is drawn through the cell at a rate of 2 L/min for 1.5 minutes, permitting at least 6 air changes in the cell. The cell valves are then closed and after an appropriate delay (about 4 hours) the alpha disintegrations from the cell are counted. Appropriate calibration factors are applied to determine the radon concentrations.

Filtered grab samples are collected over a 10 minutes period and analysed for radon daughter concentrations by applying the modified Kusnetz method (Ref. 1).

Simultaneous radon/radon daughter samples are collected inside each studied structure from various areas on each floor level. Complete sample sets are collected on several different days with the structure normally under closed and unventilated conditions. Accumulated data is used for comparison with established criteria and subsequent determination of remedial requirements.

III Radioactivity in Soil

A. Equipment

Four and a half litre metal cans, equipped with a closeable inlet and outlet line, with sealable lids are used in combination with radon scintillation cells for emanating radium -226 soil analysis.

Soil gas tubes consisting of 1.5 m lengths of perforated 8 cm diameter PVC tubing are used to accommodate collection of soil gas samples. Additionally, soil gas probes consisting of a 1 m length of 2 cm diameter (I.D.) metal pipe open on both ends, equipped with a driving rod (mandrel) inserted through the pipe, are used to accommodate soil gas analysis.

B. Technique

Soil samples are collected from various areas of interest (foundation fill, fill beneath concrete slabs, etc.), a measured amount (200-300 g) is placed in the 4.5 litre can, the lid is sealed in place and lines are closed. The sealed sampled is not disturbed for a minimum 7 day period after which a radon scintillation cell sample is drawn from the can, the cell radon concentration is measured in the usual manner, and the observed radon concentration is extrapolated to equilibrium levels. From the equilibrium quantity of radon emanated into the can, the equivalent amount of emanating radium can be estimated.

Soil gas tubes are inserted and sealed in an augered borehole and/or metal probes are driven into the soil and sealed to accommodate accumulation of soil gas. Air samples are collected from inside the sampler with the radon concentration measured in the usual manner and related to radon concentrations in the soil gas.

Isotopic analyses of soil are performed by Chalk River Nuclear Laboratories. These analyses normally include: natural uranium and its progeny, thorium-228 and potassium-40.

IV Radioactivity in Water

A. Equipment

A "degassing" unit and special glass sample collection tubes are provided by the AECB. This equipment is used to collect and analyse water samples for radon-222 and radium-226 content.

B. Technique

The standard bubbler de-emanation technique is used to accommodate analyses. For determination of radon content the sample is promptly de-emanated into an evacuated radon scintillation cell for standard analysis. For determination of radium-226 the de-emanated sample is left undisturbed for a minimum 7 day period after which time it is again de-emanated into a scintillation cell, the cell is analysed for radon content, and resulting data is extrapolated to equilibrium levels. The quantity of radon detected can then be related to the dissolved radium in the water.

V Radon Flux Measurements

A. Equipment

A combination of containers (accumulators) designed to be sealed to surface areas and accommodate accumulation of radon, are employed for radon flux determinations. The metal or wood containers incorporate an open side which can be sealed to surface areas, and closeable inlet and outlet lines to allow the recirculation of accumulated radon through a scintillation cell. The accumulators have various dimensions primarily dependent on the specialized purpose.

B. Technique

The accumulator is sealed to the surface of interest using mastic except when sampling soil surfaces where the open edge of the accumulator is forced into the soil to a depth of 2 - 3 cm. A base line (background) radon scintillation cell sample is drawn from the accumulator immediately after affixing it to the surface, the inlet/outlet lines are closed, and subsequent radon scintillation cell samples are drawn from the accumulator at measured time intervals. Radon concentration measured in each cell is related to elapsed time and the surface area covered by the accumulator to determine radon flux.

VI Other

A. Equipment

Various portable radiation surveying instruments, equipped with both alpha and beta detector probes, are used for special contamination surveys.

B. Technique

Standard contamination surveying procedures are used, i.e., the appropriate detector probe is placed near contact with the surface of interest and the resulting radiation measurement is related to the area represented by the measurement.

References - Appendix

Ref. 1. H.L. Kusnetz, "Radon Daughters in Mine Atmospheres - A field method for determining concentrations", Am. Ind. Hyg. Ass. 17:1, 1956.