THE REDUCTION OF RADIOACTIVITY FOUND IN BANCROFT ONTARIO AND ITS ENVIRONS

A report prepared for the Atomic Energy Control Board by James F. MacLaren Limited Consulting Engineers, Planners & Scientists Willowdale, Ontario

REPORT

February 1979
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. MCLAREN LIMITED
P.O. BOX 290, SUDBURY, ONTARIO"
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.
12 February 1979

Dr. R. S. Eaton
Chief
Radioactivity Remedial Action Group
Atomic Energy Control Board
270 Albert Street
Ottawa, Ontario
K1P 5G8

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. Chan, P.Eng.
Project Director

P. J. Manley, P.Eng.
Project Manager
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.
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:
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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

2.1 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.
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).
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 outcappings 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
Granite gneiss, Granite pegmatite, Pegmatite

Interbanded syenite gneiss and amphibolite. Granite gneiss, includes many sedimentary bands and relic sedimentary material

Nephaline syenite gneiss

Nephaline syenite bands replacing silicated marble

Metagabbro Hornblende plagioclase gneiss

Crystalline limestone, Marble dolomite

Hornblende gneiss and schist. Hornblende syenite, Hornblende syenite gneiss, Biotite amphibolite

Assumed fault

Figure 2.2
Geology of the Village of Bancroft

GEOLOGY FROM MAP 1957-1
Cardiff and Faraday Townships
Counties of Haliburton and Hastings
by D.F. Hewitt, Ont. Dept. of Mines
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
Vertical diamond drill hole on this property, collared in marble, reached pegmatite dikes at 182 m, drilled in 1954.
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.
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
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.
Remedial Action Criteria and Related Health Significance

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.
3.2.2 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.
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):

**Gamma Radiation Inside Buildings**

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

**Gamma Radiation Outside Buildings**

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.
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.
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
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.
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).
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**

<table>
<thead>
<tr>
<th>Identification</th>
<th>Concentration Range (pCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background (13 sites)</td>
<td>0.06 - 0.2</td>
</tr>
<tr>
<td>Overburden problem sites</td>
<td>0.06 - 0.8</td>
</tr>
<tr>
<td>Mine waste rock</td>
<td>0.2 - 6.3</td>
</tr>
<tr>
<td>Bedrock deposits</td>
<td>4.1 - 1,500</td>
</tr>
<tr>
<td>Concrete core (from basements)</td>
<td>0.06 - 0.2</td>
</tr>
</tbody>
</table>

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
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 ($^{222}\text{Rn}$) and radium ($^{226}\text{Ra}$). The results are shown in Table 4.3.

**TABLE 4.3**

Concentrations of Radon and Radium in Water

<table>
<thead>
<tr>
<th>Identification</th>
<th>$^{222}\text{Rn}$ (pCi/L)</th>
<th>$^{226}\text{Ra}$ (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background, potable water (wells &amp; lakes)</td>
<td>11 - 540</td>
<td>0.8 - 7.4</td>
</tr>
<tr>
<td>Background, lakes and streams</td>
<td>62 - 450</td>
<td>1.7 - 3.7</td>
</tr>
<tr>
<td>Background, groundwater</td>
<td>90</td>
<td>3.7</td>
</tr>
<tr>
<td>Waste rock deposits, groundwater</td>
<td>3,000</td>
<td>140</td>
</tr>
<tr>
<td>Potable well, one observation (Sect. 4.5.3 c)</td>
<td>51,000</td>
<td>18</td>
</tr>
</tbody>
</table>

Comparison from Previous Bancroft Area Study (Ref. 3)

<table>
<thead>
<tr>
<th>Identification</th>
<th>$^{222}\text{Rn}$ (pCi/L)</th>
<th>$^{226}\text{Ra}$ (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streams</td>
<td>23</td>
<td>0.9</td>
</tr>
<tr>
<td>Lakes</td>
<td>3</td>
<td>0.9</td>
</tr>
<tr>
<td>Swamps</td>
<td>20</td>
<td>0.9</td>
</tr>
<tr>
<td>Springs</td>
<td>120</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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).
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.
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·m\(^{-2}\)·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 existing concrete structures more of an art than a science.
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:

\[ F = \frac{WL \times 100}{\text{pCi/L}} \times 100 \]

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 than 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).
Figure 4.5

Mean Monthly Equilibrium 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 m³ 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 x 10⁵ 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 (T₁/₂ = 54 s) in the thorium-232 (natural thorium) decay series. Thoron and radon are identical
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 $1.3 \times 10^5$ 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 ($T_{1/2} = 10.6\text{ h}$) 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.
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.

Biccroft 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.
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⋅m⁻²⋅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.


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.
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
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 rigorous 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.
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
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
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 specifications 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
References - Remedial Techniques


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.
Figure 6.1
Remedial Measures Projection

(ON 412 TASK FORCE INVESTIGATIONAL SITES)

<table>
<thead>
<tr>
<th>W.L. Categories</th>
<th>Number of Sites</th>
<th>Remedial Measures Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.010-0.015</td>
<td>150</td>
<td>93%</td>
</tr>
<tr>
<td>0.016-0.025</td>
<td>50</td>
<td>71%</td>
</tr>
<tr>
<td>&gt;0.025</td>
<td>100</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61%</td>
</tr>
</tbody>
</table>

- NO REMEDIAL MEASURES REQUIRED: 303
- REMEDIAL MEASURES REQUIRED: 109
TABLE 6.2
PERCENTAGE COMPARISON OF DETAILED AND PRELIMINARY SURVEY RESULTS (129 SITES)

<table>
<thead>
<tr>
<th>Preliminary Task Force Survey</th>
<th>Detailed Project Survey</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requiring Remedial Work</td>
<td>≥ .02 WL</td>
<td>&lt; .02 WL</td>
</tr>
<tr>
<td>0.010 - 0.015 WL (30)</td>
<td>7 (2)</td>
<td>93 (28)</td>
<td></td>
</tr>
<tr>
<td>0.016 - 0.025 WL (24)</td>
<td>29 (7)</td>
<td>71 (17)</td>
<td></td>
</tr>
<tr>
<td>&gt; 0.025 WL (75)</td>
<td>61 (46)</td>
<td>39 (29)</td>
<td></td>
</tr>
</tbody>
</table>

( ) 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 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;
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>
<thead>
<tr>
<th>Program Function</th>
<th>1978-79 Fiscal Year</th>
<th>1979-80 Fiscal Year</th>
<th>1980-81 Fiscal Year</th>
<th>Total Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Sites</td>
<td>Cost</td>
<td>Number of Sites</td>
<td>Cost</td>
</tr>
<tr>
<td>Program Management and Site Investigations</td>
<td>160</td>
<td>452,000</td>
<td>200</td>
<td>442,000</td>
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<tr>
<td>Remedial Work</td>
<td>20*</td>
<td>100,000</td>
<td>65</td>
<td>350,000</td>
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<tr>
<td>Total Costs</td>
<td>552,000</td>
<td>792,000</td>
<td>599,200</td>
<td>1,943,200</td>
</tr>
</tbody>
</table>

* Remedial work currently underway at 16 sites.
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 accomplished 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
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.
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.