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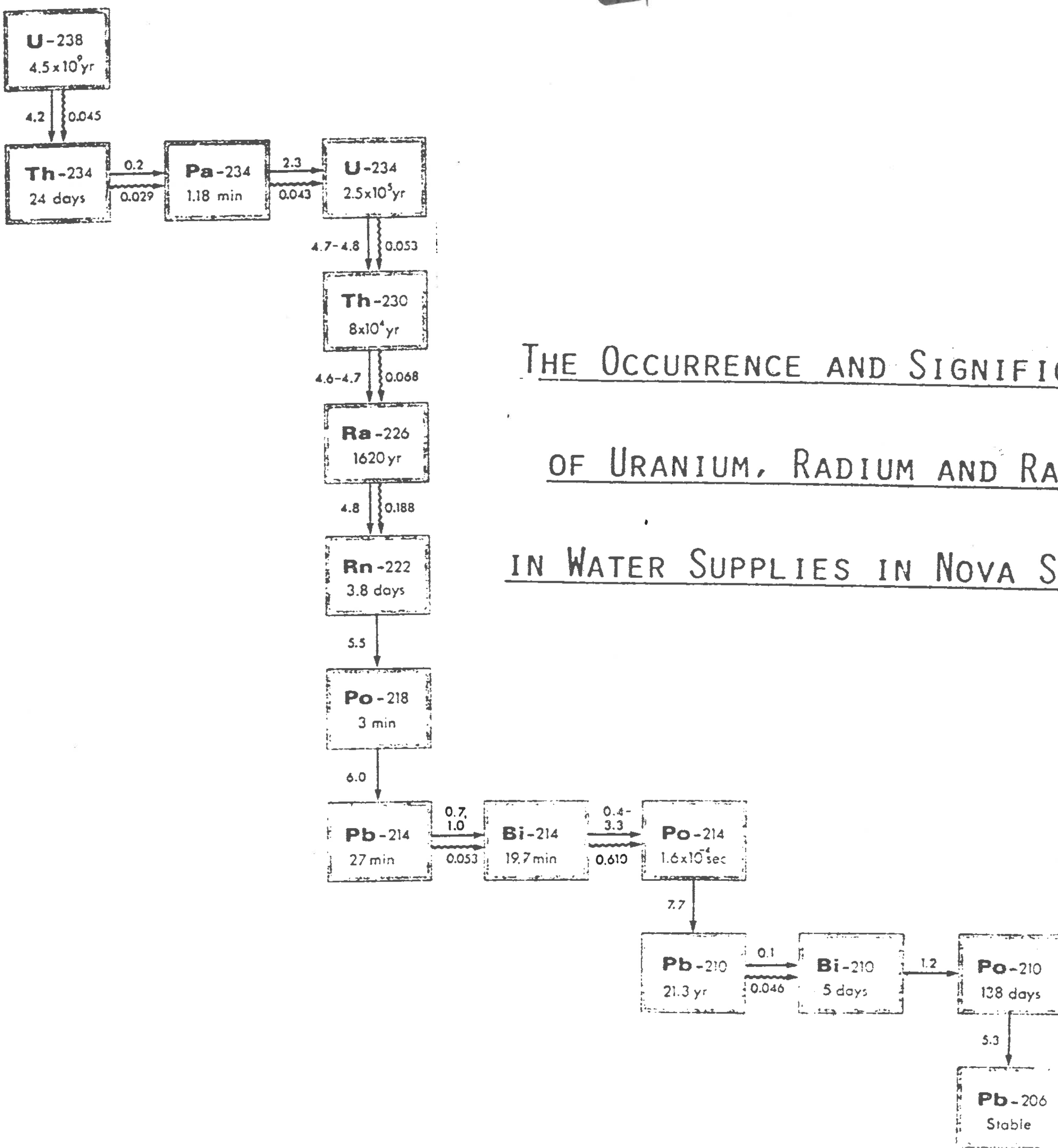

The Occurrence and Significance of Uranium, Radium and Radon in Water Supplies in Nova Scotia

A REPORT OF THE INVESTIGATION CARRIED OUT BY

THE PROVINCIAL URANIUM TASK FORCE

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OFR 86-070

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Department of Health
Province of Nova Scotia
10 March 1986

David A. Grantham, M.Eng., P.Eng.
Public Health Engineer
Chairman, Uranium Task Force

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Nova Scotia

Department of Health

ATLANTIC HEALTH UNIT

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13 March 1986

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REPORT OF THE PROVINCIAL URANIUM TASK FORCE INVESTIGATION

The report entitled "The Occurrence and Significance of Uranium, Radium and Radon in Water Supplies in Nova Scotia" is hereby submitted as the final report of the investigation carried out by the Provincial Uranium Task Force.

In order to reach the objectives set down in the terms of reference within which the Task Force operated, a wide ranging investigation program involving many disciplines was required. The investigation was necessarily complicated by the fact that any natural cccurrence of uranium gives rise to associated occurrences of radium and radon and all three must be treated as potential health hazards. Considerations of both chemical toxicity and radiological toxicity posed by uranium further complicated the work of the Task Force.

As stated in the Foreword, the body of the report was written by the chairman of the Task Force. The Task Force as a whole concurs with the conclusions reached and recommendations made and submits them for your consideration.

As you know, the Provincial Uranium Task Force is an inter-departmental committee which was established under the authority of the Minister of Health. It is therefore respectfully requested that you forward this report to the Honourable Minister.

David A. Grantham

David A. Grantham, M.Eng., P.Eng.
Public Health Engineer
Chairman, Uranium Task Force

FOREWORD

This report is a record of the investigation carried out by the Provincial Uranium Task Force into the public health significance of the natural occurrence of uranium and the related elements radium and radon in water supplies in Nova Scotia. The report was written by the chairman of the Task Force with significant contributions by some other Task Force members and their colleagues of material which is included in the body of the report in summary form and is appended to the report in its entirety.

The chairman accepts responsibility for the body of the report; the Task Force as a whole concurs with the conclusions reached and recommendations made.

The Task Force, to the best of its ability and with the resources available, discharged its duty as laid down in the terms of reference under which it operated. As indicated in the conclusions and recommendations, some follow-up research and monitoring will be necessary in order to finalize the few items which remain outstanding because they require decisions and funding beyond the scope of the Task Force.

ACKNOWLEDGEMENTS

The type of investigation pursued by the Uranium Task Force involves a variety of activities: field work, laboratory analysis of clinical and water samples, research using technical literature and other references, and contacting other jurisdictions and various experts. Given the number and complexity of these activities and the several year time span of the investigation, it is evident that the successful completion of such a project depends on the cooperation and assistance of a large number of people.

Many of these are mentioned here in recognition of their especially valuable contributions. It must be emphasized that there are many others who rendered service and support which was much needed and is very much appreciated.

The owners of Birchlee Trailer Court enabled the initial water sampling survey to take place. The Dalhousie University Trace Analysis Research Center and the Saskatchewan Research Foundation provided analytical services for the initial samples. Throughout the balance of the water sampling program and clinical studies, personnel of the Environmental Chemistry and Clinical Chemistry laboratories of the Victoria General Hospital in Halifax analyzed hundreds of samples, performing thousands of precise determinations with a high degree of accuracy.

The Halifax County Board of Health and eventually other boards in various areas of the province cooperated with the Task Force.

Background information on the geology of Harrietsfield-Williamswood was provided at the beginning of the investigation by Robert Grantham, Curator of Geology, Nova Scotia Museum. Groundwater sampling results obtained from various uranium exploration companies through the Nova Scotia Department of Mines and Energy pointed the way to several areas which became important parts of the well sampling program and hydrogeological studies. Particular thanks is given to Kidd Creek Mines Limited (formerly Aquitaine

Company of Canada) for their cooperation in assisting with the study in the Leminster-Lower Vaughan area.

The in-depth study of the hydrogeology and distribution of uranium in Nova Scotia performed by David MacFarlane, a hydrogeolist formerly with the Nova Scotia Department of the Environment, is a work of major importance and a model for such investigations in the future.

The staff of the Maritime Resource Management Service, especially Brad Fay and Margaret Campbell, were most helpful in the three projects in which they were involved: the formal technical literature search, mapping the uranium exploration company groundwater sample results, and handling the large volume of correspondence connected with the world survey of standards.

Staff of the federal Department of National Health and Welfare were a source of technical support, information and guidance. The assistance of Dr. George Becking, J. R. Hickman and Dr. A. P. Gilman of the Health Protection Branch, and R. G. McGregor, L. A. Gourgon and Dorothy Meyerhof of the Radiation Protection Bureau is especially appreciated.

The Task Force wishes to express its appreciation for information received from the following jurisdictions, agencies and persons: Atomic Energy of Canada Limited, British Columbia Ministry of Health, Maine Department of Human Services (Division of Health Engineering), Dr. Peter Warner of the Manitoba Department of Health, Dr. Allen Sourkes of the Manitoba Cancer Treatment and Research Foundation, K. L. Davies of the New Brunswick Department of Health, H. M. Prichard of the University of Texas, the U.S. Environmental Protection Agency, and the representatives of all of the countries who responded to the world survey of standards.

The Nova Scotia Department of the Environment provided staff to assist in the well sampling program as well as technical expertise in hydrogeology and geochemistry as mentioned above. Personnel of the Water Resources Planning section of the Environment Department were most helpful in offering suggestions and advice.

The Nova Scotia Department of Health played a major role as the "lead agency" in the Task Force investigation. To the many departmental personnel who were involved, the Task Force expresses its gratitude. The contributions of the following are particularly acknowledged: the community health nurses of the Atlantic and Lunenburg-Queens Health Units whose efficiency made possible the clinics held in Harrietsfield and New Ross; the area public health inspectors throughout the province who assisted in the municipal water system and well sampling programs—Keiren Tompkins, Ken Grandy, and the inspection staff of Northumberland Health Unit were especially helpful; Robert Briggs, research assistant, who perfected the sampling techniques and carried much of the load in the initial stages of the water sampling program; Gail MacIsaac, student assistant, who efficiently implemented a major part of the well sampling program; Donald Feldman, public health engineering technologist, whose practical and thorough approach led to the successful completion of several field testing and evaluation programs involving water treatment devices for uranium removal, the variation in concentration of uranium and related elements in well water with time, and the variations in radon activity in indoor air; Ted Dalgleish, senior radiation health officer, for his technical guidance and support; Patricia Joudrey who typed the report and arranged it with patience and meticulous care.

Dr. Gerald Sheehy, who was Minister of Health throughout the period during which most of the investigation was carried out, was most understanding and cooperative in ensuring that the work of the Task Force proceeded with complete independence.

Finally, sincere appreciation is expressed to the residents of all areas in which well sampling programs were implemented, especially to the people of Harrietsfield and New Ross for their cooperation in taking part in the clinical studies held in their areas.

KEY TO ABBREVIATIONS AND SYMBOLS

Various abbreviations and symbols used in this report and its appendices are explained below.

Abbreviation or Symbol	Meaning
U	uranium
Ra	radium
Rn	radon
Bi	bismuth
Pb	lead
Po	polonium
Th	thorium
U-234, U-235, U-238	various isotopes of uranium, the number is the atomic mass number of the isotope

Similarly used for isotopes of radium, radon and other elements.

Abbreviation or Symbol	Meaning
>	greater than
<	less than
g	gram
kg	kilogram
mg	milligram
μg	microgram
L	liter
mg/L	milligram per liter
ppm	parts per million
Ci	Curies (1 Curie = 3.7×10^{10} disintegrations/second)
μCi	microcuries
nCi	nanocuries
pCi	picocuries
pCi/L	picocuries per liter
Bq	Becquerels (1 Bq = 1 disintegration/second = 27.03 pCi)
Bq/L	Becquerels per liter

Abbreviation or Symbol	Meaning
WL	working levels—any combination of the short-lived decay products (daughter products or progeny) of radon in 1 liter of air which will result in the ultimate emission by them of 1.3×10^5 MeV of alpha particle energy
WLM	working level month—a unit of integrated exposure; breathing air with a concentration of 1 WL for the working hours in a month (170 hours) results in an exposure of 1 WLM
WLM/year	a unit of exposure rate; an exposure rate of 4 WLM/year will result from working 170 hours/month for 12 months in an atmosphere with a radon daughter product activity of 0.33 WL
MeV	mega electron volts = million electron volts
rad	radiation absorbed dose (measure of exposure to radiation)
Gy	Grays—the Standard International unit for absorbed radiation dose
rem	radiation equivalent man (unit of dose equivalent), equal to absorbed dose in rads multiplied by various modifying factors
mrem	millirem
Sv	Sieverts—the Standard International unit for radiation dose (1 Sv = 100 rem)
mSv	millisieverts (1 mSv = 100 mrem)

Unit Prefixes

Prefix	Abbreviation	Multiple
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Abbreviation or Symbol	Meaning
MAC	maximum acceptable concentration
NOEL	no-observable-effect-level
SNARL	suggested no-adverse-response level
ALARA	as low as is reasonably achievable
ALI	annual limit of intake
BEIR	biological effect of ionizing radiation
ASMR	age standardized mortality rate
B_2M	$Beta_2$-microglobulin
WHO	World Health Organization
ICRP	International Commission on Radiological Protection
U.S.EPA	United States Environmental Protection Agency
A.A.	activated alumina
GAC	granular activated carbon
R.O.	reverse osmosis

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1. INTRODUCTION

1.1 Background Information

The discovery of uranium in well water in Nova Scotia came about as the result of a research program to identify "normal" levels of various heavy metals found in the general population. This investigation was carried out by the Dalhousie University Trace Analysis Research Center (TARC). The researchers had analyzed hair samples from a number of subjects, chosen at random, for various elements including uranium. Although it was not known what constituted a normal hair uranium concentration, it was noted that one person's hair uranium level was much higher than those of all of the other study subjects.

Before making this known to the Nova Scotia Department of Health, the TARC staff determined that the person in question was not in contact with uranium in her occupational environment and was a resident of Birchlee Trailer Court, a mobile home park located in Harrietsfield, Halifax County. Three drilled wells serve as the source of water supply for this development. The water was sampled and analyzed by TARC, who found a uranium concentration of 0.07 mg/L.

Knowledge of the sequence of events outlined above was transmitted to the Department of Health in May 1978. This was followed by a series of meetings and discussions by departmental staff. Attempts were made to obtain information on the ramifications of the presence of uranium and radon in drinking water by preliminary literature search and contact with various individuals including personnel of: Health and Welfare Canada, particularly in the Health Protection Branch and Radiation Protection Bureau;

the International Commission of Radiological Protection; and Atomic Energy of Canada Limited (Medical Division). In the summer of 1978 the wells supplying water to Birchlee Trailer Court were sampled as a check on the results reported by the Dalhousie research group.

Initially water samples were analyzed at TARC and the Saskatchewan Research Foundation while a procedure and equipment were being established at the Environmental Chemistry Laboratory of the Victoria General Hospital in Halifax.

At the time that the Dalhousie researchers found, and the Department of Health verified, that the water being consumed by the Birchlee Trailer Court residents contained an average of about 0.07 mg/L of uranium, the current water quality criteria were the Canadian Drinking Water Standards and Objectives - 1968. These guidelines stated a "maximum permissible limit" for uranium (as uranyl ion) of 5.0 mg/L. This guideline was based solely on the aesthetic considerations of color and taste. However, Health Department staff who were involved with the Federal-Provincial Working Group on Drinking Water learned by late summer 1978 that the revised "maximum acceptable concentration" for uranium in the impending Guidelines for Canadian Drinking Water Quality - 1978 was to be 0.02 mg/L. This much lower acceptable concentration, that is, much more stringent guideline, was set as a result of the Working Group's recognition of the fact that uranium is a potentially toxic chemical.

In light of the new uranium concentration guideline, Health Department staff decided to implement further monitoring of the Birchlee Trailer Court water system and began to consider the potential necessity for a large-scale investigation. It was realized that the presence of uranium indicated the likelihood that radon gas would also be present in groundwater.

It was decided that additional water samples from the trailer court should be analyzed for radon and, given the possibility that radon can be released to the air from water as taps and showers are run, it was agreed that radon in air concentrations should be measured. Arrangements were made with the Radiation Protection Bureau to collect indoor air samples at the trailer court, the school and a house in the Harrietsfield-Williamswood area, and at several houses in other parts of Halifax County where well water had been found to contain substantial radon concentrations when the Nova Scotia Department of the Environment had carried out a survey to determine "background" radon levels some years previously. This air sampling was done early in 1979.

Later in 1979 wells serving houses and a school located adjacent to the mobile home park were sampled for uranium. Of 6 wells sampled, 2 wells: the school well and a house well, were found to have uranium concentrations exceeding 0.02 mg/L.

1.2 Uranium Task Force

At this point the Administrator, Environmental Health, and the Deputy Minister decided to recommend to the Minister of Health that a "task force" be established to investigate the occurrence of uranium in drinking water supplies in Nova Scotia. In October 1979 the Minister of Health appointed the following to comprise the Provincial Uranium Task Force:

P. C. Campbell, P. Eng., Planner
Nova Scotia Department of Municipal Affairs

Mr. Campbell was replaced in January 1983 by -
Mr. Dermot English, Planning Coordinator
Community Planning Division, Department of Municipal Affairs

Jack A. Garnett, Ph.D., P. Eng.
Assistant Deputy Minister, Mines and Minerals
Nova Scotia Department of Mines and Energy

David A. Grantham, M. Eng., P. Eng. (Chairman)
Public Health Engineer
Nova Scotia Department of Health

Dr. J. T. Hindmarsh, Director, Division of Clinical Chemistry
Department of Pathology, Victoria General Hospital

Dr. Hindmarsh was replaced in July 1980 by-
Dr. D. T. Janigan, who was in turn replaced in May 1981 by-
Dr. Michael A. Moss, Assistant Pathologist
Victoria General Hospital

Chang L. Lin, Ph.D., P. Eng., Chief, Water Resources Planning
Nova Scotia Department of the Environment

Ross F. McCurdy, Ph.D., Chief, Environmental Chemistry Laboratory
Department of Pathology, Victoria General Hospital

It should be noted that the duties performed by these individuals with regard to the Uranium Task Force were part of, and frequently additional to, their regular workload. Membership in the Task Force was not a full time pursuit; members, including the chairman, concurrently carried the responsibilities of their positions in the various agencies and departments in which they are employed. Of course, the members received no specific remuneration for their service on the Task Force.

The Provincial Uranium Task Force appointed by the Minister of Health was not connected in any way with Uranium Inquiry—Nova Scotia, the inquiry into the ramifications of uranium exploration and mining, conducted by Judge Robert McCleave. The reasons for establishing the Uranium Task Force and the Uranium Inquiry were entirely different. The respective terms of reference for the two investigations were likewise very different.

1.3 Terms of Reference

The first meeting of the Task Force was held on 26 November 1979. In the weeks following that meeting the Task Force prepared and submitted for approval terms of reference and a proposed investigation program. These were approved in March 1980 and the Task Force was directed to implement its investigation program.

The terms of reference of the Provincial Uranium Task Force are outlined below.

Goal:

To ensure that the health of provincial residents is not adversely affected by the presence of uranium in drinking water.

Objectives:

A. To develop and coordinate a program of investigation of the occurrence of uranium in drinking water in Nova Scotia.

B. To compile and clarify existing provincial, federal and international health standards for uranium as a potential heavy metal poison or intoxicant.

C. To compile and clarify the existing provincial, federal and international health standards for the radiological aspects of uranium and uranium-related elements such as radon and radium.

D. To establish the best biological index of uranium exposure.

E. To provide general procedural recommendations for government monitoring and regulation of any activities directly affecting changes in natural uranium distribution patterns.

F. To initiate the issuing of information to the public by means of an established procedure as outlined below.

G. To determine and recommend alternative solutions to the problem of uranium in drinking water as may be necessary in various locations.

1.4 Investigation Program

The Task Force drew up and adopted an investigation program which set down the predicted methods and procedures by which the objectives noted above would be achieved. It was recognized that this program would likely be modified and developed as the work proceeded.

In the outline of the investigation program below, the various tasks are not necessarily listed in order of priority, nor are they listed in time sequence; in fact, several were performed simultaneously. The extent to which the proposed program was modified and the respective aspects of the program which were augmented or diminished will be evident in subsequent sections of this report.

Following is the investigation program set out in the format as originally adopted by the Task Force:

1) Municipal-Central-Institutional Water Supplies Sampling

Phase 1: Municipal systems - All municipal water supply systems to be sampled. Sampling to consist of: a) one sample from all raw water sources; b) two treated water tap samples collected from the distribution system at different locations.

Phase 2: Small central systems such as those in subdivisions and in mobile home parks - Sampling to be as noted for Phase 1.

Phase 3: Institutions in rural areas with individual water supplies not connected to municipal or central systems, such as hospitals, schools, senior citizens' homes, and apartment complexes. Sampling to be scheduled on a priority basis: a) using results obtained in Phases 1 and 2; b) using location map of areas for which uranium exploration licenses have been issued; c) all others.

Note: Sampling for arsenic will be carried out in all Phase 2 and Phase 3 locations not already checked for arsenic where groundwater is the source of supply.

2) Concentration-Time Variation Study

Collection of data, by repeated sampling in a few locations, on variation with time of uranium and related elements in groundwater. Sampling began at two well locations at Birchlee Trailer Court, Harrietsfield, Halifax County, in June 1980, and will continue on a monthly sample collection basis. Other sample locations will be added as areas of interest are discovered around the province.

3) Harrietsfield, Halifax County, Sampling Program and Geology and Hydrogeology Study

Collection of samples from all wells located in area "A" shown on enclosed maps (refer to Figures 1 and 2). Study of results to determine whether or not sampling area should be extended. A detailed outline of the main geological features of the area to be provided by the Nova Scotia Museum. Compilation of available hydrogeological information for the area including completed questionnaires from well owners, well drilling logs, and a bedrock fracture study.

Well owners will be informed by mail of the analysis results of well water samples.

4) Area Well Sampling Program

Sampling of individual household wells is to be carried out on

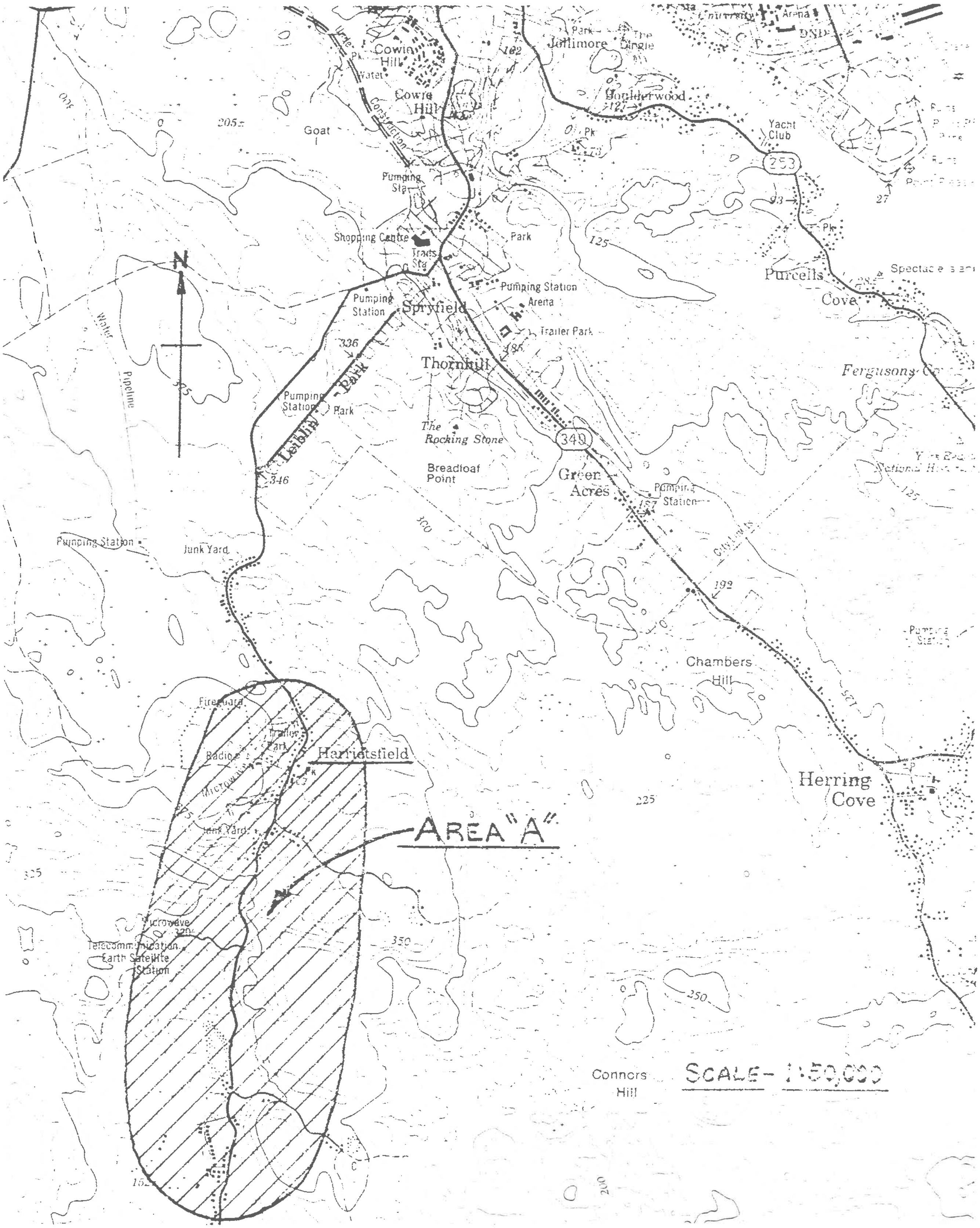

Figure 1 - Area "A" - Harrietsfield-Williamswood

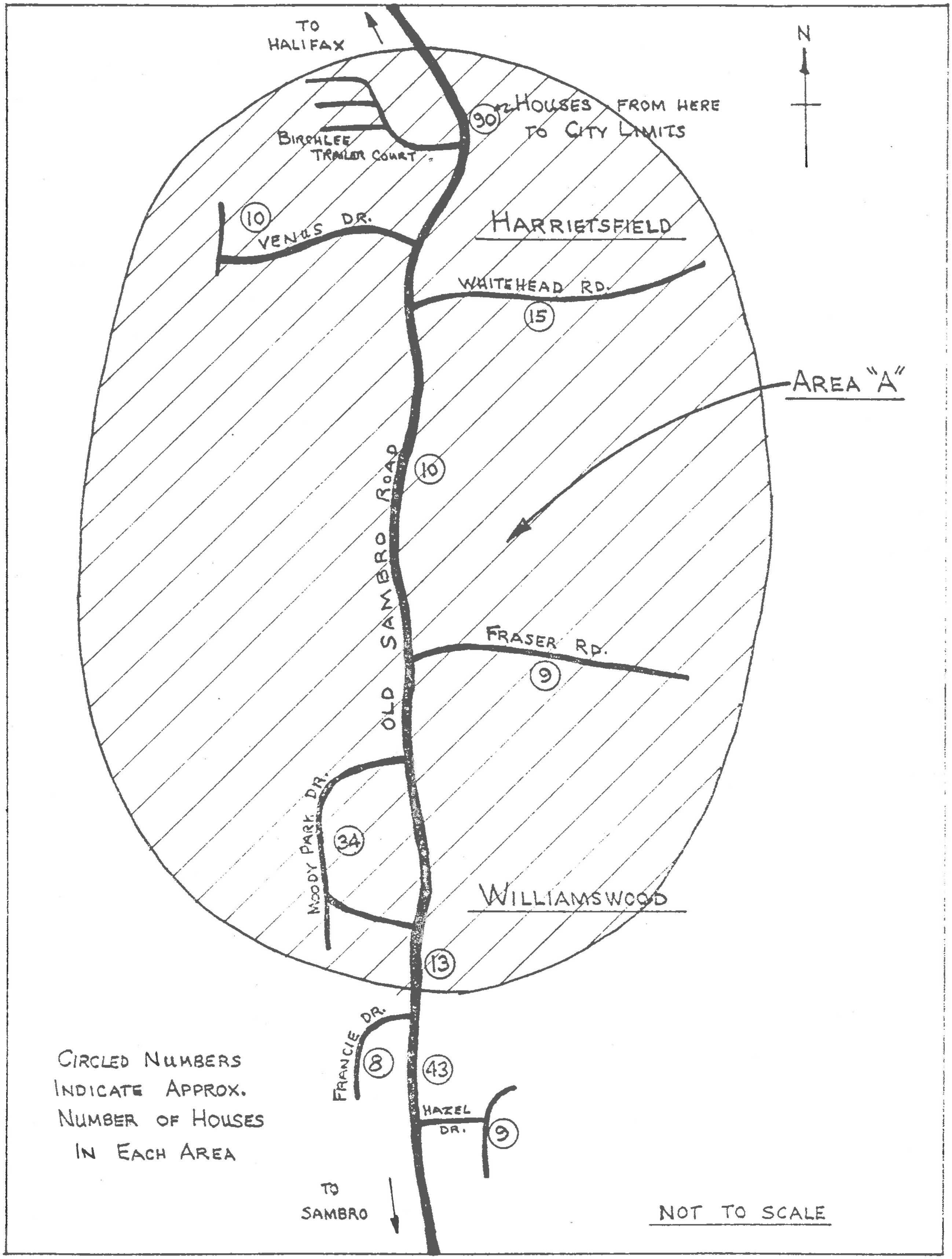

Figure 2 - Location Map - Large Scale - Area "A" - Harrietsfield-Williamswood

an area sampling survey basis. Sampling need and priority are to be based on geochemical data, geology, hydrogeology, and similarity with other areas in which uranium and related elements have been found in groundwater.

5) Falls Lake-Leminster, Hants County—Baseline Sampling

Aquitaine Company of Canada, in the course of its uranium exploration program, carried out a spring 1980 sampling program of streams, lakes, sediments, a spring, and a few wells in the area of Hants County near Falls Lake and Lower Vaughan.

Duplicate sampling for verification of results is to be carried out by the Nova Scotia Department of the Environment (streams, lakes, sediments) and by the Nova Scotia Department of Health (springs and wells). Analytical costs of the samples collected by these departments are to be charged to the province.

6) Technical Literature Search—Maritime Resource Management Service

At the request of the Task Force, a literature search for information on uranium and related elements with particular emphasis on health effects was commenced in the early summer of 1980 by MRMS.

One of the results of this search will be the compilation of various standards for the toxic chemical aspects of uranium and the radiological aspects of radium and radon.

7) Uranium Exploration and Mining Regulations

The Task Force will rely on the existing committee made up of representatives of the Mines and Energy and Environment Departments (with Health to be added) to produce uranium exploration and mining regulations. The committee should institute a liaison with the Task Force.

8) Uranium Exploration Operations as Information Source

Efforts will be made with assistance of the Mines and Energy Department to obtain from companies involved in uranium exploration in Nova Scotia any information which they have on distribution of uranium and related elements, especially with regard to groundwater sampling.

9) Health Effects of Exposure to Uranium and Related Elements and Biological Index of Health Effects

After the results of initial water sampling programs are known it is intended to follow up with some medical screening and clinical testing to attempt to determine: a) is health of those exposed to various levels of uranium and related elements in water supplies being affected? and b) what is the best biological index for monitoring exposure to uranium and related elements in water supplies?

10) Water Supply Alternatives in Areas where Existing Supplies are Unsuitable Due to Uranium and Related Elements

Within the limits of its resources, the Task Force will attempt to find and recommend alternatives to the water supply problem in areas in which the occurrence of uranium and related elements has made existing sources unsuitable. In cases in which the search for alternatives is beyond the resources of the Task Force to perform, recommendations regarding the possibility of engaging appropriate consultants will be made.

Through literature search, contact with other jurisdictions and equipment suppliers, attempts will be made to find treatment processes and equipment for removal of uranium and possibly related elements for: a) small central water systems such as mobile home parks, and b) individual household-size systems.

11) Contact with Other Agencies

The Task Force will maintain contact with other agencies, especially Health and Welfare Canada, the State of Maine, Province of British Columbia, Saskatchewan Research Foundation, and the University of Texas, for information exchange on water sampling and analysis methods, health effects of exposure to uranium and related elements, and water treatment processes for uranium removal.

12) Release of Information

Release of information through the news media, at public meetings and through community associations by means of an established procedure.

1.5 Chemical Toxicity and Radiotoxicity

As indicated above, the Task Force decided early in its deliberations to include the radiological considerations which are inherent properties of uranium and its decay products. Emphasis was placed on chemical toxicity because the preliminary literature review and contacts with other agencies indicated that, although little was known of the health effects of long-term intake of small amounts of uranium, it was generally believed that effects due to chemical toxicity would occur at lower concentrations than would effects due to radiotoxicity. It was felt by the Task Force members that, even though radiotoxicity may be secondary, this aspect must not be disregarded. With increasing knowledge on the effects of long exposure to relatively low levels of ionizing radiation, it may be found that this is more critical than believed at present.

It was therefore considered prudent to collect samples for the measurement of radium-226 and radon-222 activity concurrently with the collection of water samples for the analysis of uranium concentration. Radium-226, a product of the radioactive decay of uranium, is an isotope well known for its high radiotoxicity. Its occurrence in water is in the form of a dissolved solid as is the occurrence of uranium. Radon is a gas produced as radium undergoes radioactive decay. It is present in the environment as a radioactive gas emanating from soil and rock formations, and it can be dissolved in groundwater. At the beginning of the Task Force investigation, little was known of the implications to human health due to the presence of radon in household water supplies. It appeared that most authorities considered there to be no health hazard.

No plans were made to measure the radioactivity emitted by uranium in water samples. Natural uranium is radioactive but its half-life is so extremely long (4.5×10^9 years for U-238, and 7.13×10^8 for U-235) that its specific activity is relatively low. Therefore, at the concentrations likely in surface water and groundwater, it has been believed, as stated above, that any potential health hazard from uranium in drinking water is posed by chemical toxicity rather than radiotoxicity.

It should be noted that, throughout this report, uranium analysis results are expressed as concentration, that is, as mg/L of uranium in water. This reflects the fact that it is the chemical toxicity aspect of uranium which is of concern. On the other hand, radium and radon results are expressed as activity, that is, radioactivity in Bq/L because the concern with these elements is with regard to their radiotoxicity.

In addition, it must be pointed out that throughout this report, wherever the term "radium" appears, it is to be read as total radium. Total radium includes the various radium isotopes, especially radium-226, a product of the uranium-238 radioactive decay series, and radium-228, a product of the thorium-232 decay series. Detailed information on these radium isotopes is presented in Chapter 14 of this report.

1.6 Occurrence and Properties of Uranium

An overview of the worldwide occurrence and properties of uranium is presented in Appendix A. This appendix is a report produced by the Nova Scotia Department of the Environment entitled "The Hydrogeology and Distribution of Naturally-Occurring Uranium in Well Water in Nova Scotia". The report was prepared for the Uranium Task Force by David MacFarlane who was, at the time, a hydrogeologist with the Water Resource Planning Section of the

Environment Department. Appendix 1 of the report describes the properties of uranium and the uranium radioactive decay series. The abundance and occurrence of uranium in rock, soil, sediments and groundwater is also outlined.

1.7 Hydrogeochemistry of Uranium, Radium and Radon

The occurrence and behaviour of uranium and its radioactive decay products, radium-226 and radon-222, in groundwater and surface water systems, is a matter of great complexity. Appendix 2 of the Environment Department report, which is Appendix A of this report, explores and details the geochemistry of these elements, relating their origin in the natural environment with the many factors affecting their mobilization, transport, and distribution.

2. MUNICIPAL WATER SYSTEMS

2.1 Introduction

In view of the fact that 59% of Nova Scotians are served by municipal water systems, the Task Force decided that these systems should be the subject of the first major water sampling survey to be carried out. It was believed that there would likely by very few, if any, of these systems supplying water containing uranium concentrations above the recommended maximum because nearly all of the systems utilize surface water such as lakes and rivers as the sole, or at least major, source of supply. Initial indications and the experience of the Task Force members pointed to groundwater as the source which could be subject to uranium contamination; it was believed that surface water sources would contain at most only trace amounts of uranium.

2.2 Method

During the first four months of 1981 samples were collected from all of the municipal water systems in the province. With the concurrence of the Command Surgeon, Maritime Command Headquarters, and as a service to Canadian Armed Forces members and dependents, the water systems at those Canadian Forces bases and stations which have their own systems were also sampled. In all, 72 municipal systems and 8 Canadian Forces base systems were sampled. A list of the systems sampled is presented in Table 1. Samples were collected on-site by a research assistant employed by the Department of Health with the cooperation of the various Health Unit directors and the assistance of the area public health inspectors throughout Nova Scotia.

In each case the sampling consisted of the collection of one raw (untreated) water sample from each source and two

TABLE 1

Municipal and Canadian Forces Base Water Systems Sampled for Uranium and Related Elements

MUNICIPAL WATER SYSTEMS:

Annapolis County—

- Annapolis Royal
- Bridgetown
- Granville Ferry
- Greenwood Village
- Lawrencetown
- Margaretsville
- Middleton

Antigonish County—

- Antigonish
- Lower South River
- Saint Andrews

Cape Breton County—

- Birch Grove
- Donkin
- Glace Bay
- Grand Lake—SYSCO
- Louisbourg
- New Waterford
- North Sydney-Sydney Mines
- Point Edward
- Sydney
- Sydney River

Colchester County—

- Stewiacke
- Tatamagouche
- Truro

Cumberland County—

- Amherst
- Oxford
- Parrsboro
- Springhill

Digby County—

- Bear River
- Digby

Guysborough County—

- Canso
- Mulgrave
- Sherbrooke

Halifax County—

- Bedford-Sackville (Pockwock System)
- Dartmouth
- Halifax (Pockwock System)
- North Preston (Long Lake)

TABLE 1 (Continued)

Hants County—

Elmsdale
Enfield
Falmouth
Hantsport
Lantz
Shubenacadie
Windsor

Inverness County—

Cheticamp
Inverness
Judique
Mabou
Port Hawkesbury
Port Hood

Kings County—

Canning
Kentville
New Minas
Port Williams
Wolfville

Lunenburg County—

Bridgewater
Lunenburg
Mahone Bay

Pictou County—

New Glasgow
Pictou
Stellarton
Trenton
Westville

Queens County—

Brooklyn
Liverpool

Richmond County—

Arichat-Petit de Grat
Louisdale
St. Peters

Shelburne County—

Hayden Lake
Rodney Lake

Victoria County—

Baddeck
Dingwall

Yarmouth County—

Yarmouth

CANADIAN FORCES BASE WATER SYSTEMS:

Camp Aldershot
CFB Barrington
CFB Cornwallis
CFB Debert
CFB Greenwood
CFS Mill Cove
CFS Newport Corner
CFS Shelburne

treated water samples. Every source of raw water was sampled, that is, all wells, springs, streams, and lakes which are sources of supply for the various systems were sampled. The treated water samples were collected from typical points located in the water distribution systems.

Samples were collected for the analysis of uranium concentration, and radium* and radon-222 activity. Conductivity and hydrogen ion concentration (expressed as pH) of the samples were measured for possible use in evaluating the role of groundwater geochemistry in that aspect of the Task Force investigation. The details of the sample collection techniques and the laboratory analytical methods employed are noted in Appendix B.

2.3 Results

Summaries of the sample analysis results are presented below. The detailed results for all of the 271 samples taken are on file with the Department of Health. These results were mailed during the summer of 1981 to the owners and operators of these water systems. Copies of the letter and form used to report the results are attached as Appendix C.

2.3.1 Uranium Analysis Results

A summary of the uranium analysis results is presented in Table 2.

2.3.2 Radon Analysis Results

Radon-222 activity was generally low, with nearly all samples showing less than 100 Bq/L. The exceptions are noted in the following list.

* Samples were analyzed for total radium which includes Ra-226 and Ra-228 if any present.

1. Amherst - In 1 of the wells the radon activity was 214 Bq/L; in the distribution system, however, it was 36 Bq/L.

2. Lawrencetown - The water supplied by the well had radon activity of 781 Bq/L; the final mixture of spring and well water resulted in a radon activity of less than 4 Bq/L.

3. CFS Mill Cove - Radon in the well sample had an activity of 425 Bq/L, but the surface source had a less than 4 Bq/L reading.

4. CFB Barrington - Well #1 had radon activity of 133 Bq/L, and in well #2 it was 213 Bq/L; radon in the system was 23 Bq/L.

5. CFS Newport Corner - Radon activity was 103 Bq/L in the well; it was 13 Bq/L in the system.

2.3.3 Radium Analysis Results

All samples collected exhibited radium activity well below the maximum acceptable of 1.0 Bq/L for radium-226 and, in fact, none exceeded the "target" level of 0.1 Bq/L set in the Guidelines for Canadian Drinking Water Quality for radium-226.

2.4 Discussion

As expected, the uranium concentrations in all of the surface water supply sources were far below the current guideline for maximum acceptable concentration. Nearly all of the samples had uranium concentrations less than the detection level, that is, less than 0.005 mg/L.

TABLE 2

Municipal and Canadian Forces Base Water Systems

Summary of Uranium Results

Municipal Systems:

Number of Systems	Uranium Concentration in mg/L < 0.01	0.01 & 0.02	> 0.02
72	71	1 *	0

* Three of a total of eight wells in Amherst have uranium 0.01 mg/L.

Canadian Forces Bases & Stations:

Number of Systems	Uranium Concentration in mg/L < 0.01	0.01 & 0.02	> 0.02
8	7	1 **	0

** Two samples of water from the system at CFB Greenwood had uranium 0.01 mg/L; subsequent sampling found uranium < 0.005 mg/L in all supply wells.

Note: > = greater than
< = less than

Some of the well water supplies had measurable amounts of uranium but these were all less than 0.02 mg/L, the highest being 0.01 mg/L found in only 4 wells.

In the cases in which relatively high radon activity occurred in a few well water samples, it was found that the water in the distribution systems, that is, the water being provided to consumers, was low in radon activity. This was mainly due to the dilution effect which occurred when water from a surface source mixed with the well water.

Radium activity in all samples was so low as to be not detectable with the laboratory technique being used.

3. BOTTLED WATER

3.1 Introduction

Commercially produced bottled water was seen as an immediate alternate drinking water source by many who had been informed that their well water contained uranium at greater than the maximum acceptable concentration. In anticipation of this, the Task Force, through the Department of Health, arranged to have the most commonly used bottled waters analyzed for uranium and related elements.

Most of the bottled water consumed in Nova Scotia is supplied by two companies: Farmers Cooperative Dairy Limited and Sparkling Spring Water Limited, both of which are located in the province. It was decided to investigate the concentrations of uranium and related elements in both of these bottled waters. To do this a sampling program was conducted in April 1981.

3.2 Method

In each case samples were collected from the source and from two bottles of the product water chosen at random. Each company uses a drilled well as the source for its bottled water. The wells are both located in Colchester County, on separate properties, both near Truro. Sampling was carried out in accordance with the standard adopted procedures and analyses were performed for uranium, radon and radium.

3.3 Results

The laboratory analysis results are tabulated in Table 3.

3.4 Discussion

The samples of bottled water produced by both companies contained less than detectable concentrations of uranium, very low, if any, radon activity, and radium activity below the target level for radium-226.

The various imported bottled waters were not investigated due mainly to the fact that their cost generally precludes their use as a day-to-day source of drinking and cooking water. In addition, many of the imported waters contain other chemical compounds which exceed the Canadian drinking water quality guidelines by such an extent that they cannot be recommended for use as the regular source of daily drinking water supply regardless of what their uranium, radon, or radium content might be.

TABLE 3

Commercial Bottled Water

Results of Analysis for Uranium and Related Elements

Sample	Uranium concentration in mg/L	Radon-222 activity in Bq/L	Radium activity in Bq/L
Farmers—			
Drilled Well (untreated)	< 0.005	21	< 0.1
Bottled Water Sample #1	< 0.005	< 4	< 0.1
Bottled Water Sample #2	< 0.005	< 4	< 0.1
Sparkling Springs—			
Drilled Well (untreated)	< 0.005	14	< 0.1
Drilled Well (treated-ozonated)	< 0.005	17	< 0.1
Bottled Water Sample #1	< 0.005	< 4	< 0.1
Bottled Water Sample #2	< 0.005	< 4	< 0.1

4. WELL SAMPLING PROGRAM

4.1 Introduction

The events recounted in Section 1.1 of this report focussed concern for uranium contamination of well water, more specifically, on wells in the Harrietsfield-Williamswood area of Halifax County. Given the fact that the presence of uranium in drinking water was first detected in a well water supply located in Harrietsfield, it seemed logical to direct the main thrust of water sampling toward individual wells beginning with those located in Harrietsfield-Williamswood.

As outlined in the investigation program itemized in Section 1.4, the Task Force had a plan for well sampling beyond the Harrietsfield-Williamswood area. The plan was implemented to the extent that wells were sampled in the areas listed below. The reasons for selecting each area are noted.

Area	Basis of Selection
Halifax County -	
Brookside	Similarity of geology, hydrogeology, groundwater chemistry, with Harrietsfield-Williamswood.
Hants County -	
Leminster-Lower Vaughan	Baseline data collection in an area of concentrated uranium exploration.

Area	Basis of Selection
Lunenburg County -	
New Ross-Forties-Fraxville	Geology, results of samples collected by individuals, to broaden the base for clinical investigations.
Annapolis County -	Following up well chemistry reconnaissance programs in which uranium exploration companies had reported wells with uranium concentrations greater than 0.02 mg/L.
Middleton area	
Colchester County -	
Tatamagouche-Balfron area	
Cumberland County -	
Oxford area	
Pugwash area	
Wentworth area	
Pictou County -	
Louisville-Denmark-Middleton Corner-Brook Road;	
River John-Marshville-Welsford	

The well sampling surveys for each of the areas listed above are dealt with individually in the pages immediately following.

Summarized analysis results are presented for each area.

Additional information on the well sampling program is contained in Appendix A. Some tabulated data from that source are included in this section. Such inclusions are indicated as they appear. It should be noted that there are a few slight discrepancies in numbers of wells recorded in the tables from the Environmen Department report (Appendix A) compared with those prepared by the Health Department for this report. These differences are so slight as to have no bearing on the overall picture in each area, and certainly have no effect on the conclusions reached. The differences arise from the following:

1) All data were tabulated by hand as the investigation proceeded and subsequent data summaries were made by hand, in different offices, by different individuals, on different dates. For example, minor confusions arise over such things as one well serving two houses; such matters have been taken into account in preparing the final tables for this report, whereas a few of these minor items may have been overlooked when preparing tables for Appendix A which was being written before all well sampling had been completed.

2) During this type of investigation the main aim is to inform individual well owners as soon as possible and with complete accuracy of their well sample results. This was done and, as a result, the information collection and recording was more cumbersome and less amenable to reduction to "numbers only" data than if only numbers had been tabulated and manipulated during the course of the well sampling program.

4.2 Harrietsfield-Williamswood

4.2.1 Scope

The sampling program in the Harrietsfield-Williamswood area was a major undertaking which grew, by stages, to the point that all wells located in the communities of Harrietsfield and Williamswood from the Halifax city limit to Sambro were sampled. A total of 312 wells were sampled during the period from January to July 1981. The location of the area is shown in Figure 3

4.2.2 Method

The collection of water samples commenced in Area "A" shown in Figure 1. This area was bounded in the north by Birchlee Trailer Court and on the south by Moody Park Subdivision. Sampling by the Department of Health in Birchlee Trailer Court and vicinity, and sampling by home owners of individual wells located in Moody Park Subdivision, had detected uranium concentrations greater than the maximum acceptable. This was the basis for establishing the limits of Area "A". After sampling all wells in this area, the program was extended as it became obvious that the uranium occurrence was not likely limited to Area "A".

Door-to-door visits were made by Health Department staff and every effort was made in attempting to ensure that all wells were sampled. In cases in which occupants were not at home at the time of the visit, copies of the note attached to Appendix D* were left at the house. All samples were collected from the kitchen cold water tap, using the procedure previously described. Analyses were performed for uranium concentration, radon and radium** activity, conductivity and pH. In the case of radon, two samples were collected and analyzed for each sampling location, that is, for each well. The radon sampling technique is somewhat more complex than the typical technique used for other parameters. It was for this reason that the procedure was repeated in order to increase the probability of obtaining a reading as close as possible

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* Appendix D presents a concise procedure for carrying out sampling surveys for uranium or similar parameters.

** As noted in Section 1.5, the term "radium" is to be read as total radium.

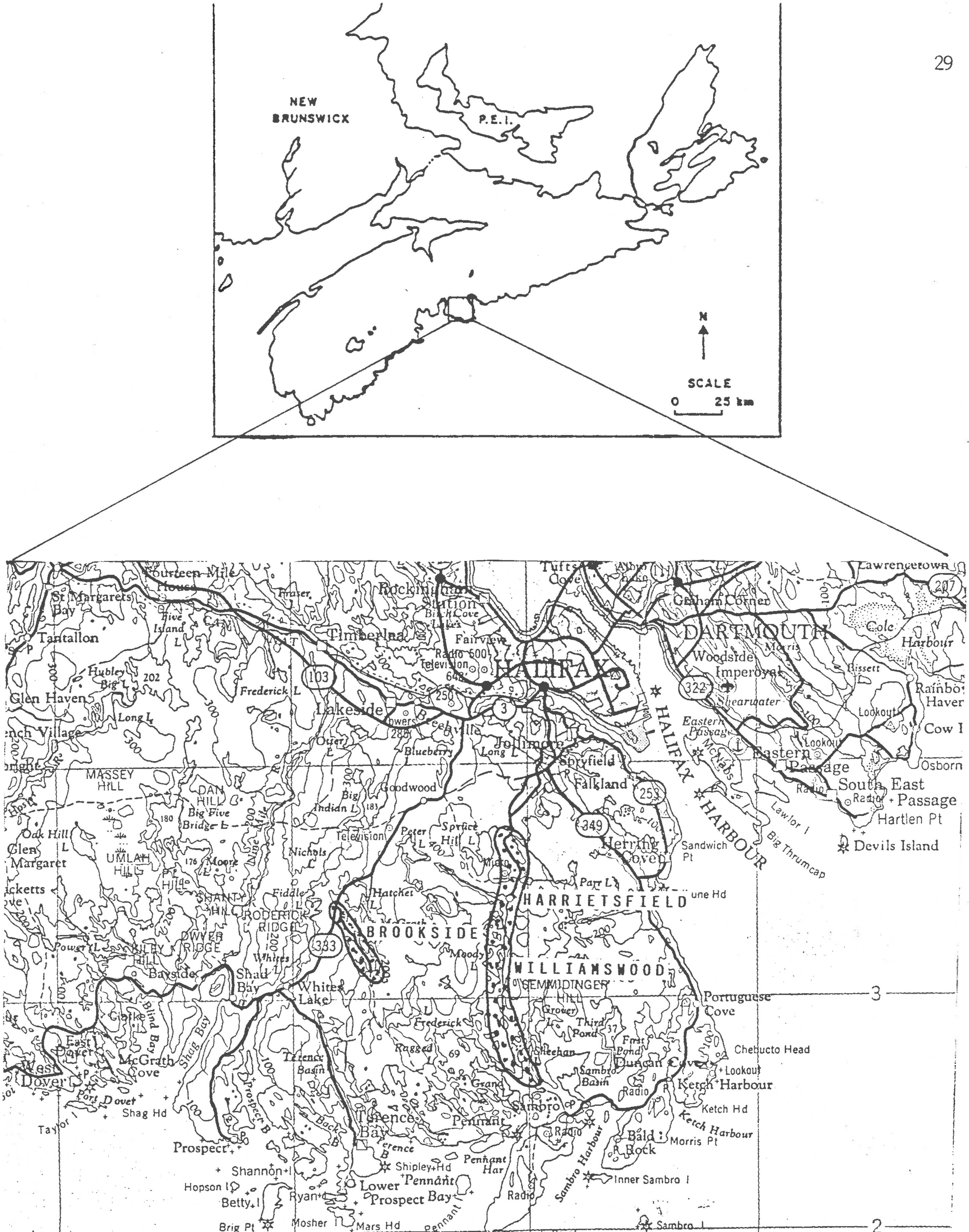

Figure 3 - Locations of Harrietsfield-Williamswood and Brookside

to the total of the radon activity present in the water. The two results were generally in close agreement, the readings usually varying by less than 3%. The higher of the two readings was reported in each instance.

In addition to collecting water samples, the survey staff interviewed occupants and completed a questionnaire at each location with the aim of obtaining as much information as possible on the well serving as the source of water supply for the house. This questionnaire, attached as Appendix E, catalogued information such as well type, date of well construction, well depth, details of construction, and operating history of the well. This information was collected mainly for use in exploring the relationship between the occurrence of uranium and related elements in groundwater, and hydrogeology and groundwater geochemistry. This aspect of the Task Force investigation program is dealt with in a subsequent section of this report.

A seemingly minor feature of the questionnaire involved the recording of the sample number assigned to the particular well, the "geographical" location or address of the well, the name, mailing address, and telephone number of the well owner, and the date of completion of the questionnaire. The exact recording of this information is absolutely essential to the success of this type of investigation. It makes possible the matching of analysis results with the well from which the samples were collected, the accurate mapping of results, the reporting of results by mail to the well owner, and telephone contact with the owner if follow-up work is required. At the beginning of the sampling program large scale maps were obtained for the part of Harrietsfield-Williamswood area for which they were available. For the balance of the area involved, large scale outline maps were prepared by the sampling staff. These maps were used in the field to plot the sample code numbers on the house locations from which the respective samples were collected. As laboratory results were received, they were plotted by using a color code and matching the sample numbers with the locations on the field map. In this way a composite picture of the geographical distribution of the wells with various concentrations of uranium was obtained.

4.2.3 Results

4.2.3.1 Reporting Process

References are made below to the various tables and a map which present the overall, summarized results of the sampling program in Harrietsfield-Williamswood. The individual laboratory analysis results for each well and the information questionnaires are filed with the Department of Health. In the interest of confidentiality, this information is not appended to this report. The Task Force and the Department of Health adhered to the policy that sample analysis results for a particular well is information which should be restricted to the Task Force, the Department of Health, the respective municipal Board of Health, and the well owner. This did not preclude the use of the information for preparation, presentation and publication of tables of summarized data and maps indicating locations of numbers of wells with various concentrations of uranium and related elements.

Individual well owners were notified by mail of the analysis results for their wells as these results became available. In light of the large number of wells sampled, form letters were used in order to expedite sending the results to owners. The letters were sent over the signature of the Director of the Atlantic Health Unit. Copies of the various form letters used are attached as Appendix F.

Three versions of the letter reporting **Uranium** results were employed. The particular version used depended on the uranium concentration being reported: less than 0.01 mg/L, 0.01 or 0.02 mg/L, greater than 0.02 mg/L. For uranium concentrations greater than 0.02 mg/L, the letter stated that "This concentration is higher than the maximum acceptable concentration of 0.02 mg/L set down in the Guidelines for Canadian Drinking Water Quality 1978" and it was recommended that "this water not be used for drinking and cooking purposes. The water can still be safely used for all other purposes..."

The same form letter was used to report all **radon** results, regardless of level of activity measured. This letter stated that: "There is at present no standard established for radon-222 activity in drinking water, and there are no known health hazards." Regarding the release of radon to the air as water runs from taps and showers, the letter stated that "the amount released is not considered hazardous." Well owners were informed that they would be advised if a radon standard is set in future.

As in the case of uranium, three versions of the letter reporting **radium** results were used according to the reported radium activity level: less than 0.9 Bq/L, 0.9 or 1.0 Bq/L, greater than 1.0 Bq/L. For radium activity greater than 1.0 Bq/L it was stated that "This concentration is higher than the maximum acceptable radium* activity of 1 Bq/L set down in the Guidelines for Canadian Drinking Water Quality 1978." It was stated that "this water is unsafe for human consumption," and it was recommended that "this water not be used for drinking and cooking purposes."

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* To be precise this statement should have used the term "radium-226" instead of "radium" as the guideline applies to radium-226, not total radium.

TABLE 4

Halifax County - Harrietsfield-Williamswood

Uranium Sampling Results

Number of Wells			Uranium Concentration in mg/L		
			< 0.01	0.01 & 0.02	> 0.02
Drilled	-	252	87 (35%)	58 (23%)	107 (43%)
Dug	-	49	49 (100%)	0	0
Unknown	-	11	9 (82%)	2 (18%)	0
TOTAL	-	312	145 (47%)	60 (19%)	107 (34%)

Number of wells includes: 3 drilled wells in Birchlee Trailer Court which serve approximately 150 mobile homes;
1 drilled well at school;
1 drilled well at fire station.

Number of wells sampled: 312

Number of homes served by wells, excluding mobile home park = 338.

9 wells are shared by 2 houses each.

2 houses use lake water as source (both have <0.005 mg/L).

Number of homes not sampled = approximately 25. These include homes whose owners refused testing, vacant homes, homes whose wells were already tested by Health Department (shared wells) and homes which did not respond to sampling offer.

TABLE 5

Halifax County - Harrietsfield-Williamswood

Wells with Uranium Concentrations > 0.02 mg/L

Numbers in Various Concentration Ranges

Total number of wells with uranium > 0.02 mg/L = 107

	Uranium Concentration Ranges in mg/L				
	0.03 - 0.10	0.11 - 0.20	0.21 - 0.30	0.31 - 0.40	> 0.40
Number of Wells	97	7	3	-	-
Ratio of Total	97/107	7/107	3/107	-	-
Percentage of Total	91%	7%	3%	-	-

TABLE 6

Halifax County - Harrietsfield-Williamswood

Radon Sampling Results

		Radon Activity in Bq/L			
		< 370*	370-500	500-1,000	> 1,000
Number of Wells:					
Drilled	259	69 (27%)	20 (8%)	76 (29%)	94 (36%)
Dug	46	46 (100%)	0	0	0
TOTAL	305	115 (38%)	20 (7%)	76 (25%)	94 (31%)
Number of Surface Sources:					
Lake	3	3	0	0	0

* 370 Bq/L = 10,000 pCi/L

Note: This table is based on data presented in Table 4 of Appendix H, which was produced by the Nova Scotia Department of the Environment.

In the cases of uranium and radium, all of the letters outlined the sampling procedure to be followed by individuals wishing to collect future samples; in the case of radon, it was pointed out that, because of the specialized equipment and technique required, sampling for radon is beyond the capability of the individual.

4.2.3.2 Uranium Sampling Data

The uranium analysis results for all of the wells sampled in Harrietsfield-Williamswood are presented in a summarized form in Table 4. Explanatory notes on the table provide information on the number of houses and mobile homes served by the wells sampled.

A breakdown of the data for wells with uranium concentration greater than 0.02 mg/L into various concentration ranges is shown in Table 5.

In subsection 4.2.2, mention was made of the preparation of a map depicting the geographical distribution of wells with various concentrations of uranium. This map, which consists of a "marked up" topographic presentation, is attached in its full size as Appendix G and it is shown in a reduced form in Figure 4.

4.2.3.3 Radon Sampling Data

The radon activity measurements for all of the Harrietsfield-Williamswood water samples have been grouped into various ranges by the Environment Department for the report which is Appendix H. These data were used as the basis for the preparation of a somewhat simplified tabulation which is presented in this section as Table 6.

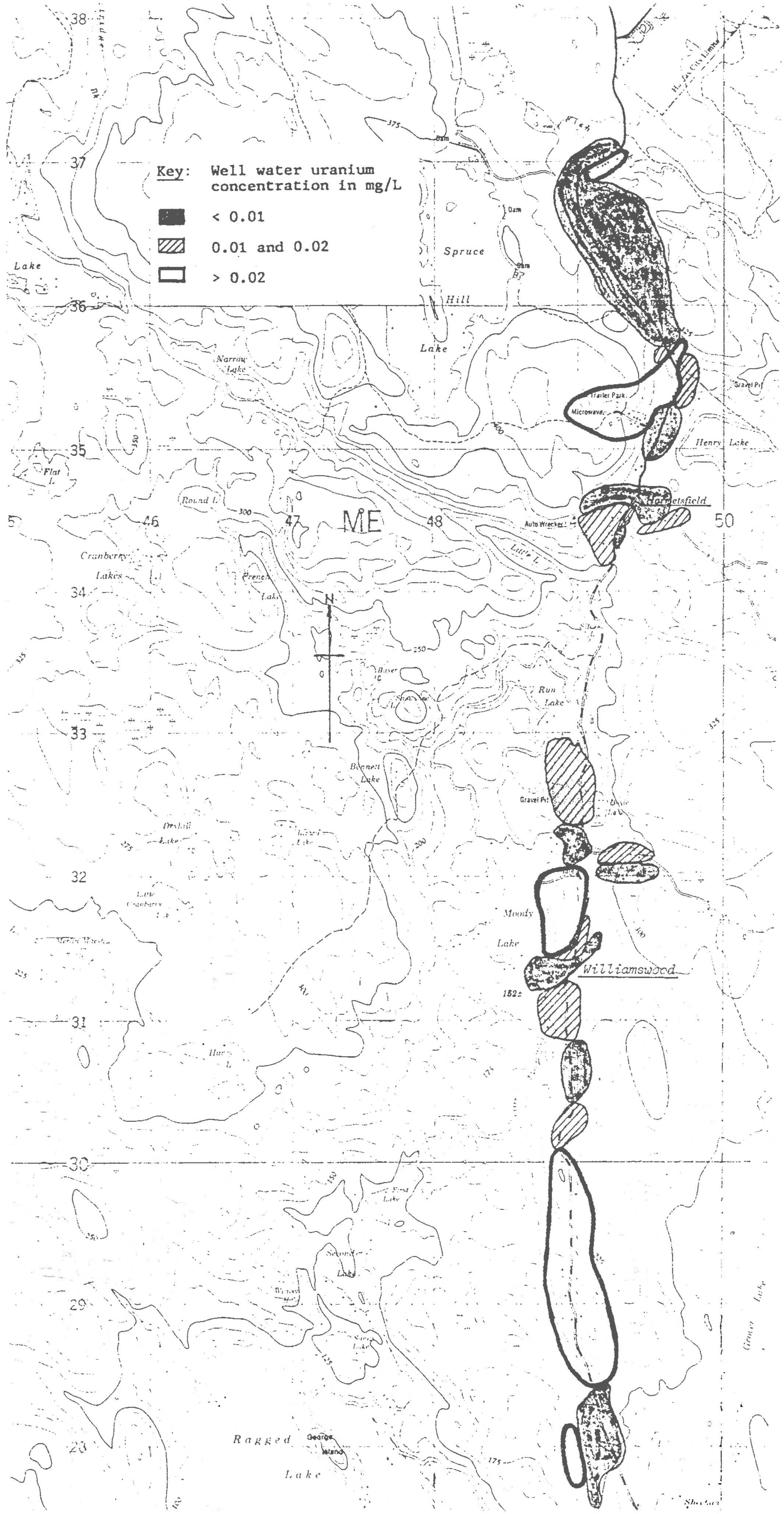

Figure 4 - Topographic Map of Harrietsfield-Williamswood Showing Geographical Distribution of Wells With Various Concentrations of Uranium

4.2.3.4 Radium Sampling Data

The summarized radium sampling results for all wells located in the Harrietsfield-Williamswood survey area are presented in Table 7.

4.2.4 Discussion

The current guideline for maximum acceptable concentration of **uranium** in drinking water was exceeded in 34% of the wells in Harrietsfield-Williamswood. All of the wells which exceeded 0.02 mg/L were drilled wells. None of the dug wells exceeded 0.02 mg/L. In all, 107 wells supplied water which exceeded 0.02 mg/L in uranium concentration. These represented 43% of the 252 drilled wells in the area.

As indicated in Table 5, nearly 91% of the wells with uranium concentrations greater than 0.02 mg/L are within the range 0.03 mg/L to 0.10 mg/L. Only 10 wells exceeded a uranium concentration of 0.10 mg/L. The highest concentration found was 0.28 mg/L.

Radon activity was generally much higher in the drilled wells than in the dug wells, with 73% of the drilled wells exceeding 370 Bq/L, which is equivalent to 10,000 pCi/L. A radon level of 10,000 pCi/L has been considered by some authorities, such as Howard M. Prichard of the University of Texas School of Public Health, to be "high". It can certainly be stated that there is considerable radon activity in water supplied by most of the drilled wells in the Harrietsfield-Williamswood area.

Measurable **radium** activity was present in a relatively small number of samples. It was greater than 0.1 Bq/L in 29 (8%) of the drilled wells, and in 14 (29%) of the dug wells.

TABLE 7

Halifax County - Harrietsfield-Williamswood

Radium Sampling Results

		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Number of Wells:				
Drilled	252	232 (92%)	18 (7%)	2 (1%)
Dug	49	35 (71%)	13 (27%)	1 (2%)
Unknown	11	10 (91%)	1 (9%)	0
TOTAL	312	277 (89%)	32 (10%)	3 (1%)
Number of Surface Sources:				
Lake	2	2	0	0

Radium, Uranium and Radon Results

For Wells with Radium > 1.0 Bq/L

Radium in Bq/L	Uranium in mg/L	Radon in Bq/L	Type of Well
3.7	0.005	188	Dug
1.4	< 0.005	925	Drilled
1.2	< 0.005	190	Drilled

As can be seen, 89% of the wells supplied water which did not exceed the target level of 0.1 Bq/L for radium-226 set down in the Guidelines. Only 3 wells of the 312 sampled had radium activity greater than the Guidelines' maximum acceptable level of 1 Bq/L for radium-226. Two of these were drilled and one was a dug well which had the highest reading: 3.7 Bq/L. The uranium and radon results corresponding to the high radium readings in the three wells are listed at the bottom of Table 7. As noted, the uranium concentrations for all three were low.

4.3 Brookside

4.3.1 Scope

The Brookside area of Halifax County is located about 7 kilometers west of Harrietsfield-Williamswood as shown in Figure 3. The area exhibits similar geology, hydrogeology, and groundwater chemistry to Harrietsfield-Williamswood and, for this reason, it was the subject of a well sampling survey. Wells were sampled at random along the entire length of Brookside Road and in the subdivisions adjacent to the road. Individual wells serving 33 of the 278 houses in the area were sampled in June 1981.

4.3.2 Method

The 33 wells sampled were selected to achieve representative coverage throughout the area and to achieve a ratio of drilled to dug wells representative of the area. Within these criteria the selection was at random and is believed to present a valid picture of wells in the area.

In all other respects, the methods used in Harrietsfield-Williamswood were followed.

4.3.3 Results

4.3.3.1 Reporting Process

Sample analysis results were presented to the well owners by the use of form letters as used in Harrietsfield-Williamswood. The letters were signed by the Director of the Atlantic Health Unit. These letters were delivered by hand due to the fact that the postal system was shut down by a strike at the time the results were available for distribution.

4.3.3.2 Uranium Sampling Data

The summarized uranium analysis results for Brookside are presented in Table 8.

4.3.3.3 Radon Sampling Data

Table 9 is based on the radon tabulations in Appendix H for the Brookside area.

4.3.3.4 Radium Sampling Data

Table 10 presents the summarized radium sampling results for the random sampling of wells in the Brookside area.

4.3.4 Discussion

Of the 33 wells sampled in Brookside, 36% exceeded the current **uranium** maximum acceptable guideline. All wells which exceeded the guideline were drilled wells. 46% of the drilled wells showed uranium concentrations greater than 0.02 mg/L. Only 1 well exhibited a concentration greater than 0.1 mg/L; it had a concentration of 0.11 mg/L.

TABLE 8

Halifax County - Brookside

Uranium Sampling Results

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	26	9 (35%)	5 (19%)	12 (46%)
Dug	7	6 (86%)	1 (14%)	0
TOTAL	33	15 (45%)	6 (18%)	12 (36%)

Number of homes in Brookside area = 278

Number of homes served by the
33 wells sampled = 33

TABLE 9

Halifax County - Brookside

Radon Sampling Results

Number of Wells		Radon Activity in Bq/L < 370	370-500	500-1,000	> 1,000
Drilled	29	6 (21%)	1 (3%)	13 (45%)	9 (31%)
Dug	8	8 (100%)	0	0	0
TOTAL	37	14 (39%)	1 (3%)	13 (35%)	9 (24%)

Note: This table is based on data presented in Table 4 of Appendix H, which was produced by the Nova Scotia Department of the Environment.

TABLE 10

Halifax County - Brookside

Radium Sampling Results

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2-1.0	> 1.0
Drilled	26	26 (100%)	0	0
Dug	7	7 (100%)	0	0
TOTAL	33	33 (100%)	0	0

There is a marked similarity between the Brookside results and those noted for Harrietsfield-Williamswood. It appears that a complete sampling of all wells serving the 278 homes in the Brookside area would reveal a situation comparable to that in Harrietsfield-Williamswood.

Results indicate that the **radon** picture is also similar to that in Harrietsfield-Williamswood, with the possible difference that there may be a larger number of wells in Brookside with radon readings in the higher ranges. As in Harrietsfield-Williamswood, none of the dug wells had radon readings greater than 370 Bq/L.

Radium activity was below the detection limit of 0.1 Bq/L in all but 2 of the wells. These 2 wells had readings of 0.1 Bq/L, the Guidelines' target level for radium-226. The random well sampling indicates, therefore, that the radium activity is generally lower in the Brookside area than in Harrietsfield-Williamswood.

4.4 Leminster-Lower Vaughan

4.4.1 Scope

The communities of Leminster and Lower Vaughan are located in Hants County along the road which runs westerly from Highway 14 to New Ross, Lunenburg County. Figure 5 serves to locate the area. These communities are situated in the general vicinity of the Millet Brook-Falls Lake site which was the scene of intensive uranium exploration activity carried out in the 1979-81 period by Kidd Creek Mines Limited (formerly Aquitaine Company of Canada).

During the course of the exploration activity, two provincial government departments, the Environment Department

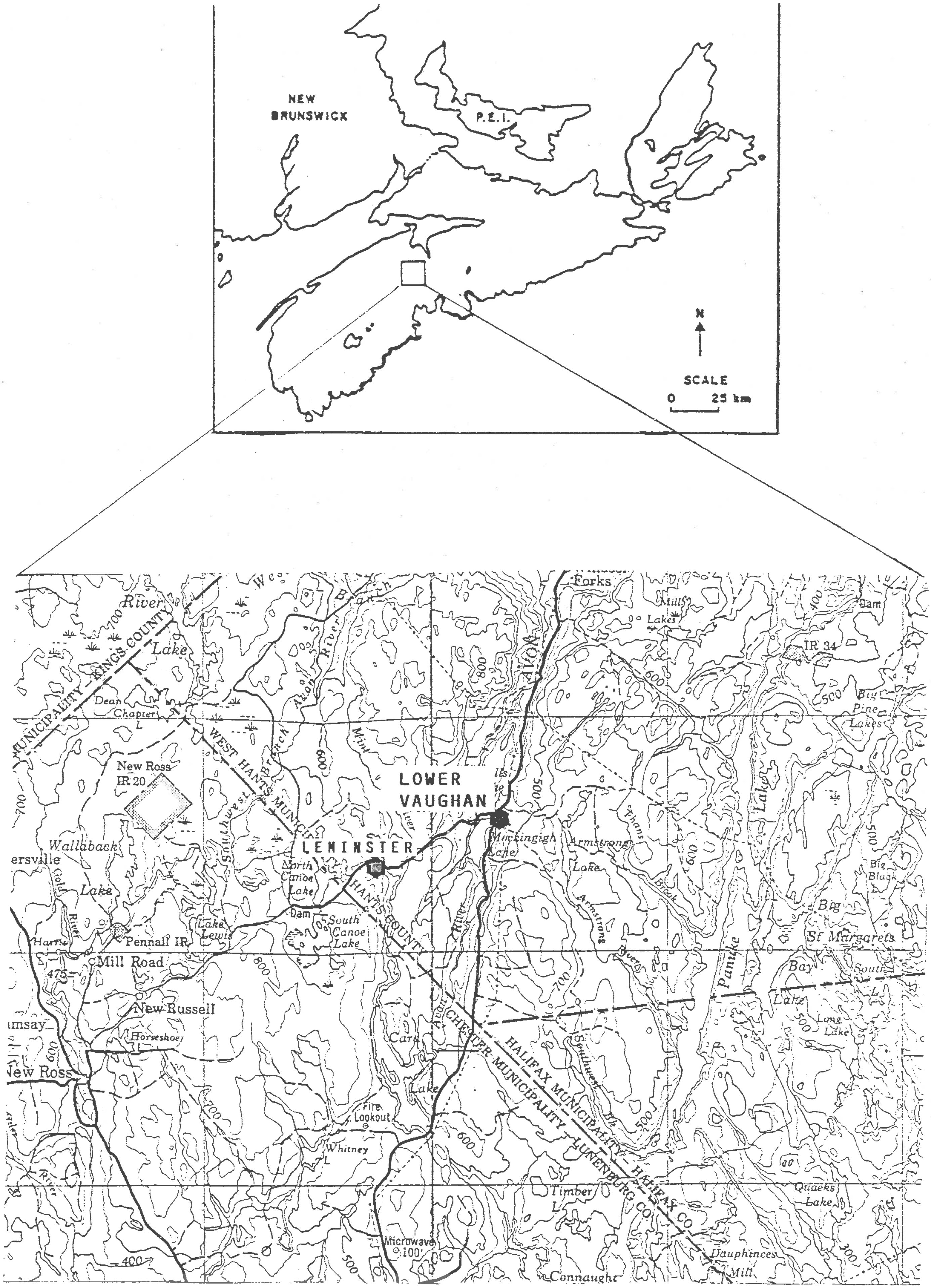

Figure 5 - Location of Leminster-Lower Vaughan

and the Mines and Energy Department, established a working relationship with the exploration company whereby steps were taken to implement controls and to make it possible to assess the environmental impact of the exploration program. It was generally agreed by the company, the Department of the Environment and the Department of Health, that it would be desirable to sample wells and water courses in the area in order to gather "baseline" data. This would be necessary in order to determine any possible effect on wells and water courses due to exploration activity. It was also obvious from the fact that the company was implementing such an exploration program that there was some evidence of uranium mineralization in the area. This being the case, it was realized that a well sampling program could obtain useful information on the potential for uranium contamination of wells in an area of known uranium mineralization. This sampling program was incorporated into the investigation of the Uranium Task Force.

Water samples were collected at nearly all of the houses located in the Lower Vaughan-Leminster area along the New Ross Road westerly from Falls Lake to Canoe Lake, along the side roads in the same area, and in Wile Settlement, which is located south of Lower Vaughan.

In all, water supplies serving 41 houses were sampled. These consisted of 36 wells, 4 springs, and 1 pond. Samples were collected from mid-June to mid-July 1981.

4.4.2 Method

The methods previously established and used in Harrietsfield-Williamswood were followed in this sampling program.

4.4.3 Results

4.4.3.1 Reporting Process

For areas such as Leminster-Lower Vaughan which are outside the Atlantic Health Unit area, the following procedure was used to report results: Laboratory reports were received by the Uranium Task Force chairman, results were tabulated and mapped, and the reports were then sent to the central office of the Department of Health. From Central Office the results were forwarded to the appropriate health unit for the area involved, in the case of Leminster-Lower Vaughan, the Fundy Health Unit. Letters were then prepared by the health unit and sent to the well owners by mail.

4.4.3.2 Uranium Sampling Data

Table 11 presents the summarized uranium sampling results for wells and other water supplies in the Leminster-Lower Vaughan area.

4.4.3.3 Radon Sampling Data

Radon sampling results for Leminster-Lower Vaughan are grouped in ranges and presented in Table 12.

4.4.3.4 Radium Sampling Data

Table 13 is a summary of the radium results for the 41 individual water supplies sampled in the Leminster-Lower Vaughan area.

4.4.4 Discussion

Only 1 well of 36 sampled exceeded the current guideline for **uranium**. The well, which had a uranium concentration

TABLE 11

Hants County - Leminster-Lower Vaughan

Uranium Sampling Results

Number of Wells		Uranium Concentration in mg/L < 0.01	0.01 & 0.02	> 0.02
Drilled	4	2 (50%)	1 (25%)	1 (25%)
Dug	32	32 (100%)	0	0
TOTAL	36	34 (94%)	1 (3%)	1 (3%)
Number of Other Sources				
Spring	4	4	0	0
Pond	1	1	0	0

Total number of individual water supplies in survey area = 51

Number of individual water supplies sampled = 41

Number of houses served by the individual water supplies sampled = 39

TABLE 12

Hants County - Leminster-Lower Vaughan

Radon Sampling Results

		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Number of Wells:					
Drilled	4	1 (25%)	0	1 (25%)	2 (50%)
Dug	32	30 (94%)	0	1 (3%)	1 (3%)
TOTAL	36	31 (86%)	0	2 (6%)	3 (8%)
Number of Other Sources:					
Spring	4	3	1	0	0
Pond	1	1	0	0	0

TABLE 13

Hants County - Leminster-Lower Vaughan

Radium Sampling Results

		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Number of Wells:				
Drilled	4	3 (75%)	1 (25%)	0
Dug	32	31 (97%)	1 (3%)	0
TOTAL	36	34 (94%)	2 (6%)	0
Number of Other Sources:				
Spring	4	4	0	0
Pond	1	1	0	0

of 0.13 mg/L, was 1 of the 4 drilled wells sampled. All 32 dug wells had uranium concentrations below 0.01 mg/L. It appears likely that the prevalence of dug rather than deep drilled wells is the reason that there is no general occurrence of uranium in well water in this area.

In the Leminster-Lower Vaughan area, 2 dug wells had **radon** activity measurements higher than 500 Bq/L, as did 3 of the 4 drilled wells. This area was the first one in which radon readings higher than 500 Bq/L were found in dug wells. The highest radon activity reading was taken on water from the drilled well which had the highest uranium concentration: The radon activity for this well was measured at 7,871 Bq/L.

Radium activity was less than 0.1 Bq/L for nearly all wells. The highest radium result was 0.4 Bq/L measured for a sample of water from a dug well.

4.5 New Ross-Forties-Fraxville

4.5.1 Scope

During the course of the Harrietsfield-Williamswood well sampling program the Uranium Task Force decided to conduct a clinical investigation of the Harrietsfield-Williamswood population as part of the study of health effects of uranium in drinking water. The preliminary results of this clinical investigation, which is fully described later in this report, indicated the need for an additional study of another population of the same size which had also been exposed to similar amounts of uranium in drinking water.

At the time that this matter was before the Task Force, at year's end in 1981, uranium analysis results for a few well water samples collected by individual well owners in New Ross came to the attention of the Uranium Task Force. These samples contained uranium in concentrations higher than 0.02 mg/L. This, combined with information provided by the Nova Scotia Department of Mines and Energy regarding the geology and considerable uranium exploration interest in the area, led to the decision that New Ross be the site for the second intensive well sampling program and clinical investigation.

The program aimed to sample all wells located in the village of New Ross and the neighboring communities to the west, Forties and Fraxville. The survey site is located on the map which is Figure 6. Wells were sampled during the period January to June 1982. In all, 252 wells and 8 springs were sampled.

4.5.2 Method

Initially a spot sampling program of 17 wells was carried out. Six of the 15 drilled wells sampled were found to contain uranium concentrations greater than 0.02 mg/L. The scattered locations of these wells pointed out the advisability of checking all of the wells in New Ross and Forties, and the decision to do this was made.

Individual water supplies were sampled in the area described below:

1) Along Highway #12 from the building occupied by a tire dealership north to and including Harriston.
2) Along Old Windsor Road to New Russell, stopping at the junction of Mill Lake Road and New Russell Road, excluding Mill Lake Road and Leville Road.
3) All of Forties Road west from New Ross to the bridge at Forty Brook.

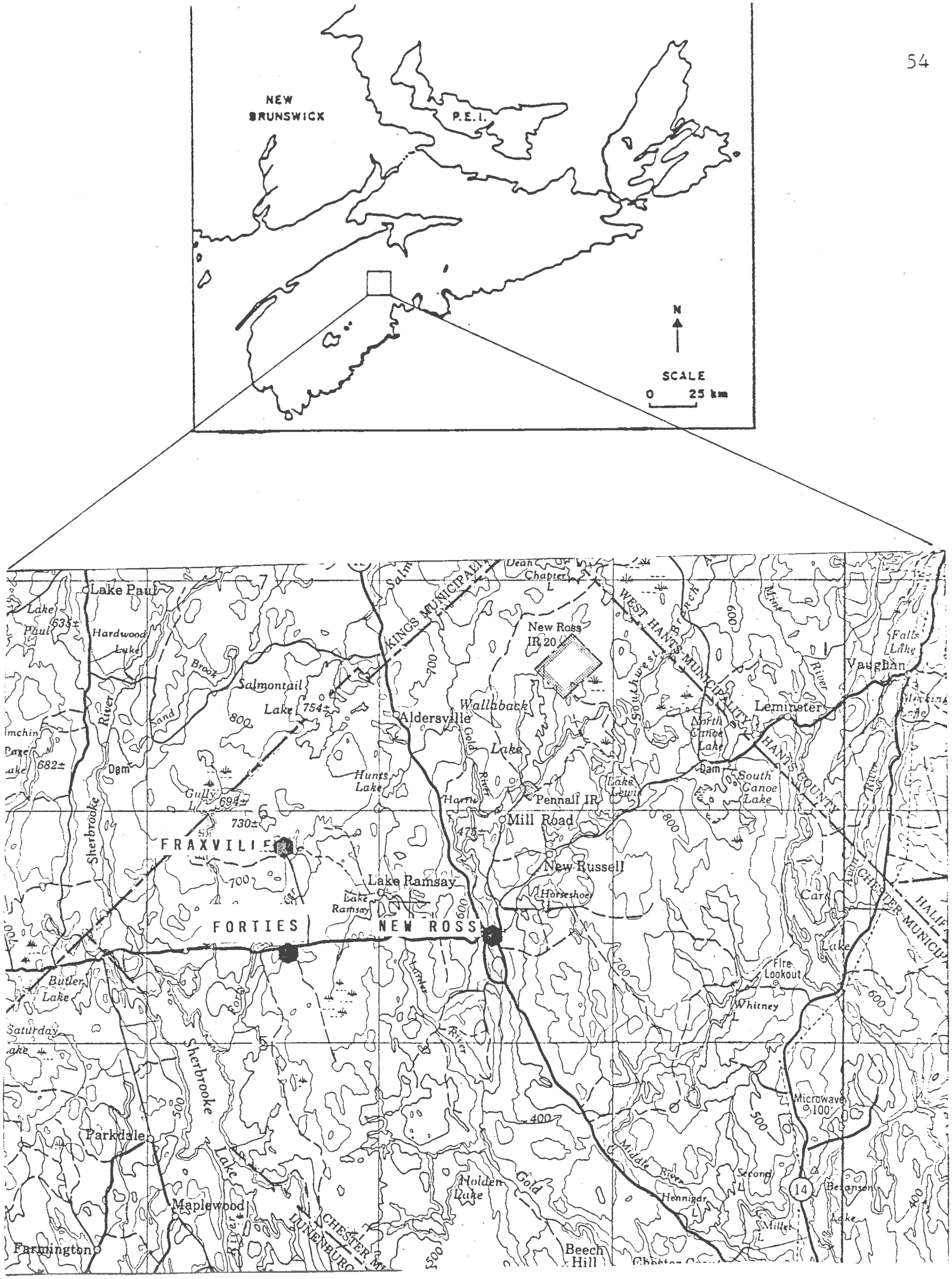

Figure 6 - Location of New Ross-Forties-Fraxville

4) Lake Ramsay Road and Fraxville Road.

The standard methods for sample collection used in the previous sampling surveys were applied.

4.5.3 Results

4.5.3.1 Reporting Process

The reporting of analysis results to residents of New Ross, Forties, Fraxville was closely coordinated with the personnel who were organizing the clinic to be held in the community. For reasons outlined in the section of this report which deals with the clinical investigations it was decided to collect all of the analysis reports, to prepare all of the letters to well owners, and to mail all of these at such a time that the letters would be received no more than two or three days before the dates of the clinic, 1 and 2 June 1982. In this case, the reporting process was administered by the Task Force chairman with the concurrence of the director of the Lunenburg-Queens Health Unit.

4.5.3.2 Uranium Sampling Data

The summarized analysis results for the 254 individual water supplies sampled are tabulated in Table 14. As done for Harrietsfield-Williamswood, a breakdown of the data for wells with uranium concentration greater than 0.02 mg/L into various concentration ranges is shown in Table 15.

4.5.3.3 Radon Sampling Data

Table 16 presents the radon activity measurements as grouped in various ranges. This table is based on the radon tabulations in Appendix H.

TABLE 14

Lunenburg County - New Ross-Forties-Fraxville

Uranium Sampling Results

		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Number of Wells				
Drilled	101	50 (50%)	20 (20%)	31 (31%)
Dug	151	146 (97%)	3 (2%)	2 (1%)
TOTAL	252	196 (78%)	23 (9%)	33 (13%)
Number of Other Sources				
Spring	8	6	2	0

TABLE 15

Lunenburg County – New Ross–Forties–Fraxville

Wells with Uranium Concentrations > 0.02 mg/L

Numbers in Various Concentration Ranges

Total number of wells with uranium > 0.02 mg/L = 33

	Uranium Concentration Ranges in mg/L				
	0.03 – 0.10	0.11 – 0.20	0.21 – 0.30	0.31 – 0.40	> 0.41
Number of Wells	21	7	3	1	1*
Ratio of Total	21/33	7/33	3/33	1/33	1/33
Percentage of Total	64%	21%	9%	3%	3%

*Highest uranium concentration— 0.70 mg/L

TABLE 16

Lunenburg County - New Ross-Forties-Fraxville

Radon Sampling Results

		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Number of Wells					
Drilled	87	26 (30%)	9 (10%)	32 (37%)	20 (23%)
Dug	130	118 (91%)	2 (2%)	4 (3%)	6 (5%)
TOTAL	217	144 (66%)	11 (5%)	36 (17%)	26 (12%)
Number of Other Sources					
Spring	6	5	1	0	0

Note: This table is based on data presented in Table 4 of Appendix H, which was produced by the Nova Scotia Department of the Environment.

4.5.3.4 Radium Sampling Data

The summarized radium sampling results for all wells sampled in the New Ross-Forties-Fraxville area are presented in Table 17.

4.5.4 Discussion

The current **uranium** maximum acceptable guideline was exceeded by 13% of the 252 wells sampled compared with 34% of wells in Harrietsfield-Williamswood, the site of the other major well sampling program. Of the 33 wells which exceeded 0.02 mg/L for uranium, all except 2 were drilled wells. Various indications leave no doubt that the extensive use of dug wells—151 dug compared to 101 drilled—has helped greatly to minimize the number of wells with potentially problematical concentrations of uranium. It should be noted that 31% of the drilled wells produced uranium concentrations in excess of 0.02 mg/L.

Table 15 indicates a situation substantially different than that seen in Harrietsfield-Williamswood. In the New Ross region, 36% of those wells with uranium levels higher than 0.02 mg/L had uranium concentrations greater than 0.10 mg/L (10% in Harrietsfield-Williamswood) and in fact 15% of the wells exceeding the guideline had uranium concentrations greater than 0.20 mg/L (3% in Harrietsfield-Williamswood). The highest uranium level found in any well was 0.70 mg/L.

Radon activity was generally higher in drilled wells than in dug wells. 70% of drilled wells had radon readings exceeding 370 Bq/L, whereas only 9% of dug wells exceeded that level. In all, there is substantial radon activity in about 35% of all wells sampled with readings in several wells being in the 2,000-7,000 Bq/L range.

TABLE 17

Lunenburg County - New Ross-Forties-Fraxville

Radium Sampling Results

		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Number of Wells				
Drilled	101	84 (83%)	16 (16%)	1 (1%)
Dug	151	145 (96%)	3 (2%)	3 (2%)
TOTAL	252	229 (91%)	19 (8%)	4 (2%)
Number of Other Sources				
Spring	8	8	0	0

Radium, Uranium and Radon Results
For Wells with Radium > 1.0 Bq/L

Radium in Bq/L	Uranium in mg/L	Radon in Bq/L	Type of Well
2.2	0.006	2,880	Drilled*
1.9	0.008	1,770	Dug
1.7	< 0.005	700	Dug
1.1	< 0.005	3,000	Dug

*Shallow—drilled 38 feet deep.

The target level of 0.1 Bq/L for **radium**-226 activity was met by 91% of all wells sampled. Radium measurements exceeded this level in 17% of the drilled wells and in 4% of the dug wells. The maximum acceptable level of radium-226 activity was exceeded in 4 wells (2% of the total number). It is interesting to note that 3 of these were dug wells. The highest radium reading in the survey area was 2.2 Bq/L in a shallow drilled well. The uranium and radon results corresponding to the 4 high radium readings are listed at the bottom of Table 17. All 4 had low uranium concentrations.

4.6 Uranium Exploration Areas in Annapolis, Colchester, Cumberland and Pictou Counties

4.6.1 Scope

In March 1981 staff of the provincial Department of Mines and Energy informed the Uranium Task Force that data collected by a number of uranium exploration companies could be useful in identifying areas of the province in which uranium may be present in well water. Some of the companies which had been engaged in uranium exploration in Nova Scotia during the period from the late 1970s to the early 1980s used well water sampling as an exploration method. The results submitted by these companies showed that there were wells in various areas which contain uranium concentrations higher than 0.02 mg/L. Mines and Energy Department staff prepared a tabulated summary of the well sampling results submitted by all of the companies using this technique. It was agreed that the Task Force would make maximum use of the information on file at the Mines and Energy Department.

Although this information was of a confidential nature, the Department of Mines and Energy offered to release it to the Uranium Task Force in light of the potential public health implications. By means described later in Section 4.6.2 this information was used to designate areas in which well spot sampling programs would be implemented. These areas, which are listed in Section 4.1, are located in Annapolis, Colchester, Cumberland and Pictou Counties. The exact locations of the areas are shown on maps as listed below. The number of wells sampled in each area is also listed.

Area	Location Map	Number of Wells Sampled
Annapolis County—		
Middleton area	Figure 7	3
Colchester County—		
Tatamagouche-Balfron area	Figure 8	18
Cumberland County—		
Oxford area	Figure 9	1
Pugwash area	Figure 9	43
Wentworth area	Figure 9	23
Pictou County—		
Louisville-Denmark-Middleton Corner-Brook Road area	Figure 10	18
River John-Marshville-Welsford area	Figure 10	42

A total of 148 wells were sampled. The sampling took place in July and August 1981 with the exception of some additional sampling which was done in River John in February 1982.

4.6.2 Method

It was obvious that reviewing, extracting and collating the uranium exploration information on file at the Mines

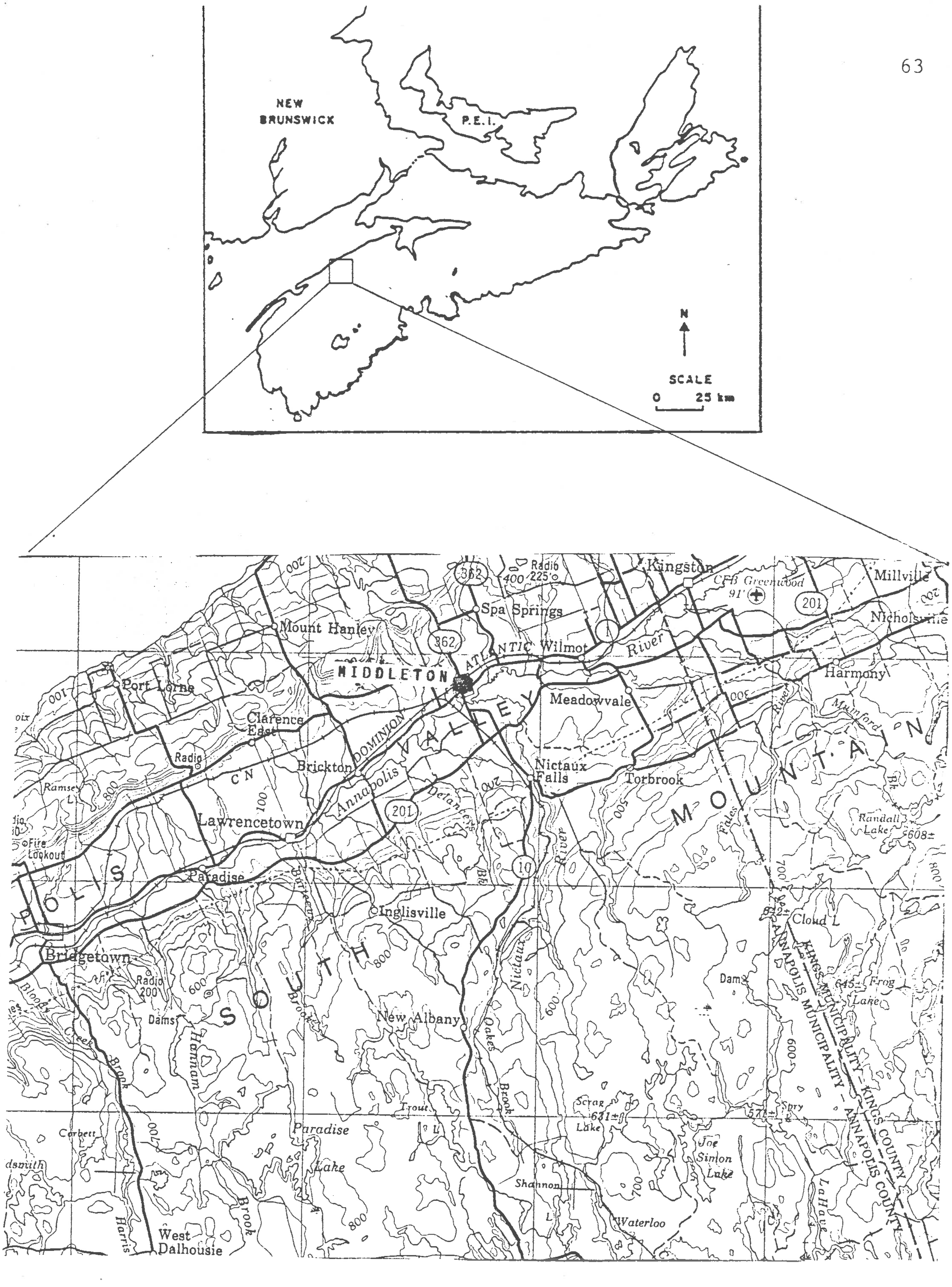

Figure 7 - Location of Middleton Area

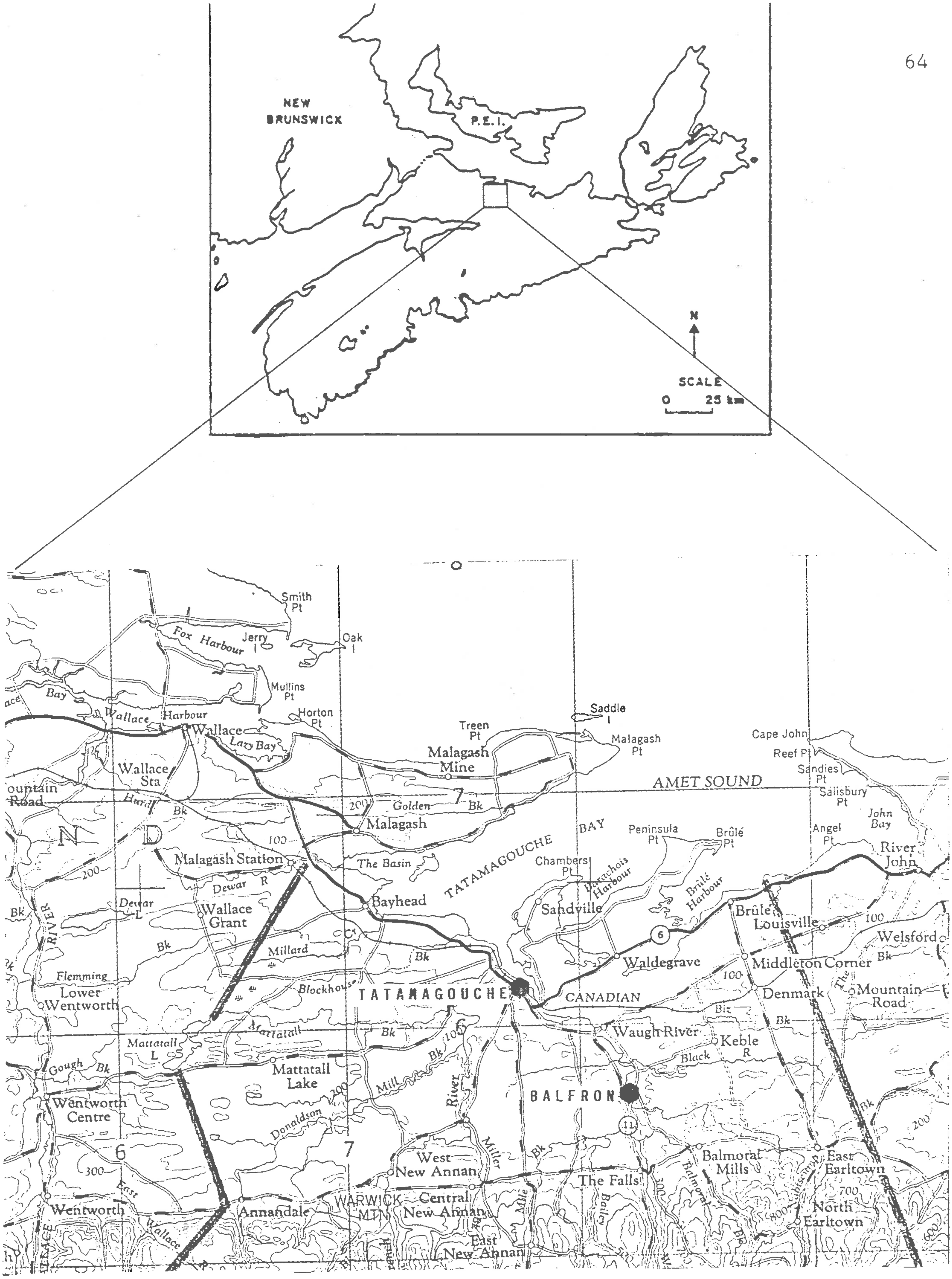

Figure 8 - Location of Tatamagouche-Balfron Area

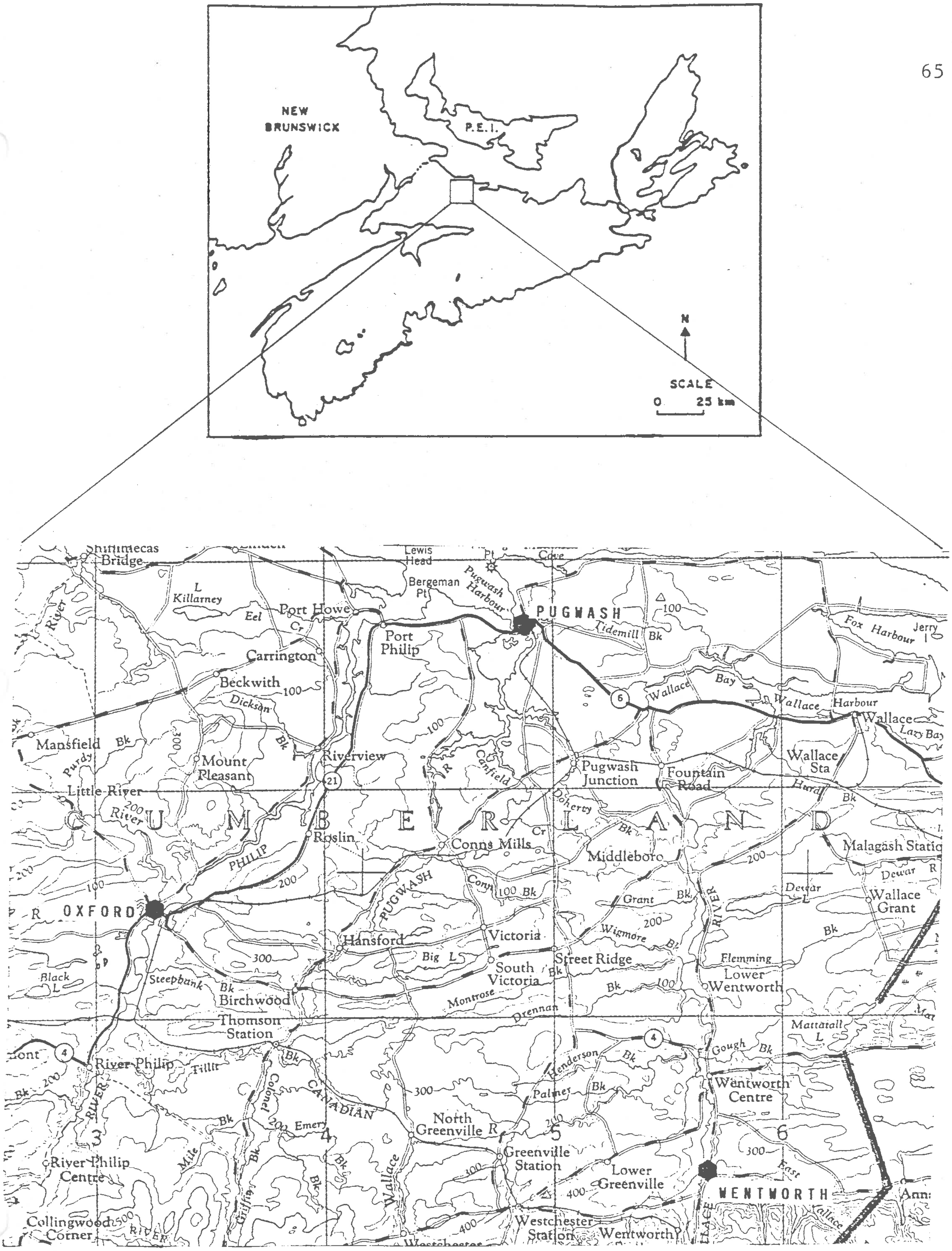

Figure 9 - Location of Oxford, Pugwash and Wentworth Areas

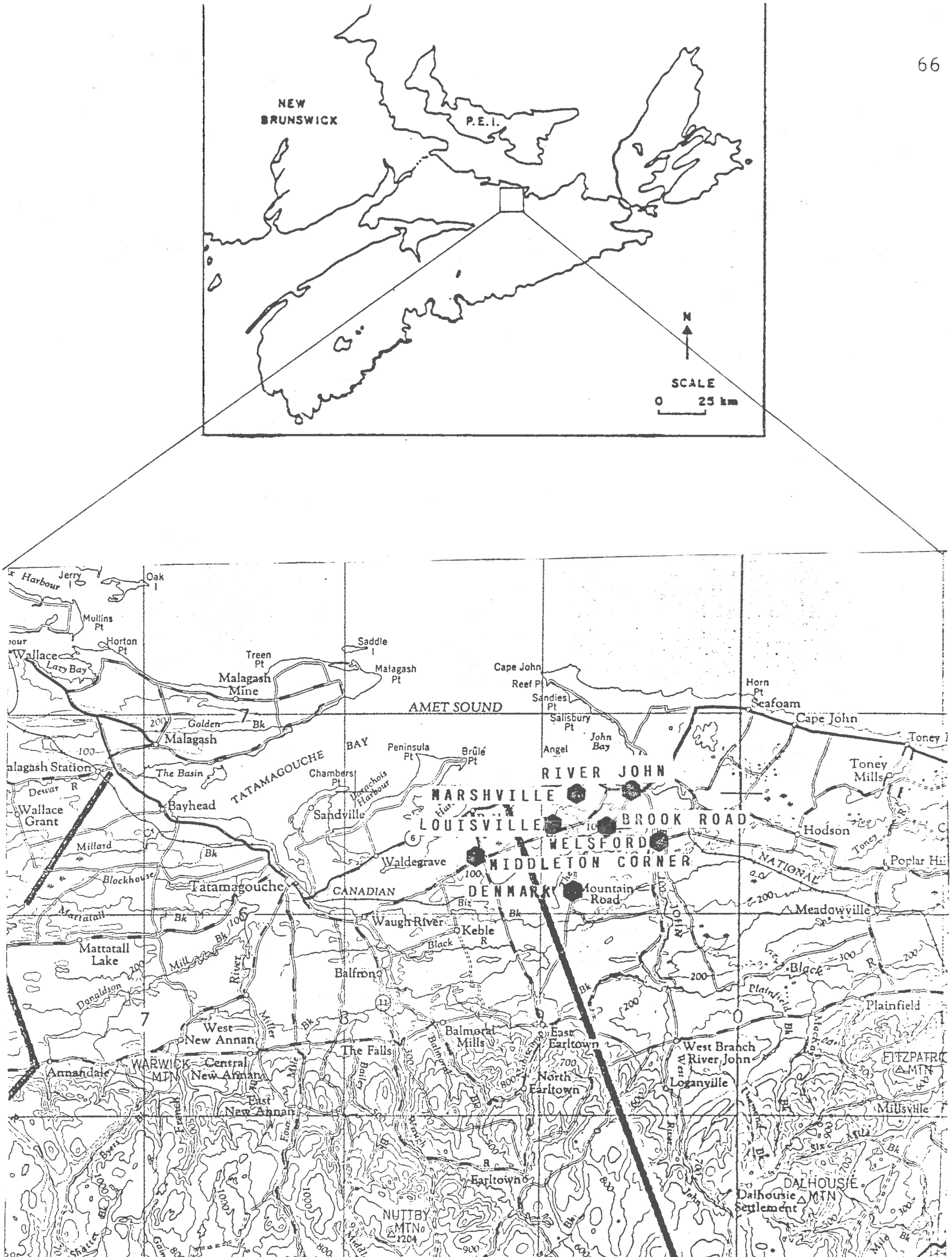

Figure 10 - Locations of Louisville-Denmark-Middleton Corner-Brook Road Area and River John-Marshville-Welsford Area

and Energy Department would be a major task. This work was contracted to the Maritime Resource Management Service. The MRMS staff used the information obtained to prepare large-scale maps, using the available ortho-photo sheets as a base, which located the wells which had been sampled by the exploration companies. In addition to location, the maps indicated, by means of a color and symbol code, whether the wells were dug, drilled, or of unknown construction, and what uranium concentration was found by the exploration companies' sampling of the wells.

These maps were used to select areas for spot sampling. Areas in which the exploration companies' sampling did not report any wells with greater than 0.02 mg/L were not resampled. Nearly all of the areas in which the maps recorded any wells with greater than 0.02 mg/L uranium were selected for resampling by the Uranium Task Force. In each of those areas all wells previously sampled by the uranium exploration company, not only those above 0.02 mg/L, were sampled for uranium, radon and radium using the standard sampling techniques.

4.6.3 Results

4.6.3.1 Reporting Process

Laboratory reports were received by the Uranium Task Force chairman, results were tabulated and mapped, and the reports were then sent to the Health Department's central office. From Central Office they were forwarded to the appropriate health unit for the area involved. Letters, based on a standard format, were then prepared by the health unit and sent by mail to the owners of all wells sampled.

It should be recorded that the uranium exploration companies did not in all cases report results of their sampling to the well owners.

4.6.3.2 Uranium Sampling Data

Summaries of the uranium sampling results for wells in various uranium exploration areas checked are found in the tables for the respective areas as listed below.

Area	Table Number
Annapolis County—Middleton area	18
Colchester County—Tatamagouche-Balfron area	19
Cumberland County—Oxford, Pugwash and Wentworth areas	20
Pictou County—Louisville-Denmark-Middleton Corner-Brook Road area, and River John-Marshville-Welsford area	21

In addition, Table 22 presents the total uranium results for all of the uranium exploration areas combined. A breakdown of the data for wells with uranium concentration greater than 0.02 mg/L into various concentration ranges is shown in Table 23.

4.6.3.3 Radon Sampling Data

Radon activity measurements have been grouped in ranges for each of the uranium exploration areas checked using the radon tabulations in Appendix H as a basis. These data summaries are presented in the tables for the individual areas as listed below.

Area	Table Number
Annapolis County—Middleton area	24
Colchester County—Tatamagouche-Balfron area	25
Cumberland County—Oxford, Pugwash and Wentworth areas	26
Pictou County—Louisville-Denmark-Middleton Corner-Brook Road area, and River John-Marshville-Welsford area	27

TABLE 18

Annapolis County - Middleton Area

Uranium Sampling Results

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	2	1 (50%)	1 (50%)	0
Dug	1	1 (100%)	0	0
TOTAL	3	2 (67%)	1 (33%)	0

TABLE 19

Colchester County - Tatamagouche-Balfron Area

Uranium Sampling Results

Number of Wells		Uranium Concentration in mg/L		
		≤ 0.01	0.01 & 0.02	≥ 0.02
Drilled	15	3 (20%)	8 (53%)	4 (27%)
Unknown	3	0	2 (67%)	1 (33%)
TOTAL	18	3 (17%)	10 (56%)	5 (28%)

TABLE 20

Cumberland County - Oxford, Pugwash and Wentworth Areas

Uranium Sampling Results

OXFORD AREA

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Unknown	1	1 (100%)	0	0
TOTAL	1	1 (100%)	0	0

PUGWASH AREA

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	36	2 (6%)	22 (61%)	12 (33%)
Dug	1	1 (100%)	0	0
Unknown	6	1 (17%)	4 (67%)	1 (17%)
TOTAL	43	4 (9%)	26 (61%)	13 (30%)

WENTWORTH AREA

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	20	2 (10%)	9 (45%)	9 (45%)
Dug	2	1 (50%)	1 (50%)	0
Unknown	1	0	0	1 (100%)
TOTAL	23	3 (13%)	10 (44%)	10 (44%)

TABLE 21

Pictou County

Louisville-Denmark-Middleton Corner-Brook Road Area

and

River John-Marshville-Welsford Area

Uranium Sampling Results

LOUISVILLE-DENMARK-MIDDLETON CORNER-BROOK ROAD AREA

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	17	10 (59%)	4 (24%)	3 (18%)
Dug	1	1 (100%)	0	0
TOTAL	18	11 (61%)	4 (22%)	3 (17%)

RIVER JOHN-MARSHVILLE-WELSFORD AREA

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	36	15 (42%)	11 (31%)	10 (28%)
Dug	5	5 (100%)	0	0
Unknown	1	0	0	1 (100%)
TOTAL	42	20 (48%)	11 (26%)	11 (26%)

TABLE 22

Uranium Exploration Areas - Combined Totals

Uranium Sampling Results

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	126	33 (26%)	55 (44%)	38 (30%)
Dug	10	9 (90%)	1 (10%)	0
Unknown	15	4 (27%)	7 (47%)	4 (27%)
TOTAL	151	46 (31%)	63 (42%)	42 (28%)

TABLE 23

Uranium Exploration Areas - Combined Totals

Wells with Uranium Concentrations > 0.02 mg/L

Numbers in Various Concentration Ranges

Total number of wells with uranium > 0.02 mg/L = 42

	Uranium Concentration Ranges in mg/L				
	0.03 - 0.10	0.11 - 0.20	0.21 - 0.30	0.31 - 0.40	> 0.41
Number of Wells	41	1	0	0	0
Ratio of Total	41/42	1/42	0	0	0
Percentage of Total	98%	2%	0	0	0

TABLE 24

Annapolis County - Middleton Area

Radon Sampling Results

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	2	2 (100%)	0	0	0
Dug	1	1 (100%)	0	0	0
TOTAL	3	3 (100%)	0	0	0

Note: This table is based on data presented in Table 4 of Appendix H which was prepared by the Nova Scotia Department of the Environment.

TABLE 25

Colchester County - Tatamagouche-Balfron Area

Radon Sampling Results

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	18	18 (100%)	0	0	0
TOTAL	18	18 (100%)	0	0	0

Note: This table is based on data presented in Table 4 of Appendix H which was prepared by the Nova Scotia Department of the Environment.

TABLE 26

Cumberland County - Oxford, Pugwash and Wentworth Areas

Radon Sampling Results

OXFORD AREA

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Unknown	1	1 (100%)	0	0	0
TOTAL	1	1 (100%)	0	0	0

PUGWASH AREA

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	41	41 (100%)	0	0	0
Dug	2	2 (100%)	0	0	0
TOTAL	43	43 (100%)	0	0	0

WENTWORTH AREA

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	21	21 (100%)	0	0	0
Dug	2	2 (100%)	0	0	0
TOTAL	23	23 (100%)	0	0	0

Note: This table is based on data presented in Table 4 of Appendix H which was prepared by the Nova Scotia Department of the Environment.

TABLE 27

Pictou County

Louisville-Denmark-Middleton Corner-Brook Road Area and

River John-Marshville-Welsford Area

Radon Sampling Results

LOUISVILLE-DENMARK-MIDDLETON CORNER-BROOK ROAD AREA

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	17	17 (100%)	0	0	0
Dug	1	1 (100%)	0	0	0
TOTAL	18	18 (100%)	0	0	0

RIVER JOHN-MARSHVILLE-WELSFORD AREA

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	22	20 (91%)	1 (5%)	0	1 (5%)
Dug	2	2 (100%)	0	0	0
TOTAL*	24	22 (92%)	1 (4%)	0	1 (4%)

*The additional sampling of 17 wells in February 1982 was for uranium only; radon and radium were not determined.

Note: This table is based on data presented in Table 4 of Appendix H which was prepared by the Nova Scotia Department of the Environment.

In addition, Table 28 presents the total radon results for all of the uranium exploration areas combined.

4.6.3.4 Radium Sampling Data

The summarized radium sampling results for wells sampled in the uranium exploration areas are presented in the tables for the individual areas as listed below.

Area	Table Number
Annapolis County—Middleton area	29
Colchester County—Tatamagouche-Balfron area	30
Cumberland County—Oxford, Pugwash and Wentworth areas	31
Pictou County—Louisville-Denmark-Middleton Corner-Brook Road area, and River John-Marshville-Welsford area	32

In addition, Table 33 presents the radium results for all of the uranium exploration areas combined.

4.6.4 Discussion

Of the total of 151 wells sampled in the seven uranium exploration areas checked, 42 wells (28%) exceeded 0.02 mg/L in **uranium** concentration. No known dug wells exceeded the guideline. In nearly all cases the Task Force sampling results were identical or close to those obtained by the exploration companies. On the average, the proportion of wells with uranium concentration in the "borderline" category—0.01 and 0.02 mg/L—was considerably higher than it was in other well survey areas. It was 42% for the combined total for the uranium exploration areas. As seen in Table 23, all but 1 of the wells with uranium greater than 0.02 mg/L had concentrations in the 0.03 to 0.10 mg/L range.

TABLE 28

Uranium Exploration Areas - Combined Totals

Radon Sampling Results

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	121	119	1	0	1
Dug	8	8	0	0	0
Unknown	1	1	0	0	0
TOTAL	130	128	1	0	1

Note: This table is based on data presented in Table 4 of Appendix H which was prepared by the Nova Scotia Department of the Environment.

TABLE 29

Annapolis County - Middleton Area

Radium Sampling Results

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	2	2 (100%)	0	0
Dug	1	1 (100%)	0	0
TOTAL	3	3 (100%)	0	0

TABLE 30

Colchester County - Tatamagouche-Balfron Area

Radium Sampling Results

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	15	15 (100%)	0	0
Unknown	3	3 (100%)	0	0
TOTAL	18	18 (100%)	0	0

TABLE 31

Cumberland County - Oxford, Pugwash and Wentworth Areas

Radium Sampling Results

OXFORD AREA

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Unknown	1	1 (100%)	0	0
TOTAL	1	1 (100%)	0	0

PUGWASH AREA

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	36	36 (100%)	0	0
Dug	1	1 (100%)	0	0
Unknown	6	6 (100%)	0	0
TOTAL	43	43 (100%)	0	0

WENTWORTH AREA

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	20	20 (100%)	0	0
Dug	2	2 (100%)	0	0
Unknown	1	1 (100%)	0	0
TOTAL	23	23 (100%)	0	0

TABLE 32

Pictou County

Louisville-Denmark-Middleton Corner-Brook Road Area and

River John-Marshville-Welsford Area

Radium Sampling Results

LOUISVILLE-DENMARK-MIDDLETON CORNER-BROOK ROAD AREA

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	17	17 (100%)	0	0
Dug	1	1 (100%)	0	0
TOTAL	18	18 (100%)	0	0

RIVER JOHN-MARSHVILLE-WELSFORD AREA

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	22	20 (91%)	1 (5%)	1 (5%)
Dug	2	2 (100%)	0	0
TOTAL*	24	22 (92%)	1 (4%)	1 (4%)

*The additional sampling of 17 wells in February 1982 was for uranium only; radon and radium were not determined.

Radium, Uranium and Radon Results

for Wells with Radium > 1.0 Bq/L

Radium in Bq/L	Uranium in mg/L	Radon in Bq/L	Type of Well
1.1	0.11	1,558	Drilled

TABLE 33

Uranium Exploration Areas - Combined Totals

Radium Sampling Results

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	112	110 (98%)	1 (1%)	1 (1%)
Dug	7	7 (100%)	0	0
Unknown	11	11 (100%)	0	0
TOTAL	130	128 (99%)	1 (0.5%)	1 (0.5%)

Radium, Uranium and Radon Results for Wells with Radium > 1.0 Bq/L

Radium in Bq/L	Uranium in mg/L	Radon in Bq/L	Type of Well
1.1	0.11	1,558	Drilled

Radon activity was noticeably lower in the wells in these areas compared with other areas sampled. Only 2 wells of 130 sampled for radon had readings higher than 370 Bq/L. These 2 were located in the River John-Marshville-Welsford area. The observation that radon levels are much lower in the uranium exploration areas than in the other areas surveyed is discussed in Appendix H and an explanation for this is proposed.

With the exception of 2 wells in the River John-Marshville-Welsford area, **radium** activity was low in the wells checked in the uranium exploration areas. Radium did not exceed the target level for radium-226 in 128 wells of the 130 sampled. Only 1 well, a drilled well located in the River John area, had a radium reading higher than the maximum acceptable 1 Bq/L for radium-226. It had a radium activity measurement of 1.1 Bq/L.

4.7 Summary

The well sampling program was a major undertaking in terms of: (1) staff time for collection of samples, recording and summarizing data and notifying well owners of results; (2) travel costs for sampling personnel; and (3) laboratory analysis costs for the more than 2,200 sample determinations performed.

In all, samples were collected from 784 individual wells, 12 springs, 2 houses using a lake, and 1 house using a pond as water supply sources.

The data totals for all wells sampled in the province for uranium and the related elements radon and radium are presented in the tables listed below.

Subject of Table	Table Number
Total Uranium Results	34
Total Numbers in Various Concentration Ranges for Wells with Uranium > 0.02 mg/L	35

TABLE 34

Well Sampling Program

Totals for all Wells Sampled

Uranium Results

Number of Wells		Uranium Concentration in mg/L		
		< 0.01	0.01 & 0.02	> 0.02
Drilled	509	181 (36%)	139 (27%)	189 (37%)
Dug	249	242 (97%)	5 (2%)	2 (1%)
Unknown	26	13 (50%)	9 (35%)	4 (15%)
TOTAL	784	436 (56%)	153 (20%)	195 (25%)

TABLE 35

Well Sampling Program - Totals for all Wells Sampled

Wells with Uranium Concentrations > 0.02 mg/L

Numbers in Various Concentration Ranges

Total number of wells with uranium > 0.02 mg/L = 195
The average uranium concentration in wells > 0.02 = 0.07 mg/L

	URANIUM CONCENTRATION RANGES IN mg/L				
	0.03 - 0.10	0.11 - 0.20	0.21 - 0.30	0.31 - 0.40	> 0.40
Number of Wells	170	17	6	1	1
Ratio of Total	170/195	17/195	6/195	1/195	1/195
Percentage of Total	87%	9%	3%	0.5%	0.5%
Average Concentration in each Range	0.05	0.14	0.25	0.32	0.7

Subject of Table	Table Number
Total Radon Results	36
Total Radium Results	37

A study of these tables and of the individual well analysis results reveals a number of facts. The most important of these are noted below.

1. Of 784 wells sampled for **uranium**, 195 (25%) had uranium concentrations greater than 0.02 mg/L, the current maximum acceptable concentration in the Canadian Drinking Water Quality Guidelines.

2. Virtually all of the wells which had uranium concentrations greater than 0.02 mg/L were drilled wells; only 2 dug wells, both located in the New Ross-Forties-Fraxville area, exceeded 0.02 mg/L in uranium concentration.

3. The concentration of uranium in the wells with uranium greater than 0.02 mg/L ranged from 0.03 mg/L to 0.7 mg/L, with the average at 0.07 mg/L.

4. Only 8 wells had uranium concentrations greater than 0.2 mg/L.

5. The highest **uranium** concentration found was 0.70 mg/L in a drilled well in the New Ross-Forties-Fraxville area.

6. Of 725 wells sampled for **radon**, 293 (40%) had radon activity readings in excess of 370 Bq/L, which is the equivalent of 10,000 pCi/L.

7. Nearly all of the wells which had radon activity greater than 370 Bq/L were drilled wells; only 14 dug wells exceeded 370 Bq/L in radon activity.

TABLE 36

Well Sampling Program

Totals for all Wells Sampled

Radon Results

Number of Wells		Radon Activity in Bq/L			
		< 370	370-500	500-1,000	> 1,000
Drilled	500	221 (44%)	31 (6%)	122 (24%)	126 (25%)
Dug	224	210 (94%)	2 (1%)	5 (2%)	7 (3%)
Unknown	1	1 (100%)	0	0	0
TOTAL	725	432 (60%)	33 (5%)	127 (18%)	133 (18%)

Note: This table is based primarily on data presented in Table 4 of Appendix H, which was prepared by the Nova Scotia Department of the Environment.

TABLE 37

Well Sampling Program

Totals for all Wells Sampled

Radium Results

Number of Wells		Radium Activity in Bq/L		
		< 0.2	0.2 - 1.0	> 1.0
Drilled	495	455 (92%)	36 (7%)	4 (1%)
Dug	246	225 (91%)	17 (7%)	4 (2%)
Unknown	22	21 (96%)	1 (5%)	0
TOTAL	763	701 (92%)	54 (7%)	8 (1%)

8. The highest **radon** activity measurement made was 7,130 Bq/L in a sample from a drilled well in the New Ross-Forties-Fraxville area (not the same well which had the highest uranium concentration).

9. Of 763 wells sampled for **radium**, only 8 (1%) had radium activity readings in excess of 1 Bq/L, the maximum acceptable level in the Canadian Drinking Water Quality Guidelines for radium-226.

10. The 8 wells which exceeded 1 Bq/L radium activity consisted of 4 drilled wells and 4 dug wells located as follows: Harrietsfield-Williamswood - 3, New Ross-Forties-Fraxville - 4, River John-Marshville-Welsford - 1.

11. A total of 54 wells had radium readings in the range 0.2 - 1.0 Bq/L leaving 701 wells with radium less than 0.2 Bq/L.

12. The highest **radium** activity measured was 3.7 Bq/L in a sample from a dug well located in the Harrietsfield-Williamswood area.

13. Only 1 well of the over 700 sampled had both **uranium** and **radium** readings greater than the maximum allowable in the current guidelines. That well, located in the River John-Marshville-Welsford area, also had a relatively high radon reading, the highest reading of the 130 checked in the uranium exploration areas. The analysis results for all three parameters for this well are: uranium - 0.11 mg/L, radon - 1,558 Bq/L, radium - 1.1 Bq/L.

Reference should be made to Appendix A for further detailed information on the results of the well sampling program and implications of these results. Of particular interest and importance is the relationship between bedrock geology types of the various well survey areas and the respective occurrence of uranium, radon and radium.

Finally, particular emphasis must be placed on these statements:

1. It was the intention of the Uranium Task Force to obtain an "overview" of the possible extent of the occurrence of uranium and related elements in drinking water supplies in Nova Scotia.

2. It was not the intention of the Task Force to attempt to find every well in Nova Scotia which is supplying water containing uranium and related elements in concentrations higher than recommended in current guidelines.

3. Not all areas which have the natural conditions which give rise to the occurrence of uranium and related elements in well water have been investigated, and therefore,

4. it is quite likely that uranium and related elements are present in many wells in various areas throughout the province in addition to those already sampled.

5. STUDIES OF CONCENTRATION VARIATION WITH TIME

5.1 Introduction

Two studies were performed in order to determine to what extent concentrations of uranium, radon and radium in water supplied by a given well vary with time. This knowledge was seen to be necessary as a means of gauging the confidence which can be placed in the results obtained by collecting single "grab" samples from individual wells.

The two studies were: (1) an intensive, short-term—short sampling interval study of one well; and (2) an extensive long-term—long sampling interval study of four wells. These investigations and their results are outlined below.

5.2 Short-Term Variation Study

The subject of this study was a drilled well which served as the water supply source for the Harrietsfield Elementary School. The study consisted of the collection of samples at half-hour intervals over a period of seven hours on one day, 21 November 1980. The samples collected were analyzed for uranium concentration, radon activity, radium activity, pH and conductivity.

The variation of uranium concentration, pH and conductivity with time over the sampling period is shown graphically in Figure 11. The variations in uranium, radon and radium values are outlined below.

Parameter	Short-Term Variation
Uranium concentration	All results within the range 0.08 - 0.09 mg/L

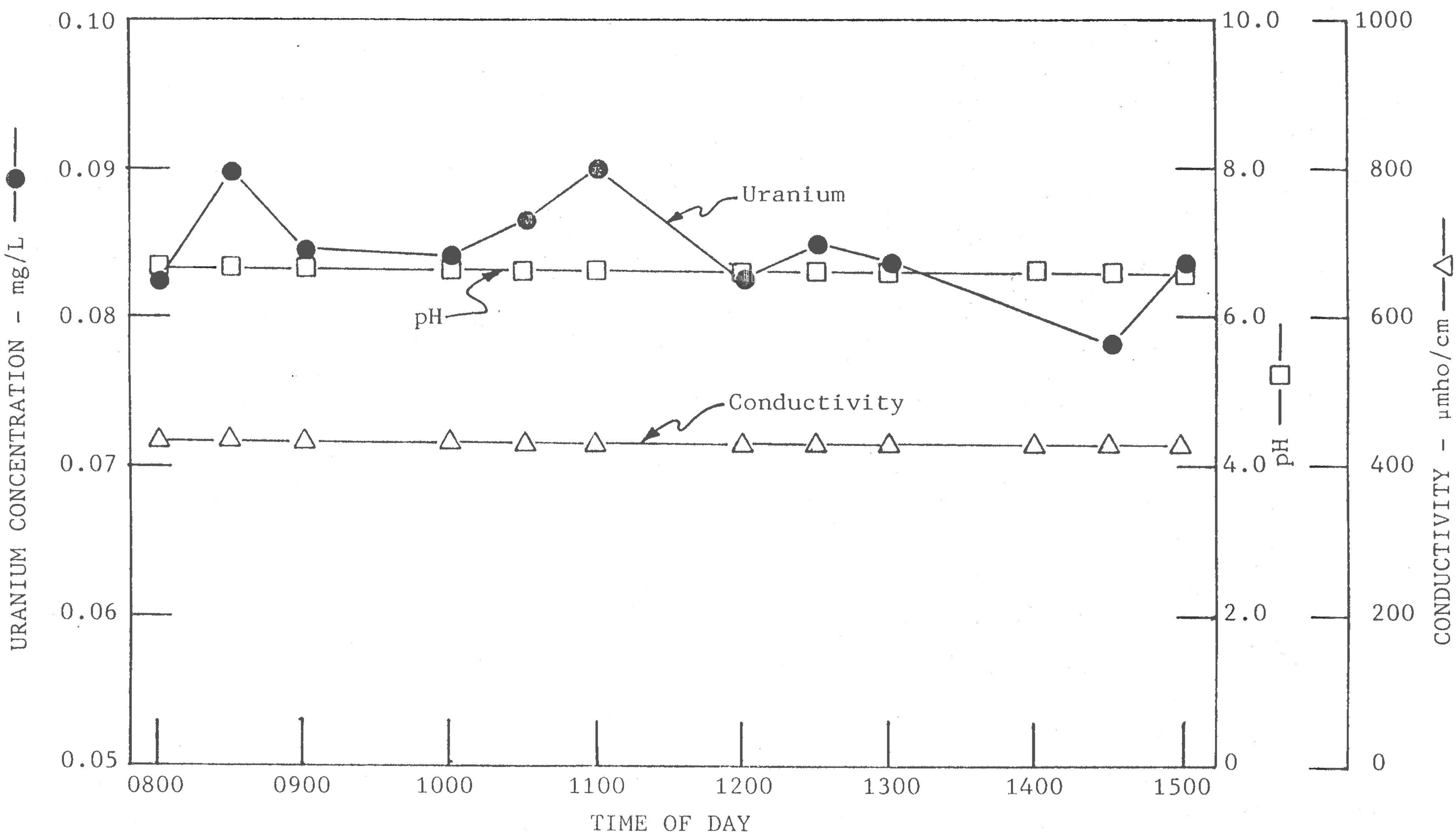

Figure 11 - Short-term Variation Study
Variation of Uranium, pH and Conductivity with Time

Parameter	Short-Term Variation	
Radon activity*	Range	Number of Readings
	0-100	3
	100-200	4
	200-300	3
	300-400	78
Radium activity	Result	Number of Readings
	< 0.1 Bq/L	19
	0.1	3

*For measurement of radon activity, four samples were collected at each sampling time.

A review of the data presented above leads to these conclusions:

1. **Uranium** concentration variation over the sampling period was negligible.

2. A few **radon** readings were lower than most of the readings; 89% of the readings were in the 300-400 Bq/L range. The variation within this range is not considered significant given all of the variables which affect the occurrence and measuring of radon in well water, as well as the uncertainties relating to the consequences of radon in well water, about which more will be noted in other sections of this report. In addition, it may be that the few lower readings were due to the fact that the sampling technique was in the stage of being perfected at the time that this study was executed.

3. The variation in **radium** results with 19 readings of < 0.1 Bq/L and 3 readings of 0.1 Bq/L is considered negligible.

5.3 Long-Term Variation Study

This study involved the sampling of four drilled wells in Halifax County: two in the Harrietsfield-Williamswood area and two in the Brookside area, once per month over a one-year period. The samples were collected from February to December 1982.

A complete report describing this study, its results and conclusions, is attached as Appendix I.

In each case, the tabulated data presented in this appendix includes the result of the original "grab" sample collected during the 1981 well sampling program.

A brief summary of the conclusions reached in this study regarding the variations of uranium, radon and radium in four wells over a one-year period are outlined below.

Parameter	Long-Term Variation
Uranium concentration	Probably not significant if well pumping rate, that is, water use is constant—significant variation has been shown if water usage changes. Additional study may be warranted.
Radon activity	Results are somehwat inconclusive but it appears that the 2 wells in which water usage was constant had somewhat less variation in radon readings than was the case in the other wells. In the case of 1 well, all radon readings were in the range 200-500 Bq/L; in the cases of the other 3 wells radon readings, though

Parameter	Long-Term Variation
Radon activity, continued . . .	variable, were all greater than 600 Bq/L, indicating that a well with a "high" radon reading will consistently produce water with a "high" reading.
Radium activity	Radium readings showed no variance, even in wells with variable water usage.

6. HYDROGEOLOGY AND DISTRIBUTION OF NATURALLY OCCURRING URANIUM

6.1 Introduction

In previous sections of this report, such as Sections 1.6, 1.7 and 4.1, references were made to Appendix A, a report produced by the Nova Scotia Department of the Environment entitled "The Hydrogeology and Distribution of Naturally-Occurring Uranium in Well Water in Nova Scotia" and to Appendix H, which consists of a data compilation by the Nova Scotia Department of the Environment issued as a supplement to the Appendix A report. These appendices describe and present the results of exhaustive studies relating the occurrence of uranium and related elements in well water samples as determined in the Task Force's well sampling program with various environmental features such as bedrock geology, topography, hydrogeology, geochemistry, and soil overburden.

It should be noted that there are some slight discrepancies in statements of numbers of wells sampled, dates, sequences of events, and Task Force methods between Appendix A and this report. These deficiencies, which are of no significant consequence, have occurred due to the reasons previously stated in Section 4.1 and for the reason that the author of the Appendix A report was not a member of the Uranium Task Force and had not been aware of the changes and adjustments in the Task Force investigation program which were made as the investigation progressed.

6.2 Highlights of Appendices A and H

Listed below are some highlights of Appendices A and H. These may be pursued in detail by referring to these appendices in their entirety.

1. Summarized uranium and radon results from the well sampling program tabulated by area include presentations of mean values and ranges.

2. Separate tabulations indicate the distribution of uranium and radon in well water by area and also by bedrock geology type.

3. The analysis results for uranium, radon, radium, pH and conductivity, as well as information on well construction for all individual wells sampled are tabulated. Names of the well owners have been deleted for reasons of confidentiality; these names are on file with the Department of Health.

4. An area-by-area study presents information on the following:
   (a) natural conditions—bedrock geology, topography, groundwater flow regime and groundwater chemical quality;
   (b) sources of uranium;
   (c) reasons for regional compared with local uranium concentration variations;
   (d) conditions giving rise to elevated uranium concentrations in groundwater, that is, the rationale for uranium occurrence;
   (e) relationships between the levels of uranium, pH, conductivity, and radon;
   (f) details on radon distribution and the reasons for varying levels of radon.

5. An analysis of sample results and bedrock types implicating Devonian granite and Pictou Group sediments of the Carboniferous Basin as the most likely bedrock types associated with uranium occurrence, but also noting anomalous uranium showings in Meguma Group (quartzite and slates) and sedimentary rocks such as the sandstones in Annapolis County.

6. General comparisons of the occurrence of uranium in granitic compared with carboniferous areas and detailed comparisons of the mean levels of uranium and radon in Harrietsfield-Williamswood, Brookside, New Ross-Forties-Fraxville, and the Carboniferous Basin.

7. An explanation for the observation that uranium and radon are often not simultaneously high in groundwater at a particular well location.

6.3 Uranium Occurrence Map

A map of Nova Scotia drawn to the scale 1:750,000 and entitled "Uranium Occurrence in Groundwater in Nova Scotia" accompanies this report as Appendix J. This map was prepared by staff of the Department of the Environment and of the Department of Health. The following information is plotted on the map:

1. The areas of the province in which bedrock is of the igneous, intrusive type (primarily granite) or the Carboniferous Basin type (primarily sandstones, conglomerate and shales).

2. Locations where the Task Force well sampling program detected concentrations of uranium in groundwater greater than 0.01 mg/L.

3. An indication by color coded symbols, of the numbers of wells, of those sampled in each location, which had uranium concentrations in the following ranges:
   (a) 0.01 mg/L to 0.09 mg/L
   (b) >0.09 mg/L

6.4 Conclusions and Recommendations

The conclusions and recommendations formulated by staff of the Department of the Environment as a result of their study of the hydrogeology and distribution of naturally-occurring uranium in Nova Scotia are listed below:

Conclusions:

1. Uranium is a common, naturally-occurring element in well waters in Nova Scotia. Available data indicate that uranium is predominantly associated with drilled wells.

2. On a province-wide scale the occurrence of uranium in well waters is dependent on the type of bedrock. Locally, uranium distribution is controlled by such factors as well depth, overburden thickness, overburden type and the hydrogeology of the aquifer, which act to modify the geochemistry of the local groundwater flow system.

3. The geological environments most likely to have elevated uranium in wells are
   (a) the granite batholiths which outcrop over much of mainland Nova Scotia (range 0.005 mg/L to 0.70 mg/L), and
   (b) the alkaline sandstone and shale of the upper Carboniferous sedimentary basin in northwestern Nova Scotia (range 0.005 mg/L to 0.11 mg/L).

   Lesser concentrations of uranium may be associated with sedimentary and metasedimentary rocks in hydraulic contact with the granites.

4. Hydrogeology is a factor affecting the distribution of uranium in wells in Nova Scotia. In granites, major fractures and shear zones could act as groundwater channels for the formation of uranium deposits and transport of uranium to wells. In the Carboniferous Basin, uranium is transported under

oxidizing alkaline conditions by circulating groundwater and deposited at reducing barriers. The more uniform distribution of uranium in the sedimentary basin than is the case in granite areas is due to the more extensive regional flow systems compared to short local fracture flow systems which predominate in granites.

5. The probability of encountering high uranium in granitic terrains can depend on the type of granite. Uranium levels in groundwater are found to increase with the acidity or the silica content of the granitic rocks. For example, in Nova Scotia, uranium becomes more enriched from the granodiorites to the monzogranites to alaskite. Lake sediment geochemical sampling (NSDME) also shows that uranium concentration in lake sediments is highest on granitic terrain, and that such concentration follows the hypothesis of uranium enrichment in later phases of igneous differentiation, as was seen for well water sampling results.

6. The concentration of uranium in wells in granites was found to increase with increasing overburden thickness for wells penetrating glacial till drumlins in Harrietsfield, Brookside and New Ross. The presence of thick overburden deposits over an aquifer is believed to act as a barrier between the atmosphere and the groundwater which affects the pH and redox potential of the underlying groundwater, e.g. the pH and alkalinity are higher and groundwater is less oxidizing than surrounding areas favoring the accumulation of uranium minerals under such conditions. It follows that little or no relationship between well depth and uranium concentration was observed in granitic areas. However, in the Carboniferous Basin, some relationship exists between uranium and well depth, likely due to stratigraphy.

7. Uranium in well water is associated with high pH, alkalinity,

phosphate, silicate, fluoride and arsenic in granites, and with high pH, hardness, alkalinity, TDS, silicate, fluoride and phosphate in the Carboniferous Basin. The mobility and distribution of uranium in groundwater is further increased by the formation of stable soluble complexes between uranium and anions such as phosphate, carbonate, silicate and fluoride. Uranium is strongly related to high groundwater pH. Elevated uranium was found to be associated with pH levels of 7.5 to 8.5 in granites and sedimentary rocks.

8. Elevated uranium levels in water wells are generally associated with elevated radium and radon gas. Divergency from this trend can be explained by the difference in solubility between uranium and its daughter radionuclides, such as radium-226, which could result in the presence of one and not the other in water samples.

9. Radium-226 is a radioactive decay product of uranium and occurs in shallow drilled wells and dug wells in the New Ross area. These samples were located near the contact between alaskite and monzogranite. Only 1% of the total number of wells sampled contained radium in excess of the 1 Bq/L maximum acceptable concentration for radium-226. The overall radium averages less than 0.1 Bq/L.

10. Radon gas is a decay product of radium. In Nova Scotia well waters, radon gas averages 130 Bq/L in dug wells and 930 Bq/L in drilled wells for granitic areas, and averages 54 Bq/L for dug wells and 118 Bq/L in drilled wells in the Pictou Group rocks. Radon is generally highest in uraniferous zones, in monzogranite and alaskite granites, or in wells containing high radium, and varies spatially with rock type, overburden thickness, well depth and aquifer permeability.

Recommendations

The investigations and findings of the study of hydrogeology and distribution of naturally-occurring uranium in well water in the province led to the following recommendations:

1. Government agencies, well drillers, the consulting community, subdivision developers and individual home builders should be advised of those areas which could potentially contain elevated uranium in groundwater. In order of decreasing probability, these include:
   (a) Granite Terrain:
      (1) Alaskite intrusions in monzogranite (New Ross, Upper Vaughan, Leminster, Card Lake, Glen Margaret, Tantallon, Glen Haven, White's Lake)
      (2) Granites overlain by till drumlins
      (3) Granites
      (4) Contact zones between granite and Meguma metasediments
      (5) Contact zone between granites and clastic sediments (Annapolis Valley, Martock, Falmouth)
      (6) Granitic areas with high pH, alkaline, slightly oxidizing groundwater, or where anomalous levels of arsenic, silica, fluoride and phosphate are encountered.
   (b) Carboniferous Basin:
      (1) Areas located hydraulically down gradient of known uranium-copper occurrences
      (2) Areas located hydraulically down gradient of granites in the Cobequid range.

2. In areas where excessive concentrations of uranium occur in groundwater, the use of dug wells or surface water sources should be considered as a feasible water supply alternative.

3. Work on controlling or reducing uranium concentrations in

well water should include consideration of the following: pH modification, and heavy pumping and development of new wells to remove uranium from the area of influence of wells in drumlin areas.

7. URANIUM EXPLORATION AND MINING

7.1 Background and Current Situation

As noted in Chapter 1, Objective E of the Uranium Task Force terms of reference was:

> "To provide general procedural recommendations for government monitoring and regulation of any activities directly affecting changes in natural uranium distribution patterns."

This statement was a general way of saying that the Task Force would develop and recommend to government various controls which might be deemed necessary to prevent environmental and health problems arising as a result of activities such as exploration and mining which would disturb natural uranium deposits.

Before the Task Force began this phase of its investigation program the provincial government commissioned Judge Robert McCleave to hold an inquiry into all aspects of uranium exploration and mining in Nova Scotia. The mandate of Judge McCleave's Uranium Inquiry—Nova Scotia completely covered what would have been investigated by the Uranium Task Force under Objective E. The Task Force decided, therefore, to not pursue this aspect of its program as the matter was well in hand and no useful purpose would be served by duplication of effort. It is the understanding of the Task Force that the McCleave Inquiry has recommended a 5-year moritorium on uranium exploration and mining while an interdepartmental committee further studies developments in uranium exploration, mining and marketing.

7.2 Uranium Exploration and Wells

Questions have been raised regarding the possible effects of uranium exploration bore holes on groundwater and existing wells because of the fact that many areas were subject to bore hole testing before the moritorium on uranium exploration was imposed.

The policy of the provincial Department of the Environment in this regard has been to recommend that exploration bore holes be properly abandoned by sealing as follows: All holes which penetrate a zone of uranium mineralization must be cemented from bottom to top and all unmineralized holes are to be plugged with concrete caps into the bedrock and in all cases at least 20 feet deep. It is considered by the Environment Department that this procedure would make it highly unlikely that problems will occur. The only possibility of contamination of wells would arise if the following events occurred: (1) the exploration holes were bored close to drilled wells; (2) the deep bore holes penetrated a uranium mineralization zone; or (3) water rose in the holes from this zone to the aquifer feeding the drilled wells, and then flowed laterally to the wells.

The Task Force does not know of any cases in which this has happened, although it should be added that this sort of situation was not actively investigated.

8. TECHNICAL LITERATURE SEARCH

8.1 Method

At the outset of its investigation, members of the Task Force, especially those employed in the Department of the Environment, the Department of Health, and the Victoria General Hospital, had immediate access to substantial reference material in their own offices and from professional collegues in the immediate area. This was augmented somewhat by contacts made with individuals in various agencies in other jurisdictions. The information which came to light in this way, combined with the background knowledge of various Task Force members, indicated that a large volume of technical literature on uranium and related elements existed. This notwithstanding, it appeared that there may not be reliable references which would present definitive, solidly based statements on the key issues of: (1) health effects due to chronic exposure to relatively low concentrations of uranium and related elements in drinking water; (2) what are the first indications which can be practically used to monitor populations potentially at risk in order to prevent health effects; and (3) what limits should be placed on uranium and related elements in drinking water.

In order to ensure that all available information was obtained and all sources were tapped, the Task Force agreed that an exhaustive literature search should be implemented. As this task was beyond the capability of the Task Force itself, representations were made to the Department of Health and the department agreed to finance a literature search by the Maritime Resource Management Service. This search was performed over a one-year period beginning in the summer of 1980.

The work carried out by MRMS consisted of the following:

(1) Meetings with individual members of the Uranium Task Force

to collect references and sources of information.

(2) Compilation of an initial bibliography of references collected and distribution of this to Task Force members.

(3) Compilation of a list of potential sources of information and contacting these sources.

(4) Compilation of a bibliography of information received from the sources contacted.

(5) Visitation of Health and Welfare Canada offices and other government agencies in Ottawa, obtaining: copies of earlier literature searches, information on present activities, information on other sources of information, listing of data bases searched by Health and Welfare Canada, and collection of copies of publications, publications lists and bibliographies.

(6) Revision of bibliography to include additional references.

(7) Review of results of contacts in Ottawa.

(8) Conducting automated bibliographic literature searches of various data bases.

(9) Review of printouts and contact of numerous potential sources of information.

(10) Review of results of replies received.

(11) Compilation of bibliography of information received from additional contacts.

(12) Selection and acquisition of copies of publications, articles and references.

(13) Compilation of master bibliography of all material acquired.

The automated bibliographic literature search which was carried out aimed mainly at finding information related to human health effects of uranium in drinking water and background documentation for establishing standards. The keywords which were used in the search are listed below:

standards	radium-226
health	uranyl ion

water	lead-210
uranium	radioactivity and health standards
radium	alpha-gamma-x-rays
radon-222	

A list of the information sources contacted by MRMS during the course of conducting the literature search is attached as Appendix K.

Throughout the intervening time period between the completion of the MRMS literature search and the writing of this report, the collection of reference material has continued. Use has been made of this information and mention has been made of it in other sections of the report.

8.2 Results

The final bibliography "master list" for the search conducted by MRMS is presented in Appendix L. The publications which were obtained for review are on file in the office of the Task Force chairman.

A breakdown of information contained in the references will not be presented in this report. Many of the references were read and some of the information was incorporated into the overall body of information which has been built up through the Task Force investigation program. The Task Force had insufficient time and staff resources to make a comprehensive review and summary of all of the material collected. Considerable use was made, however, of particular references gathered by the MRMS search, and especially of more recent information obtained by the Department of Health public health engineering division staff and by the two Task Force members employed in the clinical and environmental chemistry sections of the Victoria General Hospital.

The lack of a thorough analysis of all of the technical literature accumulated is not considered by the Task Force to be critical because of the fact that the initial expectation regarding the relevance of available reference material was largely borne out. The main advantage to having carried out a large-scale literature search seems to be that the Task Force can say with some assurance that the questions raised in the three key issues noted in Section 8.1 have not been answered by others in a definitive way.

9. PUBLIC INFORMATION RELEASES

In accordance with its terms of reference, the Task Force released information periodically to the public. The Task Force's policy has been to release all information so long as the appropriate confidentialities regarding individual health testing and well analysis results were respected.

The approved procedure for major information releases involved the reporting of information by the Task Force chairman to the Administrator, Environmental Health, and in turn through the Deputy Minister of Health to the Minister of Health, and finally to the public. Routine information releases were made directly by the Task Force chairman. Information was disseminated at public meetings, through press releases, news media interviews, correspondence with individuals by mail, and in telephone conversations with individuals.

Public meetings were held in Harrietsfield in April 1981 and in December 1984. Press releases were issued by the Minister of Health in December 1980, April 1981, and July 1981. The Task Force chairman was interviewed on several occasions by local radio and television stations and reports of press interviews were published in several weekly newspapers in the province and in the major Halifax daily newspaper. An information release which was distributed in the New Ross-Forties-Fraxville area at the commencement of the well sampling program is attached as Appendix M.

A number of letters of explanation were sent to individuals who had submitted written requests for information. Probably the most effective, although certainly the most time-consuming, mode of communication was the telephone. The Task Force chairman had numerous telephone conversations with individual members of the public. No call went unanswered and many developed into lengthy explanatory discussions.

10. STANDARDS FOR URANIUM AND RELATED ELEMENTS IN DRINKING WATER

10.1 Introduction

Given that the goal for mounting the entire Task Force investigation was to ensure that the health of Nova Scotians is not adversely affected by the presence of uranium in drinking water, it is evident that one of the key issues involved the limits which should be placed on uranium and related elements in drinking water. Such limits, often referred to as "standards" or "guidelines", are set by various jurisdictions around the world for numerous elements and compounds, using a combination of scientific knowledge, case histories and research results, and involving varying degrees of uncertainty.

As described in the introductory section of this report, the discovery in Nova Scotia of wells producing water with uranium in excess of the maximum acceptable concentration recommended in the current Canadian guidelines sparked the major investigation which is the subject of this report. The following sections outline the status of standards for uranium and related elements in drinking water in Canada and throughout the world.

10.2 Canadian Drinking Water Quality Guidelines

10.2.1 Uranium Guideline

The current (1978) Canadian Drinking Water Quality Guidelines recommend a maximum acceptable concentration of uranium of 0.02 mg/L based on an average daily water consumption of 2 liters. The previous guideline stated a "maximum permissible limit" of 5.0 mg/L based solely on aesthetic reasons such as color and taste with no consideration of health effects.

The "supporting documentation" for the guidelines contains a section on uranium. This is included in the attached Appendix N. The review refers to chronic uranium ingestion studies performed on animals in Russia. The paper describing this research is acknowledged and referenced in Chapter 11. These studies indicated that the no-observable-effect level for uranyl ion in animals is probably just in excess of 0.1 mg/kg/day. For a 70 kilogram (weight of average person) animal, therefore, 0.1 x 70 = 7 mg/day would be the no-effect level. As is accepted practice in toxicology, in the absence of more definitive knowledge, this was reduced by dividing by 10 to account for possible differences in the reactions of different species (laboratory animals compared with human subjects) and by a further divisor of 10 to account for differing susceptibilities of individuals. The result was a no-observable-effect total uranium intake of 0.07 mg/day. Based on available data, it was assumed that food and water contribute equally to total daily uranium intake. Therefore, considering half of the 0.07 mg/day NOEL, that is, about 0.04 mg/L, can be ingested in water, the maximum acceptable concentration using an average 2 liters daily water consumption was set at 0.02 mg/L.*

Over the past three years research has been carried out in Ottawa by Health and Welfare Canada staff with the aim of defining more clearly the figure which should be used as the maximum acceptable concentration for uranium in drinking water. Up to the time this report was written, neither that research, nor the investigations made by the joint federal-provincial committee which is charged with updating the Canadian Drinking Water Quality Guidelines, have resulted in a revision of the maximum acceptable concentration of uranium.

10.2.2 Radon Guideline

There is no guideline for radon-222 activity

*This line of reasoning may be defensible given the lack of knowledge at the time the "supporting documentation" was prepared; it does, however, point the need for factual information on daily uranium intake from food in the Canadian diet because of the major impact this can have on the actual daily uranium intake allowed from water.

stated in the Canadian Drinking Water Quality Guidelines. This parameter was not dealt with in the 1978 revision.

10.2.3 Radium Guideline

The Canadian Drinking Water Quality Guidelines state recommended limits for the five radionuclides which were considered to be "currently of greatest interest from a health viewpoint." Two of these five, tritium and radium-226, are naturally-occurring and, of these two, radium-226 has been associated with groundwater in areas of natural uranium occurrence. The "recommended limits" for radium-226 state a "maximum acceptable concentration" (actually, activity) of 1 Bq/L and a "target concentration" of 0.1 Bq/L.

The section of the supporting documentation which outlines the steps leading to, and the basis for, the adoption of the guideline for radium-226 is included in Appendix N.

10.3 World Health Organization Guidelines

In 1984 the Department of Health received a copy of the "Unedited Final Document" of the World Health Organization "Guidelines for Drinking Water Quality, Volume I—Recommendations". The information noted below has been extracted from this document, Section 5 of which, entitled "Radioactive Materials in Drinking Water", is Appendix O to this report.

10.3.1 Uranium Guideline

The WHO document does not present any guideline for uranium as a toxic chemical, nor does it state a specific guideline for uranium alone as a radioactive material. Uranium (U-234 and U-238) is included, however, in the list of radionuclides identified as "naturally-occurring alpha-emitting radionuclides having high toxicity." As such, uranium would be included in the radioactivity guideline which proposes a "screening level" for gross alpha activity of 0.1 Bq/L. If the alpha activity exceeds 0.1 Bq/L (excluding radon) the guideline recommends further examination to identify the actual radionuclides present and to thereby "allow the hazard to be assessed." It is then envisaged that the "competent authority" will decide whether corrective action is justified.

10.3.2 Radon Guideline

No guideline level for radon-222 is presented in the WHO guidelines. In fact the guidelines specify that the gross alpha activity screening level mentioned above excludes radon which is to be eliminated from the sample before the analysis is started. The guidelines do state:

> Where high levels of radon are known to be present, reference must be made to the competent authorities both with regard to radon and its daughter products due to the hazards resulting from ingestion and also from inhalation. Further investigations have to be carried out concerning the actual radon concentration in drinking water and the relationship between the concentration in tap water and the resulting doses due to inhalation of the released radon before a 'non-action' level in drinking water can be set.

10.3.3 Radium Guideline

A specific WHO guideline for radium-226 is not stated, rather it is included in the list of alpha-emitting radionuclides which have high radiotoxicity and which are subject to the gross alpha activity screening level of 0.1 Bq/L. The WHO recognizes the especially highly toxic nature of radium in that the guideline value, that is, the screening level, assumes the worst case, and the worst case is taken as the situation in which the gross alpha activity measured has been generated by only the most toxic of the radionuclides which could be present. These are stated to be strontium-90 and radium-226. Of these two, only radium is naturally occurring.

In other words, the WHO states, in effect, that radium-226 activity in drinking water should be limited to 0.1 Bq/L subject to the qualifications noted in Appendix O.

10.4 World Survey of Standards

10.4.1 Introduction

Preliminary information collected by the Task Force indicated a general scarcity of guidelines or standards for uranium and related elements in drinking water. In order to establish the exact status of standards worldwide, it was decided to conduct a survey in which direct contact would be made with all countries in the world. The Maritime Resource Management Service was contracted to perform the large volume of routine work involved in the survey.

10.4.2 Method

A brief questionnaire prepared by the Task Force chairman was sent by mail with a covering letter signed by the chairman to 160 countries. Copies of the questionnaire and letter, both of which were written in English and French, are attached as Appendix P. Individual questionnaires were sent to all provinces and territories of Canada and all states of the U.S.A. The covering letter stated that a summary of the results would be sent to all those who responded to the request for information.

As completed questionnaires were received, they were translated, if necessary, into English, studied, and eventually the results were summarized.

10.4.3 Results

A list of the countries, provinces and states which responded to the survey questionnaire is shown in Table 38. In the total of 84 replies, 45 countries are represented. Considerable effort was involved in reducing the replies to a summarized, tabulated form. This summary of standards and guidelines for uranium and related elements in drinking water throughout the world is presented as Table 39.

When reviewing Table 39, the following should be kept in mind:

1) The information under the heading "Comments Noted by Respondent" is as written on the completed questionnaires and accompanying letters. Most of this information is quoted directly; in some instances, in order to save space, a few words have been omitted.

2) The numbers and units are as written by respondents with the addition of the equivalent Bq/L in cases in which activity was reported in Ci/L (or μCi/L, pCi/L).

3) It is suspected that the order of magnitude of the units may have been in error for the standards as submitted by Lebanon (see note beside asterisk in table) and the Republic of South Africa (magnitude appears to be far too low).

As promised at the time of the survey, a copy of the tabulated results (Table 39 in bound form) was sent to each of those countries whose representatives responded to the questionnaire.

TABLE 38

WORLD SURVEY OF STANDARDS

Countries, Provinces and States from whom Replies were Received

Number of countries surveyed = 160

Number of countries responding = 45

Total number of responses = 84
(including U.S. states
and Canadian provinces)

ASIA	Bahrain Indonesia Iran Kuwait Lebanon	Malaysia Qatar Singapore U.S.S.R.
AFRICA	Gambia Liberia Mozambique Nigeria Republic of South Africa	Senegal South West Africa Tunisia Zimbabwe
AUSTRALASIA	Australia New Guinea New Zealand	Western Samoa Solomon Islands Tuvalu
CENTRAL AMERICA	Barbados Dominica	Haiti Panama
SOUTH AMERICA	Chile	Guyana
EUROPE	Belgium Hungary Iceland Italy Norway Romania	Spain Sweden Switzerland United Kingdom West Germany Yugoslavia

TABLE 38 (continued)

NORTH AMERICA			
	Canada	Health and Welfare Canada British Columbia New Brunswick	Prince Edward Island Yukon
	U.S.A.	Arizona Colorado Connecticut C.D.C.—Atlanta Delaware E.P.A.—Washington Florida Georgia Hawaii Idaho Illinois Iowa Kansas Maine Maryland Michigan Minnesota Missouri Montana	Nevada New Hampshire New York North Carolina North Dakota Ohio Oklahoma Pennsylvania South Dakota Tennessee Texas Vermont Virginia Washington West Virginia Wisconsin Wyoming

TABLE 39

World Survey of Standards for Uranium and Related Elements in Drinking Water

ASIA

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Bahrain	None	None	None	
Indonesia	None	None	None	
Iran	10 pCi/L (0.37 Bq/L)	None	3 pCi/L (0.1 Bq/L)	
Kuwait	5 pCi/L (0.2 Bq/L)	30 pCi/L (1.1 Bq/L)	0.27 pCi/L (0.01 Bq/L)	ICRP 30 for radon-222 and IRRP 24 ICRP 2 MPC for 168 h/week/1000; for radium-226 IAEA Safety Series 9
Lebanon	See	comments →	→	Drinking water standards do not mention any radiation standards except for alpha: 10 µCi/mL*, beta: 10 µCi/mL* *Perhaps units should be pCi/L, then would have alpha: 10 pCi/L (0.37 Bq/L)
Malaysia	None	None	None	
Qatar	0.02 mg/L "WHO Standard"	None	None	
Singapore	None	None	None	
U.S.S.R.	— **	None	1.2×10^{-10} Ci/L (4.4 Bq/L)	

**No figure noted on questionnaire; a uranium standard of 1.7 mg/L was noted in a 1975 technical paper by Yu V. Novikov and F. F. Erisman entitled "The 'Potable Water' Standard (GOST 2874-73)—A New Stage in Development of Water Hygiene"

TABLE 39 (continued)

AFRICA

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Gambia	None	None	None	
Liberia	None	None	None	Do not conduct analyses for radiactive elements like uranium, radon-222 and radium-226.
Mozambique	None	None	None	
Nigeria	See comment → →			Have no facilities to determine uranium and related elements in water.
Republic of South Africa	Recommended 0.6 μg/L (0.0006 mg/L) Maximum 4.4 μg/L (0.0044 mg/L)	None	Recommended 1 μg/L (0.001 mg/L)	Radioactivity ($\alpha + \beta$) Recommended 0.2 Bq/L; maximum 1.22 Bq/L - These are guidelines, no statutory standards applicable. - Adhere to the limits of concentration as regards uranium and related elements in drinking water as recommended by the ICRP. - No information available on uranium concentration of underground water—may be high in areas where uranium is being mined.
Senegal	See comments → →			WHO standards for gross alpha and gross beta: Gross alpha: 3 pCi/L (0.1 Bq/L); gross beta: 30 pCi/L (1.1 Bq/L) Analyses for radioactivity have not been made in practice.
South West Africa	None	None	None	Groundwater (not used) in vicinity of uranium mine: Uranium: 0.01 to 0.7 mg/L Radium, Ra-226: 0.012 to 0.767 Bq/L
Tunisia	Not available	Not available	Not available	
Zimbabwe	None	None	None	This country has not set out its own standards for potable water, but adheres, generally, to those of the E.E.C. and W.H.O., which do not refer to radioactive elements.

TABLE 39 (continued)

AUSTRALASIA

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Australia	None	None	0.4 Bq/L	Based on WHO International Standards for Drinking Water (1971). Gross alpha activity: 0.1 Bq/L; gross beta activity: 1.0 Bq/L.
New Guinea	None	None	None	
New Zealand	See	comments →	→	WHO (1982) guidelines will be adopted. Gross alpha activity 0.1 Bq/L; gross beta activity 1 Bq/L. Radium-226 (and uranium) in drinking water are both covered by the gross alpha activity screening level. However, radon-222 is excluded . . . no guideline has been set for radon pending further investigation.
Western Samoa	None	None	None	
Solomon Islands	See	comment →	→	No standard established, the Ministry of Health uses the WHO standard.
Tuvalu	None	None	None	No investigation conducted . . . to determine presence of uranium in wells.
Vanuatu	None	None	None	

TABLE 39 (continued)

REGION	COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
CENTRAL AMERICA	Barbados	None	None	None	
	Dominica	None	None	None	
	Haiti	See	comments →	→	For the physical-chemical quality of water we refer to the American standards. However, tests for radioactivity are not included in the routine tests ordinarily performed.
	Panama	See	comments →	→	We have not made chemical analysis of water which includes the determination of radioactive elements. For this reason we have not been involved with setting "standards" in this regard and we accept those set by WHO.
SOUTH AMERICA	Chile	6×10^{-10} Ci/L (22 Bq/L)	None	3×10^{-12} Ci/L (0.1 Bq/L)	Maximum acceptable values of natural uranium in water are based on uranium chemical toxicity in soluble state, and the activity from the following isotopes: U-234, U-235, U-238. Chilean standards . . . include maximum acceptable alpha level: Total alpha activity $\leq 15 \times 10^{-12}$ Ci/L (0.56 Bq/L) (including Ra-226 with other short half-life alpha emitters like Rn-222)
	Guyana	None	None	3 pCi/L (0.1 Bq/L)	Standard used is that established by PAHO/WHO. Testing for radioactive materials is not normally undertaken.

TABLE 39 (continued)

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Canada[1]	0.02 mg/L	None	1.0 Bq/L	British Columbia: Several U.S. states have suggested 2,000 pCi/L (74 Bq/L) maximum acceptable Rn-222; must be concerned with its equilibrium and concentration of Pb-210 in terms of gastro-intestinal exposure; lung exposure may not be important exposure pathway because of ventilation and Rn removal. New Brunswick: Uranium standard not enforced at present. Prince Edward Island: No analysis yet performed for U, Rn, Ra.
U.S.A.[2]				
EPA	Health Advisory of 10 pCi/L (0.37 Bq/L)	None	5 pCi/L (0.2 Bq/L) Ra-226 + Ra-228	Estimate that uranium is about half as toxic as radium.
CDC	Health Advisory of 10 pCi/L (0.37 Bq/L)	None	5 pCi/L (0.2 Bq/L) Ra-226 + Ra-228	Uranium: Based on radiotoxicity—may be more important to base on chemical toxicity.
States	None	None	5 pCi/L (0.2 Bq/L) Ra-226 + Ra-228	EPA Standards have been adopted by most states; in others EPA applies its standards directly.

1. Responses from: Federal Health & Welfare Department; four provinces (British Columbia, New Brunswick, Nova Scotia,* Prince Edward Island) and one territory (Yukon).

2. EPA = U.S. Federal Environmental Protection Agency, Washington D.C.
CDC = U.S. Centers for Disease Control, Atlanta, Georgia
States = Responses from 34 states: Arizona, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Iowa, Kansas, Maine, Maryland, Michigan, Minnesota, Missouri, Montana, Nevada, New Hampshire, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Vermont, Virginia, Washington, West Virginia, Wisoncsin, Wyoming.

* **Note**: The situation has changed in Nova Scotia since this survey was completed. In July, 1985 the Nova Scotia Department of Health adopted an "interim value" of 0.1 mg/L as the recommended maximum acceptable concentration of uranium in drinking water. This step was taken by senior departmental staff following discussions with personnel of the Health Protection Branch of Health and Welfare Canada.

TABLE 39 (continued)

EUROPE

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Belgium	None	None	10 pCi/L (0.37 Bq/L)	Uranium: The problem has not arisen. Radon: Being studied. Radium: The maximum permitted activity is based on ICRP standard for workers (168 hours—100 pCi/L).
Hungary	$7x10^{-6}$ μCi/mL (259 Bq/L)	None	$3x10^{-9}$ μCi/mL (0.1 Bq/L)	
Iceland	None	None	None	Samples of . . . tap water from the most densely populated areas . . . have been measured . . . no radon or radium was detected; detection limit of instrument 0.4 kBq/m^3 (0.4 Bq/L).
Italy	sol. $6x10^{-6}$ μCi/mL* (222 Bq/L) insol. $2x10^{-4}$ μCi/mL (7,400 Bq/L)	None	sol. $1x10^{-7}$ μCi/mL* (3.7 Bq/L) insol. $3x10^{-4}$ μCi/mL (11,100 Bq/L)	*Occupational exposure—maximum allowable doses and concentrations (on average during 13 consecutive weeks). . . in drinkable water.
Norway	None	None	None	Investigations done so far do not indicate a need for such standards. Approximately 95% of Norwegian drinking water supply is based on surface water sources.
Romania	None	None	0.1 Bq/L	
Spain	U-233 (sol.) $3x10^{-6}$ μCi/cc (111 Bq/L) U-nat (sol.) 10^{-4} μCi/cc (3,700 Bq/L)	None	$4x10^{-8}$ μCi/cc (1.5 Bq/L)	These limits are based on those set by the ICRP in 1954 and revised in 1958, and there are plans for further revision based on the directive of Council of 15 July 1980 (80/836/Euratom)
Sweden	None	None	None	Limits for radon concentration in indoor air will result in indirectly limiting the concentration in tap water. Limits for radon daughter concentration in indoor air: New houses—70 Bq/m^3; Re-built houses—200 Bq/m^3; Existing houses—400 Bq/m^3.

TABLE 39 (continued)

COUNTRY	STANDARD/GUIDELINE FOR: URANIUM	RADON-222	RADIUM-226	COMMENTS NOTED BY RESPONDENT
Switzerland	None	None	None	
United Kingdom	No specific standards—See comments			Current practice is based on the new WHO action level concepts. Gross alpha and gross beta measurements are made (if necessary). Then if the new WHO levels of 0.1 Bq/L alpha and 1 Bq/L beta are exceeded, the water would be examined further... to assess whether the water is wholesome or not... In the event of chemical toxicity exceeding the radiological hazard, as it well might with a few elements such as uranium, this would be taken into consideration.
West Germany	None	None	None	For naturally radioactive substances it is assumed that the levels of concentrations are of no concern to public health. Comparing the hypothetical health risks resulting from these concentrations in drinking water with the risks from other parts of natural radiation... no need for setting drinking water standards for naturally radioactive substances has been seen up till now.
Yugoslavia	See comments . . .			In the Regulation on Maximum Acceptable Concentration of Radioactive Contamination of Environment...there are standards for radioactive elements taken by inhalation and ingestion which correspond to the recommendations of ICRP. On the basis of this regulation, competent experts determine the concentrations in each particular drinking water.

EUROPE

10.4.4 Summary

After studying Table 39, the following comments can be made:

1) Uranium

   Number of countries with standard/guideline based on concentration = 4, of which 1, Qatar, stated "0.02 mg/L WHO Standard"—there is no such standard; Republic of South Africa stated an incredibly low figure; only the USSR and Canada seemed to have "sensible" figures.

   Number of countries with standard/guideline based on radioactivity = 15, of which about 6 refer to WHO; of the 15, 3 clearly stated that no testing is carried out, and several others appear to have had no reasons yet to apply or consider applying their standard/guideline; figures stated varied from 0.2 Bq/L to 3,700 Bq/L.

2) Radon

   Number of countries with standard/guideline = 1, Kuwait, which uses the extremely low value of 1.1 Bq/L.

3) Radium

   Number of countries with standard/guideline = 22, of these, 7 are based on WHO, 4 are based on ICRP; 4 countries stated that they have not performed radium activity measurements.

4) In general, it appears that few countries have even thought about uranium and related elements, let alone taken action such as establishing standards/guidelines or sampling and analysis programs.

5) The greatest lack is the consideration of the chemical toxicity aspect of uranium; if countries have standards/

guidelines for uranium, they are generally based on radio-toxicity.

6) Several countries have expressed interest and some concern regarding radon in water and the need or intention of further investigation.

7) More countries have standards/guidelines for radium than for uranium and radon.

8) The low percentage of returns in the survey (45/160 = 28%) indicates perhaps a lack of standards/guidelines worldwide and lack of interest in uranium and related elements in water, especially in light of the fact that a commitment was made to send the summary of results to respondents. One must also consider that many of the countries surveyed are "Third World" countries with far more basic and pressing concerns regarding water supply and other needs.

10.5 Recently Proposed Guidelines

Since the completion of the Task Force's worldwide standards survey, information has been received by the Department of Health on guidelines for uranium concentration in drinking water adopted or proposed by three different bodies. These are outlined in the following sections.

10.5.1 U.S. National Academy of Sciences

The U.S. Safe Drinking Water Act of 1974 authorized the U.S. Environmental Protection Agency to establish federal standards for harmful contaminants in drinking water. One section of the law issued a mandate to the National Academy of Sciences to conduct studies on the health effects associated with drinking water contaminants. These studies have been conducted by the Safe Drinking Water Committee of the National Academy of Sciences in conjunction with the National Research Council.

Initially, in its publication Drinking Water and Health, Volume 3, 1980, this group stated: "There is a paucity of recent human data for making a recommendation of a maximal permissible concentration for uranium in drinking water." They concluded that "calculations of the MPC should be based upon chemical toxicity." However, at that time a chronic exposure level was not proposed for the stated reason that "uranium and its compounds are suspected carcinogens."

By the time of the publication of Volume 5 of Drinking Water and Health in 1983, the committee had further investigated uranium in drinking water. This investigation included a re-evaluation of earlier information, use of additional references, and consideration of radiological effects. Reference should be made to the publication mentioned above for a detailed account of the steps leading to the conclusions outlined below. The committee stated:

1) Because there is no evidence that naturally-occurring uranium-238 is carcinogenic, it is appropriate to calculate a chronic exposure "suggested no-adverse-response level" (SNARL).

2) Studies in 1949 by Maynard and Hodge (1)* indicated that the highest dietary level of uranium tolerated by dogs was 1 mg/kg/day. Further, that in 1958 Luessenhop and his colleagues (2) found that the minimum-observed-effect dose in humans for uranium administered intravenously was 0.15 mg/kg of body weight. This amount is approximately the same as that absorbed following an oral dose of 1 mg/kg, assuming

* See list of references at end of this chapter.

20% gastrointestinal absorption (this assumption is based on other references outlined in the committee's Volume 5 publication mentioned above).

3) Using an "uncertainty factor" of 100, and assuming that a 70 kg adult consumes two liters of water daily and that 10% of total uranium intake is provided by the water, the following calculation can be made to find the SNARL:

$$\frac{1.0 \text{ mg/kg} \times 70 \text{ kg} \times 0.1}{100 \times 2 \text{ L}} = 0.035 \text{ mg/L}$$

By making the assumption that the isotopic ratios in natural uranium are in equilibrium, the committee suggested that the SNARL of 0.035 mg/L could be converted to an equivalent radioactivity level of 11.6 pCi/L, that is, 0.43 Bq/L. The assumption of equilibrium is often not valid and can lead to erroneous results as outlined later in this report in Section 10.6*.

The committee has taken a very definite stand regarding the relative significance of the hazards posed by chemical toxicity and radiation toxicity of uranium in drinking water. This stand is exemplified in the somewhat sweeping statements noted below which are quoted from Volume 5 of Drinking Water and Health.

> 1) The total absence of carcinogenic effects from ingested natural uranium in either animals or humans makes it difficult to develop an appropriate model for the radiotoxicity of that element.
>
> 2) The fact that drinking water rarely contributes more than 2% to 5% of the total uranium ingested daily leads to the conclusion that a radiation

---

* Even if equilibrium prevails, the calculation is incorrect; the result should be 23.2 pCi/L, or 0.86 Bq/L.

risk model for natural uranium is inappropriate and unjustified on the basis of present knowledge.

3) Because of its low specific activity, natural uranium does not pose a problem of radiotoxicity in drinking water. Assessment of uranium toxicity in drinking water should be based on its chemical toxicity and not on radiation toxicity.

4) The committee also recommends that toxicological assessment of uranium in water be based solely on its renal toxicity in all instances except when industrial processes result in a marked enrichment of shorter-lived uranium isotopes.

5) Additional research should be carried out to determine with greater precision the dynamics of uranium absorption from the gastrointestinal tract for different chemical forms of uranium.

10.5.2 Reports Published in the Journal of the Health Physics Society Subsequent to the US National Workshop on Radioactivity in Drinking Water

A conference entitled National Workshop on Radioactivity in Drinking Water was held in 1983 under the sponsorship of the US Environmental Protection Agency. The aim of this conference was to analyze existing information and data and to then make recommendations concerning the proposed EPA revised regulations for radioactivity in drinking water. The workshop participants were formed into seven committees, each of which was assigned a topic and instructed to produce a technical paper on that topic. Only naturally-occurring radioactivity in drinking water was discussed. The papers produced by this procedure were published in the May 1985 issue of Health Physics, the journal of the Health Physics Society. This publication contains a valuable fund of information which reflects the current thinking of a large number of experts.

Two papers in the collection are of particular interest with regard to the discussion of guidelines for uranium, radium and radon in drinking water. The material presented in these two references is summarized below.

A paper entitled "Metabolism of Ingested U and Ra" by a committee headed by M. E. Wrenn (3) puts forward the strong opinion that the guideline limiting uranium in drinking water should be based on considerations of chemical toxicity. The following statements are quoted from the committee's report:

> The committee believes that limits for natural U in drinking water should be based on chemical toxicity (which has been observed in man and quantified in animals), rather than on a hypothetical radiological toxicity in skeletal tissues (which has not been observed in either man or animals). The naturally-occurring mixture of U isotopes, U-234, U-235, and U-238, has such a long collective rate of radioactive decay (half-life), and a correspondingly low specific activity, that its biological action is predominantly that of a non-radioactive element . . . . The quantitative relationship between U intake and kidney damage has been measured in several species over a large range of dosages of many soluble U compounds administered by various routes for, in some cases, extended periods of time. Only transient kidney dysfunction has been observed in patients given homeopathic injections of $UO_2(NO_3)_2$ or in workers.

One of the references quoted by Wrenn and his associates is a paper presented at the 1982 annual meeting of the Royal College of Physicians and Surgeons of Canada by Dr. Michael Moss and Dr. Ross McCurdy, two members of the Uranium Task Force. This paper outlined the results of the initial clinical investigations carried out for the Task Force. These investigations are discussed fully in Chapter 11 of this report.

The committee developed a recommendation to limit chemical toxicity to the kidney from the ingestion of natural uranium in drinking water. This was done "using a metabolic model which estimates a higher kidney uptake of U than the new ICRP model (ICRP 79), limiting the U concentration to 1 μg U/g of kidney, and applying a safety factor of 50."

The recommended "interim guidance" value for uranium in drinking water is 0.10 mg/L based on considerations of kidney toxicity, with the application of a "safety factor" of 50-150.

Using this toxicity guideline and assuming that U-234 and U-238 are in equilibrium (as noted in Section 10.5.1 above, this is often not a valid assumption) to obtain an equivalent α activity of 67 pCi/L (2.5 Bq/L) the committee reached the conclusion: "that the limit we suggest for soluble U in drinking water, based on renal toxicity, is less than the limit based on an 'acceptable' risk of bone cancer (lifetime risk = 10^{-4})." Therefore, the committee adopted the position that "in the case of natural U, chemical toxicity is a more restrictive health effect criterion than risk of radiation-induced bone cancer, unless the cancer risk limit is set at an unrealistically low level."

Earlier in its report the committee stated that skeletal cancer is regarded as the major potential radiobiological effect of ingested α-emitting radioisotopes of radium and it is the "presumed radiobiological effect of U, if any." It is pointed out by the committee: 1) that a large amount of human and animal metabolic and toxicologic data is available to support guidelines and standards for radium, but that a lesser amount of human and animal data is available for uranium; and 2) epidemiological studies show that all of the radium nuclides can induce bone sarcomas and they also show that radium-226 can induce carcinoma of soft tissues, but that to date there are no data which suggest any radiological effects from ingested natural uranium in either animals or man.

The recommendations of the committee headed by Wrenn as reported to the Health Physics Society are listed below:

1) Use best estimates of metabolic parameters, realistic models and propagate the uncertainties. The latter may require some research.

2) Further research is needed on GI absorption of U in animals (excluding rats), and on the toxicity and pharmacokinetics of U under conditions of chronic oral intake or its equivalent.

3) It is important to obtain more and better data for natural levels of U in water, diet and human bone in different geographic areas. The distribution of U in the human body should be investigated more thoroughly, including soft tissues as well as the skeleton.

4) Gastrointestinal absorption of U should be inferred by measuring U intake and both fecal and urinary U excretion in man under controlled intake conditions.

5) Surveys of current water (and other fluids) intake are needed to better understand the

average per capita intake of local drinking water.*

6) Final limits of U in drinking water should not be set until the research identified above (at least items 3, 4 and 5) is complete. The research is reasonably short-term in nature and could be completed within a few years.

7) The interim radium-226 limits in water could be relaxed by a factor of at least 4, and still provide a very high degree of protection for individuals.**

8) For interim guidance for U, 100 μg U/L (0.10 mg/L) of water was chosen as a reasonable value, based on considerations of kidney toxicity, with the application of a safety factor of 50—150.

The second of the two papers referred to above at the beginning of this section is "Health Effects and Risks from Rn-222 in Drinking Water" by S. T. Cross, N. H. Harley and W. Hofmann (4). This paper analyzes the radiation doses received by inhalation and by ingestion from exposure to radon and radon progeny, that is, the daughter products produced by radon decay; it presents an overview of data on human and animal health effects; it calculates estimates of cancer risks due to exposure to radon and its daughter products; and it suggests limits for radon activity in drinking water and in indoor air. Information presented in this paper will be included in the general discussion of radon which comprises Chapter 13 of this report.

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* Such a survey was carried out in Canada in 1977-78 by the federal Health and Welfare Department.

** The interim limit referred to is the USEPA guideline of 5 pCi/L (0.2 Bq/L); if this were "relaxed by a factor of at least 4" it would be approximately equal to the Canadian drinking water guideline MAC for radium-226 of 1 Bq/L.

The authors of the paper develop the position that the radiation dose to the respiratory system from exposure to radon outweighs the dose to other organ systems and therefore the limits on exposure to radon in drinking water which they derive are based mainly on the inhalation risk due to radon emanating from water and other environmental sources.

Three approaches are used to derive the values suggested as possible limits for radon in household water supplies:

1) The conservative "tolerance dose" method which sets a limit at 1/10 to 1/100 of the exposures known to affect health. Using this method and various assumptions noted in the paper, for continuous inhalation exposure and the assumption that 100% of the radon in indoor air comes from the water supply, the upper limit on radon in water is suggested to be in the range 1,000 pCi/L to 10,000 pCi/L, that is, approximately 40 Bq/L to 400 Bq/L.

2) The "exposure-distribution" approach which bases risk on the distribution of population exposures to natural radioactivity. Application of this method requires knowledge of the average exposure and range of exposure received by a population. A practical upper limit can then be established on a "cost-risk-benefit, remedial-action" basis. The authors mention that the distribution approach has been used in Canada to confirm an indoor limit for radon of 0.02 WL* to a maximum of 1 WLM/year for uranium mining communities. It is stated that the U.S. EPA has used 0.02 WL as the objective for radon exposure in buildings located in proximity to uranium mine tailings.

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* The "action level" set by the Atomic Energy Control Board for houses in the uranium mining community of Elliot Lake.

After assuming an indoor radon/radon progeny equilibrium factor* of 0.5 and again assuming that all of the radon in the indoor air comes from the water supply, the authors calculate that the limit for radon in water is in the range 16,000 pCi/L to 40,000 pCi/L, that is, approximately 600 Bq/L to 1,500 Bq/L using 0.02 WL as the radon-in-air limit.

3) The "equivalent-risk" approach, which is based on estimated cancer-death risk factors associated with drinking water containing radon. Based on these factors the authors state that a water supply with a radon activity of 20,000 pCi/L (approximately 750 Bq/L) has an associated lifetime, total, cancer-death risk ranging from 8 to 16 X 10^{-3}, or approximately 1% to 1.5%. The authors consider this comparable to the risk involved in the application of the limit of radon in indoor air of 0.02 WL. They recommend that their derived limit for radon in water of 20,000 pCi/L (750 Bq/L) be considered as an action level above which further investigation would be required.

In summary, after presentation of the three approaches noted above, the report suggests <u>20,000 pCi/L (750 Bq/L)</u> as the best balanced estimate for a radon activity limit in water supplies, but concludes: "before a maximum contaminant level (MCL) for Rn in water can be firmly established, the broader issue of the MCL for Rn in indoor air must be addressed."

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* If radon and its short-lived daughters are in equilibrium, then 1 WL is equivalent to 3.7 Bq/L of radon (and, since equilibrium prevails, 3.7 Bq/L of each of the short-lived daughters). However, such an equilibrium state seldom occurs, in which case it is necessary to know the state of disequilibrium in order to convert the radon activity level to working levels. The equilibrium factor is the multiplier used in this conversion.

10.5.3 Health and Welfare Canada—Radiation Protection Bureau

The Radiation Protection Bureau of the Federal Department of Health and Welfare has calculated what would be the limiting concentration for uranium in drinking water based on radiological toxicity only, without regard for chemical toxicity. On this basis the maximum acceptable concentration would be 0.25 mg/L under the following conditions:

1) Assuming water ingestion of 2 L/day.

2) Keeping radiation dose to 1/10 of the ICRP recommended annual exposure limit to the public; this would result in a dose limit of 0.5 mSv/year (50 mrem/year).

3) Assuming U-234 and U-238 in equilibrium.

10.5.4 Province of Manitoba

The occurrence of uranium in groundwater in parts of Manitoba has been a subject of concern and investigation in that province in recent years. During the course of the investigation it was decided to discontinue the use of the Canadian drinking water quality guideline of 0.02 mg/L for the maximum acceptable concentration of uranium in drinking water. This was replaced by a uranium guideline of 0.10 mg/L which, according to Dr. Peter Warner, Director of Environmental Health Services with the Manitoba Department of Health, is used as an advisory value; it has not been established as a "standard".

The figure of 0.10 mg/L was adopted on the recommendation of Dr. Allen Sourkes of the Radiation Protection Section, Manitoba Cancer Treatment and Research Foundation. In discussions with Dr. Sourkes, it was learned that the guideline was not set as the result of medical investigations or health studies in Manitoba, but was derived using radiological considerations, with the Health and Welfare Canada Radiation Protection Bureau radiological limit for uranium as a basis.

As noted in Section 10.5.3 above, the Radiation Protection Bureau noted several conditions which apply to the derivation of its suggested radiological toxicity based limit for uranium of 0.25 mg/L. One of these conditions was that U-234 and U-238 were assumed to be in equilibrium.

In the case of equilibrium:

Specific Activity of U-238 = 12.35 Bq/mg natural uranium

and,

Specific Activity of U-234 = 12.35 Bq/mg natural uranium

therefore,

For a uranium concentration of 0.25 mg/L,

Specific Activity of U-238 = (12.35 X 0.25) Bq/L = 3.1 Bq/L

and also,

Specific Activity of U-234 = (12.35 X 0.25) Bq/L = 3.1 Bq/L

Total = 6.2 Bq/L

However, it was reported by Dr. Sourkes that the U-234/U-238 ratio was measured in water samples in Manitoba and the ratio was found to average 3/1.

In the case of U-234/U-238 = 3/1,
and for 0.25 mg/L uranium:

Specific Activity of U-238 = (3.1 X 1) Bq/L = 3.1 Bq/L

and,

Specific Activity of U-234 = (3.1 X 3) Bq/L = 9.3 Bq/L

Total = 12.4 Bq/L

Thus, in order to maintain the same radiation dose as that on which the Federal Radiation Protection Bureau radiological limit of 0.25 mg/L was based, that is, to maintain 6.2 Bq/L (which would maintain the dose limit of 0.5 mSv/year) it was decided in the Manitoba case to divide the 0.25 mg/L by 2.

This yielded 0.125 mg/L which was rounded down to allow for possible sampling errors to obtain the guideline for uranium in drinking water of 0.10 mg/L.

10.6 Difficulties, Uncertainties and Complexities in Establishing and Applying Guidelines and Standards

10.6.1 Introduction

The establishment of guidelines and standards for uranium and related elements in drinking water and the application of such guidelines and standards is fraught with difficulties, complexities and confusion. This has been somewhat evident from the material presented so far in Chapter 10 of this report. Setting guidelines for any chemical constituent in water is difficult; given the fact that the combination of uranium and its related elements radium and radon pose the dual potential health hazard of chemical toxicity and radiotoxicity, the establishment of guidelines for these elements is a very onerous task indeed.

There are many reasons why it is difficult to set guidelines for chemical elements in drinking water. Some of these are outlined below:

1) Uncertainty in scientific information. This is the result of: a) disagreements within the scientific and medical community on the relevance, validity, and acceptability of scientific data; b) the extrapolation of dose-response relationships from research studies using relatively small

groups of animals, relatively large doses and relatively short exposure times to predict risks to humans associated with smaller doses and lifetime exposure times; c) extrapolation of toxicological data from animals to man (will a different species respond differently?); d) differences in susceptibility from person to person.

2) Uncertainty about the apportioning of intake of a particular element between air, water, food and other sources of exposure such as occupational contact.

Doubts concerning both the biological and mathematical reliability of methods of extrapolating necessitate the use of somewhat arbitrary "safety factors", or more correctly "uncertainty factors", between 10 and 100.

The use of "safety factors" has been criticized for at least two reasons. The main criticism arises from the assumption which is inherent in the safety factor concept that there actually exists a threshold dose below which no adverse health effects will occur. The question of the existence of a toxic effects threshold has been the subject of much scientific discussion on which there is not unanimous agreement. A second reason for criticism is that safety factors take no account of the slope of the dose-response curve. A safety factor which provides an acceptable margin of safety for a substance with a relatively shallow dose-response curve will produce a much smaller margin of safety if the curve is relatively steep.

An additional confounding factor regarding extrapolation from experimental results to human experience is the fact that the experimental exposures are to single substances whereas in the real-life human environment a large number of potentially hazardous chemicals and other factors can interact.

With regard to substances which possess carcinogenic properties, such as radioactive elements, the concept of the "risk factor" is used. Judgements on acceptable risk levels should probably be made by representatives of society as a whole.

Radioactive substances such as radium and radon do not exhibit a toxic effects threshold, but rather have a cumulative effect and present risks which are dose dependent. The water quality aim is to follow the "ALARA" principle, that is, to keep all concentrations of radioactive contaminants in drinking water "as low as is reasonably achieveable," social and economic considerations being taken into account. Refer to Appendices N and O for more background information on the rationale for handling guidelines for radioactive substances in drinking water.

The following sections present examples and details which illustrate the confused and complicated situation outlined in this introduction.

10.6.2 The Canada and U.S.S.R. Guideline Discrepancy

The first peculiarity with regard to uranium guidelines noted by the Uranium Task Force was the glaring discrepancy between the guidelines established in Canada and in the U.S.S.R. As noted previously, the Canadian drinking water quality guideline for maxmum acceptable concentration of uranium is 0.02 mg/L. According to references in the literature (see Table 39) the guideline established in the U.S.S.R. is 1.7 mg/L.

The confusion arises from the fact that both of these guidelines are based on exactly the same animal research study which was carried out in the Soviet Union. Obviously, the discrepancy occurs from the way in which the research results were interpreted and applied in the respective countries. The rationale used in Canada is outlined in Section 10.2.1. No information was available to the Task Force on the rationale used in the U.S.S.R.

10.6.3 Comparison of Rationale Used for Guidelines Adopted in Canada and Proposed by the U.S. National Academy of Sciences

A comparison of the assumptions and calculations used to establish the uranium guideline for the Canadian Drinking Water Quality Guidelines (0.02 mg/L) and for the proposed SNARL recommended by the U.S. National Academy of Sciences (0.035 mg/L) is an excellent example of how the handling and application of research data has enormous effects on the guideline produced. The calculations are outlined below:

CANADIAN DRINKING WATER QUALITY GUIDELINES	U.S. NATIONAL ACADEMY OF SCIENCES
Assumed daily water intake = 2L	Assumed daily water intake = 2L
No-observable-effect-level (NOEL) for uranium ingestion = 0.1 mg/kg/day (reference: Novikov)	No-observable-effect-level (NOEL) for uranium ingestion = 1 mg/kg/day (references: Maynard and Hodge; Luessenhop)
Assume 50% of daily uranium intake is from food, leaving remaining 50% to come from water (based on "survey data" which indicate that "food and water contribute approximately equal amounts" to total daily uranium intake).	Assume 90% of daily uranium intake is from food, leaving remaining 10% to come from water (based on "limited measurements" made by U.S. National Council on Radiation Protection and Measurements).

Assume a 70 kg person	Assume a 70 kg person
Assume uncertainty factor = 10 to account for possible response differences of different species (lab animals and human subjects). Assume uncertainty factor = 10 to account for differing individual susceptibilities	Assume an uncertainty factor = 100
Therefore, $$MAC = \frac{0.1 \text{ mg/kg} \times 70 \text{ kg} \times 0.5}{10 \times 10 \times 2 \text{ L}} = 0.02 \text{ mg/L}$$	Therefore, $$SNARL = \frac{1.0 \text{ mg/kg} \times 70 \text{ kg} \times 0.1}{100 \times 2 \text{ L}} = 0.035 \text{ mg/L}$$

The guideline values which result from these two calculations are relatively close in magnitude and at first glance it appears as though the two groups who derived them are in fairly close agreement. This is, however, a misleading picture. A study of the two calculations reveals several similarities, but more importantly, it reveals two critical differences. The two groups are in agreement on: daily water intake, weight of average or normal person, and magnitude of uncertainty factor. They differ widely on figures used for: no-observable-effect-level for uranium ingestion and proportion of daily uranium intake which comes from water.

In actual fact, the two groups are not in close agreement, but what is most interesting in this comparison exercise is the calculation of the range of variation in MAC (or

SNARL) which results when the "NOEL" and "% daily uranium intake from water" factors used by the Canadian group and by the U.S. National Academy of Sciences group are interchanged. Since these two factors are independent of each other, there is no reason why such an interchange cannot be made. The four variations in calculation which result from this interchange of variables are presented below:

VARIATION IN CANADIAN MAC RESULT USING U.S.NAS FACTORS	VARIATION IN U.S.NAS SNARL RESULT USING CANADIAN FACTORS
If the NOEL from U.S.NAS (1 mg/kg/day) is used and all other factors kept as in original calculation above:	If the NOEL used by Canadian group (0.1 mg/kg/day) is used and all other factors kept as in original calculation above:
$\text{MAC} = \frac{1 \text{ mg/kg} \times 70 \text{ kg} \times 0.5}{10 \times 10 \times 2 \text{ L}} = 0.20 \text{ mg/L}$	$\text{SNARL} = \frac{0.1 \text{ mg/kg} \times 70 \text{ kg} \times 0.1}{100 \times 2 \text{ L}} = 0.004 \text{ mg/L}$
If the % of daily uranium intake from water assumed by U.S.NAS (10%) is used and all other factors kept as in original calculation above:	If the % of daily uranium intake from water assumed by Canadian group is used and all other factors kept as in original calculation above:
$\text{MAC} = \frac{0.1 \text{ mg/kg} \times 70 \text{ kg} \times 0.1}{10 \times 10 \times 2 \text{ L}} = 0.004 \text{ mg/L}$	$\text{SNARL} = \frac{1.0 \text{ mg/kg} \times 70 \text{ kg} \times 0.5}{100 \times 2 \text{ L}} = 0.20 \text{ mg/L}$

A cursory inspection of the results of these calculations indicates that the MAC (or SNARL) for uranium in drinking water has only been established to be in the range of

0.004 mg/L to 0.20 mg/L if the various references and assumptions applied by the groups which developed the Canadian Drinking Water Quality Guidelines and by the U.S. National Academy of Sciences Safe Drinking Water Committee are accepted.

10.6.4 Complications in Relating Uranium Concentration to Radioactivity

As mentioned above in Section 10.5.1, the Safe Drinking Water Committee of the U.S. National Academy of Sciences attempted to relate its proposed SNARL for uranium of 0.035 mg/L to an equivalent radioactivity level by assuming that the isotopic ratios in natural uranium are in equilibrium.

However, various authorities emphasize that the determination of radioactivity of a water sample by multiplying the uranium concentration by the radioactivity factor at isotopic equilibrium will produce an erroneous result if the two isotopes U-234 and U-238 are not in fact in equilibrium. According to R. L. Blanchard et al. (5), the actual factor can range from 0.33 pCi/μg if no U-234 is present, to at least 7 pCi/μg for a U-234/U-238 ratio of 20 which is not unknown. Lappenbusch and Cothern (6) state that: "The U-234/U-238 ratio for most water supplies seems to be between 1 and 3, with surface waters in the United States being closer to equilibrium than that of groundwater." They add that: "The ratio can range up to 10 - 15."

This complication was recognized in the Province of Manitoba and as described in Section 10.5.4 it was taken into account when deriving the uranium guideline which was adopted there.

Attempts were made by the Task Force to obtain analysis data which would relate uranium concentrations in water samples in Nova Scotia to actual radioactivity. However, the field work of the Task Force was ended before results could be obtained.

10.6.5 Limitations and Problems in Application of a Gross Alpha Particle Screening Guideline

Current U.S.EPA guidelines for uranium and radium are based on gross alpha particle screening. Two main problems which are inherent in the use of a gross alpha screening scheme are:

1) The method does not necessarily indicate whether radium-228 is at levels which contribute to exceeding the guideline for total radium, because radium-228 is a beta-emitter.*

2) The method, as applied by the U.S.EPA measures alpha particle activity minus radon and uranium and uses chemical uranium analysis and the assumption that U-234 and U-238 are in equilibrium; as previously noted, this assumption is not always valid.

These limitations and problems as well as others of somewhat less importance are thoroughly discussed in the report published in the May 1985 issue of Health Physics prepared by a committee chaired by R. L. Blanchard and entitled "Radiological Sampling and Analytical Methods for National Primary Drinking Water Regulations." This report was referred to above in Section 10.6.4.

The World Health Organization guidelines include screening for gross beta activity in order to avoid the limitation noted as 1) and they do not exclude uranium when applying their gross alpha screening so that problem 2) above does not arise.

*As noted previously in this report, in Nova Scotia radium activity in water samples was measured as total radium which includes radium-228, therefore this problem does not arise.

10.6.6 Uncertainties Regarding Health Implications of Ingested Radon

Knowledge of the behaviour and potential health effects of inhaled radon has advanced beyond such knowledge for ingested radon. The report by Cross and his colleagues which was referred to in Section 10.5.2 lists four uncertainties regarding the behaviour and health implications of radon ingested in drinking water. These are:

1. The unknown transit time of radon through the wall of the gastrointestinal tract.

2. The identification of organs which receive the highest radiation doses.

3. The variability in the estimates made by different investigators in whole-body radon retention.

4. The inability to account for all radon supposedly ingested.

These uncertainties indicate that the current state of knowledge is insufficient to support a guideline for radon in drinking water based on ingestion. There is, as indicated in Section 10.5.2, information which is considered by some investigators to be sufficient to suggest interim guidelines for radon in drinking water based on inhalation.

10.6.7 Summary

Section 10.6 of this report has presented information on the scientifically complex and difficult task of setting and applying guidelines for uranium and related elements in drinking water.

An overview of the numerous details and variables which are involved, the information gaps which have yet to be filled, and the uncertainties which must be dealt with is presented in the report published in the May 1985 issue of *Health Physics* entitled "Regulatory Development of the Interim and Revised Regulations for Radioactivity in Drinking Water—Past and Present Issues and Problems" by W. L. Lappenbusch and C. R. Cothern which was referred to in Section 10.6.4. The authors are staff members of the Office of Drinking Water, U.S. EPA.

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11. CLINICAL INVESTIGATIONS OF URANIUM TOXICITY

11.1 Introduction

Item 9 of the investigation program which was outlined in Section 1.4 articulated the Task Force's intentions to follow up the water sampling program with medical screening and clinical testing in an attempt to answer two questions:

1) Is the health of those exposed to various levels of uranium and related elements in water supplies being affected?

2) What is the best biological index for monitoring exposure to uranium and related elements in water supplies?

The proposed clinical studies were carried out with the cooperation of the residents of Harrietsfield-Williamswood and New Ross. These studies and their results are fully documented in a report written by Dr. Michael A. Moss entitled "Province of Nova Scotia Uranium Task Force—Report on Clinical Studies." This report is attached as Appendix Q. A summary of the metabolism and toxicology of uranium is included in the report.

11.2 Conclusions and Recommendations

The conclusions reached by Dr. Moss and his recommendations based on those conclusions are listed below:

Conclusions:

1) There was no pattern of overt disease or symptomatic complaints which could be attributed to uranium exposure.

2) Although unexplained minor hematuria was detected in 11% of persons examined in the Harrietsfield study, this was not

reproduced either in a follow-up study or in the New Ross study. In addition, the microscopic findings alone would have generally been considered normal in these persons. The remote possibility that the presence of uranium itself was responsible for false positive interference was excluded. It was concluded that the batch of test strips used in Harrietsfield was either too sensitive, or subject to unidentified false positive interference. It was concluded that major glomerular lesions had not been sustained, in view of the lack of positive findings on routine urinalysis and microscopy, and the absence of significant quantitative proteinuria. This aspect of the clinical testing resulted in an unexpected benefit; 3 asymptomatic persons (including a child), were identified as having urinary tract infections, and a presumptive diagnosis of diabetes mellitus was made in another individual.

3) Urinary uranium excretion appeared to be unreliable as an index of body burden. It appears to primarily reflect recent intake of uranium.

4) Hair uranium concentration showed promise as an index of body burden, but has been found to be sensitive to lifestyle factors such as hairwashing. As a result of this activity, hair is capable of adsorbing and accumulating uranium to concentrations more than 1000 times higher than found in the wash water. During preliminary experiments, it had been found that a mild washing procedure prior to the uranium determination made no significant difference to the analytical values obtained. It is concluded that further analytical studies are required to determine whether a more aggressive washing procedure could be developed which would release adsorbed uranium, whilst leaving behind that portion which had been incorporated endogenously.

5) A trend effect was observed of increasing urinary β_2M excretion with increasing well water uranium concentration. In both studies, the group with the highest levels of uranium in their well water were out of keeping with this trend. This was attributed to the further observation that many of these individuals had changed their source of drinking water since receiving the results of their water analysis, and had therefore significantly reduced their intake of uranium prior to the clinic. It was concluded that as a marker of tubular proteinuria, urinary β_2M may serve as a useful index of subclinical toxicity in the context of such uranium exposure, and merits further study. It should be noted, however, that this marker has the disadvantage that it rapidly degrades under conditions of low urinary pH.

Recommendations:

1) That further clinical studies of a similar type be undertaken, particularly if an exposed population can be identified which contains individuals who have been exposed to higher levels of uranium in their drinking water, and preferably if clinical observations can be made before such persons have discontinued drinking this water. Based upon the results of the continuing well-sampling program in Nova Scotia, it now seems unlikely that such a population will be identified in this province.

2) Using incidental tissue sampling from autopsy procedures in regions where persons are known to be exposed to excessive amounts of uranium in their drinking water, attempts should be made to correlate bone and kidney uranium content with hair uranium concentration. Various preparatory hair washing procedures could be assessed in conjunction with this, the goal being to remove adsorbed uranium whilst leaving behind the uranium of endogenous origin. Similar procedures have been reported for the attempted removal of adsorbed cadmium on hair. Autopsy studies could also be used to evaluate the reliability

of other tissues such as nails, as a potential index of body burden of uranium.

3) It is recommended that an animal model be developed to study the nature of the early renal tubular lesion arising as a result of chronic uranium toxicity. In particular, it is important to gain information regarding the reversibility of this lesion, and to study the progression to a threshold of irreversible change with increasing dose. Alternatives to urinary β_2M should be explored for stability and reliability as markers of tubular proteinuria. Candidate markers include retinol-binding protein, for which a sensitive latex immuno-assay has been described. Urinary excretion of retinol-binding protein has been compared with β_2M for the early detection of tubular proteinuria, and has been recently shown to have the advantage of greater stability in specimens with a pH below 5.5.

4) It is recommended that a chronically-exposed animal model be used for urinary uranium determination following administration of various chelating agents. The goal would be to determine whether this procedure could be utilized to indicate body burden of uranium as it has been in the case of lead, and whether this could be achieved without renal injury.

12. URANIUM TOXICITY—DEVELOPMENT OF AN ANIMAL MODEL

12.1 Introduction

As indicated in Chapter 11 and Appendix Q, the research performed by Dr. Moss and his colleagues suggested that two features of the toxicity of uranium on the kidney (nephrotoxicity) are: 1) early tubular proteinuria, and 2) that this effect is reversible.

The clinical studies carried out attempted to evaluate the effects of chronic exposure to concentrations of uranium in drinking water ranging up to 0.7 mg/L (generally less than 0.2 mg/L), but were unable to do so. Furthermore, literature dealing with the early nephrotoxic effects of uranium is not available.

This situation led to the recommendation by Dr. Moss noted above in Chapter 11 that an animal model be developed in order to study "the nature of the early renal tubular lesion arising as a result of chronic uranium toxicity." The particular aims of such a study would be to determine specific details regarding the reversibility, threshold of irreversible change, and identification of the most sensitive biochemical parameter for detection.

The results of the proposed animal study would form a natural link with the data obtained in the clinical studies to provide a much fuller understanding of the health implications of uranium in drinking water. This would in turn provide a sound basis for re-evaluation of the Canadian Drinking Water Quality Guideline's maximum acceptable concentration for uranium.

12.2 Funding Problems

When the proposal for an animal model study was brought to the attention of the provincial Department of Health, agreement was expressed with the view of the Task Force representatives that such a study was desirable and seemed a necessary and natural follow-up to the clinical studies which had been completed. The department's view with regard to the funding of the study was, justifiably, that the results of the study would benefit all Canadians and, therefore, the study should be financed from federal sources.

Representatives of the federal Health and Welfare Department who met with staff members of the Department of Health and representatives of the Task Force in May 1982 voiced interest and support for the proposed line of research, including the development of an animal model. There was, therefore, an expectation of financial support from the federal level when the preliminary approaches for funding were made in the fall of 1982. Such financial support was not forthcoming however, even after additional representations and requests were made.

12.3 Initial Steps Toward Development of an Animal Model

As it became clear that funding for the proposed animal study would not be immediately available from federal sources, the provincial Department of Health made it possible to initiate the study in the hope that federal funds would eventually be available to complete the main portion of the study.

The initial research work leading towards the development of an animal model consisted of a series of preliminary studies. These studies and the results proceeding from them are outlined in Appendix R, which is a report prepared by Task Force members Dr. Ross F. McCurdy and Dr. Michael A. Moss.

12.4 Conclusion

The preliminary research described in Appendix R led to the conclusion that an animal model which can be used to study the nature of the early renal tubular lesion has been developed. It was further concluded that sensitive biochemical parameters which can be employed in defining the problem have been identified.

In essence, this preliminary work has proven the validity of the proposed study and it has refined laboratory procedures to the point that the proposed animal study can be pursued to completion if funding is made available. The information gained from the completed animal study would be correlated with the data collected from the clinical studies as noted in Section 12.1. This type of correlation of the results of specially designed animal research to results of clinical studies with human subjects has never been done with respect to uranium in drinking water. It should be emphasized that animal studies being performed by the federal Health and Welfare Department have taken a different approach and could not be correlated to the clinical studies performed in Nova Scotia by the Task Force.

Because of the unique feature that the animal study proposed by the Task Force can be correlated with the already completed clinical studies, the Task Force considers the completion of the animal study to be a matter of high priority in the effort to establish more definitively a maximum acceptable concentration for uranium in drinking water.

13. RADON—POTENTIAL HEALTH HAZARDS POSED BY INGESTION AND INHALATION

13.1 Introduction

It was noted earlier in this report that virtually all water samples collected in the Task Force investigation program were analyzed for radon-222 activity. When analysis results were reported, well and water system owners were informed that up to that time no standard for radon in drinking water had been established in Canada. In addition, they were informed that there were no known health hazards related to drinking water containing radon. It was pointed out that radon can be released to the air when water is running from taps and showers, but that the resultant radon in air concentration was not considered hazardous. This latter statement was based on the results of the radon in air measurements made by staff of the federal Radiation Protection Bureau mentioned in Section 1.1 and further outlined later in Chapter 13. Finally, assurance was given that all of the available research results would be studied to determine whether or not there is any health hazard associated with radon in drinking water.

Since the time that the well sampling program was completed and the reports mentioned above were sent to well owners, considerable information on radon has been compiled. Some of the information collected is the result of field studies carried out for the Task Force; some is the result of studies performed in other jurisdictions and made available to the Task Force; the balance has been collated from various published technical papers.

In this section of the report the information on radon compiled from these three sources will be presented and examined for possible leads to developing a position on the degree of potential health hazard posed by radon by both ingestion and inhalation routes.

13.2 Radon Field Studies Performed under Task Force Direction

13.2.1 Radon in Air Measurements by Federal Radiation Protection Bureau

In the introductory section of this report mention was made of an arrangement made by the Department of Health with the Radiation Protection Bureau of the federal Department of Health and Welfare to measure levels of radon activity in indoor air in several locations in Halifax County. The request for this field investigation was made to the Radiation Protection Bureau after Health Department sampling confirmed the presence of uranium in well water in Birchlee Trailer Court at concentrations greater than the maximum acceptable concentration. It was decided to measure radioactivity levels from radon and radon progeny (daughter products) in 5 representative mobile homes in Birchlee Trailer Court, Harrietsfield, at the Harrietsfield Elementary School, in a house at nearby Williamswood and in houses located in 6 other parts of Halifax County in which well water had been found to exhibit substantial radon activity during a previous, routine Nova Scotia Department of the Environment survey carried out to determine "background" radon levels.

In this investigation the emphasis was placed on determining radon activity levels in well water supplies and the related radon/radon daughter activity levels in air inside the residences involved. The technique employed aimed at setting up situations which would result in maximum release of radon to the household air such as collecting air samples in bathrooms with doors closed and showers running.

A complete report describing this field investigation and its results was written by R. G. McGregor and L. A. Gourgon, the staff members of the Radiation Protection Bureau who carried out the air sampling project. This report is attached as Appendix S.

The results of this field study and the conclusions reached by the Radiation Protection Bureau staff are summarized below:

Results

1. Radon activity in indoor air was found to vary from the detection limit of <0.02 Bq/L (<0.5 pCi/L) to 0.71 Bq/L (19.1 pCi/L).

2. The activity of radon daughters in indoor air was found to vary from 0.001 WL to 0.025 WL.

3. Radon activity in well water supplies sampled at the tap in the residences involved varied from 1,600 Bq/L (43 nCi/L) to 13,700 Bq/L (370 nCi/L).

Conclusions

1. The radon and radon daughter activities in air observed in residences in the several locations throughout the survey area were low; only 1 home had a radon daughter in air activity reading exceeding 0.02 WL, and it exceeded that level by about 29%.

2. There was no statistically significant difference between the results measured in mobile homes and the results measured in houses with basements.

3. The transfer of radon from tap water to indoor air was confirmed, with transfer efficiencies of 37% to 70%; these findings are in agreement with similar values reported in the literature.

4. During the operation of the shower, the transfer of radon from the water raised the radon concentration substantially in the bathroom, but only marginally in the living room area; shortly after shower operation the concentration returned to normal.

13.2.2 Radon in Air Measurements by Nova Scotia Department of Health

At the time that the measurements of radon in indoor air were made by the Radiation Protection Bureau, the Department of Health was not equipped to perform these measurements. By mid-1984 the Occupational Health Division of the department had obtained sophisticated, state-of-the-art equipment capable of measuring levels of radon activity in air. With this instrumentation it became possible to collect air samples for radon measurement over extended time periods, whereas the Radiation Protection Bureau measurements made in 1979 were based on air samples over a 5-minute period.

The Department of Health sampling survey was carried out in 1984-85. The objectives of the study were:

1) To measure as accurately and as realistically as possible the actual levels of radon/radon daughter activity in indoor air to which individuals are exposed on a day-to-day basis, to compare the results obtained with the measurements made by the Radiation Protection Bureau in the 1979 survey carried out for the Task Force, and also to compare the results

obtained with results of any similar studies reported in the literature.

2) To determine whether or not radon levels in indoor air vary with season.

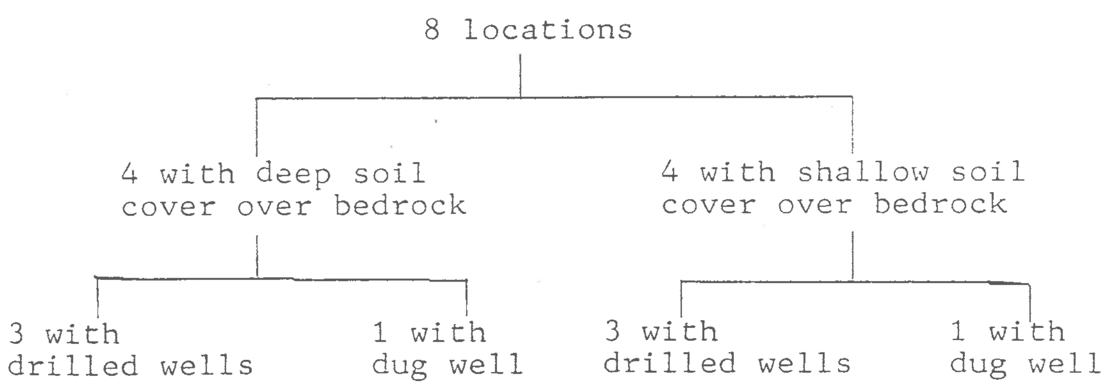
3) To examine the effects on indoor air radon levels of varying natural conditions at different locations.

Ten sample locations were used. All of these were located in Halifax County—9 locations were single family houses, 1 location was a four-storey office building. Of these, radon in air measurements were made at 1 location in 4 seasons, at 6 locations in 3 seasons, and at 3 locations in 2 seasons.

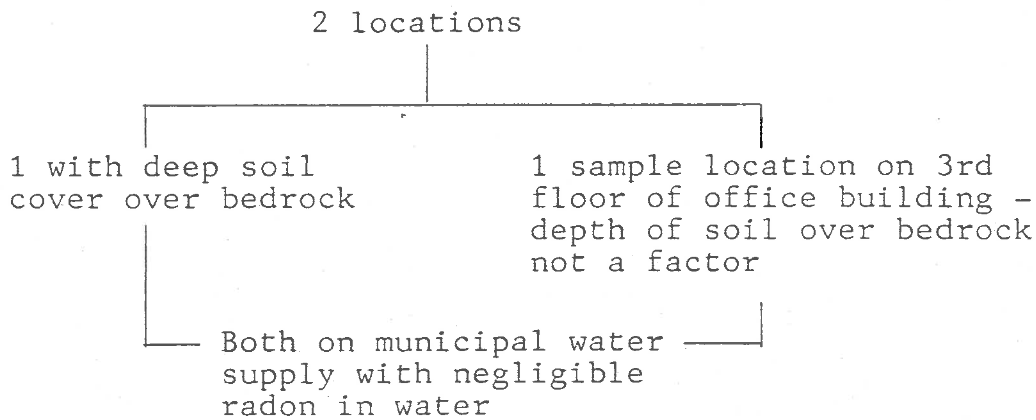
All air samples were collected over a period of at least 12 hours.

The sampling locations were chosen in order to reflect varying natural conditions as outlined below:

Areas with Uranium-Bearing Bedrock



Areas with Non-Uranium-Bearing Bedrock



In the houses used as sampling locations, air samples were collected in basements and in living rooms in order to achieve as closely as possible measurements of the highest and of the average radon activity levels respectively.

This field study was performed by Donald Feldman, public health engineering technologist with the Department of Health. His report, which presents a complete outline of the work done and the results obtained, is attached as Appendix T.

A summary of the results of this field study is presented in outline form below, followed by a list of conclusions based on the results obtained.

Results

1. Radon in air results according to levels of radon activity in water:

Locations with Radon in Well Water < 500 Bq/L		Locations with Radon in Well Water > 500 Bq/L	
Average Radon Daughter Activity in WL			
Basement	**1st Floor**	**Basement**	**1st Floor**
0.001	0	0.009	0.001

Locations on Municipal Water Supply - Radon Negligible

Average Radon Daughter Activity in WL

Basement	1st Floor
0.003	0.001

2. Radon in air results according to depth of soil cover over bedrock:

Average Radon Daughter Activity in WL

Locations with Deep Soil Cover over Bedrock		Locations with Shallow Soil Cover over Bedrock	
Basement	**1st Floor**	**Basement**	**1st Floor**
0.003	0	0.009	0.001

Note: No significant difference in results between uranium-bearing bedrock areas and non-uranium-bearing bedrock areas except as the uranium-bearing rock contributed to higher radon in well water.

3. Highest average radon daughter activity was 0.029 WL at a house in Brookside which has a drilled well with a radon level in water of 610 Bq/L and is in a location of uranium-bearing bedrock with bedrock at the ground surface.

4. Highest single reading of radon daughter activity was 0.051 WL at the same Brookside location.

Conclusions

1. The water supply appears to be a significant pathway for radon gas to enter houses.

2. The average working levels are higher in the basement samples than above-ground-level samples. Radon, being more dense than

air, tends to diffuse less in areas of restricted ventilation, and is usually more concentrated in the lowest part of the building.

3. Seasonally, the highest average working levels were measured in the summer months, which was the opposite of what was expected. It was thought that the houses would be well ventilated during the summer and the lowest measurements would be made.

4. The radon level appears to be higher in houses where the bedrock is very close to the surface.

5. The two locations which were situated in non-uranium-bearing geological areas and used a municipal water supply had average working levels similar to or higher than houses situated in a uranium-bearing geological area.

6. Measurements in this study are comparable to other studies conducted which state the average home radon concentration worldwide is 0.005 average working levels.

7. The average working level measurements determined in the mobile home were similar to basement measurements. The same conclusion was made by McGregor and Gourgon in 1979, who found no statistically significant difference between the two.

13.3 Radon Field Studies Performed in Other Jurisdictions

13.3.1 Study of Radon in Water Supplies in the State of Maine

In September 1979 a report entitled "Radon-222 in Potable Water Supplies in Maine: the Geology, Hydrology, Physics and Health Effects" was published by the Land and Water Resources

Centre of the University of Maine at Orono. The senior author of this report was Charles T. Hess. The study which is the basis of this report aimed to delineate the extent and pattern of radon in drinking water supplies in Maine and to relate this to the incidence of cancer in the state.

The study accomplished the following:

1) Approximately 700 (the report does not state an exact total) wells were sampled for radon-222.

2) 350 water samples were collected from "drilled wells, private water supplies and some public water supplies" for analysis of chemical and physical quality, and the results were related to geological characteristics of the areas in which they were collected. This information was used to "describe the geographic distribution of areas of high radon."

3) Radon in air measurements were made in 10 homes; radon activity in water supplies was also determined in these homes and house construction details were noted.

4) A map of the state showing distribution of radon levels in water was prepared.

5) The authors state that "the statistical association of radon with cancer" was calculated.

6) A state drinking water standard for radon was suggested.

7) An initial method for removing radon from water on an individual household basis was developed.

The water sampling program determined that the highest levels of radon in groundwater occurred in areas of granitic bedrock. In these areas radon activity in water was found to range from about 200 Bq/L (5,000 pCi/L) to 3,700 Bq/L (100,000 pCi/L).

Radon in indoor air ranged from 0.02 ± 0.01 Bq/L (0.56 ± 0.37 pCi/L) to 0.38 ± 0.06 Bq/L (10.30 ± 1.6 pCi/L) in the 10 houses studied, with an average reading of 0.10 Bq/L (2.60 pCi/L). It should be noted that the radon in air measurements are expressed in the report as activity per liter. The report presents a rationale for not measuring the activity in air due to radon daughters, expressed in working levels. The procedure used may present an incomplete, possibly inaccurate, picture and would be questioned by most experts in the field.

The conclusions reached by the authors of the report on the Maine radon study are quoted below:

1. Radon is present in much of Maine's water supplies in excessive amounts.

2. The radon concentrations are highest in granite grade rocks.

3. Public utility water supplies have substantially lower radon levels than private wells.

4. Levels of radon gas in the air in homes exceed recommended levels, and result in a dose rate that is associated with high risk in industrial settings.

5. Levels of radon are highly correlated with some types of cancers, especially lung and reproductive.

6. A recommended domestic water supply standard (10,000 pCi/L) is made to yield dose rates or mortality rates that do not exceed national averages.

In addition to these conclusions, it is interesting to note two other sections of the Maine report: the summary which appears at the end of the health effects statistical study and the list of recommendations made to Maine residents concerning radon in water supplies. These sections are quoted below:

> Health Effects Statistical Study Summary
>
> In summary, radon is significantly correlated with cancer, specifically with lung cancer, and reproductive cancer in males. It is correlated moderately but not significantly with connective tissue cancers in both men and women, and with brain cancer for women. This association of radon with cancer may not be unique to Maine, however, because some of the cancer rates for Maine are not higher than national averages. It is also clear that even though the relationship between radon and cancer have been demonstrated, radon is not the only factor associated with cancer in Maine.
>
> Both radon and cancer may be related to a third (or many) as yet undetermined variable.
>
> Recommendations for Maine Residents
>
> Any resident in Maine with greater than 10,000 pCi/L* of radon in his/her water supply, should be advised to: 1) use a different water supply; 2) put in removal equipment as soon as available, such as an aeration system; or 3) install adequate ventilation of all high water use rooms such as bathrooms, kitchens, and laundry rooms. This ventilation should be to the outside and occur at the time when water is used.
>
> *Note: 10,000 pCi/L = approximately 400 Bq/L

At the time it was received in 1980, the report of the Maine radon study was referred for comment to Dr. P. M. Lavigne, Provincial Epidemiologist, of the Department of Health. Following is the summary section of Dr. Lavigne's critique:

> In conclusion, the report cannot be given much "credibility". The report suffers from two major methodological deficiencies:

1) Design—A geological and hydrological survey was carried out. Such a descriptive survey was not aimed at measuring health effects, and made no attempt to control for confounding variables. This design could not have elucidated any information on the alleged health effects of radon.

2) Analysis—Instead of attempting to measure health effects, the authors chose to submit a questionable data base to "data-dredging", and failed to consider the confounding effects of other variables, or co-carcinogens. They misused the sample correlation coefficient by implying that the figures obtained suggested that a significant relationship between radon and cancer was present, whereas one could only state that the correlation coefficient was not obtained by chance and that there was a "statistical association". A simple correlation coefficient cannot be used to impute causality.

There probably is a relationship between radon and specific types of cancer in humans but this report cannot be used as evidence for or against the causal ralationship.

13.3.2 Survey of Indoor Radon and Radon Daughter Concentrations in 13 Canadian Cities

During the summers of 1977 and 1978 the Radiation Protection Bureau of the federal Department of Health and Welfare surveyed 9,999 houses in 14 cities across Canada for concentrations of radon and radon daughters present in indoor air. This study is fully reported in two technical papers published in 1980 by staff of the Radiation Protection Bureau: 1) "Mortality and Indoor Radon Daughter Concentrations in 13 Canadian Cities" by E. G. Letourneau and D. T. Wigle; and 2) "Background Concentrations of Radon and Radon Daughters in Canadian Homes" by R. G. McGregor, P. Vasudev, E. G. Letourneau, R. S. McCullough, F. A. Prantl, and H. Taniguchi.

The survey was performed in accordance with a random sampling system established by Statistics Canada in order to obtain information on the levels of naturally-occurring radon in a cross-section of Canadian homes. The data for one location was deleted from the study results due to the small size of the city and lack of adequate background data for the area.

In addition to gathering data from the measurements of radon and radon daughter levels, the study aimed to determine whether or not cancer mortality rates are significantly correlated with these levels. Toward this end the Health Division of Statistics Canada supplied figures on cancer deaths for each of the 13 study locations for the period 1957 to 1976. Age-specific and age-standardized mortality rates were calculated.

The results, discussion, conclusions, and recommendations reported in the two papers mentioned above are combined in the summary of information outlined below.

Results

Radon/Radon Daughter Measurements—Highlights

1. Geometric means for radon activity varied from 0.005 Bq/L (0.14 pCi/L) to 0.03 Bq/L (0.88 pCi/L); geometric means for radon daughter activity varied from 0.0009 WL to 0.0036 WL.

2. Highest radon activity reading was 2.78 Bq/L (75 pCi/L); highest radon daughter activity reading was 0.233 WL.

3. The results showed statistically significant geographical differences.

4. There was a strong correlation between mean radon levels by city and % of homes in which radon daughters exceeded 0.02 WL;

the % of homes in which radon daughters exceeded 0.02 WL was chosen as the radiation exposure index for correlation with cancer mortality rates.

5. Although radon daughter levels were generally very low, in the 3 "highest risk" cities (Halifax, N.S., Sherbrooke, P.Q., and Sudbury, Ont.) over 5% of all homes sampled had radon daughter levels greater than 0.02 WL.

6. Approximately 64% of all homes had radon activity levels of 0.04 Bq/L (1 pCi/L) or less; approximately 95% of all homes had radon daughter activity levels of 0.1 WL or less.

Cancer Mortality Statistics—Summary

There were no statistically significant correlations between radon daughter levels and any of the indices of cancer mortality used, namely: age standardized mortality rates (ASMR's) for each of the two time periods 1957-1965 and 1966-1976, the absolute change in ASMR over time, or the relative change in ASMR.

The results indicate essentially no correlation for either sex between radon daughter levels by city and lung cancer ASMR's in either time period.

There was a statistically significant tendency noted for male leukemia ASMR's to increase more rapidly over time in cities with higher radon daughter levels compared to cities with lower levels. No such tendency was observed for female leukemia ASMR's.

Discussion

A number of assumptions and limitations involved in the study are noted in the reports. In particular, the absence of data on tobacco smoking habits by city is noted as a major weakness in the study. Not adjusting results for variables such as city size and occupational profile were also noted as limitations which would tend to obscure any association of lung cancer with radon daughter levels.

Conclusions and Recommendations

The following conclusions and recommendations have been quoted directly from the reports:

> It has been well shown in Canada that radon daughter concentrations are not related to the type of dwelling or building materials used but are related to geographical area and the geology of the ground on which the house is actually located.
>
> It is very probable that the present study design could only detect a very strong association between radon daughter concentrations and mortality. The negative results of this study can only be interpreted as indicating in a qualitative manner, that radon daughter concentrations do not have a dominant effect on lung cancer mortality in Canadian cities studied. Although the radon daughter concentrations were generally very low in the three highest risk cities, over 5% of all homes had radon daughter concentrations exceeding 0.02 WL. Long-term residents in such homes could accumulate relatively high radon daughter exposures during a lifetime. It is suggested, therefore, that a case-control epidemiological study of lung cancer should be performed in one or more of the highest risk cities. This study would be designed to determine if household exposure to radon and radon daughters is a significant risk factor for lung cancer after adjustment for other factors including smoking and occupation.

13.3.3 Radon Measurements in New Brunswick

The village of Harvey, New Brunswick, was the subject of a radiological survey which was carried out by the New Brunswick Department of Health during the summer of 1981. This study is described in a report entitled "Natural Radioactivity Measurements for the Harvey Area, York County, New Brunswick" written by J. L. McBride and K. L. Davies of the Radiation Protection Services of the New Brunswick Department of Health.

The survey objectives were: 1) to determine if there is any correlation between levels of naturally-occurring uranium in well water and concentrations of radon in water from the same source; 2) to determine if there is any correlation between radon concentrations in water and radon daughter levels in indoor air; and 3) to determine whether or not there is a significant radiological hazard to the residents of the Harvey area. This area was selected for study because it was known to be an area of uranium-bearing bedrock.

A total of 86 houses, randomly selected, were surveyed for levels of radon in well water and radon daughters in indoor air. Radon in air samples were collected from 7 homes. All of the well water samples were analyzed for uranium concentration.

The results and conclusions of the survey are summarized below.

Results

Considerable numbers of samples were found to have high values for radon daughters in air, radon activity in water, and uranium concentration in water. There was little or no correlation between water uranium concentration and water radon activity levels, or between water radon levels and air radon daughter levels.

Radon Daughter Levels in Air

1) Radon daughter levels in air ranged from 0.001 WL to 0.600 WL.
2) Average level for radon daughters in air was 0.048 WL.
3) Radon daughter activity exceeded 0.02 WL, the Atomic Energy Control Board action level for homes in uranium mining communities, in 47.6% of homes sampled.
4) Radon daughter activity exceeded 0.05 WL in 26.2% of homes sampled.
5) Radon daughter activity exceeded 0.1 WL in 8.4% of homes sampled.

Radon Activity in Air

Radon activity in indoor air ranged from 0.70 Bq/L to 2.90 Bq/L.

Radon Activity in Well Water

1) Radon activity readings in well water samples ranged from "a few Becquerels per litre" to 3,054 Bq/L. Low readings were observed in samples from shallow wells.
2) Radon activity in water exceeded 370 Bq/L in 36.4% of homes surveyed.
3) Radon activity in water exceeded 740 Bq/L in 18.2% of homes surveyed.

Uranium Concentrations in Well Water

1) Uranium concentrations in well water samples ranged from less than 0.002 mg/L to 0.409 mg/L.
2) Uranium concentrations were greater than 0.02 mg/L in 23% of water samples, all of which were collected from drilled wells.
3) Uranium concentrations were greater than 0.10 mg/L in 4.6% of the samples.

Conclusions

The conclusions noted below are quoted from the study report:

> A large percentage of high concentrations for both radon-in-water and radon-in-air has been observed in the Harvey area, the full significance of which can be determined only by detailed site-specific investigations since these concentrations fluctuate markedly depending on climatic and other factors. However, upon relating the radon-in-water concentrations to an annual radiation dose it is shown that the high measurements probably present no major health problems to village residents*. Also, it is likely that the radon daughter concentrations in air do not present a serious health hazard since all of the locations exhibiting values in excess of 0.10 WL are unfinished basements and therefore are unlikely to be occupied for any great length of time. Since a good deal remains unknown concerning the chemical and radiological toxicities of natural uranium in drinking water, it is difficult to fully interpret the significance of the measurements recorded for the Harvey area but, of the three parameters investigated, this could perhaps be of the most consequence.

It is interesting to note, particularly when referring back to the conclusion stated in Section 12.4 of this report, that the New Brunswick report concludes with the statement: "This subject requires further investigation to establish models for uranium metabolism based on more human data ...".

13.4 Radon Information from Technical Literature

13.4.1 Introduction

Of a large number of technical papers collected by the Task Force which deal with radon in water, radon in air and the related potential health hazards, the one which is the most

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* This statement is based on an observation made by the authors that "a large fraction of the daily water intake is taken as a beverage for which water is boiled" and the fact that boiling removes practically all dissolved radon from water.

comprehensive and current was published in the May 1985 issue of the Journal of the Health Physics Society as one of the reports subsequent to the U.S. National Workshop on Radioactivity in Drinking Water. This paper, "Health Effects and Risks from Rn-222 in Drinking Water", by Cross, Harley, and Hofmann, was referred to in Chapter 10 and was listed as Reference (4) at the end of that chapter. The authors of this paper referenced a large number of sources and this Task Force report placed considerable reliance on the literature search done by Cross and his colleagues. Perhaps it should be added that, in the review of other reference material, nothing was found which would call into question the information and conclusions put forward in the Cross paper. Much of the balance of this chapter is based on that paper; other references are mentioned where appropriate.

At the point in Section 10.5.2 where the Cross paper was introduced, it was noted that the paper deals with four main topics. For clarity, these are repeated here: The paper analyzes the radiation doses received by inhalation and by ingestion from exposure to radon and radon progeny; it presents an overview of data on human and animal health effects; it calculates estimates of cancer risks due to exposure to radon and its daughter products; and it suggests limits for radon activity in drinking water and in indoor air.

In this chapter the first two of these topics will be explored in somewhat greater detail than in previous chapters of this report in order to provide a background of the current thinking on radon as a potential environmental health hazard. It is important to bear in mind when discussing radon's hazard potential that radon-222 is the initial element in a phase of the uranium radioactive decay series as illustriated in Figure 12. The radiation hazard can arise not only from radon-222 itself, but also

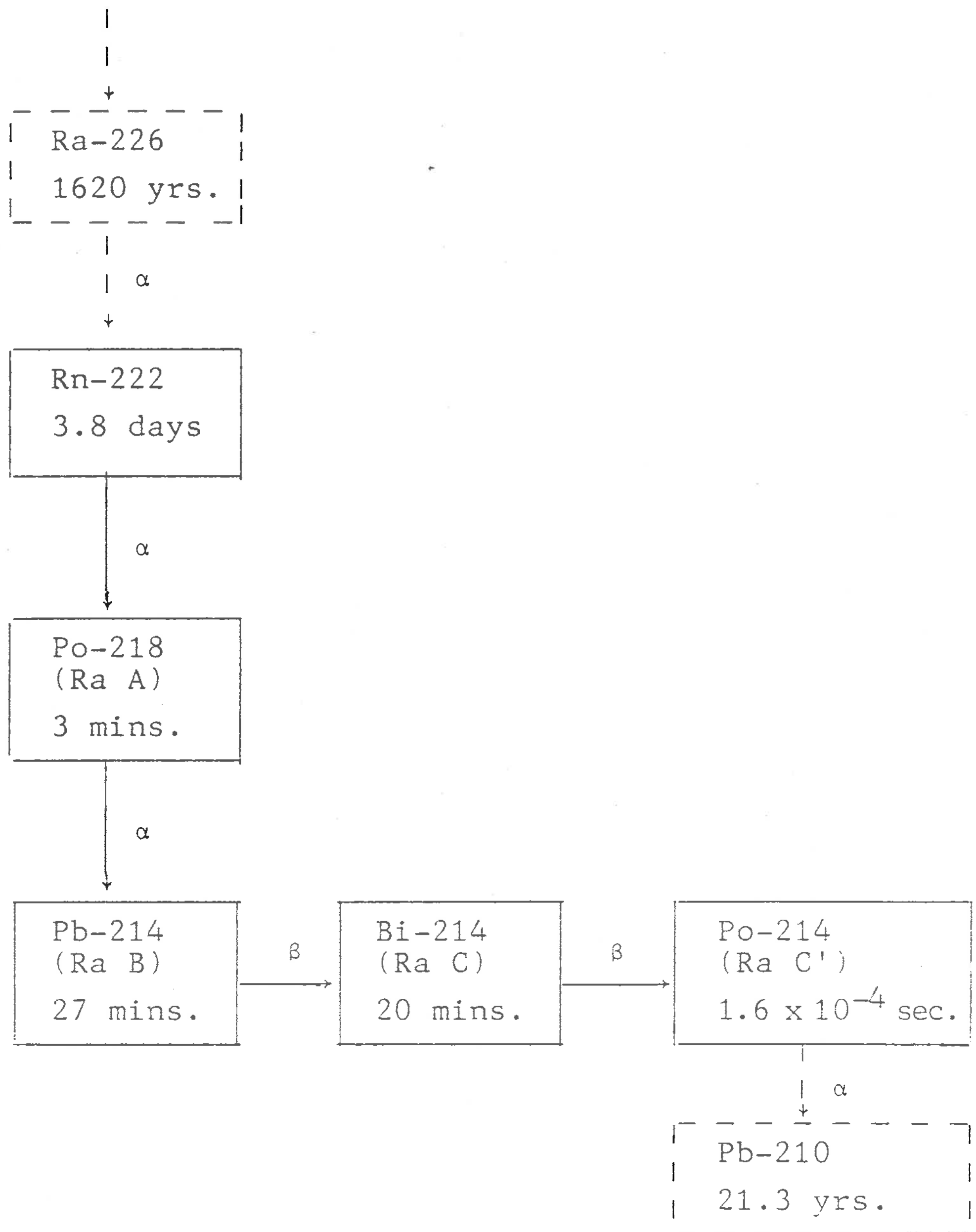

Figure 12 - Radon-222 Phase of the Uranium Radioactive Decay Series

from its short-lived progeny or daughter products: polonium-218, lead-214, bismuth-214, and polonium-214.

Radon presents a potential health hazard to the whole body because it is soluble in body fluids and fats. As previously noted, radon in water poses the possibility of exposure by ingestion through consumption of the water and by inhalation due to radon emanating from the water. The salient features of the state of knowledge of these two routes of exposure are outlined below.

13.4.2 Radon Ingestion Hazard

Whereas the radiation dose to the lung from inhaled radon and radon progeny has been studied by many investigators, relatively few have addressed the internal doses from ingested radon and radon progeny, and of those who have, most calculated the internal dose; few made experimental measurements.

The most notable experimental research on ingested radon appears to be that carried out by Hursh, et al. (1)*, the results of which were published in 1965. In this investigation, two human subjects drank water which had a radon plus radon daughters activity of 10,000 pCi/L on two occasions and were subjected to various tests. Measurements were made of radon loss in expired air, whole body "Radium C" (Bi-214) content, and radon in blood. The test results were combined with calculations to reach three conclusions: 1) the stomach is the critical organ when radon is ingested; 2) a "maximum permissible concentration" for "occupational exposure" is suggested to be 2.0×10^{-4} μCi/mL which is equivalent to 7,400 Bq/L; 3) the presence of radon daughters in the ingested water does not cause a substantially higher radiation dose and

*See list of references at end of this chapter.

therefore the suggested limit relates to radon only.

A number of references can be found in the literature which use calculation to arrive at the radiation dose received by the stomach and whole body due to ingestion of radon in drinking water. Some of these researchers have gone a step further in deriving, again by calculation, the maximum permissible concentrations of radon in water corresponding to these internal doses. The report by Cross and his collegues mentions three such references.

In addition, it could be noted that Hems (2) in 1966 as well as Simpson and Stewart (3) in 1979, performed these calculations. Hems, using the work by the Hursh group as a basis, calculated that a radon in water activity of 20,000 pCi/L (740 Bq/L) would limit the radiation dose to the stomach (which he concluded received the highest dose of any organ) to the ICRP recommendation of the day. In passing, it is of interest to note that Hems reckoned that, in temperate climates, a reasonable figure for average daily consumption of water, ingested as water, is 300 mL: the remainder being consumed as beverages for which the water is boiled, removing most of the radon by aeration. He also issued a reminder that calculation of daily radon intake from water ingestion must allow for loss of radon by aeration when drawing water from the tap and radon lost during swallowing. Most water sampling for radon activity measurement uses collection methods, such as those employed by the Task Force, which virtually eliminate radon loss to the air and, as such, could lead to overestimating the amount of radon ingested.

Simpson and Stewart, in 1979, updated the calculations made by others, including Hursh, using what they believe are more realistic (they made no reference to Hems in this regard) figures for daily water intake, the role of stomach contents and mucus, and the most recent ICRP recommendations. Their calculations led to a suggested "maximum permissible concentration" of radon in water of 6×10^{-5} $\mu Ci/cm^3$, which is equivalent to 2,200 Bq/L.

13.4.3 Radon Inhalation Hazard

As stated above, the number of researchers who have investigated the effects on the respiratory system of inhaled radon and radon progeny is far greater than the number who have studied the effects on various internal organs of ingested radon and radon progeny. Because of this, the fund of knowledge which has accumulated regarding the potential health effects of inhaled radon is greater than that which has accumulated with respect to ingested radon.

Section 10.6.6 listed four uncertainties regarding the behaviour and health implications of radon ingested in drinking water. As stated in that section, these uncertainties indicate that the current state of knowledge is insufficient to support a guideline for radon in drinking water based on ingestion effects.

With respect to inhalation effects, the Cross report states: "The complexity of the dose estimates (required to account for progeny deposition, radioactive build-up and decay, removal by physiologic clearance processes, and physical dose calculations to specific cells in bronchial mucosa) has been detailed by many authors and considered by national and international organizations." A large number of references is specified in support of this statement.

There is, according to Cross, et al., general agreement among radon inhalation effects investigators in the U.S. that the critical tissue is the bronchial epithelium and not the lung as a whole. Combining the belief that the tissue of concern is the bronchial epithelium with other "compensatory differences" listed in their report, Cross and his associates adopt a firm position that environmental and occupational exposures to the same levels of radon in air tend to result in "somewhat comparable" doses. This position, which appears to be based on sound reasoning, leads them to state "... there has been a tendency to artificially lower the cumulative exposure in the environment, presumably to account for the influence of decreased breathing rates on mean lung dose under nonworking conditions. In our opinion, this is neither warranted nor justifiable..."

It should be kept in mind throughout any discussion or consideration of inhalation exposure, that the concepts of WL and WLM must be used for specifying air concentrations of radon progeny. The definitions of these terms avoid the question of disequilibrium of the radon daughters and also the issue of whether or not the progeny are attached to dust, smoke or any other carrier aerosol.

With regard to the dose to the respiratory system per unit of cumulative radon exposure, the Cross report refers to the calculated values derived by several investigators. These will not be repeated here, but the section immediately following presents a health risk factor for radon inhalation, partially based on these values, as well as a risk factor for ingestion which is based on the dose to the stomach derived by experimental measurement and calculation as noted above in Section 13.4.2.

13.4.4 Health Risk Factors for Radon Ingestion and Inhalation

The following cancer risk factors have been put forward by Cross, Harley and Hofmann, based on the various parameters outlined in Table 40.

If the figures tabulated are accepted, it is obvious that, with the knowledge available at this time, the radon hazard to the respiratory system is greater than that to other organ systems and, therefore, any guidelines which may be proposed for the presence of radon in drinking water supplies should be based mainly on the risk to the lung posed by inhalation of radon and radon daughters.

13.4.5 Concluding Remarks

The most appropriate final remarks on the information which is available in the literature on radon as a potential environmental health hazard are these quotes from the report by Cross, et al., which has proven to be the most useful reference available.

> Comparatively few studies have investigated the exposure to natural background radiation sources. Even those few show no significant increase in lung-cancer death rate from inhalation exposure to normally occurring levels of Rn and Rn progeny ... an unequivocal association of Ra and Rn in drinking water and cancer indicence has yet to be demonstrated.
>
> Present data suggest that an absolute threshold exposure for lung-cancer induction is highly unlikely [This is also in keeping with present day views, in radiation biology and radiation protection, that radiation-induced cancer is a stochastic (nonthreshold) process.]
>
> These varied opinions seem to indicate the possibility that environmental exposure to Rn progeny (or very low-level exposures) may result in such a small lung-cancer rate as to be indistinguishable from the natural, nonradiological induction rate.*

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* As indicated by the Canadian Radiation Protection Bureau survey—see conclusion at end of Section 13.3.2.

TABLE 40

Cancer Risk Factors: Radon Ingestion and Inhalation*

Radon Exposure Route	Critical Organ	Lifetime Cancer Risk Factor	Basic Parameters
Ingestion	Stomach	$<6 \times 10^{-8}$ per pCi/L ($<2 \times 10^{-9}$ per Bq/L) radon activity in water	Calculated annual dose equivalent to stomach of 100 mrem per 1,000 pCi/L (1 mSv per 37 Bq/L) radon activity in water, and an assumed 60 year dose accumulating interval which leads to a lifetime accumulated dose equivalent to stomach of 6 rem per 1,000 pCi/L (0.06 Sv per 37 Bq/L) of radon in water or 6×10^{-3} rem per pCi/L (2×10^{-3} Sv per Bq/L)
Inhalation	Lung	3×10^{-7} to 7.5×10^{-7} per pCi/L (1×10^{-8} to 3×10^{-8} per Bq/L) radon activity in water	Using lifetime lung-cancer risk coefficients of 3×10^{-3} per pCi/L (1×10^{-4} per Bq/L) radon activity and 1×10^{-2} per WLM/yr. exposure rate, for lifetime exposure; further using a range of mean transfer coefficients of 1×10^{-4} to 2.5×10^{-4} for radon in water to radon in indoor air.

* From Reference (4), Section 10.

> In estimating the effect of Rn-progeny exposure at environmental levels (normally, less than about 20 cumulative WLM per lifetime), the attributable risk at high exposures, derived from the mining data, must somehow be extrapolated to the low-exposure region. In keeping with prudent, conventional practice, the extrapolation is linear, even though some studies suggest that exposures may be even more efficient in inducing lung cancer as the exposure rate approaches background levels. This hypothesis is in contrast to the possibility mentioned above that very low-level exposure to Rn progeny does not result in distinguishable lung cancer.

Apparent discrepancies such as that exhibited in the last quoted statement above indicate that determining the relative importance of radon as an environmental health hazard will require on-going research and epidemiological study.

REFERENCES - CHAPTER 13

1. Hursh, J. B., Morken, D. A., Davis, T. P., and Lovaas, A. "The Fate of Radon Ingested by Man", Health Physics, Vol. 11, pp. 465-476, 1965.

2. Hems, G., "Acceptable Concentration of Radon in Drinking Water", Air & Wat. Pollut. Int. J., Vol. 10, pp 769-775, 1966.

3. Simpson, S. D. and Stewart, C. G., "An Estimate of the Maximum Permissible Concentration of Radon-222 in Water", Unpublished draft paper made available to the Uranium Task Force, Atomic Energy of Canada Ltd., Chalk River, Ont., dated August 1979.

14. RADIUM—HEALTH PERSPECTIVES

14.1 Introduction

Radium is a radionuclide known for its high radiotoxicity. The tragic case of radium ingestion by the pre-1930 instrument dial painters and the history of others who were exposed to radium intake by medical administration have provided researchers with extensive experience on the effects of radium.

Two isotopes of radium which occur in the natural environment are of health concern: radium-226 and radium-228. Radium-226, which has a half-life of 1,620 years and is an alpha-emitter, is generated in the uranium-238 radioactive decay series. Radium-228, which has a half-life of 5.8 years, is a beta-emitter and is produced in the thorium-232 decay series.

The natural abundance of radium is extremely low, the radium content of rocks being roughly proportional to the amount of uranium or thorium present, but at much lower concentrations.

14.2 Health Effects and Cancer Risks

Radium is a "bone-seeker". The health effects of long-term radium ingestion have generally been accepted to be bone cancer and leukemia. However, actual studies of individuals exposed to radium isotopes have shown that the leukemia risk is insignificant relative to the risk of bone cancer. This finding is mentioned in the paper by Wrenn, et al., which was listed as Reference (3) at the end of Chapter 10, and also in another report prepared in conjunction with the 1983 U.S. National Workshop on Radioactivity in Drinking Water written by Mays, Rowland and Stehney (1)* who stated: "...it is now firmly established by direct observation of humans exposed to graded levels of α radiation emitted from mineral bone that the risk from induced leukemia is very small compared to the risk from induced bone sarcomas."

With regard to the types of cancer induced by radium isotopes, Mays and his colleagues further state:

> At low and medium doses of internally deposited Ra, the most severe biological damage is cancer arising from skeletal tissue. For Ra-226, the following two types of malignancy are induced: (1) bone sarcomas (mostly osteosarcomas, fibrosarcomas and chondrosarcomas) and (2) head carcinomas (carcinomas of the paranasal sinuses and the mastoid air cells).

These authors report that head sarcomas have not been observed in persons internally exposed to radium-228 unless the dose from radium-226 was also high. It is suggested that the decay of radium-226 within the body gives rise to the accumulation of radon-222 gas in the head cavities and it is this presence of radon which induces these cancers. Radium-228 does not produce radon-222 and therefore, for this isotope, the risk from head carcinomas is considered insignificant compared with the risk of bone cancers.

Although positive correlations have been reported for radium-226 in drinking water and cancer incidence, there are no reports available of studies which definitely establish a relationship between the presence of radium in drinking water and cancer incidence. In the absence of more exact information, various

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* See list of references at end of this chapter.

researchers have calculated cancer risk figures for specific levels of radium activity in drinking water consumed over a lifetime. The figures obtained from three such sources are presented below.

1) Mays, Rowland and Stehney (Reference 1, Chapter 14)
Cumulative lifetime risk to 1 million persons, each ingesting 5 pCi/day (0.2 Bq/day) of a radium isotope —
for Ra-226: 9 bone sarcomas plus 12 head carcinomas
for Ra-228: 22 bone sarcomas and 0 head carcinomas

An average adult water consumption of 1 L/day from the "local water system" (household tap water) is assumed by these researchers, therefore, the risk figures noted are those for a water radium activity level of 5 pCi/L (0.2 Bq/L). They use average daily water consumption rather than intake by the individual who consumes the maximum amount because they have calculated risk to an entire population assuming a linear dose-response relationship (in contrast, for threshold type of toxicity, as chemical toxicity, it is appropriate to consider higher than average intake to ensure all individuals are protected).

As noted, these risk figures are based on a linear dose-response. However, if the true dose-response at low doses varies with the square of the dose, it is suggested by Mays and his colleagues that "...virtually no cancers would be expected from environmental levels of Ra..."

2) Wrenn, et al. (Reference 3, Chapter 10)
A lifetime consumption of 1.7 L/day of water with a Ra-226 activity of 31 pCi/L (1.2 Bq/L) or with a Ra-228 activity of 32 pCi/L (1.2 Bq/L) would result in a lifetime risk of inducing bone sarcoma of 10^{-4}, that is, 1/10,000.

3) U.S. Environmental Protection Agency*
At a radium (combined Ra-226 and Ra-228) level in drinking water of 5 pCi/L (0.2 Bq/L) the "incremental lifetime cancer risk" is stated to be 26 X 10^{-6}, that is, 26/1,000,000 or 1/38,500.

14.3 Radium-226 and Radium-228

14.3.1 Background Information

In Section 14.1 above, mention was made of the fact that two radium isotopes of health concern, Ra-226 and Ra-228, can occur naturally in the environment. As previously stated in this report, in Nova Scotia radium activity in water samples was measured as total radium which includes radium-226 and radium-228.

The literature most recently available, especially the reports published in the May 1985 issue of Health Physics which have been referenced in Chapters 10, 13 and 14 of this report, discloses a number of facts and comments concerning radium-228 which are worthy of consideration. These are noted below.

1) The occurrence of Ra-228 in the United States is not well known in contrast to fairly extensive knowledge on the occurrence of Ra-226.

2) Those who prepared the U.S. EPA interim primary regulations for radioactivity in drinking water expected that the Ra-226/Ra-228 ratio would generally be 3/2 or greater; this has not

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* Letter dated 31 January 1984 from Region 1 Water Supply Branch staff to New Hampshire Water Supply and Pollution Control Commission—copy sent to N.S. Department of Health by U.S.EPA.

proven to be the case, resulting in the problem noted in Section 10.6.5 in using the gross alpha screening scheme for radium determination. In short, the screening scheme cannot be depended on to assure that total radium levels are below the guideline unless the Ra-226/Ra-228 ratio can be predicted for a particular aquifer.

3) Extensive measurements of Ra-228 would be difficult because of problems with the existing analytical methods which are "...technique-dependent, time-intensive and costly..." according to Blanchard, et al. (Reference 5, Chapter 10).

4) An alternative to extensive measurements which is suggested by Hess, et al. (2) is:

> ...to develop a conceptual, predictive model for Ra-228 occurrence, based on geochemical principles, to identify specific types of aquifers which are likely to have Ra-228 problems. Once verified, this model should be the basis for developing regional guidelines for monitoring in areas more likely to have high Ra-228.

These comments should not give rise to concern because they are not, on the whole, applicable in Nova Scotia. In effect, radium-228 occurrence in Nova Scotia has been investigated due to the fact that radium activity in water samples was measured as total radium activity, thereby including activity from radium-228.

With regard to potential health hazard, it appears that radium-228 is at least as significant as radium-226 and is possibly a more potent cancer inducer. In its publication entitled "National Revised Primary Drinking Water Regulations; Advance Notice of Proposed Rulemaking" dated October 5, 1983, the U.S. EPA states: "From animal data, it appears that radium-228 is 2 to 3 times more toxic than radium-226." The cancer risk estimates calculated by Mays, et al. and noted in Section 14.2, reflect this view.

14.3.2 Occurrence in Nova Scotia

The Task Force water sampling program revealed that radium is widespread, occurring at detectable activity levels in most of the areas in which wells were sampled. On the whole, levels were not high, the Canadian Drinking Water Quality Guidelines' maximum acceptable activity for radium-226 being exceeded in only 8 wells of 763 sampled. Highest radium activity levels were found in groundwater samples collected in areas with granitic bedrock.

The 1982 publication by the Nova Scotia Department of Mines and Energy entitled "Uranium in Nova Scotia: a Background Summary for the Uranium Inquiry, Nova Scotia" details and maps known thorium occurrences in the province. This would serve as a useful guide in planning a well water sampling program for thorium, the parent of radium-228. Thorium is a potential radiotoxicity hazard.

14.4 The Canadian Drinking Water Quality Guideline for Radium in Retrospect

The current Canadian Drinking Water Quality Guidelines place the maximum acceptable concentration (activity) for radium-226 at 1 Bq/L with a target concentration (activity) of 0.1 Bq/L. No guidelines are listed for radium-228 or its parent, thorium-232.

A review of the Canadian guidelines in light of the information gleaned from various sources such as those mentioned in this section, indicates that the radium-226 guideline provides adequate health protection, but that consideration must be given to setting guidelines for radium-228 and possibly thorium.

In support of the adequacy of the radium-226 guideline, the following references are noted.

1) Report of the British Columbia Royal Commission of Inquiry into Uranium Mining dated October 30, 1980. In its chapter on Worker and Public Health the commission stated that "... the ingestion standard for radium-226 appears to rest on a reasonable data base" and concluded: "that the present Canadian standard of 1 becquerel per litre as the maximum acceptable concentration of radium-226 in drinking water provides an acceptable safety margin for the human population."

2) Statement by R. E. Rowland of the Centre for Human Radiobiology, Argonne National Laboratory, to the British Columbia Royal Commission. The concluding sentence of this statement is: "This observation enforces my belief that the risk of drinking water containing 100 pCi/L of radium is insignificant." Note: 100 pCi/L is equivalent to 3.7 Bq/L.

3) Wrenn, it al. (Reference 3, Chapter 10) In Section 10.5.2 of this report these authors were quoted to the effect that in their judgement the U.S. EPA interim limit for radium-226 in drinking water could be relaxed by a factor of at least 4 and still provide a high level of protection. It was noted that the result of this proposal would be a limit approximately equal to the Canadian guideline of 1 Bq/L.

REFERENCES - CHAPTER 14

1. Mays, C.W., Rowland, R.E., and Stehney, A.F., "Cancer Risk from the Lifetime Intake of Ra and U Isotopes", Health Physics, Vol. 48, No. 5, pp. 635-647, May 1985.

2. Hess, C.T., Michel, J., Horton, T.R., Pritchard, H.M. and Coniglio, W.A., "The Occurrence of Radioactivity in Public Water Supplies in the United States". Health Physics, Vol. 48, No. 5, pp. 553-586, May 1985.

15. OPTIONS TO WATER SUPPLIES WITH ELEVATED URANIUM, RADIUM AND RADON LEVELS

15.1 Introduction

When uranium, radium or radon are found in drinking water supplies, the question of whether or not the water is safe to consume arises (and, in the case of radon, whether or not indoor air quality is safe). Unless the answer strongly affirms that no health hazard exists, a second question which often follows the first is that which asks what options to the original water supply are available.

The situation experienced by personnel of the Department of Health in dealing with potential water contaminants such as uranium, radium, radon, arsenic, and volatile organic chemicals is that it is necessary to have available options which can be recommended in order to meet a real need or demand created by any or all of the following: (1) existence of a real, demonstrated health hazard, (2) levels of contaminants in excess of adopted guidelines, (3) apprehension by some members of the public that a health hazard exists.

In the balance of this chapter of the report, various options to existing water supplies found to contain uranium, radium, or radon, alone or in combination, will be presented without regard to specifying the concentrations or radioactivity levels at which these options must or should be employed.

15.2 List of Available Options

Applicability of various options is somewhat dependent on the size of water system and source of supply. Generally, when considering the occurrence of uranium and related elements, the main distinction to be made is that between central water systems and individual household water supplies. The applicability of each option to dealing with uranium, radium, and radon is noted in the listings below. The most appropriate option in a particular case depends on the exact circumstances pertaining to that individual situation.

Options Applicable to Central Water Systems

As seen in Chapter 2, there is no real or perceived need to exercise options to the existing municipal central water systems in the province with regard to uranium and related elements. The options listed below could be applied to smaller central water systems such as those found in some rural subdivisions, mobile home parks and institutions. These options are available for consideration:

1) Importing drinking water such as "bottled water" from an approved source. This will eliminate any potential problems with uranium or radium, but will not prevent radon from entering indoor air by emanation from taps and showers which will still be supplied from the original source. Although this option may be an expeditious and reasonable temporary remedy, it is not likely a feasible long-term solution.

2) Connection of the central water distribution system to an existing municipal water system. This will eliminate all potential problems from uranium and related elements.

3) Changing the source of supply for the central water distribution system from drilled wells to a surface water source, since occurrences of uranium and related elements in the province have been confined to groundwater. Installation of an approved intake, supply pipeline and treatment system are required. All potential problems from uranium and related elements will be eliminated if this is done.

4) Installation of water treatment equipment designed to reduce levels of uranium, radium, or radon to acceptable levels.

Details on treatment methods are outlined below in Section 15.3.

Options Applicable to Individual Household Water Supplies

The options listed below can be used to alleviate real or perceived problems arising from the presence of uranium and related elements in well water supplies for existing homes; some of these options could also be applied to avert potential problems which could arise if wells, especially drilled wells, were to be constructed in certain areas of Nova Scotia.

1) Importing drinking water such as "bottled water" or carrying water from an approved source. Considering that the average household requires no more than about 10 liters (2 gallons) per day for drinking and cooking purposes, this may for some individuals prove to be a feasible solution although it would generally be considered a temporary remedy. As noted above, the provision of potable drinking water will eliminate any potential problem with uranium and radium, but will not prevent radon from entering indoor air by release from taps and showers which will still be supplied from the original well source.

2) Connection of the dwelling served by the well in question to an existing municipal water system. This will eliminate all potential problems from uranium and related elements.

3) Construction of a dug well if the existing problem well is a drilled well. This option is limited to locations in which natural conditions of soil and bedrock elevation, as well as constraints imposed by presence of on-site sewage disposal systems are such that it is possible to dig a well which will supply a sufficient quantity of water of satisfactory quality (considering bacterial and chemical parameters other than uranium and related elements). If the dug well capacity is insufficient to supply all household requirements, a "split"

system can be used, such that the dug well is connected only to a tap or taps supplying drinking and cooking water, the original drilled well being used to supply all other requirements. Given the fact that any potential uranium problem is virtually restricted to drilled wells (99% of wells with uranium > 0.02 mg/L were drilled wells) the construction of dug wells where possible is a satisfactory long-term solution.

With regard to radium, 4 of the 8 wells which exceeded the maximum acceptable were drilled and 4 were dug. Therefore, it appears that in some cases the construction of a dug well could effect a solution, while in others (the locations with radium-contaminated dug wells) it would not. The construction of drilled wells at locations with radium-contaminated dug wells is not recommended due to the fairly high probability of encountering uranium in drilled wells in such locations.

Radon activity levels are generally much lower in dug wells than in drilled wells (95% of wells with radon activity >370 Bq/L were drilled wells) and therefore it is probable that a dug well replacing a drilled well will result in lower radon activity in drinking water and in indoor air. If a split system is used, the radon in indoor air will not be reduced since the drilled well will still be supplying showers and most taps in the house.

4) Changing the source of supply from a well to a surface source such as a lake or river. This is, of course, only possible where a surface source of adequate quality is located within close proximity of the house in question. The proper installation of an intake and supply pipeline and the provision of satisfactory treatment (minimum of filtration plus disinfection) are essential. All potential problems from the presence of uranium and related elements in the well water will be eliminated if this option is adopted.

5) Changing the source of supply from a well to rainwater. Studies performed in Nova Scotia have proven that the entire water supply requirements of an individual house can be met by rainwater collected from roof drainage provided adequate storage and treatment facilities are installed in the house. Because a large storage tank is needed, it may not be feasible to convert entirely to rainwater supply for an existing house, in which case a split system, using a smaller storage and treatment system sized to supply drinking and cooking water only may be suitable. A rainwater supply will eliminate potential problems from uranium and radium in drinking water; it will entirely eliminate radon from drinking water, and it will entirely or partially eliminate radon release from water to indoor air, depending whether an entire or split system is used. This option is more practical for proposed new houses than for existing dwellings as a large storage tank can be incorporated in the design and construction of a new house relatively simply and economically. The Nova Scotia Department of Health has an information package available for those who wish to consider the collection and treatment of rainwater as a source of household water supply.

6) Installation of a water treatment device designed to reduce levels of uranium, radium or radon to acceptable levels in an individual household application. Some devices are capable of treating the entire household supply, others are sized to supply drinking-cooking water only. Section 15.3 presents detailed information on such devices.

15.3 Water Treatment Processes and Devices for Uranium, Radium and Radon Removal

15.3.1 Water Treatment Information and General Principles

Information on water treatment processes and devices for removal of uranium, radium and radon from water supplies was gathered by the Task Force from technical literature, from agencies in other jurisdictions, from the operating experience of one particular unit installed in an institution in Nova Scotia, and from the results of performance tests of three devices installed for evaluation in actual individual household situations.

Throughout any discussion of water treatment processes and equipment certain principles which have general application must be borne in mind. Water treatment is easier on a large scale than on a small scale. In particular, treatment for the removal of contaminants is more economical and can utilize more complex and effective processes when dealing with large-scale plants for central supply and distribution systems. Trained personnel for operation and maintenance are available in such cases and frequent, if not continuous, monitoring of the process equipment is standard procedure. As the size of the system decreases the unit cost of providing treatment generally increases, the quality of operation and maintenance and frequency of monitoring generally decreases and finally, when the size of the system is that required for individual household application, the treatment options available are severely limited by the necessity to reduce cost, operational requirements, and equipment complexity to a minimum. Individual household treatment devices must be inexpensive, simple, effective, reliable, and if possible, incorporate fail-safe features.

Another complicating feature of water treatment arises from the nature of water chemistry and the interrelationship of various parameters such that a process established to reduce the concentration of one parameter may suffer from interference by the presence of others, or may cause a "side effect" which results in a water quality deterioration due to the modification of the form or concentration of other parameters.

15.3.2 Available Technology for Uranium, Radium and Radon Removal

A summary of available technology for uranium, radium and radon removal from water supplies is presented in Table 41. The information tabulated on this chart was obtained from the four sources mentioned at the beginning of Section 15.3.1. The main literature references used are listed at the end of this chapter. The paper by Reid, Lassovszky, and Hathaway (1) was particularly informative. Agencies which provided information on this topic directly to the Department of Health are: U.S. Environmental Protection Agency (Boston office), Maine Department of Human Services (Division of Health Engineering), British Columbia Ministry of Health, and Atomic Energy of Canada Limited (Whiteshell Nuclear Research Establishment).

With reference to Table 41, a number of qualifying and explanatory statements must be made.

1) This chart indicates what processes and devices have the capability to remove uranium, radium and radon from water.

2) As noted at the bottom of the chart, satisfactory performance is defined as the ability to reduce the contaminants in question to acceptable levels without regard to cost and potential operating problems. No attempt is made in Table 41 to weigh or compare the relative merits of the various processes and devices listed with regard to practical considerations such as cost (capital and operating), ease of operation, or maintenance requirements. This is done later in Section 15.3.5.

3) The Task Force has first-hand experience with only those processes and devices indicated as "N.S." in the table; of these, one was an installation for uranium removal from a

TABLE 41

Summary of Available Technology for Uranium, Radium and Radon Removal

		Processes and Devices										
	PARAMETER	ACTIVATED ALUMINA	AERATION	ANION EXCHANGE	CATION EXCHANGE	DISTILLATION	ELECTRODIALYSIS	GRANULAR ACTIVATED CARBON (GAC)	LIME-SOFTENING with $Ca(OH)_2$ and/or COAGULATION with Aluminum Sulfate or Ferric Sulfate	MANGANESE DIOXIDE IMPREGNATED ACRYLIC FIBERS	PRECIPITATION BY BARIUM COMPOUNDS	REVERSE OSMOSIS
Central Water Systems (Subdivisions, Mobile Home Parks, Institutions)	URANIUM	L E S		L,P E S			X Possible in Theory		L,P E S			L,F E,N.S. S
	RADIUM				F E S		F E S		F E S		X Possible in Theory	F E S
	RADON		L,P,F E S*					L,P,F E S				
Individual Household Well Supplies	URANIUM	L E S		L,P E S		F N.S. S	X Possible in Theory					L,F N.S. S*
	RADIUM				F E S	X Likely will be S	F E S			L,P E S		F E S
	RADON		L,P,F E S*			F N.S. S*		L,P,F E S				

Key: X,L,P,F ← Testing or operating experience: X = no testing or operating experience; L = laboratory; P = pilot plant; F = full size.
E,N.S. ← Location of testing or operation: E = elsewhere; N.S. = Nova Scotia.
S,S*,U ← Performance: S = satisfactory; S* = satisfactory with reservations; U = unsatisfactory.

[shaded] = Not Applicable

NOTE: In this summary satisfactory performance is defined as ability to reduce the contaminants in question to acceptable levels without regard to cost and potential operating problems.

school water supply, the others were tests of devices installed in individual houses. Detailed accounts of these Nova Scotia experiences are presented below in Section 15.3.3.

4) The several processes and devices which were subject to testing or operating experience elsewhere ("E" in the chart) have been assigned a performance rating based on the reports of others as gleaned from various references. Most of these methods and some others which are denoted in Table 41 as "possible in theory" are based on sound principles and will likely be effective in removing the various contaminants of interest.

5) The practicality of some of the processes and devices listed in Table 41 with regard to such criteria as cost (capital and operating), ease of operation, complexity, rate of production of treated water, and reliability is somewhat doubtful. Section 15.3.5 gives an indication as to the predicted long-term, overall suitability of the processes and devices listed in the chart.

6) Information on the Nova Scotia experience with some of the treatment devices is presented in Section 15.3.3; the salient features of research projects carried out in British Columbia, Manitoba (at the Whiteshell Nuclear Research Establishment), and Maine are described in Section 15.3.4.

15.3.3 Evaluation and Testing in Nova Scotia of Processes and Devices for Uranium, Radium and Radon Removal

As shown in Table 41 and as introduced above, some investigation into water treatment processes and equipment for removal of uranium was performed in Nova Scotia. The specific projects and results obtained are outlined below.

"Seagold" Reverse Osmosis Unit—New Ross Consolidated School, Lunenburg County

In 1981 an approach was made to the Department of Health by Marine Equipment Limited of Halifax, representing Seagold Industries Corporation of Burnaby, British Columbia, regarding possible testing to evaluate the suitability of Seagold reverse osmosis devices for arsenic and uranium removal from well water supplies. These units were originally designed as desalination units for marine use and several are currently installed in vessels operating from Maritime province ports.

A small-sized, hand-pumped version of the larger units was subjected to a one-day laboratory test in September 1981. Samples of raw water collected from wells known to have high concentrations of arsenic or uranium were batch-processed through the unit. All samples had the contaminants reduced to concentrations well below the maximum acceptable guidelines. For example, raw water uranium concentrations of 0.11 mg/L and 0.25 mg/L were both reduced to < 0.005 mg/L in the treated water. The principle of operation of the Seagold reverse osmosis process had been proven.

In the following year, after the discovery of a uranium concentration exceeding current guidelines in the New Ross Consolidated School water supply, the municipal school board asked Marine Equipment Limited for a proposal to install a Seagold reverse osmosis unit at the school. A unit which was basically of the type designed and fabricated to marine use specifications was eventually installed. Cost of the unit was approximately $13,000 and its rated capacity with raw feed water at a temperature of 25°C is 2,000 U.S. gallons/day. As the actual well water temperature at the school averages 10°C, the capacity of the unit is somewhat lower.

Because the actual capacity of the unit is insufficient to treat the entire water requirements of the school, it was decided to use a split system, modifying the plumbing so that the Seagold unit supplies treated water to drinking fountains and to the cafeteria; all other needs are supplied by raw well water. The reverse osmosis process produces a considerably lower volume of treated water than the total volume of raw feed water to the unit. The large volume of "reject" water produced is basically raw water with increased concentrations of the chemical constituents, including uranium, removed from the raw feed water. In a typical situation the increase in uranium concentration in the reject water would be in the order of 25% over the uranium concentration in the raw water. In the case of the New Ross school, the reject water is piped to toilets and wash basins.

After some initial start-up problems, due in part to incorrect installation by forces not under the control of the supplier, the unit went into service satisfactorily in late 1982.

Since that time, uranium has been consistently reduced from an average of 0.1 mg/L in the raw well water to <0.01 mg/L in the treated water. Because the treated water is largely demineralized and approximates distilled water in its chemistry, it tends to have corrosive tendencies. Some pick-up of copper and lead from the school plumbing has been noted, but concentrations have not exceeded acceptable levels.

In summary, the Seagold reverse osmosis unit has been successful in achieving the desired results in this application.

"Seagold" Reverse Osmosis Individual Household Size Unit—Testing Program—Williamswood, Halifax County

As a result of the satisfactory performances of Seagold reverse osmosis devices in the laboratory test and especially at the school in New Ross, it was decided to conclude arrangements with the local representatives and with the manufacturer to supply a unit, sized for individual household use, for a testing program to be conducted by the Department of Health. The device was designed to be in an acceptable price range (about $1,000) and it was sized to supply water for drinking and cooking purposes only.

The unit was tested and evaluated under actual field conditions at a house in Williamswood, Halifax County, which had a drilled well uranium concentration averaging 0.22 mg/L. The test began in October 1983 and was to have continued for one year, but was discontinued after two weeks due to the obvious failure of the unit to produce treated water at an adequate rate.

Uranium removal was satisfactory with all samples showing a uranium reduction from about 0.22 mg/L in the raw water to < 0.005 mg/L in the treated water. As in other R.O. units, the reject water volume was greater than the product, treated water volume.

A report on the testing of this unit, prepared by Donald Feldman, Public Health Engineering Technologist, is attached as Appendix U. In summary, it can be stated that the unit effected satisfactory reduction in uranium concentration, but it failed to produce treated water at a rate sufficiently high to meet household drinking and cooking requirements.

"Culligan" Reverse Osmosis Individual Household Size Unit—Testing Program—Williamswood, Halifax County

In a further attempt to find a reverse osmosis treatment unit which would be suitable for uranium removal from water in an individual household application, arrangements were made with Culligan Canada Limited to test a unit which is manufactured by that company. This unit is priced at about $1,200 and is designed to supply treated water sufficient to meet drinking and cooking requirements.

A major difference between this unit and the other small R.O. unit tested is that the Culligan unit is equipped with a booster pump to increase the pressure of the raw feed water to the unit to considerably higher than the well pump supply pressure. This is done in order to increase the rate of production of treated water.

The test was performed under actual operating conditions by installing the unit at a house in Williamswood, Halifax County, which had a drilled well water supply. The raw well water uranium concentration ranged from 0.12 mg/L to 0.20 mg/L during the test period which ran from mid-April to early November 1985. The treated water uranium concentrations ranged from < 0.005 mg/L to 0.03 mg/L. Average uranium removal during the test period was about 87%. It was noted that radon activity in the treated water was generally much lower than that in the raw water. It could be that this reduction was due to aeration effects which occur as the raw water is pumped at high pressure through the R.O. membrane and to the dissipation and radioactive decay which occur as the water is held in the treated water storage tank in the unit.

The rate of production of treated water seemed adequate to supply drinking and cooking requirements.

Details of the testing and evaluation project for the Culligan R.O. unit are outlined in the report attached as Appendix V. It was concluded from this test program that the Culligan R.O. unit can reduce uranium by 80% to 90% and that the unit can provide adequate treated water for drinking and cooking purposes in individual household application. Whether or not the % reduction of uranium concentration is satisfactory depends on the uranium concentration in the raw water and on what is considered an acceptable concentration in the treated water.

"Lifetime Stainless Steel" Distillation Unit—Testing Program—Harrietsfield, Halifax County

Late in 1984 the Department of Health was contacted by the local representative for Lifetime Stainless Steel Cookware, suppliers of the "AV H_2O Distiller", a small distillation unit designed and manufactured in Ontario. The company and the department agreed to carry out a 6-month testing program to evaluate the unit as a uranium removal device.

The distiller, which sells for slightly under $1,000, was installed in late January 1985 in a house located in Harrietsfield, Halifax County. The house was chosen as the test location because its drilled well supplies water with a uranium concentration averaging 0.26 mg/L. The unit's rated capacity is 30 liters (6.6 imperial gallons) per 24 hours of operation. As the average household requires about 10 liters per day for drinking and cooking purposes, the test unit appeared to be in the appropriate size range in that it could produce the required daily treated water volume by operating for about 8 hours.

The testing and evaluation ended in June 1985. All samples of treated, that is, distilled water analyzed during the entire test period had uranium concentrations < 0.005 mg/L. This reduction of uranium from over 0.2 mg/L to below the detection level represents virtually 100% removal. Radium removal efficiency could not be determined because radium levels were so low in the raw water. The distiller proved to be effective for radon removal as expected due to the fact that boiling drives off nearly all of the radon gas dissolved in the raw water. Based on mean values for radon activity in raw and treated water over the test period, the radon removal averaged about 98%.

Appendix W is a report, prepared by Donald Feldman, Public Health Engineering Technologist, who implemented the testing program. This report is a full account of the methods used, observations made, and results obtained. It will be noted that such potential difficulties as "consumer acceptance" of the unit, which is only partially automated, and taste of the distilled water, proved to be no problem. Likewise the build-up of residue in the boiling chamber and disposal of this material presents no problem as noted in the report.

The AV H_2O distiller manufactured by Lifetime Stainless Steel was proven to be a very effective device for removing uranium and radon from household well water supplies contaminated with these elements. Over the 6-month test period the unit provided sufficient treated water to supply the drinking and cooking needs of an average household and it was entirely acceptable to the occupants of the home which was the test location.

15.3.4 Research into Processes for Uranium, Radium and Radon Removal in Other Jurisdictions

In addition to the experience gained by evaluating and testing various treatment units in Nova Scotia, the Department of Health has received reports directly from the three agencies named in Section 15.3.2. Brief outlines of the information gained in this way follow.

Anion Exchange Resins for Uranium Removal—British Columbia

Under the auspices of the British Columbia Ministry of Health, research was conducted in the Department of Civil Engineering of the University of British Columbia, into removal of uranium from water by the use of several methods. The investigation, carried out by S. Jasper and W. Oldham, eventually concentrated on anion exchange resins as being the best process of those investigated. The testing did not go beyond the laboratory stage and the investigators recommended that a full-scale system be developed and evaluated.

A report issued in 1982 concluded:

> The laboratory-scale column tests have definitely shown that Dowex SBR resin has a large capacity for preferentially removing uranium from solution

in the well water tested. The general applicability of the resin has not been tested, and in situations where uranium is in solution in a cationic state, this resin will almost assuredly be very ineffective.

"EXPURRT"* System for Uranium and Radium Removal—Whiteshell Nuclear Research Establishment, Manitoba

A project at the Whiteshell Nuclear Research Establishment of Atomic Energy of Canada Limited has developed a treatment device for individual household use in reducing levels of uranium and radium in drinking water. The unit is of a size which will fit under a kitchen counter connected to the cold water line to provide treated water from the regular cold water tap or possibly from a third tap since the flow rate through the unit is somewhat restricted. A draft report by M. Gascoyne and A. Wehlau entitled "A Treatment Technology for Removal of Radioactivity from Groundwater" dated January 1985 details all of the aspects and results of the research and development project.

The system utilizes an anion exchange resin for uranium extraction and manganese dioxide-impregnated acrylic fiber for sorption of radium. The anion resin used is "Amberlite IRA 400 C". The materials are loaded into standard water filter casings and the units are connected in series. Testing was carried out in laboratory experiments using actual well water samples and a field evaluation was performed in one household installation over a 1-year period. Reported removal efficiencies are over 90% for uranium and 70% for radium in treatment of 4,000 liters of water. Maximum removal occurs at low flow rates and a maximum flow of 2 liters/minute is recommended. Experience with the test units indicates for an average household that the anion resin would require regeneration or replacement at about one year, and the MnO_2-fiber material would require replacement in about six months.

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* Experimental Uranium and Radium Removal Technology

Experience in Nova Scotia indicates that in most cases only the uranium removal (anion exchange) portion of the system would be required since elevated uranium levels are much more prevalent than elevated radium levels.

The researchers recommend further testing with groundwater of various chemical qualities and state that:

> ...the main requirements of any water to be treated are neutral to alkaline pH (6 to 10) and appreciable levels of bicarbonate in solution. This should ensure that all uranium is present as carbonate complexes and will, therefore, adsorb on anion resin.

Several advantages such as low capital and operating cost, long life, no change in water chemistry other than uranium and radium reduction, are claimed for the EXPURRT system which is now commercially available.

Granular Activated Carbon for Radon Removal—State of Maine

The problems and impracticalities involved in using aeration as a means of removing radon from water led to the search for a more satisfactory process for this purpose. The Department of Civil Engineering at the University of Maine at Orono, in cooperation with the Division of Health Engineering of the Maine Department of Human Services has published an "information digest" on the use of granular activated carbon (GAC) adsorption as a process for removing radon from water supplies, particularly in individual household situations.

This pamphlet, entitled "Removing Radon from Water Using Granular Activated Carbon Adsorption" was based on a report written by J. D. Lowry. A copy of this useful publication is attached as Appendix X. Radon removals of 80% to 100% are reported, the higher removals generally occurring when the largest GAC units are used. Other factors involved are listed. Information on recommended installation and operation procedures are noted and methods for avoiding any possible radiation exposure from radon accumulation in a GAC unit are outlined.

Granular activated carbon units are readily available at most water treatment equipment dealers. Capital cost (usually under $1,000) and operating costs are not high and the units are relatively simple to install and maintain. These features, combined with high radon removal efficiencies, indicate that GAC adsorption is a satisfactory process for radon removal.

15.3.5 Appraisal of Uranium, Radium and Radon Removal Processes and Devices

After all of the mass of technical detail presented to this point in Chapter 15, it may be useful to give some guidance to aid in interpreting and applying the information contained in Table 41. In order to do this, individual appraisal sheets have been prepared for each of the processes and devices listed in the table for each of the contaminants (uranium, radium and radon) to be removed.

These appraisals are somewhat subjective, being based on the Nova Scotian tests, perusal of the literature (especially the reports summarized above in Section 15.3.4) and on basic knowledge of water treatment and water chemistry.

The appraisal sheets follow. They are arranged in this order: uranium removal, radium removal and radon removal.

APPRAISAL OF URANIUM REMOVAL PROCESSES AND DEVICES

Activated Alumina

Anion Exchange

Distillation

Electrodialysis

Lime Softening and/or Coagulation

Reverse Osmosis

APPRAISAL SHEET

URANIUM REMOVAL **Activated Alumina**

1. Application—central, institution, individual household:
   Institutions and individual households.

2. Drinking water* only or entire supply:
   Both possible but economically more feasible for drinking water only.

3. Testing and operating experience:
   Laboratory testing only, in U.S.

4. Effectiveness/efficiency: 90% removal indicated.

5. Performance affected by raw water quality?: Not appreciably.

6. Practicality—operation and maintenance—degree of difficulty:
   Relatively easy to operate and maintain; practical for household use.

7. Reliability: Reliable if media replaced at required intervals.

8. Fail-safe?: Probably, but not proven.

9. Availability: A.A. units sold for other purposes are available.

10. Capital cost: Affordable for institutions and most householders.

11. Operating cost: Not excessive.

12. Lifetime of unit/components: Unit—long life/A.A. media replacement required at intervals.

13. Contaminants removed from water accumulate in unit?: Yes.

14. Disposal of contaminant waste and reject water—high volume?:
    Waste disposal not likely a problem—could landfill—small volume for d.w. only application; no reject water.

15. Removes other contaminants also: Likely arsenic.

16. "Side effects" detrimental to water quality:
    Some initial water quality changes possible at start-up, likely none later.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

URANIUM REMOVAL **Anion Exchange**

1. Application—central, institution, individual household:

   Small central systems, institutions and individual households.

2. Drinking water* only or entire supply:

   Both possible, but economically more feasible for drinking water only.

3. Testing and operating experience:

   Laboratory and pilot plant experience in the U.S. and at Whiteshell Nuclear Research Establishment and laboratory testing in British Columbia.

4. Effectiveness/efficiency: 90% + removal.

5. Performance affected by raw water quality?:

   Yes; require pH in range 6-10, appreciable levels of bicarbonate in solution, uranium not in cationic state.

6. Practicality—operation and maintenance—degree of difficulty:

   Relatively easy to operate and maintain, practical for household use.

7. Reliability:

   Reliable if exchange resin replaced at required intervals and raw water quality does not change greatly.

8. Fail-safe?: Probably, but not proven.

9. Availability:

   Could be made available in very short time.

10. Capital cost: Affordable for small central systems, institutions and most householders.

11. Operating cost: Not excessive — will vary with raw water quality.

12. Lifetime of unit/components:

    Unit—long life/exchange resin regeneration or replacement required at intervals.

13. Contaminants removed from water accumulate in unit?:

    Yes.

14. Disposal of contaminant waste and reject water—high volume?:

    Backwash regeneration water requires disposal at the site; replaced exchange resin could be disposed of in sanitary landfills; no reject water.

15. Removes other contaminants also: No.

16. "Side effects" detrimental to water quality:

    Some initial water quality changes possible at start-up, likely none later.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

URANIUM REMOVAL **Distillation**

1. Application—central, institution, individual household:
   Individual households.
2. Drinking water* only or entire supply:
   Drinking water only.
3. Testing and operating experience:
   Unit from one manufacturer tested in Nova Scotia under actual operating conditions in household use for 6 months.
4. Effectiveness/efficiency:
   100% removal.
5. Performance affected by raw water quality?:
   No.
6. Practicality—operation and maintenance—degree of difficulty:
   Simple to operate, practical for household use, good consumer acceptance.
7. Reliability:
   Very reliable.
8. Fail-safe?:
   Yes.
9. Availability:
   Available now in Nova Scotia.
10. Capital cost:
    Affordable for most householders.
11. Operating cost:
    No exact data, only operating cost is for electricity, does not appear to be excessive.
12. Lifetime of unit/components:
    Unit—long life/heating element and fan motor will eventually require replacement.
13. Contaminants removed from water accumulate in unit?:
    Yes in boiling chamber, but cannot enter the treated water.
14. Disposal of contaminant waste and reject water—high volume?:
    Very low volume, can be flushed to on-site sewage disposal system when boiling chamber is periodically cleaned.
15. Removes other contaminants also:
    Yes, radon: 98% removal; arsenic: 100% removal.
16. "Side effects" detrimental to water quality:
    Distilled water has corrosive tendencies, but in household installation is not a problem.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

URANIUM REMOVAL **Electrodialysis**

1. Application—central, institution, individual household:
   Small central systems, institutions, individual households.

2. Drinking water* only or entire supply:
   For central systems only, entire supply is possible; for institutions and households, likely only drinking water is economically feasible.

3. Testing and operating experience:
   No testing or operating experience for uranium removal.

4. Effectiveness/efficiency:
   Theoretically about 90% removal.

5. Performance affected by raw water quality?:
   Possibly, if high concentrations of suspended solids, turbidity, minerals present.

6. Practicality—operation and maintenance—degree of difficulty:
   Complex device, operation and maintenance problems expected, not as practical for household use as some other processes.

7. Reliability:
   Expect some "down time" due to complexity of process and equipment.

8. Fail-safe?:
   Probably.

9. Availability:
   Not available at present.

10. Capital cost:
    Higher than most, perhaps all other devices.

11. Operating cost:
    No information available, likely similar to reverse osmosis.

12. Lifetime of unit/components:
    No information available.

13. Contaminants removed from water accumulate in unit?:
    No.

14. Disposal of contaminant waste and reject water—high volume?:
    High volume of wastewater may create disposal problems in larger applications.

15. Removes other contaminants also:
    Likely other mineral contaminants.

16. "Side effects" detrimental to water quality:
    Corrosive tendencies in treated water.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

URANIUM REMOVAL — Lime-Softening and/or Coagulation

1. Application—central, institution, individual household:
   Large (municipal size) or possibly medium sized central systems.

2. Drinking water* only or entire supply:
   Entire water supply.

3. Testing and operating experience:
   Laboratory testing and pilot plant experience in U.S.

4. Effectiveness/efficiency:
   80% to 90% removal indicated.

5. Performance affected by raw water quality?:
   Yes, pH must be carefully adjusted and controlled for optimum performance.

6. Practicality—operation and maintenance—degree of difficulty:
   Trained operators required, practical for water treatment plant type operation and maintenance, these processes are in common use for other purposes.

7. Reliability:
   Reliable with good operation.

8. Fail-safe?:
   No, although worst effect of process failure would simply be non-removal of uranium.

9. Availability:
   Available, processes are in common use for other purposes.

10. Capital cost: High if these processes are not already in use in the water treatment facility, low if they are.

11. Operating cost: Similar to cost of operating medium and large scale treatment processes for water softening, color and turbidity removal.

12. Lifetime of unit/components:
    Process equipment—long life/continuous addition of chemicals required.

13. Contaminants removed from water accumulate in unit?:
    No.

14. Disposal of contaminant waste and reject water—high volume?:
    Waste sludge can be disposed of in a number of ways—method chosen depends on situation.

15. Removes other contaminants also:
    Yes, radium: 80%-90% removal indicated.

16. "Side effects" detrimental to water quality:
    Possible corrosive tendencies in treated water, may require addition of neutralizing chemicals.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

URANIUM REMOVAL **Reverse Osmosis**

1. Application—central, institution, individual household:

   Small central systems, institutions, and individual households.

2. Drinking water* only or entire supply:

   For central systems only, entire supply is possible; for institutions and households, likely only drinking water is economically feasible.

3. Testing and operating experience: Laboratory testing in U.S.; central systems—full scale experience for radium removal in U.S; institution and household—laboratory and full scale experience under actual conditions for lengthy periods (3 years for institution unit, 6 months for household unit) in Nova Scotia.

4. Effectiveness/efficiency:

   90% removal—institution size unit; 80%-90% removal—household unit

5. Performance affected by raw water quality?:

   Possibly; must remove suspended solids, turbidity, high iron concentrations, chlorine.

6. Practicality—operation and maintenance—degree of difficulty:

   Fairly complex device, but generally simple operation and maintenance; practical for institutional and household use and likely practical for small central systems if in each case high quality units are installed.

7. Reliability:

   Satisfactory reliability.

8. Fail-safe?: Generally yes, but a perforated membrane will allow untreated water (with no greater than raw water uranium concentration) to pass through the unit.

9. Availability:

   Available now in Nova Scotia.

10. Capital cost: High for central system and institution size, affordable for most households in drinking water only size.

11. Operating cost: Probably not excessive, lower than some other processes although cost of membrane replacement could be high in some cases.

12. Lifetime of unit/components:

    Unit—long life/membrane—variable depending on each situation.

13. Contaminants removed from water accumulate in unit?:

    No.

14. Disposal of contaminant waste and reject water—high volume?:

    High volume of reject water—disposal generally not a problem because re-use is often possible.

15. Removes other contaminants also:

    Yes, radium: 90%+ reported; arsenic: 90%+; radon: preliminary data indicate high removals, but should not be considered a reliable method for radon removal.

16. "Side effects" detrimental to water quality:

    Treated water has corrosive tendencies because it is largely de-mineralized—could result in need for neutralizing treatment in central systems, little or no problem in institution and household applications.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL OF RADIUM REMOVAL PROCESSES AND DEVICES

Cation Exchange

Distillation

Electrodialysis

Lime-Softening and/or Coagulation

Manganese Dioxide Impregnated Acrylic Fibers

Precipitation by Barium Compounds

Reverse Osmosis

APPRAISAL SHEET

RADIUM REMOVAL — Cation Exchange

1. Application—central, institution, individual household:
   Small central systems, institutions and individual households.

2. Drinking water* only or entire supply:
   Both possible, but economically more feasible for drinking water only.

3. Testing and operating experience:
   Full-scale experience in actual field installations in U.S.

4. Effectiveness/efficiency:
   81%-97% removal reported.

5. Performance affected by raw water quality?:
   Not likely for reasonably normal raw water quality.

6. Practicality—operation and maintenance—degree of difficulty:
   Relatively easy to operate and maintain; practical for household use; same basic process has been used for many years in water softeners.

7. Reliability:
   Reliable if exchange resin regenerated by backwashing with NaCl solution or replaced at required intervals.

8. Fail-safe?:
   Probably.

9. Availability: Similar units available in Nova Scotia although the specific resin which gives optimum performance may have to to be obtained elsewhere.

10. Capital cost:
    Affordable for small central systems, institutions, & most householders.

11. Operating cost:
    Not excessive—will vary with raw water quality.

12. Lifetime of unit/components:
    Unit—long life/exchange resin regeneration or replacement required at intervals.

13. Contaminants removed from water accumulate in unit?:
    Yes.

14. Disposal of contaminant waste and reject water—high volume?:
    Backwash regeneration water requires disposal at the site; replaced exchange resin could be disposed of in sanitary landfill; no reject water.

15. Removes other contaminants also:
    No.

16. "Side effects" detrimental to water quality:
    Increase in sodium and corrosive tendencies in treated water.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL **Distillation**

1. Application—central, institution, individual household:
   Individual households.
2. Drinking water* only or entire supply:
   Drinking water only.
3. Testing and operating experience:
   Unit from one manufacturer tested in Nova Scotia for uranium removal under actual operating conditions in household use for 6 months; same unit will very likely be satisfactory for radium removal.
4. Effectiveness/efficiency:
   100% removal is probable.
5. Performance affected by raw water quality?:
   No.
6. Practicality—operation and maintenance—degree of difficulty:
   Simple to operate, practical for household use, good consumer acceptance.
7. Reliability:
   Very reliable.
8. Fail-safe?:
   Yes.
9. Availability:
   Available now in Nova Scotia.
10. Capital cost:
    Affordable for most householders.
11. Operating cost:
    No exact data, only operating cost is for electricity, does not appear to be excessive.
12. Lifetime of unit/components:
    Unit—long life/heating element and fan motor will eventually require replacement.
13. Contaminants removed from water accumulate in unit?:
    Yes in boiling chamber, but cannot enter the treated water.
14. Disposal of contaminant waste and reject water—high volume?:
    Very low volume, can be flushed to on-site sewage disposal system when boiling chamber is periodically cleaned.
15. Removes other contaminants also:
    Yes, uranium: 100% removal, radon: 98% removal, arsenic: 100% removal.
16. "Side effects" detrimental to water quality:
    Distilled water has corrosive tendencies, but in household installation is not a problem.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL **Electrodialysis**

1. Application—central, institution, individual household:
   Small central systems, institutions and individual households.
2. Drinking water* only or entire supply:
   For central systems only, entire supply is possible; for institutions and households, likely only drinking water is economically feasible.
3. Testing and operating experience:
   Full-scale experience in U.S.
4. Effectiveness/efficiency:
   90% removal reported.
5. Performance affected by raw water quality?:
   Possibly, if high concentrations of suspended solids, turbidity, minerals present.
6. Practicality—operation and maintenance—degree of difficulty:
   Complex device, operation and maintenance problems expected, not as practical for household use as some other processes.
7. Reliability:
   Expect some "down time" due to complexity of process and equipment.
8. Fail-safe?:
   Probably.
9. Availability:
   Available elsewhere, not in Nova Scotia at present.
10. Capital cost:
    Higher than most, perhaps all other devices.
11. Operating cost:
    No information available, likely similar to reverse osmosis.
12. Lifetime of unit/components:
    No information available.
13. Contaminants removed from water accumulate in unit?:
    No.
14. Disposal of contaminant waste and reject water—high volume?:
    High volume of wastewater may create disposal problems in larger applications.
15. Removes other contaminants also:
    Likely other mineral contaminants.
16. "Side effects" detrimental to water quality:
    Corrosive tendencies in treated water.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL Lime-Softening and/or Coagulation

1. Application—central, institution, individual household:
   Large (municipal size) or possibly medium sized central systems.

2. Drinking water* only or entire supply:
   Entire water supply.

3. Testing and operating experience:
   Full-scale experience in U.S.

4. Effectiveness/efficiency:
   80% to 90% removal reported.

5. Performance affected by raw water quality?:
   Yes, pH must be carefully adjusted and controlled for optimum performance.

6. Practicality—operation and maintenance—degree of difficulty:
   Trained operators required, practical for water treatment plant type operation and maintenance, these processes are in common use for other purposes.

7. Reliability:
   Reliable with good operation.

8. Fail-safe?:
   No, although worst effect of process failure would simply be non-removal of radium.

9. Availability:
   Available, processes are in common use for other purposes.

10. Capital cost: High if these processes are not already in use in the water treatment facility, low if they are.

11. Operating cost: Similar to cost of operating medium and large-scale treatment processes for water softening, color and turbidity removal.

12. Lifetime of unit/components:
    Process equipment—long life/ continuous addition of chemicals required.

13. Contaminants removed from water accumulate in unit?:
    No.

14. Disposal of contaminant waste and reject water—high volume?:
    Waste sludge can be disposed of in a number of ways—method chosen depends on situation.

15. Removes other contaminants also:
    Possibly uranium if pH range is compatible.

16. "Side effects" detrimental to water quality:
    Possible corrosive tendencies in treated water, may require addition of neutralizing chemicals.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL **Manganese Dioxide Impregnated Acrylic Fibers**

1. Application—central, institution, individual household:
   Individual households.

2. Drinking water* only or entire supply:
   Both possible, but economically more feasible for drinking water only.

3. Testing and operating experience:
   Laboratory testing in U.S. and at Whiteshell Nuclear Research Establishment and pilot plant experience in Manitoba (Whiteshell).

4. Effectiveness/efficiency:
   70% removal.

5. Performance affected by raw water quality?:
   Probably not, except for high amounts of suspended solids or chemical precipitates formed in raw water supply line.

6. Practicality—operation and maintenance—degree of difficulty:
   Relatively easy to operate and maintain; practical for household use.

7. Reliability:
   Reliable if MnO_2-fibers are replaced at required intervals and raw water quality does not change greatly.

8. Fail-safe?:
   Probably, but not proven.

9. Availability:
   Commercially available in Canada.

10. Capital cost:
    Affordable for most householders.

11. Operating cost:
    Not excessive.

12. Lifetime of unit/components:
    Unit—long life/MnO_2-fibers require replacement at intervals.

13. Contaminants removed from water accumulate in unit?:
    Yes.

14. Disposal of contaminant waste and reject water—high volume?:
    Replaced MnO_2-fibers could likely be disposed of in sanitary landfills; no reject water.

15. Removes other contaminants also:
    No.

16. "Side effects" detrimental to water quality:
    Possible increase in manganese concentration of treated water.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL — Precipitation by Barium Compounds

1. Application—central, institution, individual household:
   Large (municipal size) or possibly medium sized central systems.

2. Drinking water* only or entire supply:
   Entire water supply.

3. Testing and operating experience:
   No testing or operating experience except for wastewater treatment.

4. Effectiveness/efficiency:
   No information available.

5. Performance affected by raw water quality?:
   Not likely.

6. Practicality—operation and maintenance—degree of difficulty:
   Trained operators required, practical for water treatment plant type operation and maintenance.

7. Reliability:
   Probably reliable with good operation.

8. Fail-safe?:
   No, although worst effect of process failure would probably be non-removal of radium.

9. Availability:
   Not yet available — theoretical only.

10. Capital cost: Depends on availability of process equipment already installed in particular water treatment plant.

11. Operating cost: Similar to cost of operating medium and large-scale treatment processes for water softening, color and turbidity removal.

12. Lifetime of unit/components:
    Process equipment—long life/continuous addition of chemicals required.

13. Contaminants removed from water accumulate in unit?:
    No.

14. Disposal of contaminant waste and reject water—high volume?:
    Waste sludge can be disposed of in a number of ways—method chosen depends on situation.

15. Removes other contaminants also:
    No.

16. "Side effects" detrimental to water quality:
    Barium concentration in treated water would require careful monitoring, barium can be toxic at high concentrations.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADIUM REMOVAL **Reverse Osmosis**

1. Application—central, institution, individual household:
   Small central systems, institutions, and individual households.

2. Drinking water* only or entire supply:
   For central systems only, entire supply is possible; for institutions and households, likely only drinking water is economically feasible.

3. Testing and operating experience: Central systems—full-scale operating experience in U.S; institution and household—laboratory and full-scale experience under actual conditions for lengthy periods (3 years for institution unit, 6 months for household unit) for uranium removal in Nova Scotia; same units will likely be satisfactory for radium removal.

4. Effectiveness/efficiency:
   90%+ removal reported from U.S. experience.

5. Performance affected by raw water quality?:
   Possibly; must remove suspended solids, turbidity, high iron concentrations, chlorine.

6. Practicality—operation and maintenance—degree of difficulty:
   Fairly complex device, but generally simple operation and maintenance; practical for institutional and household use and likely practical for small central systems if in each case high quality units are installed.

7. Reliability:
   Likely reliable.

8. Fail-safe?: Generally yes, but a perforated membrane will allow untreated water (with no greater than raw water radium concentration) to pass through the unit.

9. Availability:
   Available now in Nova Scotia.

10. Capital cost: High for central system and institution size, affordable for most households in drinking water only size.

11. Operating cost: Probably not excessive, lower than some other processes although cost of membrane replacement could be high in some cases.

12. Lifetime of unit/components:
    Unit—long life/membrane—variable depending on each situation.

13. Contaminants removed from water accumulate in unit?:
    No.

14. Disposal of contaminant waste and reject water—high volume?:
    High volume of reject water—disposal generally not a problem because re-use is often possible.

15. Removes other contaminants also:
    Yes, uranium: 80%-90%, arsenic: 90%+, radon: preliminary data indicate high removals, but should not be considered a reliable method for radon removal.

16. "Side effects" detrimental to water quality:
    Treated water has corrosive tendencies because it is largely de-mineralized—could result in need for neutralizing treatment in central systems, little or no problem in institution and household applications.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL OF RADON REMOVAL PROCESSES AND DEVICES

Aeration

Distillation

Granular Activated Carbon (GAC)

APPRAISAL SHEET

RADON REMOVAL **Aeration**

1. Application—central, institution, individual household:
   Central systems (large and small), institutions and individual households.
2. Drinking water* only or entire supply:
   Both, but generally would be applied to entire water supply in order to eliminate radon release to indoor air from water.
3. Testing and operating experience:
   Laboratory, pilot plant and full-scale testing in U.S.
4. Effectiveness/efficiency:
   90%+ reported.
5. Performance affected by raw water quality?:
   No.
6. Practicality—operation and maintenance—degree of difficulty:
   Basic equipment (spray aeration for large systems, diffused aeration tanks for small systems), likely no major operating or maintenance problems, but frequent operating attention is required even in household applications.
7. Reliability:
   Reliable provided equipment is functioning.
8. Fail-safe?:
   If equipment fails the result would simply be non-removal of radon.
9. Availability:
   Available in U.S.
10. Capital cost: For central systems comparable to cost of other types of treatment equipment, institution and household systems affordable in most cases.
11. Operating cost: Main operating cost would be cost of electrical power—could be considerable—would include aeration equipment power and in many cases ventilation fan power (and heat loss from building).
12. Lifetime of unit/components:
    Equipment would likely have fairly long life.
13. Contaminants removed from water accumulate in unit?:
    No, but ventilation to outside may be required.
14. Disposal of contaminant waste and reject water—high volume?:
    None.
15. Removes other contaminants also:
    No.
16. "Side effects" detrimental to water quality:
    None to water quality, but radon in air near the treatment unit would increase greatly, requiring exhaust ventilation to outside of building.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADON REMOVAL **Distillation**

1. Application—central, institution, individual household:
   Individual households.
2. Drinking water* only or entire supply:
   Drinking water only, radon would still be released to indoor air from taps and showers.
3. Testing and operating experience:
   Unit from one manufacturer tested in Nova Scotia primarily for uranium removal under actual operating conditions in household use for 6 months, performance in removing radon was also tested.
4. Effectiveness/efficiency:
   98% removal.
5. Performance affected by raw water quality?:
   No.
6. Practicality—operation and maintenance—degree of difficulty:
   Simple to operate, practical for household use, good consumer acceptance.
7. Reliability:
   Very reliable.
8. Fail-safe?:
   Yes.
9. Availability:
   Available now in Nova Scotia.
10. Capital cost:
    Affordable for most householders.
11. Operating cost:
    No exact data, only operating cost is for electricity, does not appear to be excessive.
12. Lifetime of unit/components:
    Unit—long life/heating element and fan motor will eventually require replacement.
13. Contaminants removed from water accumulate in unit?: No, but some radon is released to surrounding indoor air, not considered hazardous because low volume.
14. Disposal of contaminant waste and reject water—high volume?:
    See 13. above.
15. Removes other contaminants also:
    Yes, uranium: 100% removal, radium: probably 100% removal, arsenic: 100% removal.
16. "Side effects" detrimental to water quality:
    Distilled water has corrosive tendencies, but in household installation is not a problem.

*On this form "drinking water" means water for drinking and cooking purposes.

APPRAISAL SHEET

RADON REMOVAL Granular Activated Carbon (GAC)

1. Application—central, institution, individual household:
   Small central systems, institutions and individual households.

2. Drinking water* only or entire supply:
   Both, but generally would be applied to entire water supply in order to eliminate radon release to indoor air from water.

3. Testing and operating experience:
   Laboratory, pilot plant testing and full-scale experience in U.S.

4. Effectiveness/efficiency: 80% to 100% removal depending on size of GAC unit and other factors, generally 90%+ removal.

5. Performance affected by raw water quality?:
   Not likely for reasonably normal raw water quality.

6. Practicality—operation and maintenance—degree of difficulty:
   Relatively easy to operate, practical for household use.

7. Reliability:
   Reliable.

8. Fail-safe?: Probably, as indicated by experience to date, not completely certain.

9. Availability:
   Standard GAC units can be used—available in Nova Scotia.

10. Capital cost:
    Affordable by most householders.

11. Operating cost:
    Insignificant.

12. Lifetime of unit/components: Unit and GAC adsorption media—long lif addition of media required after several years of operation to replace the small amount lost in infrequently required (generally twice yearly) backwashes.

13. Contaminants removed from water accumulate in unit?:
    Yes, and decay radioactivity within unit.

14. Disposal of contaminant waste and reject water—high volume?:
    Not a significant problem—the wastewater from the average twice yearly backwashing contains some radioactive material and therefore disposal requires appropriate approval.

15. Removes other contaminants also:
    No (with possible exception of some organic compounds).

16. "Side effects" detrimental to water quality:
    Possible increase in numbers of bacteria in treated water due to bacterial growth in GAC unit—not likely significant, if so, can install disinfection treatment downstream from GAC unit.

*On this form "drinking water" means water for drinking and cooking purposes.

REFERENCES - CHAPTER 15

1. Reid, G.W., Lassovszky, P., and Hathaway, S., "Treatment, Waste Management and Cost for Removal of Radioactivity from Drinking Water", Health Physics, Vol. 48, No. 5, pp. 671-694, May 1985.

2. Lee, S.Y. and Bondietti, E.A., "Removing Uranium from Drinking Water by Metal Hydroxides and Anion-Exchange Resin", Journal AWWA, pp. 536-539, October 1983.

3. Brinck, W.L., Schliekelman, R.J., Bennett, D.L., Bell, C.R., and Markwood, I.M., "Radium-Removal Efficiencies in Water-Treatment Processes", Journal AWWA, pp. 31-35, January 1978

16. CONCLUSIONS AND RECOMMENDATIONS

16.1 Introduction

The conclusions and recommendations which follow are based on the results of the investigation carried out by the Provincial Uranium Task Force as presented in this report. They are grouped under topic headings and they are numbered consecutively. The numerical order of the conclusions and recommendations respectively does not necessarily indicate their relative importance or priority.

It was stated in the Foreword that this report of the Task Force investigation was written by the chairman with notable contributions by some other Task Force members of material which is appended to the report in its entirety and is incorporated into the report in summary and quotation form.

This being stated, it should be added and emphasized that the Uranium Task Force as a whole concurs with the conclusions and recommendations which follow.

16.2 Conclusions

The following conclusions have been reached by the Provincial Uranium Task Force:

Occurrence of Uranium, Radium and Radon: Water Supply Sampling Results and Hydrogeology

C-1 Water supplied by all 72 municipal and 8 Canadian Forces base water systems sampled meets the current Guidelines for Canadian Drinking Water Quality for uranium and radium and presents no potential health hazard from uranium, radium, or radon. This is due mainly to the fact that nearly all of the systems utilize surface water as the sole, or at least major, source of supply.

C-2 Bottled water produced by Farmers Cooperative Dairy Limited and Sparkling Spring Water Limited contains less than detectable concentrations of uranium, radium activity below the target level for radium-226 in the current Canadian Drinking Water Quality Guidelines, and very low, if any, radon activity. These bottled waters therefore present no potential health hazard from uranium, radium or radon.

C-3 **Uranium** is a common, naturally-occurring element in well waters in Nova Scotia. Sampling of wells in a number of areas which exhibit certain natural characteristics believed to be associated with the presence of uranium produced the following results:

1. Of 784 wells sampled for **uranium**, 195 (25%) had uranium concentrations greater than 0.02 mg/L, the current maximum acceptable concentration in the Canadian Drinking Water Quality Guidelines.

2. Any potential uranium problem is virtually restricted to drilled wells. 99% of the wells which had uranium concentrations greater than 0.02 mg/L were drilled wells.

3. The concentration of uranium in the wells with uranium greater than 0.02 mg/L ranged from 0.03 mg/L to 0.7 mg/L, with the average at 0.07 mg/L.

4. Only 8 wells had uranium concentrations greater than 0.2 mg/L.

5. The <u>highest</u> **<u>uranium</u>** concentration found was 0.70 mg/L in a drilled well in the New Ross-Forties-Fraxville area.

C-4 On a province-wide scale the occurrence of uranium in well waters is dependent on the type of bedrock. Locally, uranium distribution is controlled by such factors as well depth, overburden thickness, overburden type and the hydrogeology of the aquifer, which act to modify the geochemistry of the local groundwater flow system.

C-5 The geological environments most likely to have elevated uranium in wells are:

(a) the granite batholiths which outcrop over much of mainland Nova Scotia (range of uranium in wells: 0.005 mg/L to 0.70 mg/L),
and

(b) the alkaline sandstone and shale of the upper Carboniferous sedimentary basin in northwestern Nova Scotia (range of uranium in wells: 0.005 mg/L to 0.11 mg/L).

Lesser concentrations of uranium may be associated with sedimentary and metasedimentary rocks in hydraulic contact with the granites.

C-6 Hydrogeology is a factor affecting the distribution of uranium in wells in Nova Scotia. In granites, major fractures and shear zones could act as groundwater channels for the formation of uranium deposits and transport of uranium to wells. In the Carboniferous Basin, uranium is transported under oxidizing alkaline conditions by circulating groundwater and deposited at reducing barriers. The more uniform distribution of uranium in the sedimentary basin than is the case in granite areas is due to the more extensive regional flow systems compared to short local fracture flow systems which predominate in granites.

C-7 The probability of encountering high uranium in granitic terrains can depend on the type of granite. Uranium levels in groundwater are found to increase with the acidity or the silica content of the granitic rocks. For example, in Nova Scotia uranium becomes more enriched from the granodiorites to the monzogranites to alaskite. Lake sediment geochemical sampling also shows that uranium concentration in lake sediments is highest on granitic terrain, and that such concentration follows the hypothesis of uranium enrichment in later phases of igneous differentiation, as was seen for well water sampling results.

C-8 The concentration of uranium in wells in granites was found to increase with increasing overburden thickness for wells penetrating glacial till drumlins in Harrietsfield, Brookside and New Ross. The presence of thick overburden deposits over an aquifer is believed to act as a barrier between the atmosphere and the groundwater which affects the pH and redox potential of the underlying groundwater, for example, the pH and alkalinity are higher and groundwater is less oxidizing than surrounding areas favoring the accumulation of uranium minerals under such conditions. It follows that little or no relationship between well depth and uranium concentration was observed in granitic areas. However, in the Carboniferous Basin, some relationship exists between uranium and well depth, likely due to stratigraphy.

C-9 Uranium in well water is associated with high pH, alkalinity, phosphate, silicate, fluoride and arsenic in granites, and with high pH, hardness, alkalinity, TDS, silicate, fluoride and phosphate in the Carboniferous Basin. The mobility and distribution of uranium in groundwater is further increased by the formation of stable soluble complexes between uranium and anions such as phosphate, carbonate, silicate and fluoride. Uranium is strongly related to high groundwater pH. Elevated uranium was found to be associated with pH levels of 7.5 to 8.5 in granites and sedimentary rocks.

C-10 Elevated uranium levels in water wells are generally associated with elevated radium and radon gas. Divergency from this trend can be explained by the difference in solubility between uranium and its daughter radionuclides, such as radium-226, which could result in the presence of one and not the other in water samples.

C-11 Although **radium** is widespread in groundwater in Nova Scotia, occurring at detectable activity levels in most of the areas in which wells were sampled, on the whole levels were not high. Sampling of wells in the areas investigated for uranium in groundwater produced the following results:

1. Of 763 wells sampled for **radium**, only 8 (1%) had radium activity readings in excess of 1 Bq/L, the maximum acceptable level in the Canadian Drinking Water Quality Guidelines for radium-226.

2. The 8 wells which exceeded 1 Bq/L radium activity consisted of 4 drilled wells and 4 dug wells located as follows: Harrietsfield-Williamswood - 3, New Ross-Forties-Fraxville - 4, River John-Marshville-Welsford - 1.

3. A total of 54 wells had radium readings in the range 0.2 - 1.0 Bq/L, that is, greater than the Guidelines' target level" but less than the maximum acceptable; 701 wells had radium activity which was equal to or less than the target level.

4. The highest **radium** activity measured was 3.7 Bq/L in a

sample from a dug well located in the Harrietsfield-Williamswood area.

5. Only 1 well of the over 700 sampled had both **uranium** and **radium** readings greater than the maximum allowable in the current guidelines. That well, located in the River John-Marshville-Welsford area, also had a relatively high radon reading, the highest reading of the 130 wells checked in the uranium exploration areas. The analysis results for all three parameters for this well are: uranium - 0.11 mg/L, radon - 1,558 Bq/L, radium - 1.1 Bq/L.

C-12 The two sampling areas where radium was most prevalent were Harrietsfield-Williamswood and New Ross-Forties-Fraxville; in these areas 11% and 9% respectively of the wells sampled had radium activity > 0.1 Bq/L, the "target" level. Both of these are granitic bedrock areas. In the New Ross area the highest radium readings occurred in wells located near the contact between alaskite and monzogranite.

C-13 **Radon** activity is considerable in groundwater in most of the areas in which wells were sampled for uranium and it is very high in many individual wells. Well sampling for radon produced the following results:

1. Of 725 wells sampled for **radon**, 293 (40%) had radon activity readings in excess of 370 Bq/L, which is the equivalent of 10,000 pCi/L.

2. Radon activity levels are generally much lower in dug wells than in drilled wells; 95% of wells with radon activity > 370 Bq/L were drilled wells.

3. The highest **radon** activity measurement made was 7,130 Bq/L in a sample from a drilled well in the New Ross-

Forties-Fraxville area (not the same well which had the highest uranium concentration).

C-14 Radon activity averages 130 Bq/L in dug wells and 930 Bq/L in drilled wells in granitic areas, and it averages 54 Bq/L in dug wells and 118 Bq/L in drilled wells in the Carboniferous Basin bedrock areas.

C-15 Radon is generally highest in uraniferous zones, in monzogranite and alaskite granites, or in wells containing high radium, and varies spatially with rock type, overburden thickness, well depth and aquifer permeability.

C-16 For any particular well, over a short-term period of less than one day (samples collected at ½-hour intervals for 7 hours), the variations in uranium concentration and radium activity are negligible and the variation in radon activity, although noticeable, is considered insignificant in view of all factors involved.

Furthermore, for any particular well, over a long-term period of one year (samples collected at monthly intervals for one year), the variation in uranium concentration is probably not significant if the well pumping rate, that is, household water use, is reasonably constant; significant variation has been shown if water usage changes. Additional study may be warranted. Radium activity shows little or no variance over the long term even with variable water usage and, although somewhat inconclusive, results indicate that radon activity exhibits considerable variation but these variations are lower where water usage is most constant.

C-17 Not all areas which have the natural conditions which give rise to the occurrence of uranium and related elements in groundwater have been investigated, and therefore it is quite likely that uranium and related elements are present in many wells in various areas of the province in addition to those sampled as part of this investigation.

Clinical Investigation Results—Health Effects

C-18 Clinical studies carried out by the Task Force found no pattern of overt disease or symptomatic complaints which could be attributed to uranium exposure.

C-19 Although unexplained minor hematuria was detected in 11% of persons examined in the Harrietsfield clinical study, this was not reproduced either in a follow-up study or in the New Ross study. In addition, the microscopic findings alone would have generally been considered normal in these persons. The remote possibility that the presence of uranium itself was responsible for false positive interference was excluded. It was concluded that the batch of test strips used in Harrietsfield was either too sensitive, or subject to unidentified false positive interference. It was concluded that major glomerular lesions had not been sustained, in view of the lack of positive findings on routine urinalysis and microscopy, and the absence of significant quantitative proteinuria.

C-20 Urinary uranium excretion appears to be unreliable as an index of body burden. It appears to primarily reflect recent intake of uranium.

C-21 Hair uranium concentration shows promise as an index of body burden, but has been found to be sensitive to lifestyle factors such as hairwashing. As a result of this activity, hair is capable of adsorbing and accumulating uranium to concentrations more than 1000 times higher than found in the wash water. During preliminary experiments, it had been found that a mild washing procedure prior to the uranium determination made no significant difference to the analytical values obtained. It is concluded that further analytical studies are required to determine whether a more aggressive washing procedure could be developed which would release adsorbed uranium, whilst leaving behind that portion which had been incorporated endogenously.

C-22 A trend effect was observed of increasing urinary β_2M excretion with increasing well water uranium concentration. In both studies, the group with the highest levels of uranium in their well water were out of keeping with this trend. This was attributed to the further observation that many of these individuals had changed their source of drinking water since receiving the results of their water analysis, and had therefore significantly reduced their intake of uranium prior to the clinic. It was concluded that, as a marker of tubular proteinuria, urinary β_2M may serve as a useful index of subclinical toxicity in the context of such uranium exposure, and merits further study. It should be noted, however, that this marker has the disadvantage that it rapidly degrades under conditions of low urinary pH.

C-23 An animal model which can be used to study the nature of the early renal tubular lesion has been developed. It was further concluded that sensitive biochemical parameters which can be employed in defining the problem have been identified.

Standards/Guidelines and Health Hazards

C-24 There is a lack of knowledge worldwide on the amount of uranium which can be ingested daily in drinking water over a period of years before adverse health effects will occur. This is reflected in the scarcity of standards or guidelines on allowable concentrations of uranium in drinking water.

The consideration of the chemical toxicity aspect of uranium is the most notable lack; the few countries which have standards or guidelines for uranium in drinking water have almost exclusively used radiotoxicity as a basis.

A world survey of standards carried out for the Task Force indicates that Canada (0.02 mg/L) and the U.S.S.R. (1.7 mg/L) are the only countries with established guidelines for uranium in drinking water based on chemical toxicity. Fifteen countries have standards or guidelines based on radiotoxicity but these offer little guidance as the range of values is virtually incredible: 0.2 Bq/L to 3,500 Bq/L.

Some direction has been obtained from guidelines recently proposed by the U.S. National Academy of Sciences and by a committee established subsequent to the U.S. National Workshop on Radioactivity in Drinking Water, as well as from developments in the Province of Manitoba.

C-25 Although exact information relating specific levels of radium activity in drinking water with health effects is lacking, sufficient general information on the health effects of radium is available to enable informed estimates of health risk to be made. This has led to guidelines being established.

The Task Force determined that 22 countries have standards or guidelines for radium in drinking water; half of these are values recommended by either the WHO or ICRP. Most guidelines are in the range 0.1 Bq/L to 4 Bq/L, including the Canadian guideline for radium-226 (1 Bq/L).

C-26 Interest and concern expressed by many countries with regard to the potential health hazard arising from radon in drinking water and especially radon in indoor air (released from water and from other sources) has not yet been translated into standards or guidelines in any country, including Canada.

Information on which to base estimates of health risk factors and guidelines for radon in water supplies has been obtained from these sources: the committee reports of the U.S. National Workshop on Radioactivity in Drinking Water, the State of Maine, Atomic Energy of Canada Ltd., and the literature.

C-27 The establishment and application of guidelines for uranium, radium and radon in water supplies is far more complex and difficult than is the case for most other potential contaminants and in several cases the guidelines which have been adopted or proposed exhibit discrepancies, uncertainties and limitations which detract greatly from their credibility and usefulness.

C-28 Study of the most recent information available from the most reliable sources indicates that the primary health hazards posed by uranium, radium and radon in water supplies which should form the basis of guidelines for the respective contaminants are:

uranium - chemical toxicity to the kidney
radium - bone cancer
radon - lung cancer (from inhalation of radon in indoor air)

C-29 With regard to the Guidelines for Canadian Drinking Water Quality, the following conclusions were reached:

Uranium

In light of Conclusion C-18, that is, that "no pattern of overt disease or symptomatic complaints which could be attributed to uranium exposure" were found in the clinical studies, it is concluded that the current maximum acceptable concentration of 0.02 mg/L for uranium in the Guidelines for Canadian Drinking Water Quality need not be reduced to a lower concentration and, in fact, the maximum acceptable concentration could probably be raised to a value as yet undetermined.

It is concluded that a limit must be placed on the amount of uranium ingested in drinking water because of the potential long-term hazard of chemical toxicity to the kidney.

Radium

The maximum acceptable concentration (activity) of 1 Bq/L for radium-226 set down in the current Guidelines for Canadian Drinking Water Quality provides adequate health protection.

This conclusion is supported by the references noted in Section 14.4.

Radon

When the current Canadian Drinking Water Quality Guidelines were issued (1978), the state of knowledge was such that a guideline for radon in water supplies could not have been rationally adopted.

This absence of a guideline has probably not been a critical deficiency as indicated by the results of this investigation noted below:

1. With the knowledge available at this time the radon hazard to the respiratory system due to inhalation of radon in indoor air is considered greater than that to other organ systems, including the stomach, due to ingestion of radon in drinking water.

2. Measurements of radon and radon daughter activities in indoor air in four studies described in Sections 13.2 and 13.3, especially in the two studies conducted in Nova Scotia, indicated that levels are within generally accepted limits even in houses which had relatively high levels of radon in their well water supplies.

3. Results of a federal Radiation Protection Bureau survey in cities across Canada and opinions in the literature indicate the possibility that environmental exposures to radon and radon progeny in air may result in such a small lung cancer rate that it is indistinguishable from the non-radon induced rate.

In summary, therefore, it is concluded that, if radon inhalation is more hazardous than radon ingestion and radon/radon daughters in air are within generally accepted limits even where radon activity in water is high, there does not seem to be an urgent need to adopt a guideline for radon in water supplies. In view of the cancer risk factors proposed by some experts, the presence of radon in water supplies cannot be entirely ignored and the determination of the relative importance of radon in water and in indoor air as an environmental health hazard will require on-going research and epidemiological study.

C-30 On the basis of radiotoxicity only, without regard for chemical toxicity, the maximum acceptable concentration for uranium in drinking water is considered to be 0.25 mg/L and, in fact, depending on the uranium-234/uranium-238 ratio, this figure may have to be reduced, as it has been in Manitoba where a maximum acceptable advisory value of 0.10 mg/L is in effect based on radiotoxicity only and an average measured U-234/U-238 ratio of 3/1.

No measurements of the U-234/U-238 ratio have been made in Nova Scotia.

Options Available

C-31 A number of various options to water supplies with elevated uranium, radium and radon levels are available as outlined in Section 15.2.

16.3 Recommendations

The Provincial Uranium Task Force recommends that:

Organization, Methods and Procedures

R-1 Personnel requirements for any future investigations of a size and complexity similar to this investigation be provided in one of the following ways: (1) engage a technical consulting firm to perform the investigation under the direction of a monitoring committee which would have a composition similar to that of the Task Force; (2) engage a full-time coordinator appointed to implement all day-to-day functions of the investigation and to compile data and research information as the study proceeds, all under direction and guidance of a monitoring committee similar to the Task Force in composition; or (3) use a task force similar to the Uranium Task Force, but with the exception that the chairman be relieved from the regular duties of his departmental position for the duration of the project.

R-2 Electronic information handling systems such as computers and word processors be made available to personnel involved in future investigations of this nature and that these be used from the start of the investigation to alleviate routine workload and to expedite data compilation and information reporting.

R-3 Water sampling programs which may be part of similar future investigations utilize the procedures for sampling, recording and reporting detailed in Sections 4.2.2 and 4.2.3 and summarized in Appendix D, with appropriate maps, questionnaires and form letters as typified in Appendices C, D, E, F, and G.

R-4 Laboratory forms reporting results of bacteriological analysis of water samples submitted by the public be revised to include a clear cautionary note stating that the analysis was carried out for bacterial quality only and that chemical constituents such as arsenic and uranium which may make water unsafe for drinking were **NOT** analyzed.

R-5 Future surveys of radon in indoor air and guidelines which may be proposed for radon in indoor air use working levels (WL) as the unit of measure as was done in the radon in air studies performed in Nova Scotia by the federal Radiation Protection Bureau and by the Nova Scotia Department of Health which were part of the Task Force investigation. This is the only way to obtain an accurate picture of radon-radon daughter activity because it avoids the question of possible disequilibrium of the radon daughters and also the issue of whether or not the progeny are attached to dust, smoke or any other carrier aerosol.

Distribution of Report

R-6 This report be submitted in its entirety to the interdepartmental committee established pursuant to Judge Robert McCleave's report on the results of Uranium Inquiry—Nova Scotia to study all aspects of uranium exploration and mining.

R-7 This report be released to the public and the information contained in this report be given as wide a distribution as possible for the purposes of providing guidance to the public and background information for other researchers.

Consideration be given to holding public meetings in Harrietsfield-Williamswood, New Ross and possibly Brookside and River

John, for the purpose of presenting the conclusions and recommendations resulting from this investigation directly to the residents of these areas.

Information to Well Owners

R-8 The Nova Scotia Department of Health re-contact all well owners who were previously advised to discontinue drinking their well water because it contained uranium concentrations greater than 0.02 mg/L, informing them, by form letter, of the results of the clinical studies performed as part of the Task Force investigation as well as advising them of the current situation concerning the guideline for the maximum acceptable concentration of uranium in drinking water; the form letter should include a re-statement of the results for each individual well of the uranium sampling which had been done during the Task Force well sampling program.

Natural Distribution of Uranium, Radium and Radon in Groundwater— Problem Prevention

R-9 Government and planning agencies, well drillers, the consulting community, subdivision developers and individual home builders be advised of those areas of the province which have the highest potential for the occurrence of elevated concentrations of uranium in groundwater. In order of decreasing probability, these include:

(a) Granite Terrain:
   (1) Alaskite intrusions in monzogranite (New Ross, Upper Vaughan, Leminster, Card Lake, Glen Margaret, Tantallon, Glen Haven, White's Lake)
   (2) Granites overlain by till drumlins
   (3) Granites

(4) Contact zones between granite and Meguma metasediments
(5) Contact zone between granites and clastic sediments (Annapolis Valley, Martock, Falmouth)
(6) Granitic areas with high pH, alkaline, slightly oxidizing groundwater, or where anomalous levels of arsenic, silica, fluoride and phosphate are encountered

(b) Carboniferous Basin:
(1) Areas located hydraulically down gradient of known uranium-copper occurrences
(2) Areas located hydraulically down gradient of granites in the Cobequid range

The most effective means of disseminating this information to the various groups and persons mentioned above would be best devised by the provincial departments involved. Widespread distribution of the map attached as Appendix J would aid greatly in this educational process.

R-10 Department of Health personnel be instructed to include a cautionary note when writing reports of assessment of lands proposed to be subdivided and when preparing on-site sewage disposal permit forms for lots in areas of the province which have the highest potential for the occurrence of elevated concentrations of uranium in groundwater. The note should be worded as follows:

> These lots are located in an area in which high uranium concentrations may be encountered in drilled wells. Lot purchasers are advised to consider alternate means of water supply. If wells are drilled, they should be sampled by the owners and analyzed for uranium and radium. Such sampling should be carried out after the well has been in use for about two months. If unacceptable levels of uranium or radium are found, appropriate water treatment equipment can be installed to eliminate the potential health hazard.

It is further recommended that this cautionary note be placed on the registered plan of subdivision by the Development Officer for the municipality involved.

R-11 Before decisions are made to utilize wells as new sources of supply for municipal water systems, smaller central systems, or institutions, appropriate consideration be given to the possibility of encountering uranium and related elements in such wells; the investigation process should include a study of the report presented as Appendix A and the map presented as Appendix J, as well as the results of sampling existing wells in the area concerned.

It is further recommended that any new wells which are constructed for these applications be analyzed for uranium, radium, and radon before they are connected to the systems.

R-12 Work on controlling or reducing uranium concentrations in well water should include consideration of the following: pH modification, and heavy pumping and development of new wells to remove uranium from the area of influence of wells in drumlin areas.

Clinical Investigations and Animal Study

R-13 Further clinical studies of a type similar to those carried out in this investigation be undertaken, particularly if an exposed population can be identified which contains individuals who have been exposed to higher levels of uranium in their drinking water, and preferably if clinical observations can be made before such persons have discontinued drinking this water. Based upon the results of the well sampling program in Nova Scotia, it seems unlikely that such a population will be identified in this province.

R-14 Using incidental tissue sampling from autopsy procedures in regions where persons are known to be exposed to elevated levels of uranium in their drinking water, attempts should be made to correlate bone and kidney uranium content with hair uranium concentration. Various preparatory hair washing procedures could be assessed in conjunction with this, the goal being to remove adsorbed uranium whilst leaving behind the uranium of endogenous origin. Similar procedures have been reported for the attempted removal of adsorbed cadmium on hair. Autopsy studies could also be used to evaluate the reliability of other tissues, such as nails, as a potential index of body burden of uranium.

R-15 A study utilizing the animal model which has been developed to investigate the nature of the early renal tubular lesion be completed. The Task Force considers the completion of this animal study to be a matter of high priority in the effort to establish more definitively a maximum acceptable concentration for uranium in drinking water and therefore further recommends that the funds for completion of this study be made available without delay from provincial sources if financial support continues to remain unavailable from the federal level.

Standards/Guidelines

R-16 A definitive standard for the maximum acceptable concentration of uranium in drinking water in Nova Scotia be established as soon as possible, using as a basis the results of the animal study recommended in R-15 correlated with the clinical studies completed by the Task Force. This should be done with or without involvement of federal Health and Welfare Department personnel or financial assistance, depending on what course produces results in the shortest time.

R-17 Surveys be carried out across Canada as a whole and in Nova Scotia in particular to determine the amount of uranium ingested daily from food consumed by residents of areas in which individual wells are used as a source of water supply.

This figure has a direct bearing on setting the amount of uranium which can be safely ingested daily from drinking water.

The results of the proposed surveys should be applied to any revision of the guideline for maximum acceptable concentration of uranium in drinking water.

R-18 Given the absence of guidelines for radon activity in water supplies and the concern expressed by some well owners, the Department of Health should make it known that, for those who wish to eliminate any possible potential health hazard, treatment devices are available which will effectively and economically remove radon from water. Section 15.3.5 provides details of these devices.

R-19 Consideration be given, in cooperation with the Federal-Provincial Advisory Committee on Environmental and Occupational Health, to establishing guidelines for thorium-232, thorium-228 and radium-228 in drinking water.

Options—Selection

R-20 If options to existing water supplies are contemplated because of the presence of uranium, radium, or radon, each situation be assessed individually to determine the best option to apply under the particular circumstances, of the various options outlined in Chapter 15.

This recommendation applies to all size water supply systems, from large central systems to individual household well supplies.

Water Treatment Devices

R-21 If the procedure recommended in R-20 leads to a decision to install water treatment equipment, the selection of the process or device be made by using Table 41 and the "appraisal sheets" included in Section 15.3.5 as guides. The choice depends on the specifics of each individual case.

R-22 Based on the results of the water treatment tests or evaluations carried out in Nova Scotia on 4 different uranium removal devices, the following recommendations can be made:

"Seagold" Reverse Osmosis Unit - New Ross Consolidated School: Recommended for use under similar circumstances.

"Seagold" Reverse Osmosis Individual Household-Size Unit - Williamswood: Not recommended.

"Culligan" Reverse Osmosis Individual Household-Size Unit - Williamswood: Recommended on condition that an 80% to 90% uranium removal is sufficient for particular cases where its use is proposed.

"Lifetime Stainless Steel" Distillation Unit - Harrietsfield: Recommended without reservation for 100% removal of uranium.

Monitoring and Further Testing

R-23 Commercially produced bottled water from sources in Nova Scotia other than the two verified as satisfactory in this investigation be analyzed for uranium, radium and radon, with appropriate action taken if levels exceed adopted guidelines.

R-24 All new wells constructed in Nova Scotia be sampled by well owners after the wells have been in use for about two months and that these samples be analyzed for heavy metals including arsenic and uranium, radium, and any other potentially toxic chemical which may in future be found to naturally occur in in groundwater in the province. Further, that owners of existing wells be encouraged by a public information program to submit water samples for the same analysis.

Sample bottles and instructions for collecting the samples should be made available at municipal offices and issued along with on-site sewage disposal permits.

R-25 Additional well sampling be carried out to further study the variation in levels of uranium and related elements in wells over long-term periods.

R-26 The Department of Health assign to a member of its staff the responsibility to follow, on a continuous basis, the state of knowledge on the health effects of, and recommended guidelines for, radon in drinking water and radon in indoor air. This should be done by literature review and by maintaining contact with individuals and agencies known to the Task Force, many of whom have been referred to in this report. In addition, the Department of Health should actively promote and participate in epidemiological studies such as that suggested in the Radiation Protection Bureau report described in Section 13.3.2.

As indicated in Conclusion C-29, there does not at this time appear to be a problem caused by the presence of radon in well water supplies but, as seen in the literature, the cancer risk factors which have been proposed dictate that it would be prudent to follow the course of action outlined above.

R-27 Measurements be made to determine the uranium-234/uranium-238 ratio in groundwater samples in various areas of the province in order to quantify the actual radioactivity in groundwater caused by the presence of uranium.

Although the Task Force has concluded that it is probably not the primary factor controlling the maximum acceptable concentration of uranium in drinking water, the radioactivity of uranium cannot be entirely dismissed and as a precaution this follow-up work, which should be based on the Manitoba model, should be done.

R-28 A well "spot sampling" program be carried out in areas of known thorium occurrences as identified by the Nova Scotia Department of Mines and Energy in order to obtain an overview of the presence of this potential contaminant in groundwater in Nova Scotia.

R-29 In the event that any granular activated carbon (GAC) units are installed in Nova Scotia for removal of radon from water supplies, that the Department of Health monitor the performance of these units. GAC adsorption has been demonstrated elsewhere to be the most effective and practical means of radon removal, especially in smaller applications such as individual households.

R-30 If water treatment for uranium removal is required in a large number of locations, that the Department of Health initiate field testing of:

(1) full-size anion exchange units similar to those researched in the British Columbia laboratory tests;

(2) the Atomic Energy of Canada Limited "EXPURRT" device;

(3) full-size activated alumina units.