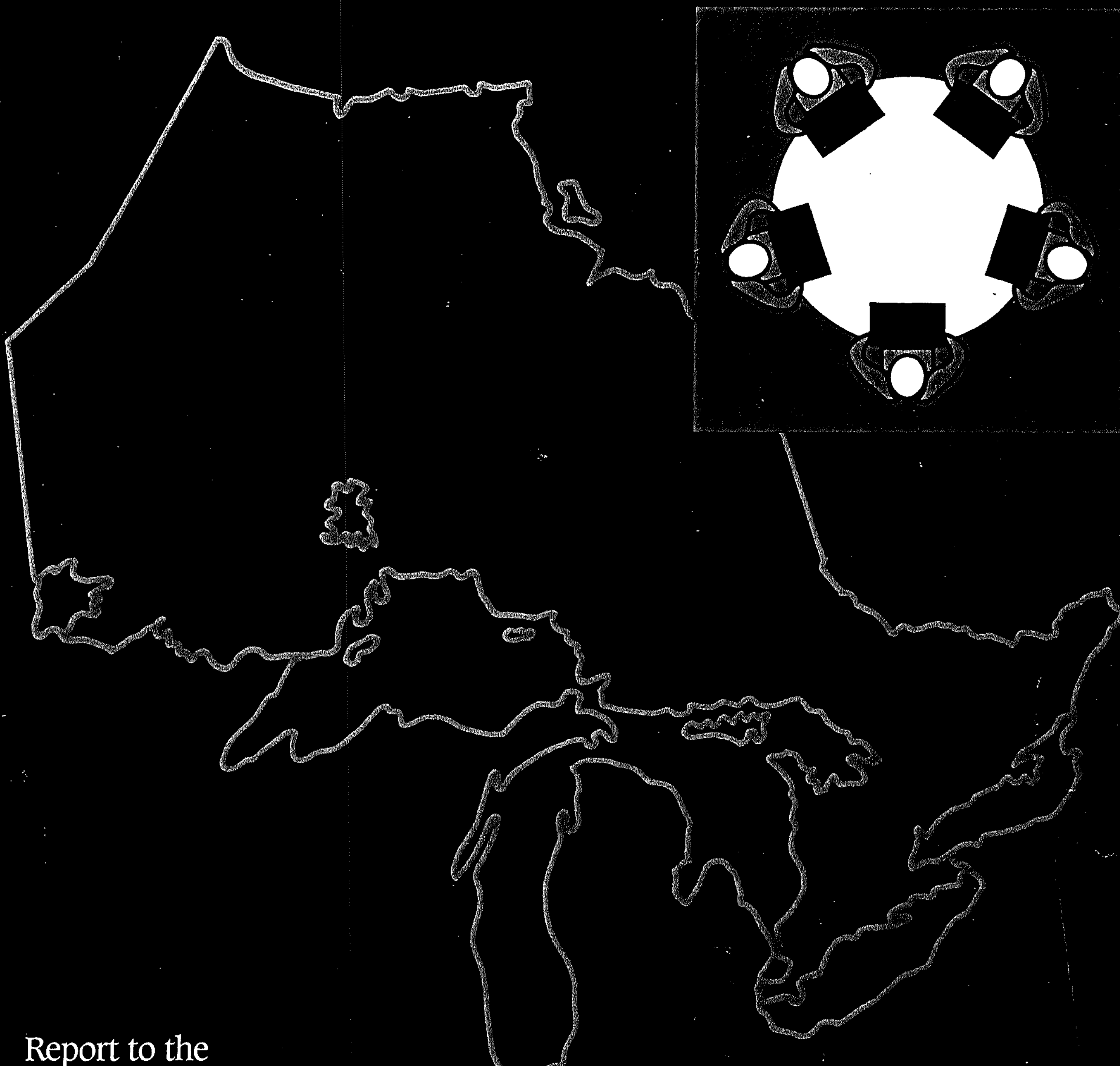
Inventory of waste quantities



Report to the
Siting Process Task Force
on Low-Level Radioactive
Waste Disposal

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on Low-Level Radioactive Waste Disposal

Inventory of Waste Quantities

Prepared by

Low-Level Radioactive Waste Management Office
Atomic Energy of Canada Limited
Research Company Head Office

August 1987

N Rubin,
Energy Probe

On December 11, 1986, The Honourable Gerald S. Merrithew, Minister of State (Forestry and Mines), appointed an independent Task Force to design a less confrontational siting process for a low-level radioactive waste disposal facility in Ontario. This action arose as a result of citizen unrest following the application of traditional site selection methods in the Port Hope area.

As part of its mandate, the Task Force was requested to study the low-level radioactive waste situation within the province of Ontario, the various approaches used to assess long-term management or disposal of such wastes, to investigate the economic consequences of various courses of action, and to analyze social implications surrounding this issue. To meet these requirements, the Task Force commissioned four reports. They are entitled: A Review of Low-Level Radioactive Waste Disposal Technology; Inventory of Waste Quantities; Regulatory Issues, and a Preliminary Study of the Costs Associated with Transporting Low-Level Radioactive Waste Out of the Port Hope Area; and Socially Responsive Impact Management.

This report, Inventory of Waste Quantities, is a companion document to the report of the Siting Process Task Force. The Inventory of Waste Quantities details the specific characteristics of each known waste accumulation within the province of Ontario. It presents the magnitude of the issue and such special considerations as the presence of chemical toxins in some of the wastes. This study was carried out by the Low-Level Radioactive Waste Management Office of Atomic Energy of Canada Limited.

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INVENTORY OF WASTE QUANTITIES

INTRODUCTION

This report provides an overview of the low-level radioactive wastes which have accumulated in the Province of Ontario. The information has been organized into three sections. The first deals with uranium mine tailings and the second with wastes from the use of naturally radioactive materials in industries, with no intent to exploit their radioactive properties. These are termed incidental wastes. The following section covers wastes from development and use of nuclear energy and the production of radioisotopes and their use in industry, research and medicine in a way which takes advantage of their radioactivity.

The most important characteristics of low-level radioactive wastes are the volume of the waste and the properties and concentrations of the radionuclides which it contains. Different radionuclides may produce different types of radiation. For example, alpha radiation is only a threat if the emitting radionuclide is inhaled or ingested, but gamma radiation can penetrate tissue, and radionuclides producing gamma radiation are, therefore, also an external hazard. Beta radiation also has the ability to penetrate tissues. Every radionuclide has a half-life, which is the time it takes for half of the atoms to transform to a different atomic structure. The new structure may be stable, in which case the atoms which have transformed are no longer radioactive, or it may be unstable, and be a source of additional radiation. The process whereby an atom may transform from one type to another and then another, etc., is called a decay chain. Appendix A describes the decay chains of three common, naturally-occurring radioisotopes: Uranium-238, Uranium-235, and Thorium-232. By this process of decay, all radioactive materials tend towards a stable atomic structure. However, the half-lives of radionuclides, and consequently the time it takes for most atoms to achieve a stable condition, vary considerably. Some radioactive wastes present a hazard for only a short time, whereas others remain radioactive for thousands of years. The longevity of the radionuclides and their concentration in the waste are factors of major importance in selecting disposal technology. Technology appropriate for disposal of wastes containing short-lived radioisotopes may not be suitable for dealing with long-lived radioisotopes unless they are at very low concentrations.

Table 1 lists some of the more common radioisotopes and their half-lives. A time interval of ten half-lives reduces the concentration of the radioisotope in the waste by a factor of approximately 1000. Radioisotopes with long half-lives are less radioactive than those with short half-lives, because at any given instant a smaller fraction of their atoms is decaying. Some wastes have other important characteristics. For example, many of the wastes from mineral processing contain non-radioactive constituents, such as arsenic, which, because they do not decay, are a potential hazard forever. These characteristics have also been identified. Uranium also has a greater potential for harm because of its chemical toxicity than from its radioactive properties.

To put some of the information concerning radiation fields and concentrations of naturally-occurring radionuclides in wastes into context, Appendix B presents information on background levels in Ontario.

The locations of waste accumulations have been identified, together with an indication of the type of setting in which they are found and the way in which they are being managed currently.

The final section of the report summarizes, compares and contrasts the various waste types in terms of volume, total activity and rate of production.

URANIUM MINE TAILINGS

Uranium mine tailings in Ontario are found in the general vicinity of Elliot Lake, Espanola and Bancroft. These towns are identified in Figure 1. In the Elliot Lake area and Bancroft area there are deposits from several mines. Table 2 lists data for each mine, grouped according to location. Accumulations are tabulated, the period of operation is identified and some information is given on the current status of the deposit. The location of each deposit is identified by the number of a map from The National Topographic System of Canada (1) and a reference number for that map.

In the extraction process the rock from the mine is ground into a sand-like consistency and is treated with chemicals to dissolve and then extract the uranium. The ground-up rock, after treatment, is pumped as a slurry to the tailings impoundment. Typically two thirds of the solids have a particle size equivalent to coarse sand, with the remainder much finer. The finer fraction, called slimes, contains a higher concentration of radionuclides and is slower to settle. Following settling of the solid material, the water flows into ponds, in which water treatment is performed to purify it before release. Although most of the radium remains with the tailings, some is dissolved and is removed during water treatment. Barium chloride is added to the effluent from the tailings and forms a precipitate of barium sulphate, which, in precipitating, also takes the radium out of solution. The deposition of tailings and associated water treatment is illustrated schematically by Figure 2.

Tailings have usually been deposited in depressions, commonly in the location of former lakes or swamps. Often a dyke or dam is constructed to complete the impoundment, but the naturally-sloping surrounding terrain forms most of the perimeter. Because of this, and because in some instances the tailings incompletely fill lakes, some of the deposits are seasonally or permanently under water. The tailings deposits in the Elliot Lake area are as much as 20 metres thick. Although, in some cases, there may be gates on roads leading to them, the older tailings deposits are readily accessible, typically being neither fenced nor manned.

The tailings contain virtually all of the constituents of the original ore except for most of the uranium. The grade of ore determines the level of radioactivity of the tailings. There is not much variability in the uranium content of Ontario ores, and 0.1% would be a typical value. This results in about 13.5 MBq/cu.m. of each of the radionuclides in the Uranium-238 decay chain, including Radium-226, in the tailings. Ores may contain small

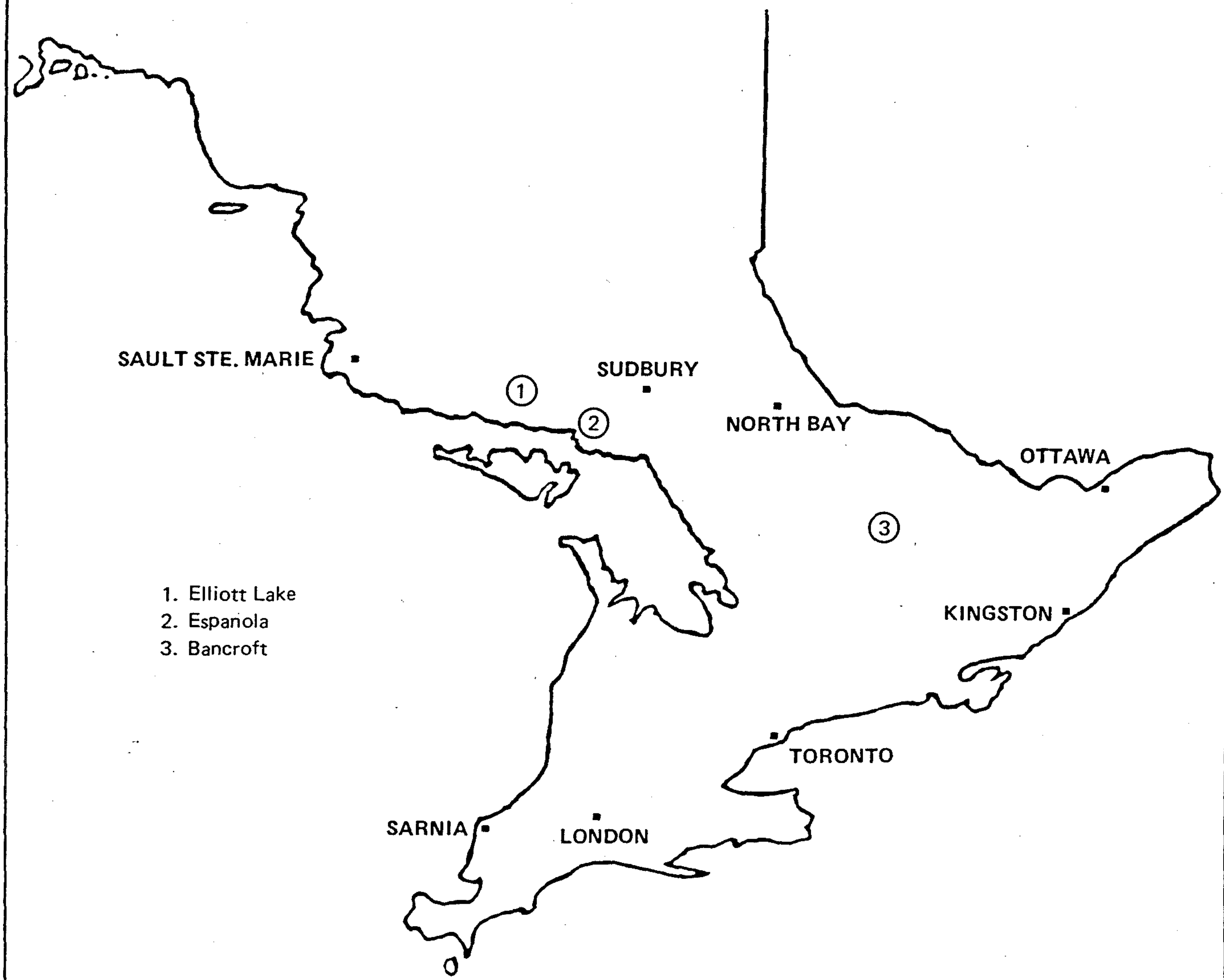

Figure 1: Deposits of Uranium Mine Tailings in Ontario

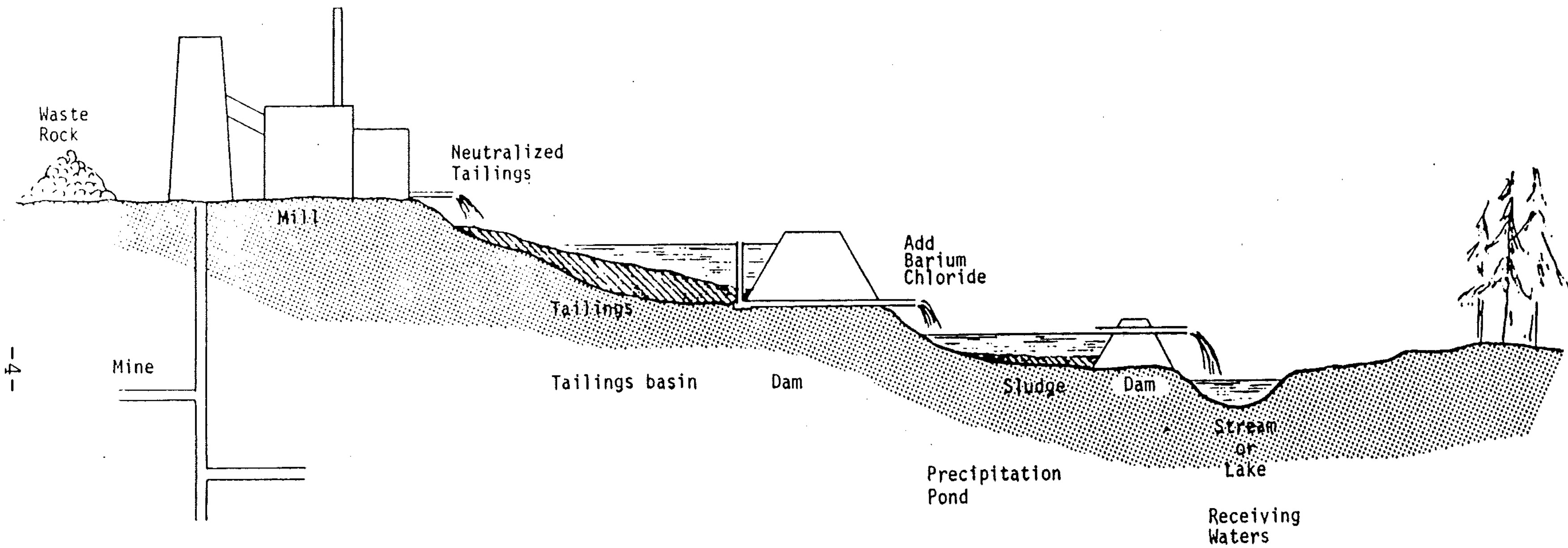

Figure 2: Schematic Representation of Uranium Mine Tailings Management

quantities of nickel, cobalt, copper, selenium, vanadium, molybdenum, antimony, arsenic, iron, fluoride, monazite and other rare earth minerals. Many of the radionuclides and trace elements are dissolved during the uranium extraction process, but are precipitated as hydroxides before the tailings are deposited. As they are no longer an integral part of the rock, they may be more susceptible to leaching. Often, tailings deposits contain pyrite, which is a sulphide mineral. This oxidizes on contact with air and moisture to form a very acidic solution. The formation of this acidic leachate is a major environmental problem in many tailings disposal situations. The acidity of the water draining from the tailings is, in itself, an environmental threat, but acidity also enhances the dissolution of some of the metals. Acidic leachate has been found to contain 0.2-1.6 Bq/L of Radium-226 and 0.06 to 11.5 mg/L of trace metals such as copper, zinc, nickel and lead (2).

Elliot Lake Area

The bulk of Canada's uranium tailings are situated in the Elliot Lake area. Many of the deposits are no longer being used, but those which are active are accumulating tailings on a large scale. In 1986, approximately 4,400,000 cu.m.* of tailings were deposited from the four active mines (3).

Figure 3 shows the location of the tailings deposits in this area. Because of the scale of continuing operations, several of the deposits are much larger than shown in the latest topographical maps. As the tailings typically fill the lake as an advancing "beach", it is difficult to estimate their area at any given time. Therefore, in Table 2 the final size of these active deposits, based on their design, is presented.

The closest deposits (all inactive) are 2.5 to 6 km from the town of Elliot Lake (popn.17984). There are scatterings of seasonal and permanent dwellings much closer to some of them. The Pronto deposit is about 19 km south of Elliot Lake, but is quite close to the Trans-Canada Highway, which has low-density development along it. To the north, the Quirke and Panel mines are about 15 km from town.

Espanola Area

The only former uranium mine in the Espanola area is located a few kilometers north of Agnew Lake. Its location is shown in Figure 4. The mine was served by a 10 km long dedicated road. Maps show no development near the mine and only scattered dwellings near the other end of the access road, seemingly associated with a hydro-electric facility on the Spanish River. The closest community is Nairn (popn.459) about 11 km south of the mine. Espanola (popn.5491) is about 20 km to the southwest.

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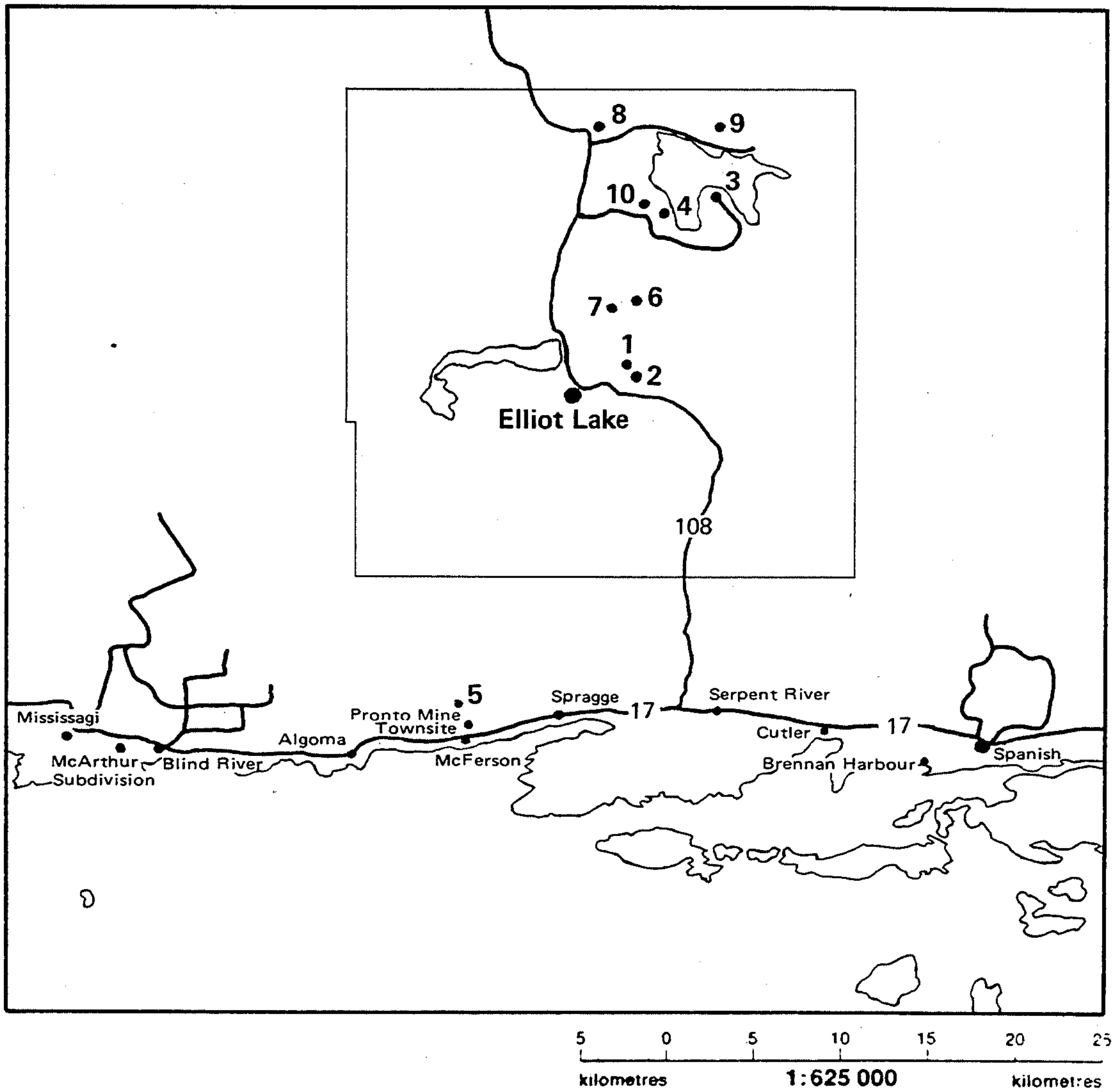
* In the interest of consistency, quantities throughout the report have been quoted in cubic metres. This has sometimes involved conversion of figures reported as a weight, using an estimate for the density. Therefore, quantities should be regarded as approximate.

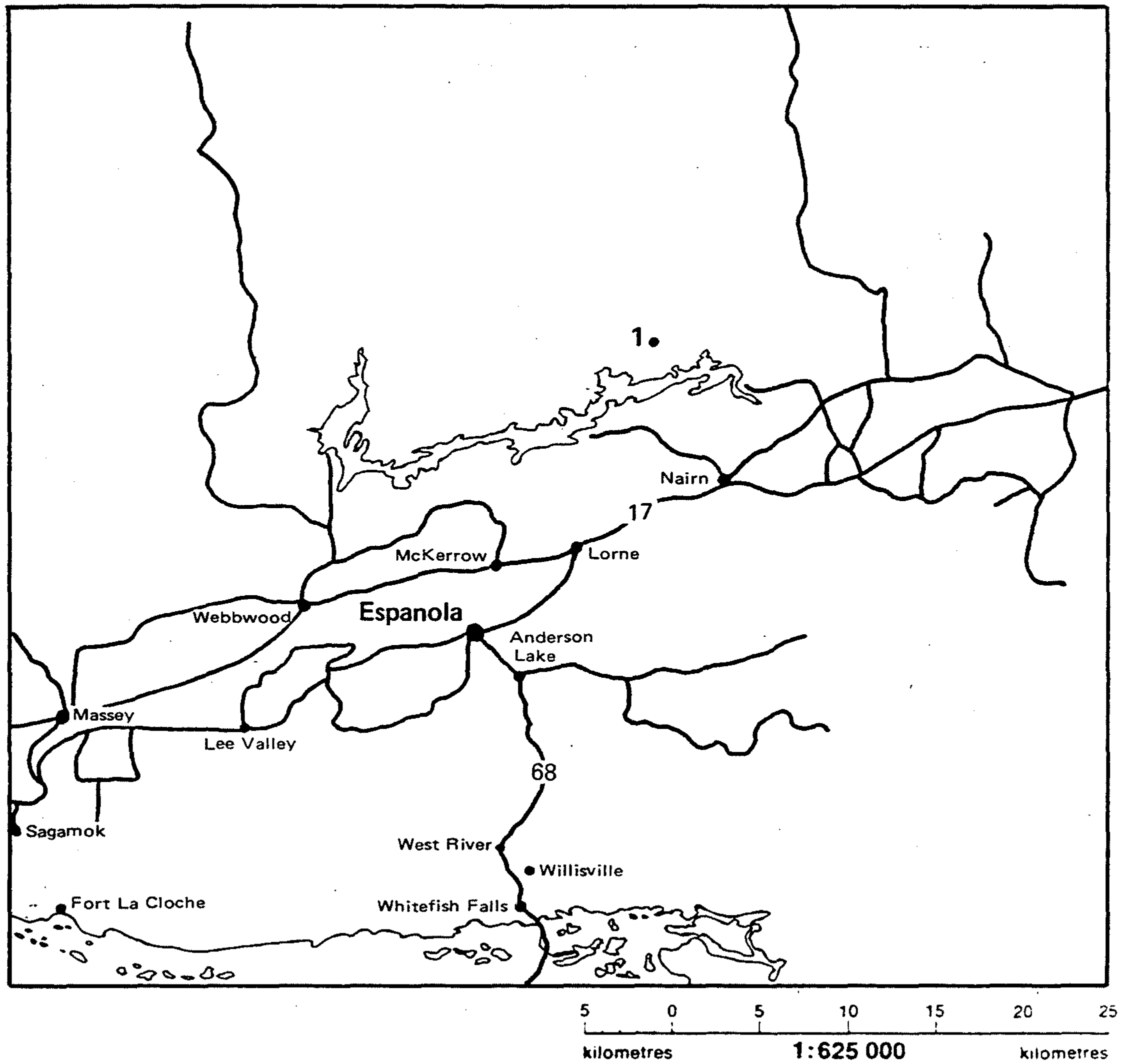
ELLIOT LAKE AREA



1. Lacnor Mine
2. Nordic Mine
3. Stanrock - Can-Met Mine
4. Spanish-American Mine
5. Pronto Mine
6. Milliken-Stanleigh Mine
7. Stanleigh Mine
8. Quirke Mine
9. Panel Mine
10. Denison Mine

Figure 3

ESPANOLA AREA



1. Agnew Lake Mine

Figure 4

Bancroft

There are six deposits of tailings resulting from four former mines in the Bancroft area. Figure 5 identifies the mines. The most recently operated mine (Madawaska Mines) closed in 1982. The tailings deposits in this region are the least remote from habitation. Although the nearest deposits are about 6 km from Bancroft (popn.2363), they are immediately adjacent to Highway 28 which has residences and tourist-related commercial establishments beside it. In fact, there is a cluster of permanent dwellings within 100 m of the Madawaska Mines deposit. The Bicroft deposits are within 2 km of the small community of Cardiff (popn.555). In addition to the scattered permanent dwellings throughout this area, there are many cottages located on lakes close to the tailings deposits; most notably on Paudash Lake and Lower Paudash Lake.

INCIDENTAL WASTES

Incidental wastes are produced by industries using raw materials containing above-average concentrations of naturally-occurring radionuclides. However, the radionuclides are either impurities irrelevant to the process or product, or have been added for a reason other than their radioactivity, such as the use of thorium to strengthen magnesium alloys in the aerospace industry. The production of incidental waste in Ontario has diminished in the last five years. Only Hawker Siddeley in Mississauga and Norton Industries in Niagara Falls generated incidental LLRW in 1986. Their waste consists of metal turnings and filter dust, respectively. It amounts to only a few cubic metres per year of new waste material.

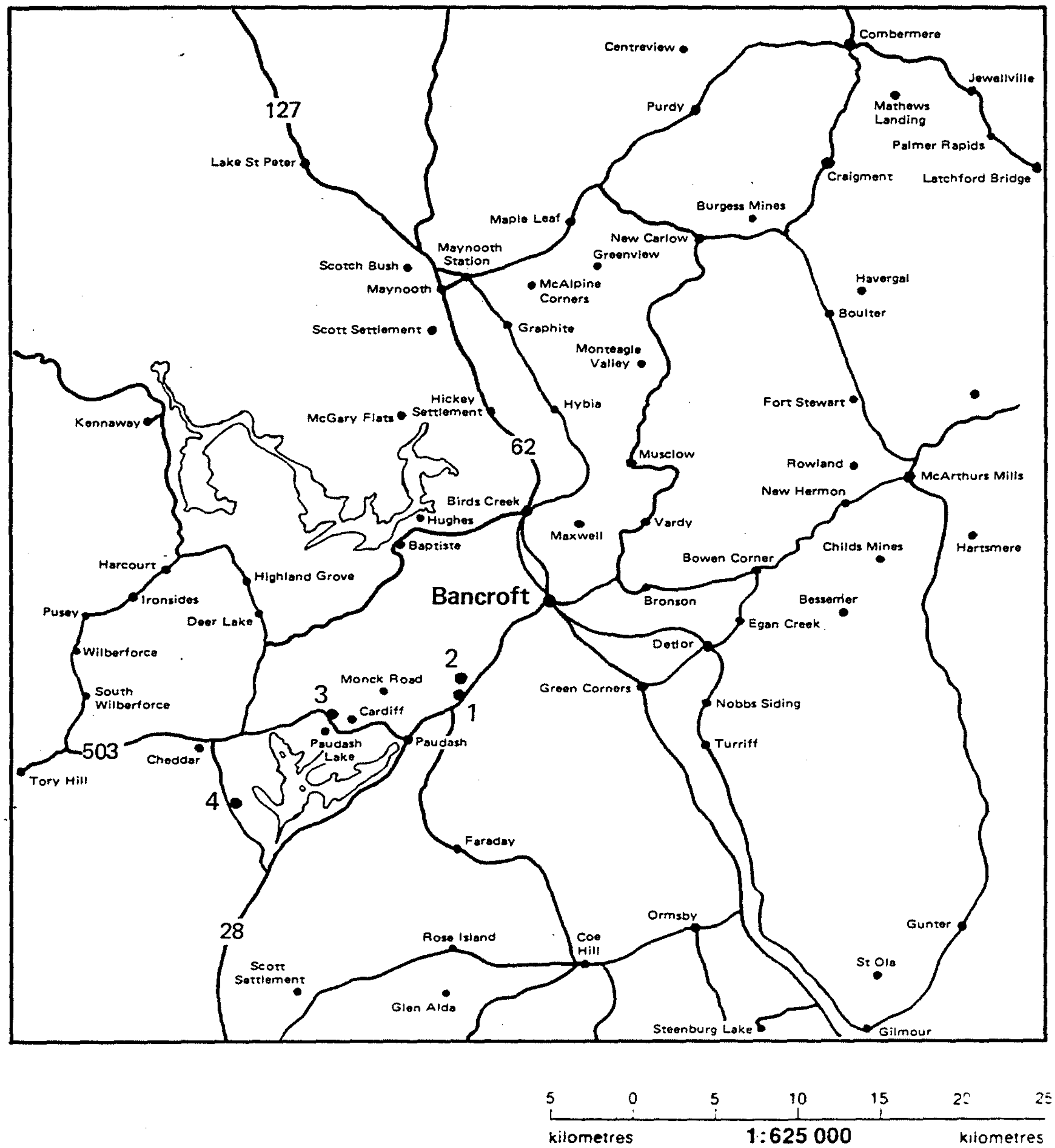
In the past, the phosphate fertilizer industry was the largest generator of incidental waste in Ontario, producing about 900,000 cu.m. per year of naturally-contaminated phosphogypsum waste. Phosphogypsum results from the chemical treatment of phosphate rock and contains low concentrations of uranium and radium, which render it unsuitable for unrestricted use. The major cause for concern is the production of radioactive radon gas from the decay of radium. Because all soils contain some radium, the air, and particularly the air in houses with basements which allow easy entry of soil gases through cracks and penetrations, contains some level of radon gas. If houses are built on materials with elevated levels of radium, or if these materials are used as fill around houses, it can result in an increase in radon levels in the dwellings. Misuse of uranium mining and processing residues in Canada and the United States has necessitated costly remedial measures (4).

All Ontario phosphate fertilizer plants are now closed. However, they could be re-activated with an upswing in the demand for their products. Most of the provincial inventory of incidental waste consists of phosphogypsum waste (14.3 million cu.m.) on two sites at Courtright and Port Maitland.

Figure 6 shows the locations of incidental waste accumulations, and Table 3 provides details on each occurrence.

In addition to the phosphogypsum producers, there are incidental waste inventories on five other industrial sites. However, these amount only to roughly a further 8,000 cu.m. Unquantified amounts of potentially

BANCROFT AREA



1. Faraday Mine
2. Madawaska Mine
3. Bicroft Mine
4. Dyno Mine

Figure 5

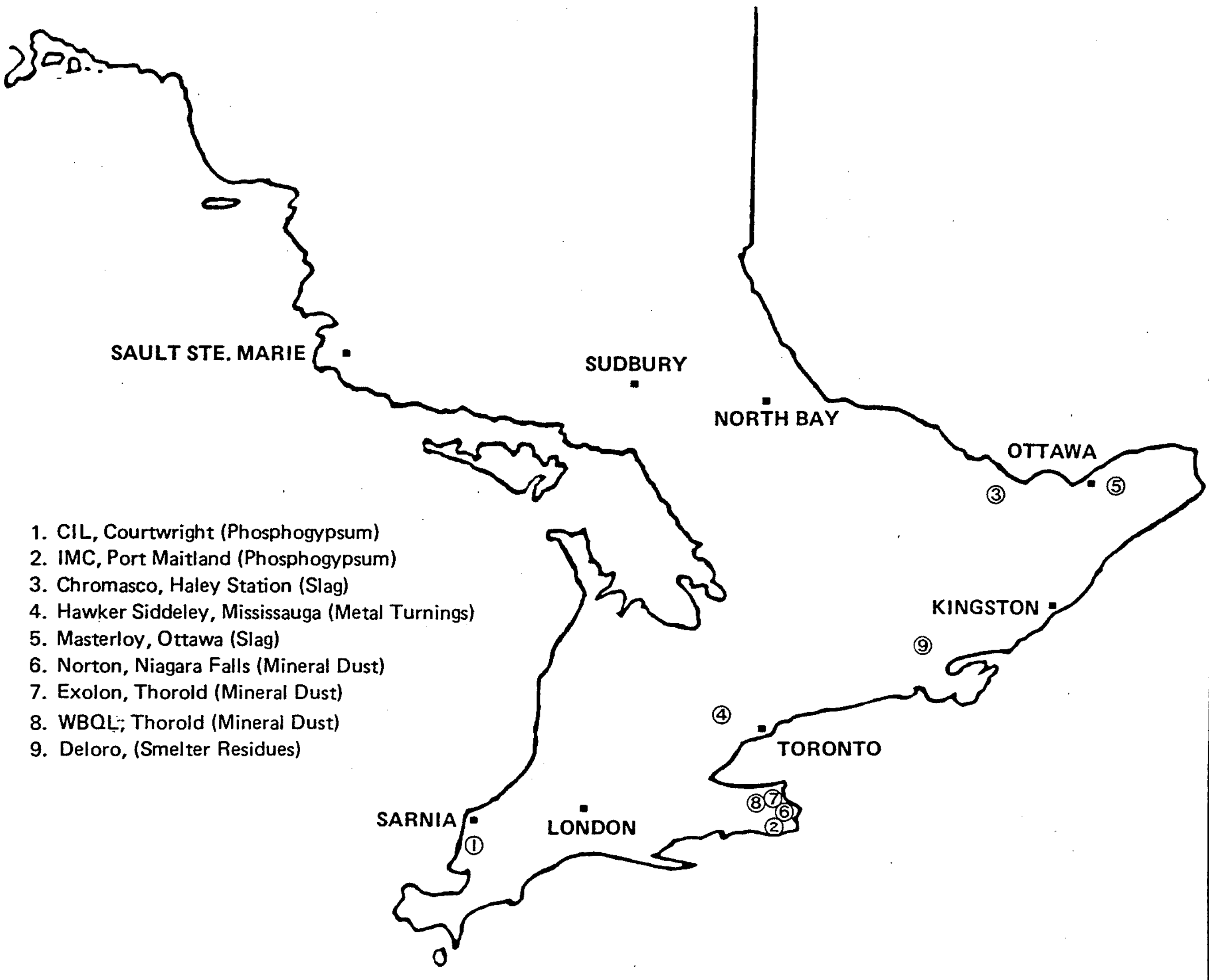


Figure 6: Locations of Incidental LLRW Accumulations

contaminated soil at some storage sites where waste is held in stockpiles could contribute further volumes if the material were to be relocated.

Some incidental wastes have been placed in an industrial waste disposal site at Thorold, and the Government of Ontario administers a site with large quantities of waste from a metal smelter at Deloro.

Phosphogypsum Management Techniques

Ontario phosphogypsum has radionuclide concentrations in the range shown in Table 3 for the CIL site. Migration of fluoride from these sites is also a source of concern.

Two techniques are used in phosphogypsum waste management. These employ wet "ponds" such as at the IMC site or dry "stacks", such as at the CIL site. For each technique, dykes are made of the waste material itself. Upon hardening and drying, dykes of this kind can contain fresh slurry material produced in the wet-process method of manufacturing phosphate fertilizer. Slurry is pumped through movable pipelines to appropriate locations in the pond or the stack. Process water can be recovered from the dyked areas for further use. With time, evaporation and sedimentation occur and the waste solidifies. Radionuclide contaminated filter cloths, which are a further waste from the manufacturing process, are also added to the disposal site.

Dry stacks are simply ponds taken to higher and higher elevations. This is achieved by constructing successive levels of dykes on top of solidified waste.

On closure of sites, clay top covers and vegetation may be established. This reduces percolation of water through the waste, reduces radon emanation and eliminates the effect of wind erosion. The water cover over the phosphogypsum in ponds or in settling areas on top of dry stacks, reduces wind erosion and radon emanation during operation of the disposal area.

Site Descriptions

Canadian Industries Limited (CIL), Courtright, Ontario

CIL operated a phosphate fertilizer operation here at its Lambton Works Site until the mid 1980's. The site is still an active industrial site. The phosphogypsum stack occupies 40 hectares and reaches heights of up to 18 metres. It has a volume of roughly 5.8 million cu.m. Agricultural land, also owned by CIL, is adjacent to the south and east of the site. The St. Clair River is located about one kilometre to the west. The village of Sombra (popn.420) is approximately 2 km to the south and Courtright (popn.1020) is 5 km to the north.

International Minerals and Chemical Corporation (IMC), Port Maitland, Ontario

The IMC fertilizer plant is located on the east bank of the Grand River near the river's mouth at Lake Erie about 1 km from Port Maitland (popn.420). The town of Dunnville (popn.5,300) is 5 km to the northwest.

Five phosphogypsum ponds are associated with the plant, three of them close to the river. The other two are south-east of the plant in an agricultural area just under one kilometre from the river.

Other land uses on the river include the ERCO chemical plant to the south and harbour-related businesses such as mooring, repair operations and scrap metal recovery from ships. There is also agriculture in the area. Rock Point Provincial Park is only separated from two of the ponds by a road.

About 8.5 million cu.m. of phosphogypsum waste had accumulated on the site up to the closing of fertilizer operations in about 1984. Plans are being developed to decommission the ponds. In the interim, surface water is being collected and treated from a 160-hectare area including the ponds and the plant property. The largest "pond" or stack occupies 40 hectares and rises about 4 metres above the original terrain. It has been covered with topsoil.

Chromasco Limited,
Haley Station, Ontario

Chromasco Limited has mined dolomite and has smelted magnesium at its site since 1942. In producing magnesium-thorium alloys during the 1960's, waste contaminated with Thorium-232 was produced for a short period.

Approximately 60 cu.m. of slag containing about 2% by weight Thorium-232 was generated. This material was drummed and placed on a waste pile on the property. A further 680 cu.m. of slightly contaminated soils from the site of this smelting operation were excavated in the 1970's and added to the same waste pile. Some cleaning and decontamination supplies used to clean up equipment were also added.

The Chromasco property consists of about 285 hectares in several parcels situated in an area of low grade farmland. A 60-hectare parcel accommodates one of Chromasco's two operating open pits, the smelter, offices and the two large waste stockpiles. One of these contains the radioactive waste, now mixed with a larger quantity of other materials. The original plant town site (known as Haley (popn.90)) is located near the smelting plant. Haley Station (popn.94) is about 1 km to the south-west. The waste stockpiles measure roughly 20 metres high, each with a base diameter of perhaps 60 metres. Approximately 90 cu.m. of non-radioactive waste is added to these piles each day of operation. The waste includes magnesium fines, calcium fines, plant refuse, and a calcium silicate cover material. The MOE monitors surface water run-off from the site and expects no environmental concerns.

Hawker Siddeley Canada Ltd.
Mississauga, Ontario

The Hawker Siddeley site is in an industrial park, located at Malton (popn.33,300) in the City of Mississauga. The company uses magnesium-thorium alloys and produces a metal turnings waste containing Thorium-232. During the 60's, on-site burial was abandoned as a waste management practice. Existing wastes were uncovered and drummed. Approximately 385 drums (75 cu.m.) have been stacked in a fenced area on the Mississauga plant site. An AECB licence for possession of this material was issued in 1979. The waste contains approximately 3.0% Thorium-232 and is still being generated at a rate of about 2.5 cu.m. per year.

Masterloy Products Ltd.
Ottawa, Ontario

Masterloy Products Ltd. manufactures metal alloys. Slag generated in the production of ferro-niobium alloys in the 1960's and 1970's is stored in a stockpile and in drums on the site. The 4,050 cu.m. of slag in the pile contains Uranium-238, Thorium-232 and Radium-226. Non-radioactive waste from other smelting processes undertaken at Masterloy were also incorporated into the stockpile. Some of these wastes contain arsenic. Slag produced after about 1974 was stored in drums and amounts to about 60 cu.m. In February 1976 production of radioactive waste ceased except for a brief period in 1979.

The Masterloy site is located in an industrial area in Gloucester. The community of South Gloucester (popn.500) is located 3 km to the south. Quarrying operations exist on three sides and other businesses in the area serve the construction industry. Arsenic contamination of soils on site has previously necessitated some soil stripping and off-site disposal (approx. 5000 cu.m.) at a municipal landfill.

Norton Research Corporation
Niagara Falls, Ontario

Norton Research Corporation produces fused abrasives and other products. A Baddeleyite feedstock leads to the generation of contaminated dust collected in air filters. The dust contains levels of uranium, thorium and radium higher than in the feedstock. Before the early 1980's, this material was disposed at the Walker Brothers Quarry Limited (WBQL) industrial landfill in Thorold. Since that time, it has been stored on-site. Some is pelletized and bagged for re-use in the waste reduction and recycling procedure adopted by the company in 1986.

The Norton site is an industrial property adjacent to a major recreation attraction (Marineland) in the community of Chippewa (popn.5400). On three sides, there is relatively little development. Manufacturing activities and private homes are situated on the final side.

Volume estimates are very approximate. About 6300 cu.m. of filter dust was sent to WBQL to the end of the 1970's. About 2700 cu.m. is now stored on-site in two metal clad buildings and a concrete silo. The waste inventory on site is not growing at present because the new waste volumes are offset by a reduction in the waste stockpile through the application of re-use and recycling techniques. Estimates of radionuclide concentrations in the waste are shown in Table 3.

Exolon Company of Canada,
Thorold, Ontario

Exolon produced a LLRW until the early 1980's in the manufacture of fused abrasives. Essentially the same waste was produced as at the Norton site discussed above. The Exolon property is located in an industrial area experiencing encroaching residential development. An old residential area is adjacent to the plant to the east. Newer sub-divisions begin 200 m to the north and 400 m. to the west. There is an estimated population of 1300 within half a kilometre of the plant.

Before 1976, wastes were stored on site. Then wastes were shipped to the Walker Brothers Quarries Limited industrial landfill site until 1982 (see below). It has recently been estimated that Exolon shipped under 3,500 cu.m. to the industrial landfill site in total and that only several hundred cubic metres remain buried on the Exolon site. No estimate is available for any soils contaminated by stockpiling of waste and raw materials, as practiced on the site during the late 70's and early 80's.

Walker Brothers Quarries Limited,
Thorold, Ontario

The site accommodates major landfilling, rock quarrying, and aggregate crushing operations. Before about 1980, the excavated west quarry was a permitted industrial waste landfill. The east quarry now accommodates on-going quarrying and a recently permitted "non-hazardous solid industrial waste" landfill operation.

Large volumes of industrial waste have been disposed of at the west quarry site and the new east quarry site has a capacity to serve industrial clients in the Niagara Region over the next 20 years. The site was used for disposal of dust from the dust collection systems in the Norton and Exolon plants. It is estimated that about 6300 cu.m. of this material came from the Norton plant and less than 3500 cu.m. originated from the Exolon plant.

All LLRW was deposited in the now closed west quarry. It was spread evenly over the dumping area and covered daily according to AECB recommended practice at the time. A clay top cover now seals the landfill. The LLRW is, therefore, mixed with a large volume of other wastes and cover materials. Readings of radiation levels at the surface are not above background.

Neighbouring the site, one finds rural and open space land uses. The old Welland ship canal passes the site on the west, as do Niagara Escarpment lands on the north. Few residences are nearby.

Deloro, Ont.

In the late 1800s, gold and arsenic were mined in the Deloro area, and in 1907 silver and arsenic were produced in a newly built refinery in Deloro. The first commercial cobalt smelter in the world was established at Deloro in 1914. It processed a variety of minerals from a variety of sources until the plant closed in 1961. Included in the operations was the smelting of refinery residues from the Port Hope area, which were shipped to the smelter in 1951-52 and in 1959-60. The waste from the smelter is in the form of a slag. There is an accumulation of about 100,000 cu.m. of slag, but this has contaminated an additional 300,000 cu.m. of soil. It is estimated that only 1800 cu.m. of residues were relocated from Port Hope. There is evidence of radioactive contamination over a wide area of the site. It is not clear that radioactive wastes came from other sources, but this possibility cannot be ruled out. When the smelter closed, tons of arsenite refuse were buried on the site.

The site is immediately adjacent to the Moira River and has been a source of contamination of the river by leachate. However, the primary concern regarding the leachate is its arsenic content. A leachate collection and arsenic removal system has been installed and is operated by the Ontario MOE. Consequently the Deloro waste problem could be regarded as an arsenic-containing waste problem, with a relatively small, although widely dispersed, fraction also contaminated by radioactive constituents. The site is in close proximity to the small community of Deloro (popn. 161). At the time of the AECB cleanup activities, one house very close to the slag was found to have high concentrations of radon daughter products and high gamma fields. The family was moved and the house was demolished. Radon reduction work was performed on three other houses, although the source was probably natural.

LOW-LEVEL WASTES FROM NUCLEAR ENERGY AND RADIOISOTOPE PRODUCTION AND USE

Low-Level radioactive wastes from the development and use of nuclear energy are found in and near Port Hope as a result of refining and processing of uranium, at the Bruce Nuclear Power Development, where Ontario Hydro operates storage facilities for low-level wastes from all of its nuclear installations (except the NPD reactor at Rolphton), and at Chalk River Nuclear Laboratories (CRNL) where AECL has similar storage facilities for the wastes produced in its nuclear research activities and from the operation of its own research reactors and the NPD reactor.

Some of the wastes in the Port Hope area pre-date the uranium industry and are derived from the extraction of radium in the 1930s and 1940s. Radium was used as a radiation source for medical treatment and to produce luminous paint for watch and instrument dials. Similarly, some of the wastes at Chalk River result from applications other than the development of nuclear energy. AECL is a major international supplier of man-made radioisotopes for cancer treatment, medical diagnostics, research and industrial applications, such as sterilization of medical supplies and radiography of welds and aircraft structures. Some of these radioisotopes are produced by irradiation of sources in AECL's reactors, followed by processing to purify and package them in facilities at Kanata. The wastes produced during processing are returned to CRNL for storage. CRNL also accepts, for a fee, wastes resulting from the use of radioisotopes by some of the 5000 licensed users in Canada. Wastes resulting from the fabrication of nuclear reactor fuel are also consigned to CRNL.

An additional location of wastes in this category is Scarborough, where 40 residential properties are contaminated with wastes derived from the use of luminous paint and from the use of radium refinery residues for experimental purposes. These various locations are identified on Figure 7 and the information on these wastes is summarized in Table 4.

Port Hope Area

History of Port Hope Operations

Eldorado Resources Limited's uranium processing facilities are located at Port Hope, on the north shore of Lake Ontario. There have been operations at this location since 1933.

Initially, the plant processed high-grade uranium ores to recover radium. A by-product of the refining process was uranium oxide, and, with increasing interest in nuclear energy, the emphasis switched to uranium production. By 1942, uranium extraction from ores had become the primary process and radium refining ceased in 1953. The radium circuit was dismantled in 1955, and replaced by a uranium refining circuit, which processed uranium concentrates (yellowcake) rather than uranium ores. This changed the characteristics of the wastes produced, because most of the impurities in the ore (including arsenic and radioactive elements other than uranium) then remained with the uranium mill tailings at the mine sites. In 1970, a production facility was added to convert refined uranium oxide to uranium hexafluoride for export. The hexafluoride conversion facility was expanded in 1983, and the uranium refinery was shut down, as this process is now carried out at a new Eldorado refinery in Blind River, Ontario. Since the feed material to the Port Hope plant is now refined uranium, the only significant radioactive contaminant in ERL's current wastes is uranium, without its radioactive daughter elements. Processing wastes from the Blind River refinery are in the form of a sulphuric acid solution which is recycled to a uranium mill at Elliot Lake. The sulphuric acid is a useful reagent in the milling process, and the impurities from the refining process are returned to the tailings from the mill. A small amount of ash, from the incineration of plant trash, is stored at the refinery.

From 1933 to 1948, wastes from the Port Hope operations were deposited at several sites within the town of Port Hope. These sites were replaced in 1948 by the Welcome Waste Management Facility in Hope Township. Disposal at Welcome continued until 1955, when ERL's currently operating Port Granby Waste Management Facility was opened in the Town of Newcastle. Materials at some of the Port Hope waste sites were relocated to Port Granby.

Eldorado Port Hope Plant

Since 1977, a magnesium fluoride waste has been stored at the Port Hope plant in 210 L drums. The waste results from the production of uranium metal and contains several percent uranium. The current volume of this waste is about 2,500 cu.m. It may eventually be recycled. The storage building is located on ERL property on a central earthen pier separating Port Hope Harbour from the Ganaraska River. When the plant refined

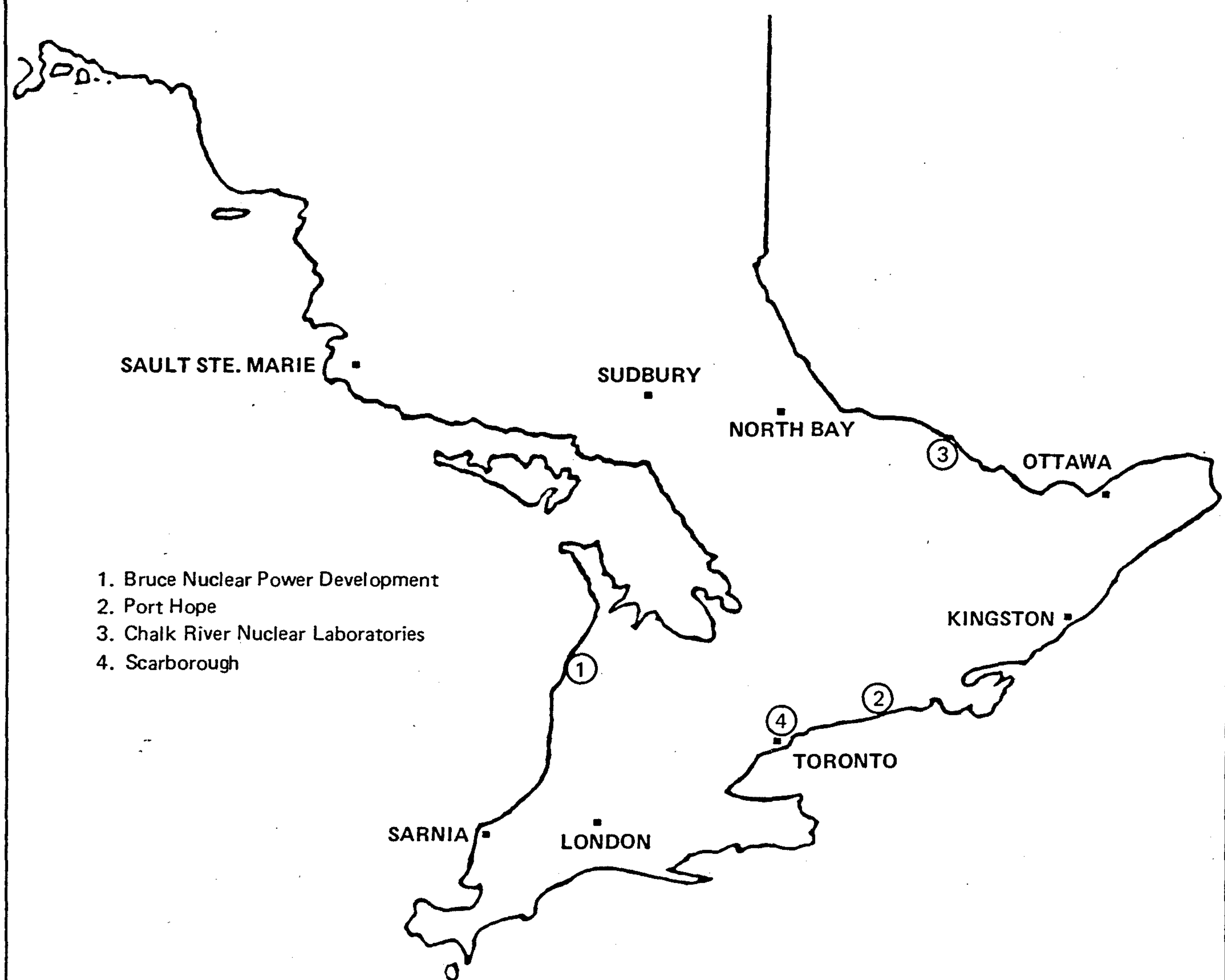


Figure 7: LLRW Accumulations from Nuclear Energy and Radioisotope Production and Uses

uranium from yellowcake, the acidic solutions, which are now recycled from the new Blind River refinery, were neutralized with lime to precipitate the impurities. Some of these "limed-raffinate" residues are stored at the plant, but are gradually being recycled.

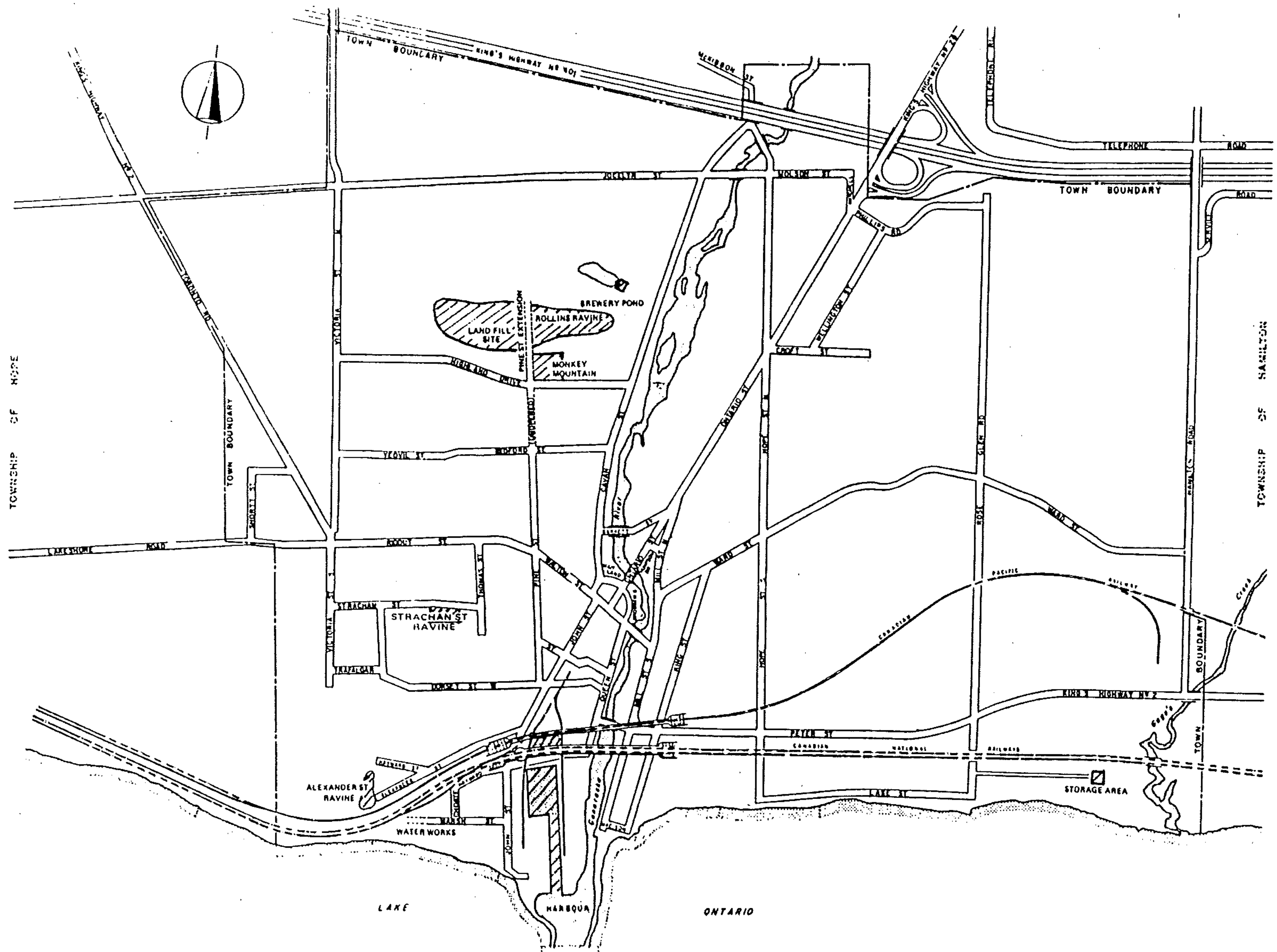
The Town of Port Hope

During the early period of operations of the Port Hope plant in the thirties and forties, the need to exercise care in waste management was not as well recognized as it is today. Wastes were dumped at several locations around the town, and were used as a convenient source of fill material during construction and landscaping activities. Those wastes which represented a more immediate source of hazard were removed from around residential, public and commercial buildings during cleanup activities conducted by the AECB in the mid- to late 1970s. However, waste deposits were left at less accessible locations in the town and, because the AECB used a specific set of cleanup criteria, low levels of contamination remain on many properties throughout the town.

Figure 8 is a map of the town with the major occurrences identified. Wastes are found beneath the municipal landfill site and at the bottom of the town's harbour. Three steeply-sloped, heavily-wooded ravines have had waste dumped over their sides. An open area, known as Monkey Mountain, formerly used for waste storage is still contaminated even though most of the waste has been removed. Soil is contaminated at the water treatment plant and wastes, some of which are thought to have been dredged from the harbour, have been dumped on open, grassy ground between the two railway lines north of the harbour. A waste storage site is adjacent to the sewage treatment plant, close to Lake Ontario, at the east end of town. Brewery pond is a scenic man-made feature just west of Cavan St. and north-east of the municipal landfill. The dam which forms the pond has been constructed partly from radioactive wastes, and the overflow from the dam flows through a waste deposit behind the dam and thence to the Ganaraska River. Some details concerning these major waste deposits are presented in Table 5. It is estimated that an additional 69,000 cu.m. of contaminated soil may require removal from a large number of occurrences at smaller sites throughout the town. There is little control over the Port Hope wastes and they are exposed at the surface in many locations.

Any cleanup activity raises the question of how clean is clean. The volumes presented in Table 5 are estimated for two levels of residual radium contamination. The lower, 0.44 MBq/cu.m., is the level to which Eldorado conducted cleanup around the Welcome site. Clearly, the number of questionable properties and the volume of material to be excavated increases rapidly the closer one approaches background. This is illustrated by Figure 9 which has assigned each property in Port Hope to a category based on the highest radiation level recorded on the property. The appropriate level of cleanup may vary between, say, the harbour, the municipal landfill and actual or potential residential properties.

The dominant contaminants of the Port Hope area wastes are uranium, arsenic, thorium, radium. The harbour contains a spectrum of other heavy metal contaminants, above the limits for lake disposal of dredging



TOWN OF PORT HOPE (Not all streets shown)

Figure 8: Location of Major Waste Deposits in Port Hop..

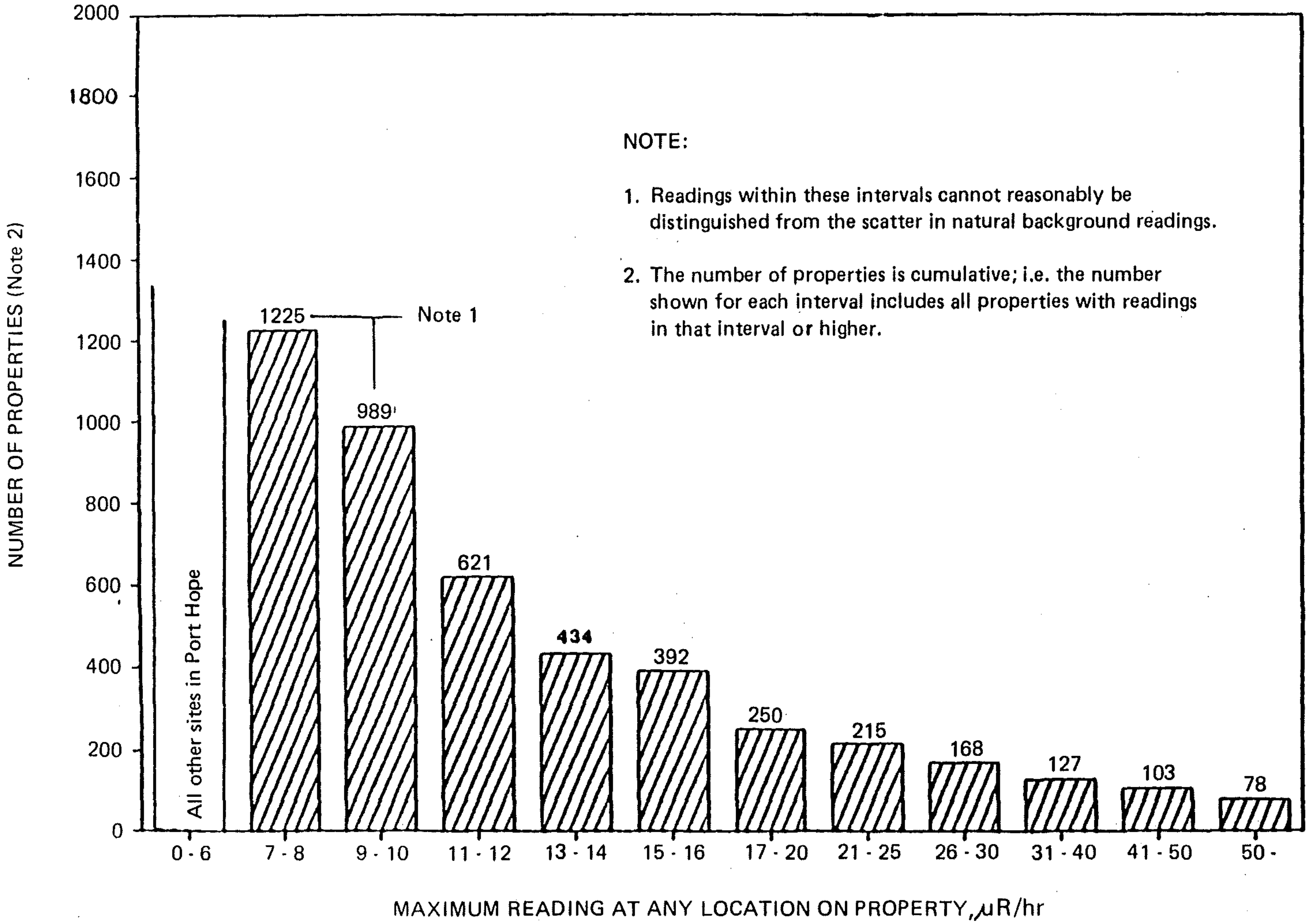


Figure 9: Effect of Clean-up Criteria on Number of Properties Requiring Clean-up

spoils, and some PCBs. A typical analysis of the sediments is presented in Table 6. The municipal landfill contains household refuse and other industrial wastes as well as refinery process residues. Investigations to date have not identified major quantities of other hazardous wastes, but it is reasonable to assume that there is an inventory of heavy metals and perhaps organic chemical wastes typical of a small urban refuse dump operated over the last forty years. A typical analysis of leachate from the vicinity of the garbage dump is presented in Table 7.

The physical characteristics of Port Hope wastes are very variable. The excavated wastes would include sediments from the harbour, sandy soils, contaminated refuse, and vegetation from the stripping of contaminated open spaces, ravines and residential properties. Some of the wastes are cinders, others are ashes or process residues. Large amounts of foam rubber are mixed with the wastes at the municipal landfill.

Welcome Waste Management Facility (5)

The Welcome Waste Management Facility is located about a kilometre northwest of Port Hope and immediately south of Highway 401, in Hope Township; see Figure 10. The L-shaped, 36-hectare site is bounded by township roads on the west and east, and by agricultural land to the south. Northeast of the site is an auto wrecker on land which was formerly a gravel pit. Land usage in the general area is agricultural. The nearest population centres are the village of Welcome (popn.293) and the town of Port Hope (popn.10281) each about 1 km away.

The fenced property slopes gently from its highest point on the southeastern boundary towards the northwest. Wastes are buried in a 5 ha. inner fenced area in the southeast portion of the site. A water collection and treatment facility is located in the northwest portion of the site. Although it has not been in active use since 1955, the site is licensed by the Atomic Energy Control Board under a Waste Management Facility Operating Licence first issued in 1978.

The volumes and general characteristics of the wastes stored at Welcome are shown in Table 8. The pre-1955 processing circuit generated two principle residues: iron residue from uranium recovery operations and carbonate residue from radium recovery operations. The iron residue is a mixture of insoluble metal carbonates (iron, cobalt, nickel, etc.), while carbonate residues contain silica, trace amounts of radium and other impurities. Typical compositions of these residues are shown in Table 9 (6). From the data shown, it is apparent that a number of metals, including uranium, arsenic, cobalt, copper, iron, nickel and zinc are present at concentrations of 0.3 to 10%. ERL quotes a volume of 267,000 cu.m., which includes a 20% contingency to allow for uncertainties in excavation. Because contingencies have not been included in estimates of other wastes, they have been dropped from the ERL figures in this report. Separation of wastes from contaminated soil is not considered by ERL to be feasible.

Limestone bedrock at the site is overlain by a sand and till deposit formed by glacial action. The uppermost layer consists of sand and gravel, up to 11 m thick in the waste burial area. Groundwater and

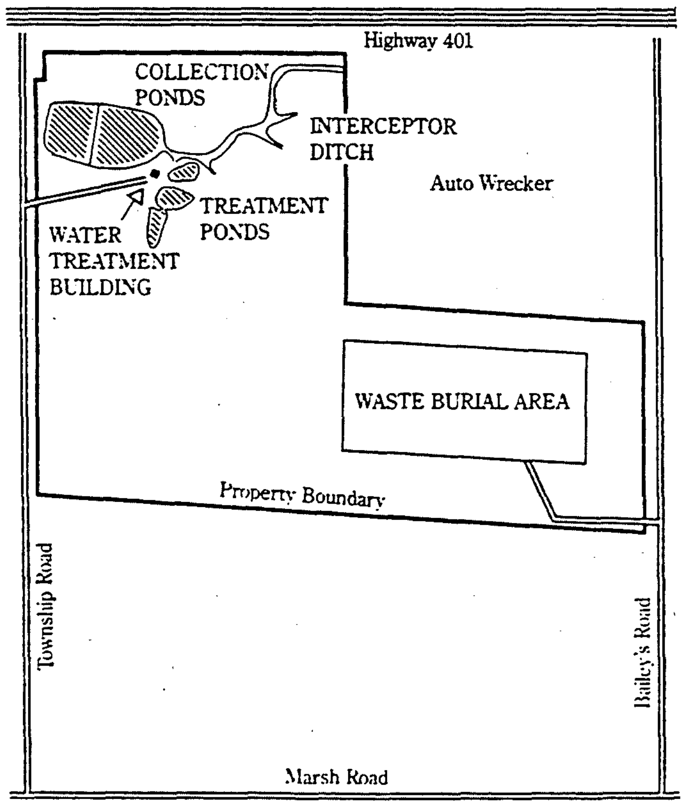


Figure 10: Eldorado's Welcome Waste Management Area

surface run-off at Welcome generally flow in a north westerly direction. The groundwater flow is mainly horizontal through the upper shallow sand and gravel layer; vertical flow below this layer is limited due to the relatively impervious nature of the underlying till.

Ditches around the perimeter of the burial area direct surface run-off towards the northwest. Surface and groundwater are intercepted there by a large ditch, which leads to the collection and treatment ponds. This system was expanded in 1986, to improve the collection of groundwater (estimated now at >95% of the groundwater plume) and to prevent overflow of the collection ponds during heavy rainfalls.

Most of the wastes were initially placed on the ground surface. Most of these exposed wastes were covered with clean fill and vegetated in 1969, and additional cover was added in 1981 and 1982. During the 1984-86 period, ERL cleaned up areas with low-level contamination around the site, the result of wind and water erosion during its early years of operation. The excavated soils were added to the burial area which was then contoured and vegetated.

Port Granby Waste Management Facility (7)

The Port Granby waste management facility is located on the north shore of Lake Ontario about 16 km west of Port Hope. The 17 hectare, fenced site is bounded on the east and west by agricultural land, and on the north by a municipal road and then agricultural land. Land usage in the general area is agricultural. The nearest population centres are the villages of Port Granby (popn. approx. 20) at a distance of ~1 km, and Wesleyville (popn.16) at ~3 km distance.

The property consists of a relatively flat plain, referred to as the Central Plateau, which terminates abruptly in steep bluffs falling about 35 metres to the shoreline. Two deep valleys, referred to as the East and West Gorges, cut through the bluffs on either side of the site and extend about 170 metres into the Central Plateau. Wastes are buried in the Central Plateau between and to the north of the East and West Gorges, and in the gorges. Run-off and groundwater are collected in two reservoirs at the base of the gorges, and are pumped to a water treatment facility north of the buried wastes. The site is licensed by the AECB under a Waste Management Facility Operating License first issued in 1976.

Most of the waste materials at Port Granby were produced after 1955, when relatively low-radioactivity and low-arsenic uranium concentrates were processed at the Port Hope plant. The volumes and characteristics of these wastes are given in Table 8, and a plan of the site is shown in Figure 11. The location of the Welcome and Port Granby sites relative to Port Hope is shown in Figure 12.

Limestone bedrock at the site is overlain by numerous layers of sands, silts and tills deposited by lake and glacial action. The wastes are buried in pits, 10 to 12 metres wide and of variable length, in the uppermost sandy layer. The pits are excavated down to the water table, generally five to six metres below the ground surface.

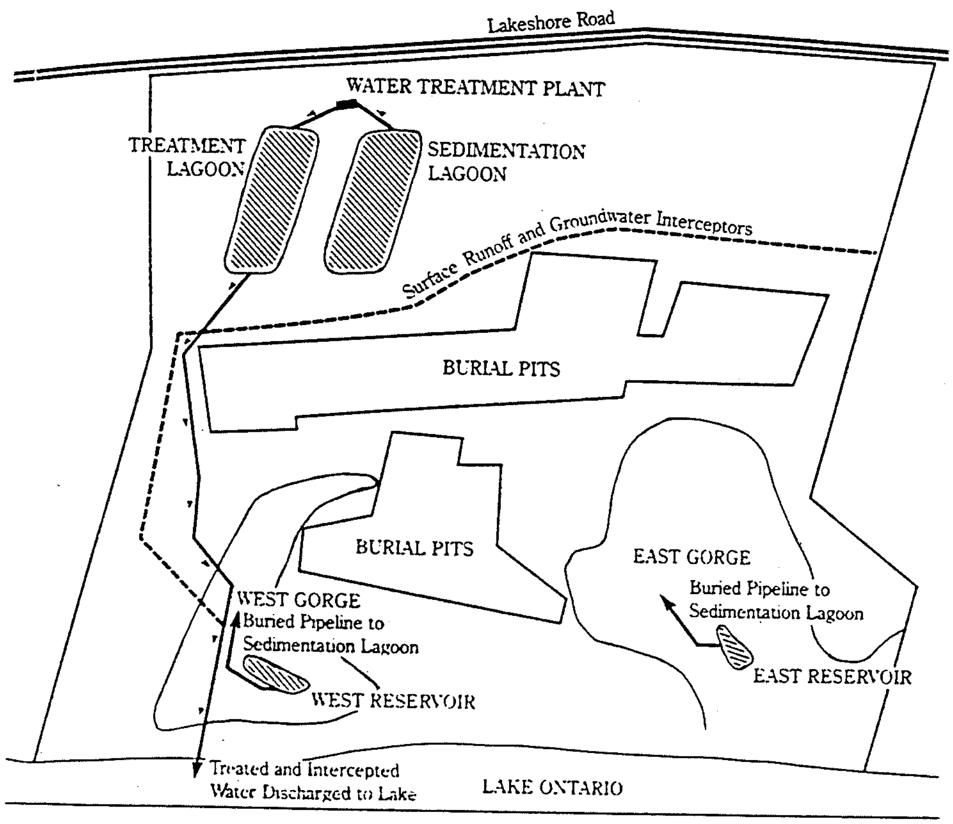


Figure 11: Eldorado's Port Granby Waste Management Area

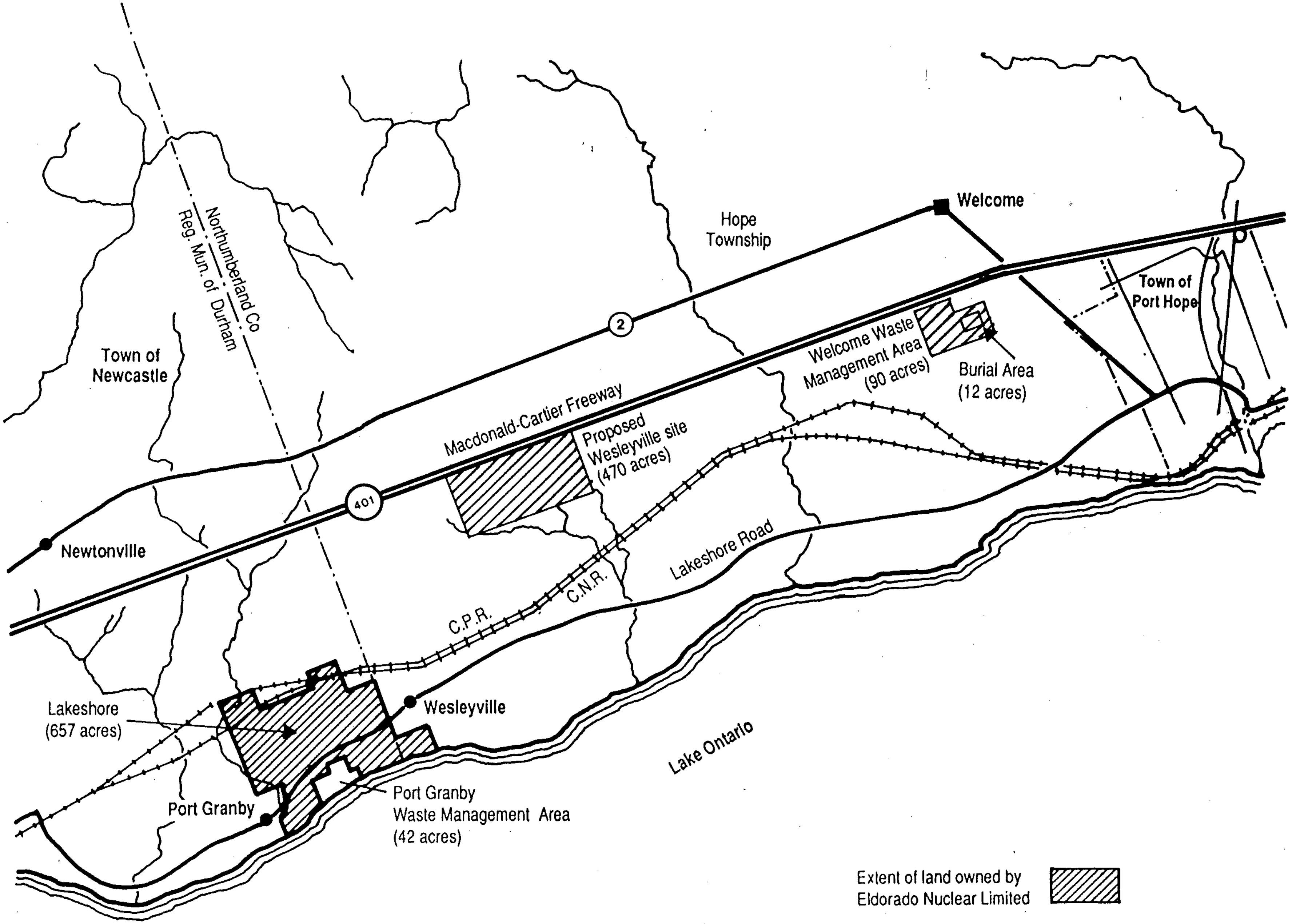


Figure 12: Map of Port Hope Area

Surface run-off and groundwater at the site flow towards the lake. Groundwater that emerges as seepage into the gorge, and surface run-off, are collected in the east and west reservoirs and pumped to the water treatment facility. Groundwater from a lower sandy layer is not collected; however, regular monitoring of this groundwater shows that an intermediate till layer effectively prevents the infiltration of contaminants from the wastes.

Long-term erosion of the bluffs could expose the wastes. ERL have developed a contingency stabilization plan should this threaten to occur before the site is decommissioned.

Chalk River Nuclear Laboratory

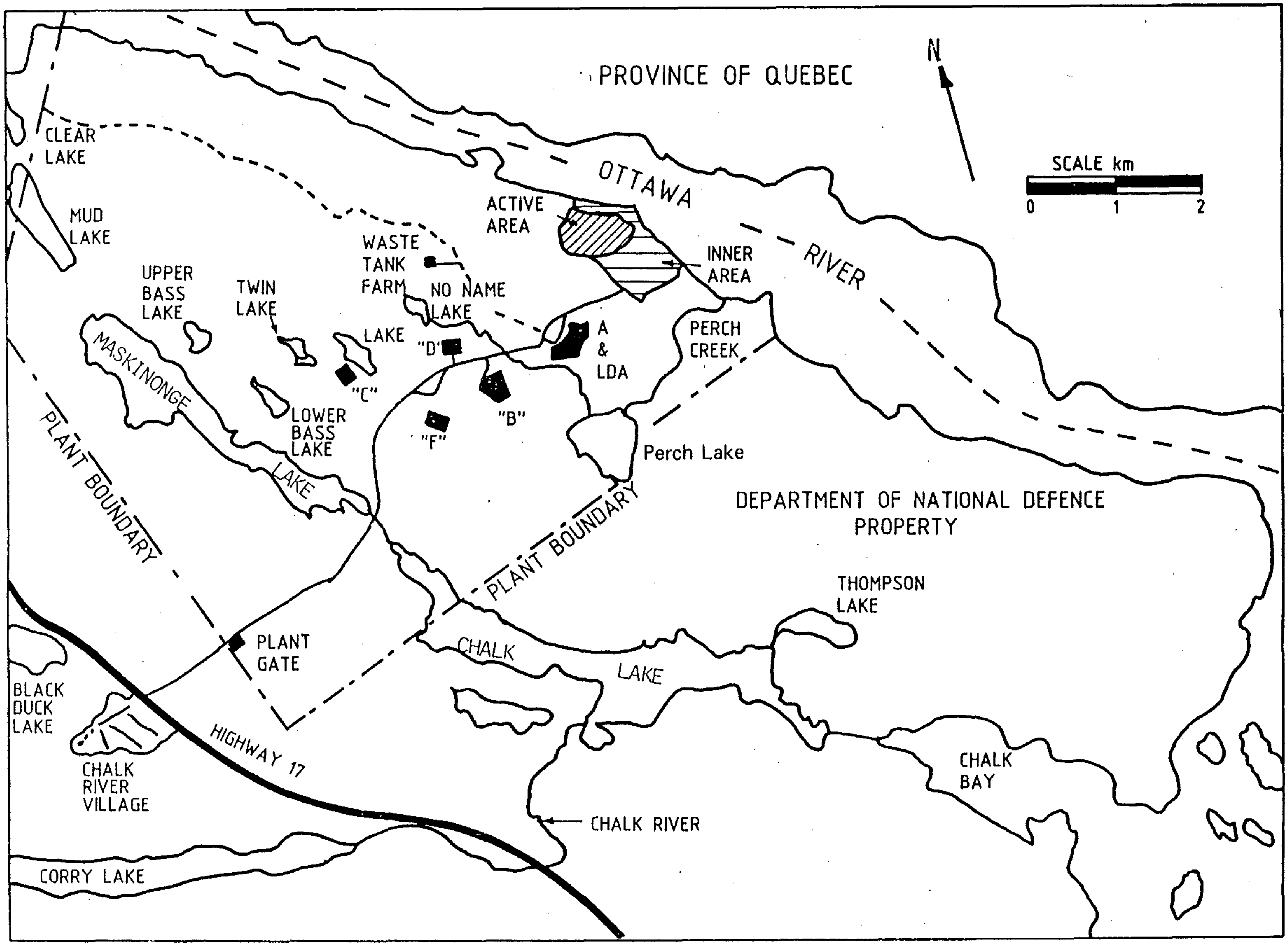
Summary of CRNL Operations and Site

CRNL is located on the south shore of the Ottawa River, between Deep River and Pembroke, about 160 km northwest of Ottawa. Atomic Energy of Canada Limited (AECL) has been operating research facilities, for the development of nuclear power and radioisotope uses, continuously at the site since 1946.

The area of the CRNL property is 3700 ha and it extends about 6 km back from the river. This restricted access area is composed of an Outer Area, and a much smaller Inner Area close to the river. Guards maintain site security on a 24-hour basis. A separately fenced Active Area, containing most of the nuclear facilities, is contained within the fenced inner area. Major facilities include four research reactors, shielded facilities with remote handling tools for examining and testing highly radioactive materials, other laboratory and maintenance facilities where slightly radioactive materials are handled, and a waste treatment centre. The remaining laboratories and support facilities are located in the inner area but outside of the active area. The LLRW and industrial wastes generated by operations at the site, and LLRW received from off-site, are stored or buried in several fenced-in monitored locations in the outer area of the site. These are collectively known as the Waste Management Areas.

Figure 13 shows the CRNL plant property, the locations of the various waste management areas within the property, and the immediately surrounding area. The surrounding terrain, except for the Laurentian Mountains across the Ottawa River, consists of gently rolling hills, interspersed with many small lakes. The land is covered by forest of relatively small commercial value, and is used little for agriculture. The Petawawa Military Reserve abuts the CRNL area along the southwest side.

The population surrounding CRNL live either in Renfrew County, Ontario, which has a widespread population of approximately 88,000 people, or in Pontiac County, Quebec, a sparsely populated area with about 20,000 people. The nearest population centres to the CRNL inner area are Chalk River (popn.1000, 7 km), Deep River (popn.5100, 10 km) and Petawawa township, village and military base (popn.20,000, 20 km).



Plan of the CRNL Property and the Surrounding Area

CRNL Waste Management Areas (8)

The CRNL property consists of gently rolling hills (mainly bedrock outcrops), interspersed with several small lakes and marshes. In many areas between outcrops, pockets of glacial till and sediments are covered by extensive sand deposits which, particularly at higher elevations, drifted into deep dunes before vegetation stabilized the topography. The water table in elevated dune areas is usually several metres below the surface. Existing waste management areas, occupying a total of about 20 ha are located in these well-drained sandy uplands.

Radioactive solid waste is monitored and segregated for consignment to various storage facilities based on radiation fields, and the type of radionuclides contained. Wastes containing significant quantities of radioactivity are stored in engineered facilities, most of which are concrete bunkers, with lined holes set into the ground being used for the highest radioactivity fraction. These are located in Area B, above the water table in free draining sands. Wastes with lower radioactivity content are buried in trenches in the sand at Area C, with the trench bottom above the water table. LLRW received from offsite is similarly segregated and stored. Area D has an open area used for equipment storage, and a storage building operated by CRNL for the Low-Level Radioactive Waste Management Office. Other operational waste management areas are a waste tank farm for interim storage of liquid wastes to be solidified, and a liquid dispersal area where water with low contamination levels has been discharged to dispersal pits. The liquid dispersal area will be phased out as the Waste Treatment Centre becomes fully operational, and will then only function as a backup in the event of unavailability of the treatment centre.

There are two shut down waste management areas at CRNL. Area A was used for trench burial of LLRW during the initial years of site operation. Contaminated water, from the NRX accident in 1952, was dispersed into the ground at Area A, and two experimental disposals of acidic liquid waste were made to this area in 1954 and 1955. Area F was operated from 1976 until 1979 and contains wastes and associated soil contaminated with natural radionuclides from the AECB cleanup activities in Port Hope, at two industrial sites in Ottawa and at a farm in Mono Mills where wastes from the use of radium had been deposited. Tables 10 and 11 provide a more detailed description of the CRNL waste management areas and their inventories.

There have also been a number of special emplacements of wastes into the sand, or into storage facilities designed for a specific waste, during the 1950's, 1960's and early 1970's. Contaminated equipment, pipes and the damaged NRX calandria from the 1952 NRX accident are buried in Area A. Area B contains several types of special storage facilities, ranging from concrete monoliths to steel standpipes, as well as individual items of equipment including the calandrias replaced in NRX in 1970 and NRU in 1973. Additional areas used for specific burials are listed in Table 11 together with shutdown waste management areas.

Table 12 provides a summary of waste arisings at CRNL, and from offsite, for 1986. The total volume of waste handled was about 3,900 cu.m., about 60% of which originated from CRNL or was classed as AECL intersite waste.

Surface water run-off and groundwater flow from the waste management areas discharge to either the Perch Lake drainage basin or the Maskinonge Lake drainage basin, on CRNL property. Outlet flow from these lakes is to the Ottawa River by small creeks.

Groundwater contaminant plumes, from dispersal of liquid wastes, or leaching of contaminants from solid wastes, have been extensively studied and surface waters are routinely monitored. At current rates of movement, the radioactivity of the contaminants will have decayed to insignificant amounts before reaching surface waters leading to release to the Ottawa River. Current plans for these areas are thus to continue to monitor and track plumes, control access, and monitor releases. In the long term, it will be necessary to determine what action, if any, must be taken to redesignate the areas as disposal situations.

Bruce Nuclear Power Development (BNPD)

Summary of BNPD Operations and Site

BNPD is located on the east shore of Lake Huron, near Kincardine and Port Elgin, about 220 km northwest of Toronto. Ontario Hydro has been operating facilities at the site since 1963, when construction of the Douglas Point reactor began.

Major facilities at BNPD include three nuclear electric generating stations (Douglas Point, Bruce A and Bruce B), three heavy water production plants and support facilities. The latter include two radioactive waste storage sites, which are used to store LLRW from all Ontario Hydro reactor stations, except NPD, and from their research and maintenance facilities. The Bruce Energy Centre is an agricultural and industrial development, adjacent to the BNPD site, planned to take advantage of the opportunities for expanded use of existing steam production.

The area of the BNPD property is about 1000 ha, and it extends about 2.5 km back from the lake. Figure 14 shows the site layout, including the locations of the waste storage sites, and the immediately surrounding area. The property is bounded to the south by Inverhuron Park, a day use provincial park, and to the east by land being developed for the Bruce Energy Centre. The immediately adjoining land to the north is wooded and is used for scattered residences and seasonal cottages. Land use in the surrounding area is classed as either vacational (along the shoreline) or agricultural (inland). Land at the BNPD site is considered sub-marginal cropland and poor pasture. Apart from the employment and industrial development associated with BNPD, tourism is the major industry in the area.

Approximately 900 people live within 8 km of BNPD, and 40,000 within about 40 km. The latter total includes 25,000 in 10 towns and villages,

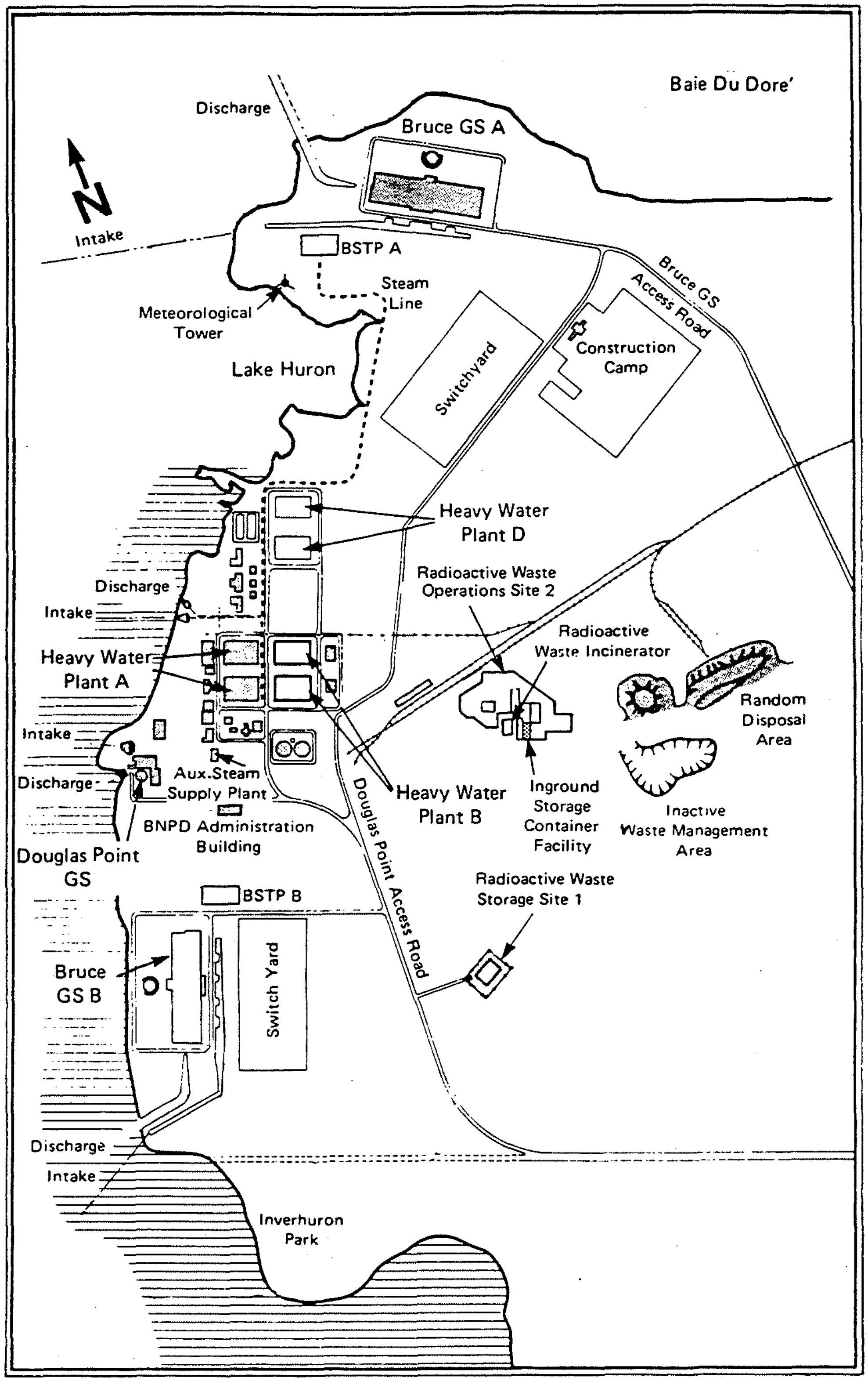


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Figure 14: Plan of the BNPD Site

of which the closest to BNPD are Tiverton (popn.752, 8 km), Kincardine (popn.5930, 16 km) and Port Elgin (popn.6159, 20 km).

The dolomite and limestone bedrock in the BNPD area is generally overlain by layers of dense glacial till, consisting of sandy silt with a trace of clay, with small gravel cobbles and boulders in some parts. These are in turn overlain by recent beach deposits composed of sand, gravel and cobbles with boulders. The area is relatively flat to gently rolling.

Radioactive Waste Storage Sites (9)

Site 1 comprises about 0.6 hectares, and was developed to receive wastes from the Douglas Point reactor. No new waste has been added since November 1976.

Site 2 comprises about 8 hectares, and was developed as the central waste processing and storage site for Ontario Hydro nuclear stations. Operations started in 1975 and are ongoing. Above ground and in-ground engineered storage facilities are constructed in stages, with the current (November 1986) storage capacity being about 20,000 cu.m. The different types of facilities and their inventories are listed in Table 13.

Surface water and ground water are extensively monitored. Drainage collection systems direct surface water to monitoring stations. A sub-surface drainage collection system collects groundwater adjacent to the storage structures, and directs it to monitoring stations. Water sampling holes around the storage sites are also used to monitor general groundwater flow.

The variation in radioactivity concentration is evident in Table 13 which demonstrates that most of the radioactivity is in only a small fraction of the waste. For example, during the third quarter of 1986, 1,520 cu.m. of waste were received. About 67% of the volume (1,018 cu.m.) was incinerable, and had an average radioactivity concentration of <37 MBq/cu.m., corresponding to <0.02% of the total radioactivity inventory for the quarter. Even after incineration, the radioactivity concentration of the ash is <3.7 GBq/cu.m. A further 31% (474 cu.m.) was either compactible or non-processible, and had an average radioactivity concentration of <3.7 GBq/cu.m., corresponding to <1% of the total radioactivity inventory. Of the remaining approximately 2% of the total volume (29.4 cu.m.), 28.4 cu.m. consisting primarily of resins and filters, had an average radioactivity concentration of about 0.6 TBq/cu.m., corresponding to about 26% of the radioactivity inventory and 1 cu.m. (<0.1% of the total volume), consisting primarily of non-processible waste, had an average radioactivity concentration of about 44 TBq/cu.m. contributing about 73% of the total radioactivity.

Scarborough

The historic wastes in Scarborough derive from incineration of materials containing radium, mainly from the use of luminous paint, and from the use of radium processing residues for agricultural experimentation. These activities took place on what was then a small farm. Although the intent of the incineration was to recover the ash for recycling of the radium, the technology employed was primitive and resulted in dispersion of some of the ash. These activities took place in the 1940s, and the entrepreneur responsible is dead. The federal government has accepted responsibility for disposal of these wastes under an agreement with Ontario.

The farm property was developed as low-income housing in the 1970s and the waste were further mixed with soil and dispersed. Extensive survey work has been performed and 40 contaminated residential properties have been identified. The contamination ranges from just marginally above background to levels which result in readings above 100 uR/hr at one relatively small area. On several of the properties the contaminated soil has been buried during development, and no surface readings above background are apparent. The concentrations of radon and radon daughter products in the housing are not elevated relative to a control sample of houses in other parts of the city.

The removal of all contamination from the properties will require the disposal of an estimated 3,300 cu.m. of soil. Radium is the principal contaminant, and the average concentration has been estimated as less than 2 MBq/cu.m. The soil also contains traces of uranium and arsenic.

SUMMARY

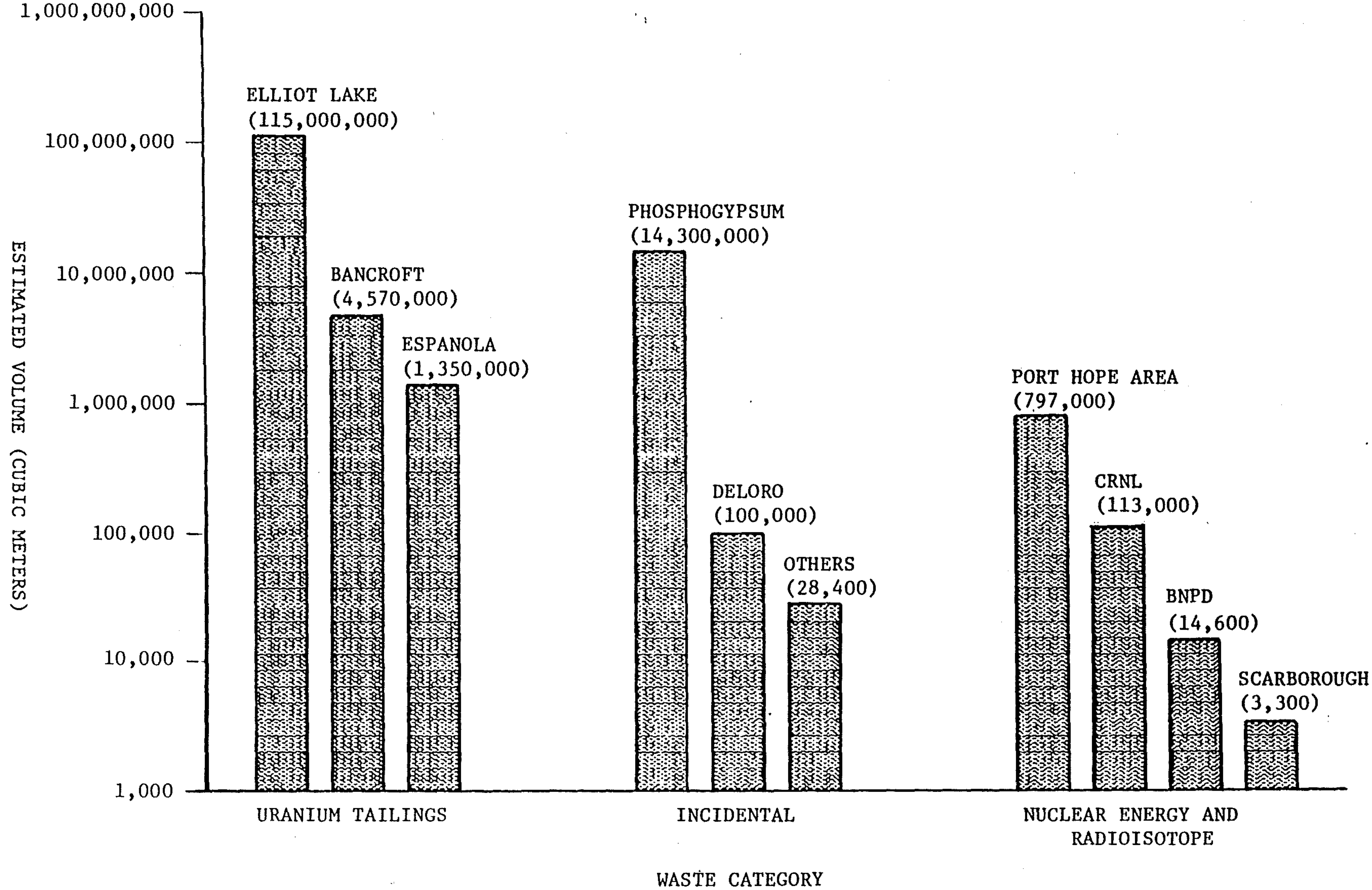
Table 14 summarizes the information contained in this report, with the waste occurrences grouped into the three main categories.

Figure 15 shows the volumes of the different types of waste. By far the largest category of waste is the uranium mine tailings, and the vast majority of these are in the Elliot Lake area. These wastes are typically massive deposits of sand-like material, commonly placed in a former lake or marshy depression, so that they are largely confined by the natural geography, although dams are often used to complete the containment. The tailings are often saturated or even under water in some instances, and because most of the tailings areas are associated with mines which closed years ago, they are frequently re-vegetated to some extent. However, these old tailings sites have not usually had any reclamation work performed on them. Although most tailings sites are no longer used, the ones which remain in operation are used on a massive scale, and it is at these (exclusively in the Elliot Lake area) where most of the tailings are found.

The next most voluminous waste type also derives from mineral processing. In this case the mineral is phosphate rock and the resulting waste is phosphogypsum, a form of calcium sulphate. Millions of cubic metres of this type of material are found on two industrial sites at Port Maitland and Courtright. The phosphogypsum wastes are the major component of the incidental waste category, but they are no longer produced. Production could resume in the future. The mineral processing wastes under the control of the Ontario government at Deloro are the next most voluminous source of incidental wastes, followed by the abrasives industry wastes which have been placed in an industrial waste disposal site at Thorold.

There are several other much smaller accumulations of incidental wastes still in the hands of the waste producers. With the exception of turnings of a

FIGURE 15: SUMMARY OF WASTE INVENTORIES



magnesium-thorium alloy belonging to Hawker Siddeley, they are all slags and mineral processing residues.

The volume of radium and uranium refining and processing wastes, and associated contaminated soils, belonging to Eldorado Resources Ltd., in the Welcome and Port Granby Waste Management areas is also very substantial. In addition to the radium and uranium contained in these materials, there is a non-radioactive element, arsenic, which is a source of significant concern. Additional quantities of similar, but more dilute wastes and soils are found in the town of Port Hope and in Scarborough.

In contrast to the volumes of waste produced by uranium extraction and processing the amount of waste resulting from exploitation of atomic energy in the production of nuclear electricity and in the many uses of radioisotopes is quite small, and is confined to two sites belonging to AECL and Ontario Hydro. However, the physical characteristics and the radionuclides contained in the wastes are much more varied than for the other waste accumulations. It should be noted that the volume shown for CRNL is inflated by 72,000 cu.m. of wastes from the uranium, radium and mineral processing industries relocated there as a result of cleanup activities by the AECB.

Figure 16 shows estimates of the rate of current annual production of wastes in these various categories. Uranium tailings are still the dominant factor. Incidental wastes production is very low because the phosphate industry and other mineral processing operations have closed down. Similarly, Eldorado's waste production rate is only a small fraction of what was produced in past years, largely due to recycle and re-use of waste streams.

The nuclear energy and radioisotope sources, represented by Ontario Hydro and AECL (both as a producer of waste and a receiver of wastes from others) continue to generate significant quantities.

Figure 17 presents an estimate of the initial inventory of radioactivity in each category identified by volume in Figure 14. These figures should be considered very approximate as they involve a number of assumptions about the state of equilibrium between radionuclides in decay chains and include significant uncertainties in the estimates of the concentration of radionuclides in some of the wastes. In addition, the inventories at CRNL will have been reduced by decay, because most of the radionuclides have a relatively short half life.

In conclusion, the accumulations of low-level radioactive waste in Ontario are dominated by the large volumes of uranium mine tailings. Bulk wastes containing various amounts of uranium, radium and, often, arsenic or other non-radioactive contaminants are the next most voluminous source. These wastes have more in common with the uranium mine tailings than with the much more varied low-level radioactive wastes resulting from nuclear power production and the production and use of radioisotopes. The volume of waste produced by uranium processing is much reduced from former years. In the incidental waste category, phosphogypsum wastes are no longer produced and the volume produced by other industries has been substantially reduced.

FIGURE 16: CURRENT ANNUAL PRODUCTIONS

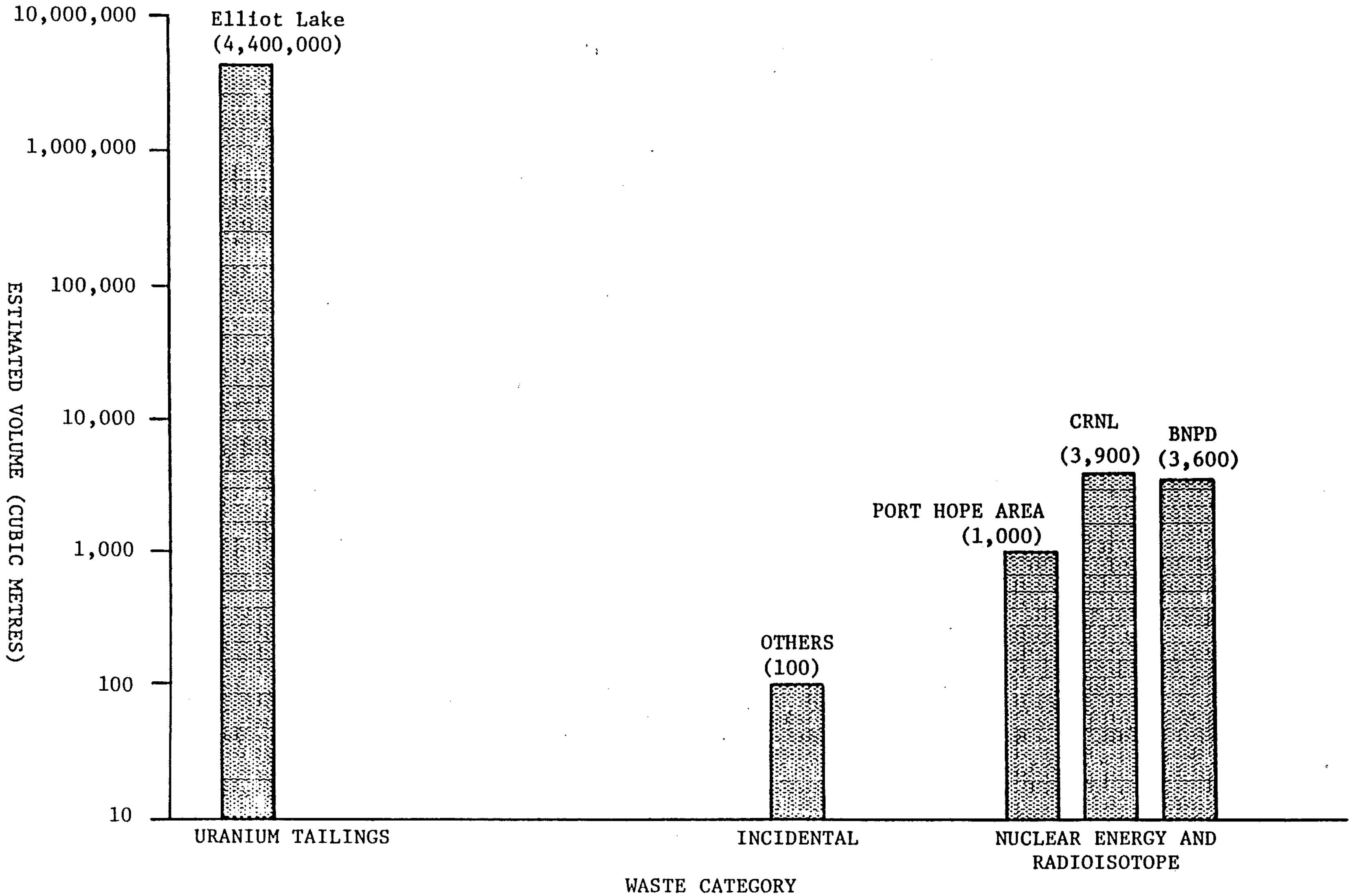


Figure 17: INVENTORY OF RADIOACTIVITY WHEN INITIALLY STORED

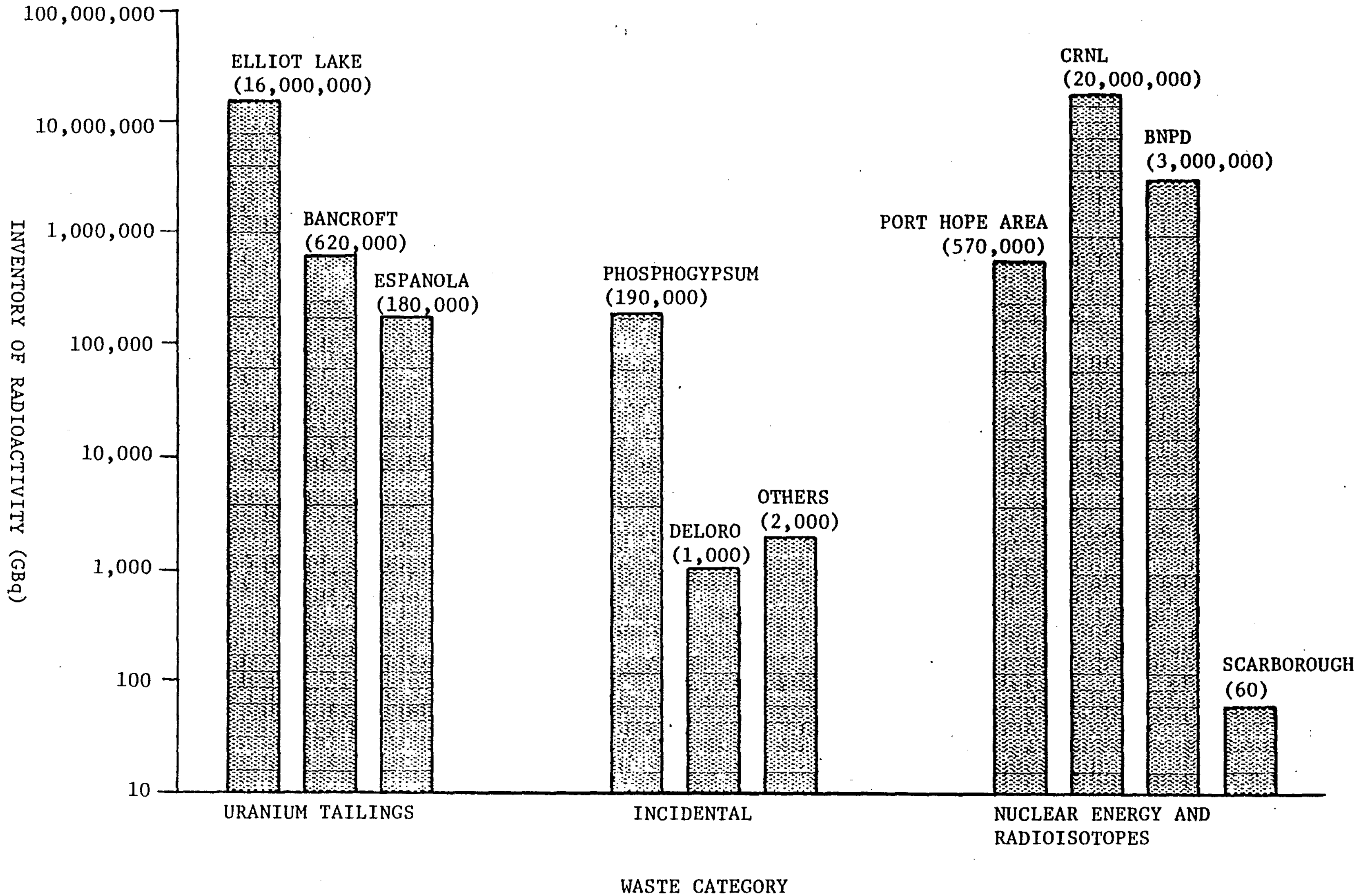


TABLE 1

HALF-LIVES OF SOME COMMON RADIONUCLIDES
AND WASTES IN WHICH THEY ARE FOUND

Radioisotope	Half-Life	Decay Mode	Typical Waste Sources
Tritium (Hydrogen-3)	12.33 y	Beta	Power reactor wastes, wastes from biological research
Carbon-14	5730 y	Beta	Power reactor wastes, wastes from biological research
Cobalt-60	5.271 y	Beta & Gamma	Maintenance of nuclear reactors
Phosphorus-32	14.28 d	Beta	Biological research
Strontium-90	28.8 y	Beta	Atomic Energy research and development
Technetium-99	2.1×10^5 y	Beta & Gamma	Medical diagnostics
Caesium-137	30.17 y	Beta & Gamma	Atomic Energy research and development
Iodine-131	8.04 d	Beta & Gamma	Medical diagnostics and radiotherapy
Iridium-192	74.2 d	Beta & Gamma	Industrial radiography
Radium-226	1600 y	Alpha & Gamma	Uranium tailings and uranium processing residues
Thorium-230	8.0×10^4 y	Alpha & Gamma	Uranium tailings and uranium processing residues
Uranium-238	4.468×10^9 y	Alpha & Gamma	Uranium tailings and uranium processing residues
Americium-241	433 y	Alpha & Gamma	Manufacture of smoke detectors

TABLE 2

DEPOSITS OF URANIUM MINE TAILINGS IN ONTARIO

Mine	Volume, cu.m.*	Surface Area, ha.	Date of Operations	Current Status	Map Reference
ELLIOT LAKE AREA					
Lacnor	2,000,000	24	1957-60	Mainly re-vegetated except for area with poor drainage. Portion under water.	41 J/7 780390
Nordic	8,100,000	101	1957-68	Re-vegetated; seepage and run-off collection and treatment system.	41 J/7 780380
Stanrock - Can-Met	5,700,000	71	1958-64	One tailings dam failed. Seepage and run-off treatment. Some natural re-vegetation.	41 J/7 815467 and 828459
Spanish-American	330,000	5	1958-59	Re-vegetated except for area under water. Seepage flows to Denison treatment facilities.	41 J/7 780480
Pronto (Blind River, Ontario)	1,550,000	47	1955-66	Re-vegetated except for area covered by copper mine tailings.	41 J/2 690188
Milliken-Stanleigh	5,550,000	33	1958-64	Re-activated; see below.	41 J/7 760417
Stanleigh	8,200,000 (to end of 1985)	400 (design)	1983-	Operating. Tailings area is an expansion of the former Milliken - Stanleigh area into Crotch Lake.	41 J/7 760417
Quirke	28,000,000 (to end of 1985)	162 (design)	1956-61, 1968-	Operating.	41 J/10 720515
Panel	6,900,000 (to end of 1985)	70 (design)	1958-61, 1979-	Operating.	41 J/10 815520 + 3 adjacent
Denison	49,000,000 (to end of 1985)	182 (design)	1957-	Operating. Some reclamation work on the older deposits.	41 J/7 760482 + 1 adjacent
ESPANOLA AREA					
Agnew Lake	1,350,000	13	1979-82	Not conventional tailings. Leached ore and leachate processing wastes. Covered and re-vegetated.	41 I/5 527418
BANCROFT AREA					
Faraday	1,300,000	2	1957-64	Reclamation with a cover of overburden. Good cover of seeded vegetation.	31 F/4 700890
Madawaska	1,500,000	2	1962-1982	Reclamation with a cover of waste rock and gravel.	31 F/4 697895
Bicroft	1,500,000	4	1958-63	Partially underwater, some re-vegetation.	31 D/16 330865, 335855 and 339869
Dyno	270,000	4	1958-60	Abandoned, condition not known.	31 D/16 563813

* In some cases volumes have been estimated from weight data using a conversion factor of 1.35 Mg/cu.m. dry density.

TABLE 3 INCIDENTAL LLRW WASTE ACCUMULATIONS

Location	Site Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
CIL, Courtright	Gypsum ponds at the CIL Lampton Works site set within agricultural buffer area.	5,800,000	Phosphogypsum has typical concentrations of 0.02-0.3 MBq/cu.m.U-238 0.7 MBq/cu.m. Th-230 0.01-0.015 MBq/cu.m. Th-232, 0.7-2.2 MBq/cu.m. Ra-226. Fluoride migration can occur.	Phosphogypsum tailings from phosphate fertilizer production.	to mid 1980s
IMC, Port Maitland	Three old gypsum ponds adjacent to the Grand River. Two engineered ponds inland. Industrial area with few nearby residences.	8,500,000	As above.	As above.	to mid 1980s
Chromasco Ltd. Haley Station	Open pit mining operation with large waste-piles in a low grade agricultural area.	60 cu.m. drummed slag, 680 cu.m. loose soil and cleaning material, incorporated in a much larger pile of other wastes.	2.0% Th-232 in drummed slag.	Drummed pyrochlore slag, loose soils, and decontamination material.	1960s, 1970s
Hawker Siddeley, Mississauga	Drums are stored in fenced area on an industrial site in an industrial park.	75 (in 385 drums)	3.0% Th-232	Metal turnings from magnesium - thorium alloys.	1960s, 1970s, currently generating 2.5 cu.m./yr
Masterloy Products Ltd., Ottawa	A slag pile and two lots of drums are stored on this industrial site. The area has quarrying operations on 3 sides. Other businesses in the area serve the construction industry.	4050 cu.m. stockpiled slag and 60 cu.m. drummed slag. Any additional contaminated soil beneath the slag pile has not been estimated.	Concentrations of nuclides in slag: 0.001-0.03% U-238, 0.001-0.4% Th-232, 2.1 MBq/cu.m. Ra-226. Arsenic from other process waste has become mixed in with radioactive slag at up to 0.015% concentration	Slag from manufacture of ferro - niobium alloys. Early slag was mixed with non-radioactive waste. Later wastes were drummed. Some arsenic-bearing waste has been removed to the Nepean landfill.	late 1960s through late 1970s
Norton Research Corp. Niagara Falls	An industrial site but adjacent to recreational areas. On-site waste storage in concrete silo and 2 metal-clad buildings.	3,000	- up to 0.026% U-238 - up to 0.04% Th-232 - up to 1.4 MBq/cu.m. Ra-226 - up to 0.28 MBq/cu.m. Ra-224	Baddeleyite feedstock in the production of fused abrasives leads to generation of low-level radioactive dust.	Since 1950s Prior to 1980 wastes were sent off-site.
Exolon Co. of Canada, Thorold	An industrial site in a long-established industrial area with recent nearby residential development.	Several hundred tonnes, say 500 cu.m.	Similar to Norton but with concentrations as follows: - up to 0.03% U-238 - up to 0.01% Th-232 - 0.78 MBq/cu.m. Ra-226	Similar to Norton above.	1970s
Deloro	Former metal smelter on the banks of the Moira River and adjacent to the town of Deloro.	100,000 plus an unknown quantity of contaminated soil, estimated at ~300,000.	~5.5 MBq/cu.m. Radium ~100 µg/g Uranium ~160 µg/g Arsenic Also contains substantial amounts of silver and probably other heavy metals.	Slag and contaminated soil from the smelting of concentrates from several sources, mainly to extract cobalt and arsenic. Arsenic residues buried on the site.	1914-61 Port Hope wastes shipped to site in 1951-52 and 1959-60
Walker Bros. Quarry Ltd., Thorold	Large quarry operation with two commercial waste disposal areas, one of which (containing the LLRW) is closed and capped with clay.	< 20,000 cu.m. abrasives industry wastes, perhaps mixed with three or more times as much other wastes.	Original waste contained: - up to 0.03% U-238 - up to 0.04% Th-232 - up to 1.4 MBq/cu.m. Ra-226 - up to 0.27 MBq/cu.m. Ra-224 Degree of dilution is unknown.	Material is from the dust collection system in the production of fused abrasives. The quantity and type of other wastes mixed with it at the disposal site is unknown.	late 1970s until 1982

TABLE 4

LLRW ACCUMULATIONS FROM NUCLEAR ENERGY
(EXCLUDING URANIUM TAILINGS) AND RADIOISOTOPE PRODUCTION AND USES

Location	Site Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Port Hope Area	Deposits throughout the town of Port Hope. Wastes mounded and covered at Welcome and placed in covered trenches at Port Granby	797,000	Uranium, Th-230, Ra-226 and its daughters, arsenic and other metals.	Contaminated chemical residues and miscellaneous solid wastes from radium and uranium refining, and contaminated soils.	1933 - ongoing
Chalk River Nuclear Laboratories	Wastes stored in engineered facilities and buried in the ground within AECL's large nuclear research site.	113,000*	Tritium, C-14, Co-60, Sr-90 and Cs-137. Trace quantities of natural uranium in some off-site wastes.	Contaminated materials from CRNL operations, and from off-site LLRW generators (radioisotope users and nuclear fuel fabricators). Contaminated soils from Port Hope.	1946 - ongoing
Bruce Nuclear Power Development	Wastes stored in engineered facilities at the site of a major nuclear power installation.	14,600	Tritium, C-14, Co-60, Sr-90 and Cs-137.	Reactor maintenance and purification systems wastes.	1968-ongoing*
Scarborough	40 contaminated residential properties in urban Scarborough	3,300	Radium and Arsenic	Contaminated soils.	1940s

* This volume does not include contaminated soils at CRNL where the radionuclides are expected to decay in-situ to insignificant concentrations.

TABLE 5

WASTES IN THE TOWN OF PORT HOPE

Location	Site Description	Estimated Volume >0.44MBq/cu.m	>1.4MBq/cu.m.	Typical Concentration of Contaminants	Waste Chacteristics
Harbour	Entrance channel and the turning basin of the harbour. Wastes under 2-4 metres of water. Harbour used for intake and discharge of ERL's plant water.	85,430*	47,700*	22 MBq/cu.m. Ra-226 310 µg/g Uranium 400 µg/g Arsenic	Sediments with a range of particles sizes from fine silts to sand and gravel.
CN/CP Viaduct area	Open area of grassy land north of harbour and between the two railway lines. Believed to have been a low spot filled with wastes, perhaps from dredging of harbour.	7,220	2,250	Believed to be similar to harbour.	Contaminated soils and cinders.
Water Works	Two buildings, ponds, paved and grassy areas and three large underground tanks.	6,515	1,395	Relatively low.	Contaminated soils under the pavement, around buildings, over the tanks and throughout much of the open area
Sewage Treatment Plant Storage Site	Excavated soils piled on an asphalt base and covered by a heavy synthetic sheet.	2,000	2,000	Relatively low.	Contaminated soils and some building debris and rubble.
Alexander St. Ravine	Wastes cover the east side of the ravine at the end of Alexander St. Slope is very steep, heavily-wooded and quite wet at the bottom.	2,500	1,745	55 MBq/cu.m. Ra-226 990 µg/g Uranium 124 µg/g Arsenic	Contaminated soil, process wastes, ash, misc. refuse.
Strachan St. Ravine	Wastes cover most of the north face of the ravine and extend under the road itself. Smaller patches on south slope.	1,770	1,200	39MBq/cu.m. Radium-226 256 µg/g Uranium 36 µg/g Arsenic	Contaminated soils, process wastes, ash, misc. refuse.
Brewery Pond	Dam constructed partially of process wastes to a depth of 6 metres. Small gully behind dam back-filled with waste. Overflow from pond runs through area as a small stream.	5,535	4,510	Analysed in a combined sample with Rollins Ravine material.	Process residues, contaminated soils.
Monkey Mountain	Open grassy area at the NE corner of the junction between Pine St. extension and Highland Drive. Formerly an ERL waste storage area.	6,240	5,145	Analysed in combined sample with Rollin's Ravine material.	Contaminated sandy soils with some small lenses of process wastes remaining after previous excavations.
Rollins Ravine	Materials dumped over sides of the heavily wooded ravine. Much of the surrounding area has surface contamination from runoff or wind dispersion of wastes in the ravine, the landfill site or Monkey Mountain.	5,920	2,585	0.2 GBq/cu.m. Ra-226 975 µg/g Uranium 86 µg/g Arsenic	Process residues and misc. refuse in the ravine. Contaminated soils in the ravine and over the surrounding area.
Pine St. Extension	An unpaved road between Rollins Ravine and the Landfill Site. The road spans the ravine which has been backfilled with process residues.	5,085	3,835	0.6 GBq/cu.m. Ra-226 1,060 µg/g Uranium 106 µg/g Arsenic	Process residues covered by sand and gravel. Pockets of heavy contamination. Barium sulphate residues identified.
Landfill Site	Wastes mainly towards the bottom of the 10 m deep landfill site. Mixed with household and industrial refuse and covered by a layer of more lightly contaminated refuse.	60,000	32,300	17 MBq/cu.m. Ra-226 38 µg/g Uranium 94 µg/g Arsenic These figures may not be truly representative due to difficulty in sample recovery.	Process residues from refinery operations. Large quantity of foam rubber and trash typical of a town with some manufacturing industry.

* The lower volume assumes dredging of exposed wastes only. The higher volume assumes dredging of all wastes followed by suction cleaning. These actions do not necessarily correspond to 0.44MBq/cu.m. and 1.4MBq/cu.m. limits.

TABLE 6

CHEMICAL ANALYSIS OF A FAIRLY
HIGHLY CONTAMINATED HARBOUR SEDIMENT SAMPLE

Boron	10
Phosphorus	1,000
Aluminum	10,000
Arsenic	2,350
Barium	480
Berrylium	4.3
Calcium	260,000
Cadmium	7.1
Cobalt	350
Chromium	61
Copper	1,100
Iron	20,000
Potassium	1,700
Magnesium	7,200
Manganese	700
Molybdenum	3.4
Sodium	820
Nickel	590
Lead	21,000
Titanium	480
Vanadium	56
Tungsten	< 2
Zinc	230
Lead 210	300
Radium 226	100
Thorium 230	550
Thorium, by mass	9.8
Uranium	2,340

All concentrations are in $\mu g/g$ except for Lead-210, Radium-226 and Thorium-230 which are in Bq/g.

TABLE 7

TYPICAL PORT HOPE MUNICIPAL LANDFILL LEACHATE COMPARED TO HEALTH AND WELFARE CANADA MAXIMUM ACCEPTABLE CONCENTRATION (MAC) AND OBJECTIVE CONCENTRATION (OC) GUIDELINES FOR DRINKING WATER

ANALYTE	LEACHATE	MAC	OC
Chloride	449	250	<250
Sulphate	5.3	500	<150
Alkalinity	1810	-	-
Carbon, dissolved organic	160	-	-
Boron	45	5	<0.01
Phosphorus	0.9	-	-
Phenol	0.068	0.002	<0.002
Silver	<0.001	-	-
Aluminum	0.28	-	-
Arsenic	0.026	0.05	<0.005
Barium	16	1	<0.1
Berrylium	0.001	-	-
Calcium	.05	-	-
Cadmium	0.001	0.005	<0.001
Cobalt	0.013	-	-
Chromium	0.021	0.050	<0.0002
Copper	0.013	-	-
Iron	4.3	0.3	<0.05
Potassium	227	-	-
Magnesium	72	-	-
Manganese	0.14	0.05	<0.01
Molybdenum	0.025	-	-
Sodium	441	-	-
Nickel	0.018	-	-
Lead	<0.005	0.05	<0.001
Silicon	3.1	-	-
Titanium	<0.001	-	-
Vanadium	0.03	-	-
Tungsten	0.025	-	-
Zinc	0.017	5.0	<5.0
Lead 210	<0.02	-	-
Radium 226	0.40	1	0.1
Thorium 230	<0.0002	-	-
Uranium	0.032	0.02	<0.001

All concentrations are in mg/L except for Lead-210, Radium-226 and Thorium-230 which are in Bq/L.

TABLE 8

ELDORADO RESOURCES LIMITED WASTE MANAGEMENT AREAS

Location	Type of Waste	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Welcome Waste Management Facility	Refinery wastes	12,000	Uranium, Th-230, Ra-226 and its daughters, and metals such as arsenic, iron, cobalt, nickel and manganese.	Carbonate residue and iron residue produced during extraction of radium and uranium from ores, and ore rejects too low-grade for processing.	1948 - 1955
	Radium contaminated materials	Included in soils volume	Ra-226	Radium contaminated equipment and building rubble from dismantling of the radium circuit.	1953 - 1955
	Contaminated soil	210,500	Uranium, arsenic and radium.	Contaminated surface soils and subsoils. Includes some (~16,000 cu.m) of soil from remedial works in Port Hope, used as cover material.	n/a
	Total (Welcome)	222,500	Average Concentrations: As: 2810 µg/g Th: 8 µg/g U: 140 µg/g Th-230: 0.08 GBq/cu.m. Ra-226: 0.09 GBq/cu.m.		
Port Granby Waste Management Facility	Limed raffinate	64,200	Up to 0.5% unrecovered uranium and traces of radium and thorium.	A wet neutral residue produced during refining of uranium concentrate to uranium trioxide, consisting primarily of calcium sulphate.	1955 - 1980 Raffinate now recycled to mill for uranium recovery.
	Ammonium nitrate	n/a	Traces of radium and uranium.	Dilute liquid produced during conversion of uranium trioxide to uranium dioxide.	1955 - 1977 Now recycled for use as a fertilizer.
	Magnesium fluoride	1,700	A few percent uranium.	Slag generated during production of uranium metal.	early 1970's to 1979 Now stored at plant.
	Calcium floride	25,000 (as of 1985)	Less than 0.5% uranium.	Alkaline residue produced during conversion of uranium trioxide to uranium hexafluoride.	Early 1970's ongoing. Annual volume of about 900 cu.m.
	Process wastes and contaminated soils.	46,300	Uranium, Th-230, Ra-226 and daughters, and arsenic.	Process wastes and contaminated soils from remedial work at older waste sites in Port Hope.	1956 - 1975
	Miscellaneous contaminated materials.	64,100	Uranium, uranium concentrates, and traces of Th-230 and Ra-226 in earlier wastes.	Miscellaneous plant waste such as paper, cloth, wood, plastic, crushed drums, scrap equipment, and soil and building rubble from construction activities.	1955-ongoing Annual volume about 400 cu.m.
	Contaminated soil.	147,000	Uranium, Th-230, Ra-226 and daughters, and arsenic.	Contaminated soil resulting from waste emplacement at the Port Granby site.	-
	Total (Port Granby)	348,000	Average Concentrations: As: 2720 µg/g Th: 370 µg/g U: 450 µg/g Th-230: 0.1 GBq/cu.m. Ra-226: 0.07 GBq/cu.m.		
Port Hope Plant	Magnesium Fluoride drums at warehouse	2,500	Uranium	Slag generated during production of uranium metal.	1979 -ongoing

TABLE 9

COMPOSITION OF IRON AND CARBONATE RESIDUES

Element	Typical Iron Residue (% dry weight)	Typical Carbonate Residue (% dry weight)
Silver	< 0.01	0.05
Aluminum	5	5
Arsenic	7	7
Boron	< 0.01	< 0.01
Bismuth	0.3	1
Calcium	7	7
Cobalt	2.3 to 2.4	0.3 to 1.0
Chromium	0.01	< 0.01
Copper	2.0 to 2.1	1.0 to 1.4
Iron	10	10
Magnesium	5	1
Manganese	0.5	0.3
Molybdenum	< 0.1	< 0.1
Sodium	5	3
Nickel	1.1 to 1.2	0.4 to 0.9
Phosphorus	< 1	< 1
Lead	0.5	1
Silicon	15	20
Tin	< 0.1	< 0.1
Titanium	0.3	0.8
Uranium	0.36	0.36
Vanadium	< 0.1	< 0.1
Zinc	1	1

TABLE 10

OPERATING WASTE MANAGEMENT AREAS AT CRNL

Location	Site Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Liquid Dispersal Area	Natural sand mound with six pits, one natural and five man-made. Subsurface drainage moves toward a swampy area, which drains to Perch Lake on the CRNL property.	n/a The plume of contamination will not require excavation. The radionuclides will decay to very low levels before they could leave the CRNL site.	Tritium (H-3) and mixed fission products (MFP) and mixed activation products (MAP) are reported in terms of total Beta radioactivity and total Alpha radioactivity. Average concentrations (of time of discharge) have been about 0.4 MBq/L (Beta). 0.4 KBq/L (Alpha) and 0.7 MBq/L (H-3). Major radionuclides are H-3 and Sr-90.	Contaminated water, and water collected from areas where there is a potential source of contamination. Radionuclides now largely absorbed onto soil particles.	1953 - ongoing. The majority of the water was discharged to these pits prior to 1960.
Area B	Elevated and cleared sandy area, of about 8 hectares, within the Perch Lake drainage basin. Burial of solid LLRW in unlined sand trenches between 1953 and 1963. Storage of waste in engineered facilities began in 1955 with the construction of asphalt lined trenches, followed by cylindrical bunkers and tileholes currently in use.	13,600 (sand trenches) 7,100 (engineered storage facilities)	H-3 MFP and MAP Major radionuclides are Co-60, Sr-90 and Cs-137. Radioactivity concentrations (at time of emplacement) typically: - 0.4 GBq/cu.m. in sand trenches. - 37 GBq/cu.m. in asphalt trenches and concrete bunkers. - 3.7 TBq/cu.m. tileholes.	Contaminated materials from CRNL operations, including cloth, paper, wood, plastics, glass, rubber and sheet metal materials, metal piping, equipment and components, air filters, ion exchange resins, bitumenized ash, bitumenized aqueous waste and materials from decommissioning and construction activities. Off-site generated wastes include: - tested and crated equipment with sealed sources, such as gauges, special industrial cameras, and static electricity eliminators. - industrial trash containing natural uranium dust. - medical treatment and university research contaminated trash, such as animal carcasses, scintillation vials, liquids, filters, syringes, wipes and gloves. - contaminated trash from radioisotope processing, such as cloth, paper, plastics, glass and metal tubing and equipment.	1953 - ongoing
Area C	Cleared and levelled sandy area, of about 4.2 hectares, in the Maskinonge Lake drainage area on CRNL property. A series of 30 parallel and separate trenches, approximately 4m wide by 3m deep by 90m long have been filled. Since 1982 the method of burial has been changed to continuous trench (i.e. one side is extended as the other side is filled and covered).	19,300 (after in situ compaction from the trench cover)	H-3: ~22 GBq/cu.m. (of original volume) MAP & MFP: ~0.07 GBq/cu.m average (of original volume) with a range from background to ~3.7 GBq/cu.m.	As above for Area B.	1963 - ongoing

cont'd...

TABLE 10 (continued)

OPERATING WASTE MANAGEMENT AREAS AT CRNL

Location	Site Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Waste Tank Farm	0.07 hectare area with six underground steel tanks for interim storage of concentrated liquid wastes.	n/a Some of these wastes are to be immobilized in glass, and the remainder in bitumen.	-	-	-
Area D	Cleared and levelled area, of about 1.3 hectares. Site is used for above ground storage of equipment known or suspected to have low levels of contamination, but of potential future value.	n/a			
	Metal clad building.	200 (waste in drums)	Up to 0.37 GBq/cu.m. Ra-226	Debris from decontamination of properties where luminous paint has been used.	1983 - ongoing

TABLE 11

CLOSED WASTE MANAGEMENT AREAS AT CRNL

Location	Site Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Area A	Flat area, of about 1.2 hectares, in the Perch Lake drainage basin. Solid wastes were buried in sand trenches. Three liquid dispersals, one as a result of the 1952 NRX accident, and two in 1954 and 1955, for experimental purposes.	700 (miscellaneous solid wastes) Volumes are not applicable to liquid waste disposals. They are expected to decay in situ.	Miscellaneous low specific activity. Solid wastes - as per Area C Liquid wastes - mixed fission products. The total Bq content of Sr-90, the controlling radionuclide in terms of half-life, mobility and radiological dose if ingested, estimated at about 52 TBq.	Miscellaneous solid wastes as per Area B. Liquid wastes: 1952 - contaminated water 1954/55 - strongly acidic high-level processing waste.	1946 - 1955
Area F	Partially filled valley. Wastes covered with clay and top soil, and seeded.	72,000 Bulk wastes	7 MBq/cu.m. Ra-226 140 µg/g As	Contaminated soils and debris from remedial work in Port Hope and Mono Mills and slag and contaminated soils from two sites in Ottawa.	1976 - 1979
Ammonium Nitrate Decomposition Plant	Plant site and liquid disposal pit contained in a fenced area, of about 0.75 hectares, on a sandy ridge about 150 m north of Area C. Chemical plant, for decomposition of ammonium nitrate in liquid waste, was operated in 1953/1954.	Not applicable.	Mixed fission products, including about 37 TBq of Sr-90	Distillate from the plant was discharged to a lime filled pit nearby. Plant malfunctions resulted in release of MFP with the distillate. Plant was dismantled and much of the equipment buried in situ.	1953 - 1954
Thorium Nitrate Pit	Fenced disposal pit, immediately north of Area C.	Not applicable.	Thorium nitrate and mixed fission products, including about 0.2 TBq of Sr-90	Ammonium nitrate liquid waste	1955
Glass Block Experiments	Two fenced locations near Area A, where glass blocks have been buried below the water table, and the area monitored, since 1958.	Not applicable.	About 52 TBq of mixed fission products.	Fifty glass blocks which have released insignificant amounts of radionuclides.	1958

TABLE 12

SUMMARY OF LLRW STORED AT CRNL DURING 1986

I. SUMMARY BY SOURCE OF WASTE

Waste Generator/Shipper	1986 Volume (cu.m.)	Percent of Total
CRNL Site Operations	1,819	46
AECL Intersite Waste (1)	596	15
Industrial, Medical and Research Radioisotope Users	720	18
AECL Radiochemical Company Radioisotope Production	185	5
Nuclear Fuel Fabricators	463	12
Miscellaneous LLRW	130	3
	3,913	

II. SUMMARY BY VOLUME TO STORAGE FACILITY

Facility	Volume (cu.m.)	Average Concentration of Major Radionuclides, GBq/cu.m.									
		H-3	C-14	P-32	S-35	Co-60	Sr-90	I-125/131	Cs-137	Ra-226	Am-241
Sand Trench	3298	0.015	0.003	0.015	0.003	0.004	N/A (2)	0.022	0.0002	-	-
Bunker	587	96	0.03	0.011	0.033	0.33	N/A (2)	0.74	2.6	0.0004	4.8
Tile Hole	29	-	1850	-	-	92,500	-	3700	-	-	-

(1) Waste originating from CANDU Operations, NPD reactor at Rolphton, and decommissioning of former isotope processing plant in Ottawa.

(2) Not directly measurable, but comparable to Cs-137.

TABLE 13

WASTE STORAGE FACILITIES AT BNPD

Location	Facility Description	Estimated Volume (cu.m.)	Contaminants	Waste Characteristics	Emplacement Date
Site 1	In-ground concrete trenches and tileholes.	1,080	H-3, C-14, Co-60 and MFP including Sr-90 and Cs-137. Average specific activity ~0.1 TBq/cu.m.	Reactor maintenance and purification system wastes from the Douglas Point reactor.	1968 - 1976
Site 2	Above ground low-level waste storage buildings.	7,870	As above. Average specific activity ~2.6 GBq/cu.m.	Reactor maintenance wastes from Pickering, Bruce, and in future, Darlington nuclear generating stations Materials include cloth, paper, wood, plastic, glass, rubber and sheet metal materials, metal piping and equipment, and incinerator ash.	1975 - ongoing
	In-ground concrete trenches.	5,220	As above. Average specific activity ~37 GBq/cu.m.	Reactor maintenance wastes, and purification system wastes such as ion exchange resin columns, and filters.	1975 - ongoing
	Above ground concrete quadricells, and in-ground concrete tile-holes and concrete and steel containers.	400	As above for resins and filters. Average specific activity ~ 1.9 TBq/cu.m. Irradiated core components contain neutron activation products such as Fe-55 and Co-60, with specific activities of the order of 37 - 370 TBq/cu.m.	Reactor purification system wastes such as bulk ion exchange resins, resin columns and filters; and irradiated core components.	1975 - ongoing

TABLE 14

SUMMARY OF WASTE QUANTITIES

Waste Category	Locations	Estimated Volume (cu.m.)	Principal Contaminants	Characteristics
Uranium Mine Tailings	Elliot Lake, Espanola and Bancroft	121,000,000	Radium and thorium. Various non-radioactive heavy metals.	Sand-size and smaller particulate material, often saturated with moisture. Old tailings commonly re-vegetated. Production of acidic leachate a major problem.
Nuclear Energy and Radioisotope Wastes	Port Hope area	797,000	Arsenic, radium and uranium.	Various chemical processing residues, contaminated soils and demolition debris.
	CRNL	113,000	Mixed fission products, and activation products. Major radionuclides are tritium, Cobalt-60, Strontium-90, Caesium-137, Carbon-14. Contaminated soils from Port Hope.	Reactor maintenance wastes, laboratory and hospital trash and sealed radioisotope sources.
	BNPD	14,600	Similar to CRNL wastes.	Reactor maintenance wastes, laboratory trash.
	Scarborough	3,300	Radium and arsenic.	Contaminated soils.
Incidental wastes	Courtright and Port Maitland	14,300,000	Radium, uranium and thorium. Fluoride is a non-radioactive component.	Large mounds or ponds of phosphogypsum (calcium sulphate).
	Haley Station, Mississauga, Ottawa, Niagara Falls and Thorold	28,400	Thorium, radium and uranium	Metal turnings, slags and mineral dust.
	Deloro	100,000 (plus about 300,000 cu.m. of contaminated soil)	Arsenic, radium and uranium plus other heavy metals.	Metal refinery slag and contaminated soils.

References

1) Maps are available from regional dealers or: Canada Map Office, 615 Booth St., Ottawa, K1A 0E9.

2) Report of the National Technical Planning Group on Uranium Tailings Research to CANMET, Energy Mines and Resources Canada, September 1981.

3) Verbal communication with the Elliot Lake office of the Atomic Energy Control Board.

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5) Welcome Waste Management Facility. Information series pamphlet published by Eldorado Resources Ltd., Port Hope, Ontario, 1987.

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8) D.F. Dixon. A Program for Evolution from Storage to Disposal of Radioactive Wastes at CRNL. Report AECL-7083, Atomic Energy of Canada Ltd., Chalk River, Ontario, 1985.

9) Ontario Hydro, Nuclear Generation Division. Bruce Nuclear Power Development Radioactive Waste Operations and Central Maintenance Facility. 1986 Quarterly Technical Report, Third Quarter. Report B50-22-86-Q3.

APPENDIX A: DECAY SERIES FOR NATURAL URANIUM AND THORIUM

All elements found in natural sources with atomic number greater than 83 (bismuth) are radioactive. They belong to chains of successive decays, and all the species in one such chain constitute a radioactive family or series. Three of these series, shown in Figure A1, include all natural radionuclides in this region of the periodic chart.

One series has Uranium-238 (4.5 billion year half-life) as the parent substance and after 14 transformations, eight of them by alpha-particle emission (vertical arrows downward in Figure A1) and six by beta-particle emission (diagonal arrows upward in Figure A1), reaches the stable end product Lead-206. This series is generally referred to as the uranium series. In addition to Uranium-238, other members with half-lives greater than one year include Uranium-234 (250,000 year half-life), Thorium-230 (80,000 year half-life), Radium-226 (1600 year half-life), and Lead-210 (22 year half-life).

Thorium-232 (14 billion year half-life) is the parent substance of the thorium series, which ends at Lead-208, after ten transformations (6 alpha, 4 beta). The only other members of this series with half-lives greater than one year are Radium-228 (6.7 year half-life) and Thorium-228 (1.9 year half-life). The actinium series, has Uranium-235 (0.7 billion years half-life) as the parent, and ends at Lead-207. Although Uranium-235 plays a major role in nuclear reactors, it constitutes only about 0.7% of the mass of natural uranium, corresponding to about 2% of the natural uranium radioactivity. It is thus of little significance in terms of the characteristics of waste materials or soils contaminated with uranium or thorium or their daughter products.

If there has been no chemical separation of the various elements in a radioactive series, for a period of a few times longer than the half-life of the longest-lived daughter substance, the rate of radioactive decay will be the same for all members in the series. Thus in a uranium ore body, each member of the series will have the same radioactivity as the parent Uranium-238, about 10 Bq per gram of ore, for a grade of 0.1%. Because their half-lives are much less than that of Uranium-238, however, the mass of all the other members will be much less than that of Uranium-238. For example, the mass of Radium-226 corresponding to 10 Bq per gram of ore is about 270 parts per trillion.

Chemical separation can lead to separation of the various elements of a series from one another, but not to separation of different isotopes of the same element, such as Uranium-234, Uranium-235 and Uranium-238. Milling of uranium ores thus results in most of the uranium being concentrated on the yellowcake product, with very little of the Thorium-230, Radium-226 or Lead-210 daughters, as the remain in the tailings.

In each of the three families there is an isotope of element number 86. Although they are all isotopes of radon, these radioactive rare gas isotopes are frequently referred to as radon (Radon-222), thoron (Radon-220) and actinon (Radon-219). Because they are gaseous and chemically non-reactive, they can move relatively quickly through soils by gaseous diffusion. Although their daughter products are not gaseous, and hence are immobile in soil, once the gas escapes into an air atmosphere (indoors or outdoors), the short-lived decay products are also formed in the atmosphere. The four decay products which are formed successively within minutes following the decay of Radon-222 are referred to as radon daughters. Their inhalation causes a major contribution to natural background radiation exposures (see Appendix B). Because of their much shorter half-lives, thoron and actinon do not diffuse out of the soil to the same extent as does radon.

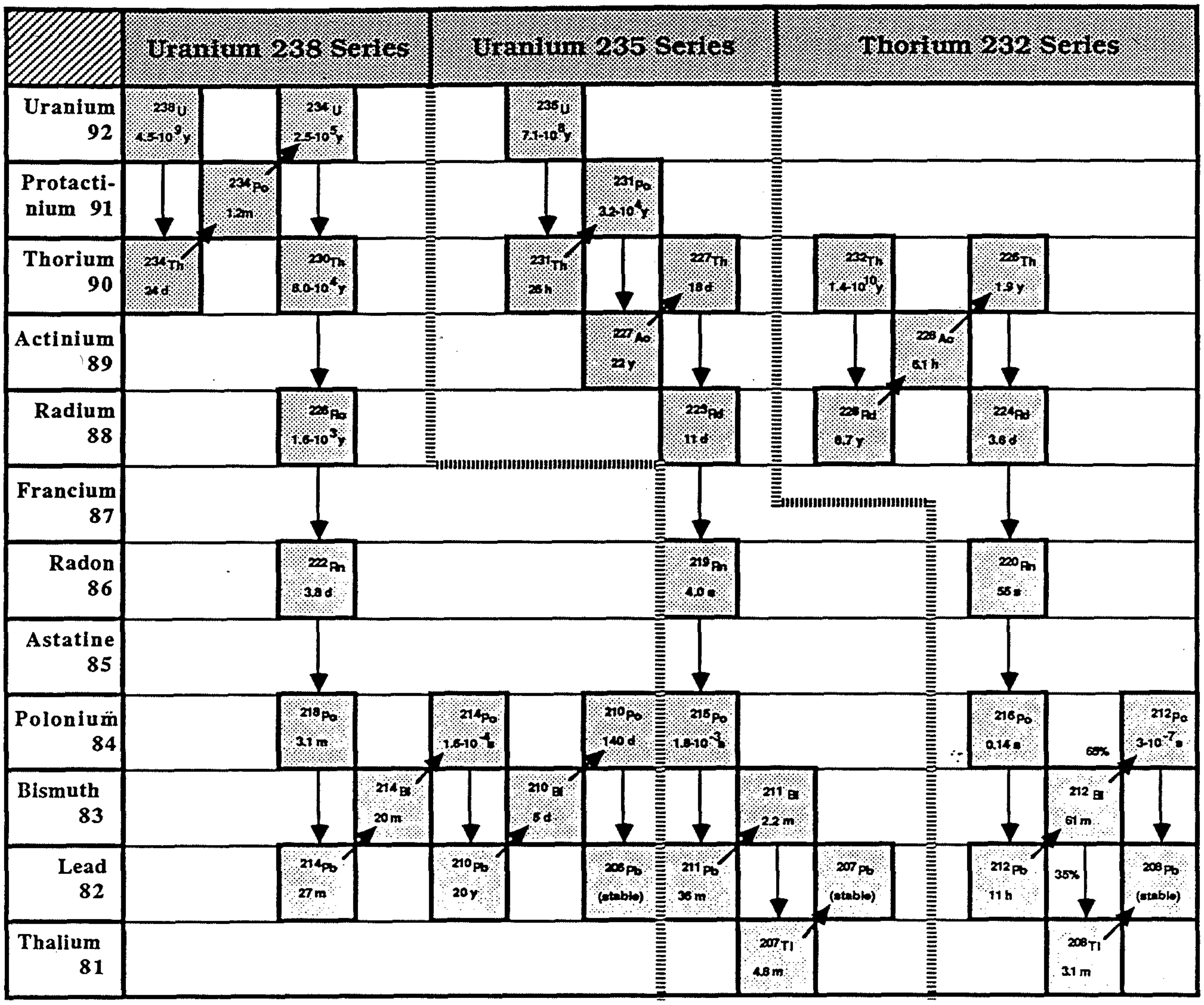

Figure A1: Uranium-238, Uranium-235 and Thorium-232 Radioactive Decay Series.

APPENDIX B: EXPOSURE TO NATURAL BACKGROUND RADIOACTIVITY IN ONTARIO

As a benchmark for comparisons, estimates of annual radiation doses (global average) from natural background radioactivity are summarized in Table B1, using data from Reference B1.

TABLE B1

ESTIMATED ANNUAL DOSE FROM NATURAL BACKGROUND RADIOACTIVITY

Source of Irradiation	Annual Dose Equivalent (mSv) External	Internal	Total
Cosmic rays (sea level)	0.30	-	0.30
Radionuclides from cosmic rays	-	0.015	0.015
Terrestrial radionuclides			
- Potassium-40	0.12	0.18	0.30
- Rubidium-87	-	0.006	0.006
- Uranium-238 and Thorium-232 series (excluding Radon and Thoron)	0.23	0.17	0.40
- Radon and daughters (inhalation)	-	0.80	0.80
- Thoron and daughters	-	0.17	0.17
Total	0.65	1.34	1.99 (say 2.0 mSv)

It can be seen from Table B1 that about 50% of the estimated annual dose is due to inhalation of radon and thoron daughters. Exposure while indoors is the dominant contributor in temperate climates, due to both the increased concentration found indoors, and the relatively high fraction of their time which the majority of people spend indoors. Substantial data on the distributions of radon daughter concentrations among residences within a geographic area, and among different geographic areas, have become available within the past decade. Data for several Ontario communities, from References B2 and B3, are shown in Table B2. Also shown are data for the communities with the maximum and minimum concentrations (geometric mean) from Canadian and U.S. surveys (References B2 and B4). An approximate conversion from radon daughter concentration to effective dose equivalent is that exposure to a radon daughter concentration of 0.02 WL corresponds to about 5 mSv/a, for 100% occupancy time and for a lifestyle typical of that for a general member of the public. Considering the Canadian data only, it can be seen that by using the mean values for the cities identified, the radiation dose from radon daughters may vary sixfold. Individual properties exhibit a much greater range.

TABLE B2

INDOOR RADON AND RADON DAUGHTER CONCENTRATIONS IN RESIDENCES IN ONTARIO AND NORTH AMERICAN COMMUNITIES

Community	Radon Daughter Concentration Geometric Mean (W.L.)	Percent of Houses Exceeding 0.02 WL %
Port Hope, Ontario[1]	~.005[2]	01
Sudbury, Ontario	0.0036	6.9
Thunder Bay, Ontario	0.0025	2.2
Toronto, Ontario	0.0018	0.9
Winnipeg, Manitoba[3]	0.0058	15.9
Vancouver, B.C.[3]	0.0009	0.0
Fargo, N.D.[4]	0.028[2]	n/a
San Francisco, Cal.[4]	0.0017[2]	n/a

1. From original Port Hope survey, excluding concentrations exceeding 0.02 WL as a number of these houses were affected by the presence of soil contaminated with Radium-226.
2. An equilibrium ratio of 0.5 has been used to convert from the measurements of radon concentration to radon daughter concentrations. This corresponds to the average value measured in Port Hope, and is also the value frequently used in other studies where only radon concentrations are available.
3. In the Canadian survey, data from Winnipeg had the highest geometric mean concentration, and data from Vancouver the lowest.
4. In the U.S. survey, data from Fargo had the highest geometric mean concentration, and data from San Francisco the lowest.

Table B2 shows that the Ontario data falls within the range of North American data, and is not clustered at either extreme. Using the conversion noted above, the geometric mean radon daughter concentrations for the Ontario communities correspond to effective dose equivalents of 0.5 to 1.25 mSv/a. Two-thirds of the individual properties within a community are estimated to be within a factor of 2 to 3 either way from these mean values. There are, however, some houses with radon daughter concentrations exceeding 0.02 WL in all Ontario communities surveyed, corresponding to effective dose equivalents exceeding 5 mSv/a for full time occupancy.

External gamma radiation exposure accounts for about 30% of the estimated annual dose shown in Table B1, with the contribution from cosmic rays, and the contribution from background soil concentrations of Potassium-40, the Uranium-238 series and the Thorium-232 series being approximately equal. Exposure from cosmic rays varies with height above sea level. The difference in doses from cosmic rays between sea level and Banff, Alta, (elevation 1400 m) is only about 0.13 mSv/a, so there will be much less variation from this source across Ontario. Substantial data on the variations in concentrations of Potasium-40, Uranium-238 and Thorium-232, in Canadian rocks and soils, and the resulting variation in external gamma exposure rates, have been collected through airborne surveys conducted for the Department of Energy, Mines and Resources, and other surveys (References B5 and B6). Table B3 contains concentration data for a number of common rock types and soils (Reference B7), airborne survey data for the four areas surveyed in Ontario, and maximum, minimum and average data for all Canadian areas surveyed by air. It can be seen that the spread in mean soil concentrations, and in mean gamma exposure rates from radioactivity in the soil, is about a factor of 5 among the different areas of Canada.

There are also substantial variations within an individual area. Table B4 shows the variation of outdoor gamma exposure rates within the area identified in Table B3. For the four Ontario areas, the median radiation field would result in annual radiation doses from 0.13 to 0.20 mSv/a. However, the lowest quartile reading in the Ignace, Sioux Lookout area would cause an annual dose of 0.09 Sv/a, and the highest decile reading in the Blind River area would result in an exposure of 0.40 Sv/a, in all cases assuming full-time residence in these locations. Canadian data shows, on average, lower dose rates than for other countries. For example, Reference B5 contains estimated average outdoor exposure rates for 11 countries. The Canadian average is second lowest, and is about half the highest average exposure rate.

Internal exposure from Potassium-40 contained in the body, and from trace quantities of radionuclides inhaled, and ingested in food and water, accounts for less than 20% of the estimated annual average dose shown in Table B1. About half of this results from Uranium-238, Thorium-232 and their daughters, primarily through food ingestion. There are substantial data in published reports, on the ratios of radionuclide concentrations in vegetation to radionuclide concentrations in soil. These show wide variations, both by vegetation types and with soil characteristics. These factors, combined with the lack of geographical data on variations in radionuclide concentrations in vegetation, do not allow estimation of the differences in internal doses by geographic area. As many foodstuffs are imported from a common source, or grown within a fairly well defined area, and because internal doses from ingestion of Uranium-238 and Thorium-232 series radionuclides represent only about 10% of estimated average annual doses, variations in annual doses to individuals from this source are likely to be much less than the variations due to exposure to radon daughters and to external gamma radiation.

TABLE B3

POTASSIUM, URANIUM AND THORIUM CONCENTRATIONS IN DIFFERENT GLASSES OF ROCK, AND MEASURED AVERAGE CONCENTRATIONS FOR SURFACE SOILS IN DIFFERENT AREAS OF ONTARIO AND CANADA

Rock Class	Example	K (%) Mean	K (%) Range	K (%) Mean	K (%) Range	Th (ppm) Mean	Th (ppm) Range	Mean Exposure Rate($\mu R/h^{-1}$)[2]
Acid Extrusives	rhyolite	3.1	1 - 6	4.1	1 - 16	11.9	1 - 40	10.9
Acid Intrusives	granite	3.4	0 - 8	4.5	0 - 30	25.7	0 - 250	15.9
Basic Extrusives	basalt	0.7	0 - 2	0.8	0 - 3	2.2	0 - 9	2.2
Basic Intrusives	gabbro	0.8	0 - 3	0.8	0 - 6	2.3	0 - 1	2.4
Ultrabasic	dunite	0.3	0 - 1	0.3	0 - 2	1.4	0 - 8	1.1
Chemical Sedimentary Rocks	gypsum	0.6	0 - 8	3.6	0 - 27	14.9	0 - 130	7.8
Carbonates	limestone	0.3	0 - 4	2.0	0 - 18	1.3	0 - 11	2.1
Detrital Sedimentary Rocks	sandstone	1.5	0 - 10	4.8	0 - 80	12.4	0 - 360	9.1
Metamorphosed Igneous Rocks	orthogneiss	2.5	0 - 6	4.0	0 - 150	14.8	0 - 105	10.9
Metamorphosed Sedimentary Rocks	paragneiss	2.1	0 - 5	3.0	0 - 53	12.0	0 - 90	8.8
Average continental crust		2.1		2.7		9.6		7.8
Soils from:	Location[1]							
Ontario - Area 31F[1]	Pembroke	1.2		0.8		3.5		3.4
Ontario - Area 31C	Kingston	1.4		1.0		3.7		3.8
Ontario - Area 41J	Blind River	1.3		1.3		6.1		4.7
Ontario - Area 52G, J	Ignace Sioux Lookout	0.9		0.6		3.5		2.9
Ontario - Average		1.2		0.9		4.0		3.6
Manitoba - 64N	Kasmere Lake	2.1		not max.		10.9		7.6
NWT - 85J, I (parts)	Yellowknife W.	not max.		2.2		not max.		not max.
Sask. - 74F	Lloyd Lake	0.4		0.3		not min.		1.61
Quebec - 12L	Havre St.Pierre	not min.		not min.		2.2		not min.
Canada - Average		1.4		1.2		6.0		4.75

1. Area designations refer to the map designation in the series of national topographic maps produced by Energy, Mines and Resources Canada. Location refers to the title of the map for the general geographical area.
2. Exposure rates refer to the gamma radiation exposure rate in air, 1 m above the surface of the soil or rock, and do not include any contribution from cosmic rays. Values for the different rock classes have been calculated, using the same conversion factors as Reference 5.

TABLE B4

VARIATION OF OUTDOOR EXPOSURE RATES WITHIN AREAS
OF ONTARIO AND CANADA

Area	Location	Number of Measurements	Exposure Rates (μR/h) for Various Percentiles				
			25	50	75	90	99
Ontario - 31F	Pembroke	25366	2.4	3.2	3.9	4.6	6.3
Ontario - 31C	Kingston	25048	2.4	3.5	4.5	5.5	7.1
Ontario - 41J	Blind River	20153	2.7	3.8	5.3	7.6	11.7
Ontario - 52G, J	Ignace, Sioux Lookout	41102	1.7	2.5	3.5	4.7	8.0
Ontario - All	-	111669	2.2	3.1	4.1	5.4	9.2
Manitoba - 64N	Kasmore Lake	19852	4.3	6.6	9.1	12.2	19.1
Saskatchewan -74F	Lloyd Lake	15549	1.2	1.5	1.9	2.5	3.7
Canada - All	-	890446	2.5	3.9	5.7	7.7	13.3

In summary, the available data show that annual average doses in Ontario from background radioactivity are likely to be less than the global average estimated in Reference B1. There are, however, substantial variations in the annual doses received by different individuals, primarily due to differences in indoor air concentrations of radon daughters, and secondarily due to differences in external gamma radiation exposures. A few percent of the Ontario population are exposed to indoor radon daughter concentrations corresponding to annual doses exceeding the 5 mSv annual dose limit set by regulation, for exposure of members of the public resulting from the operation of a nuclear facility.

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