GREAT LAKES
WATER QUALITY BOARD

INTERNATIONAL JOINT COMMISSION

GREAT LAKES WATER QUALITY 1978
APPENDIX D
RADIOACTIVITY
SUBCOMMITTEE REPORT

GREAT LAKES WATER QUALITY

SEVENTH ANNUAL REPORT

APPENDIX D

ANNUAL REPORT OF THE RADIOACTIVITY SUBCOMMITTEE

TO THE
IMPLEMENTATION COMMITTEE
GREAT LAKES
WATER QUALITY BOARD
JULY 1979

WINDSOR, ONTARIO

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100 Ouellette Avenue
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PREFACE

Appendix D to the 1978 Annual Report on Great Lakes Water Quality is the fourth annual report submitted by the Radioactivity Subcommittee to the Implementation Committee and to the Great Lakes Water Quality Board. The Appendix contains detailed information and data available as of May 1979 regarding radioactivity in the Great Lakes Basin. A summary of this Appendix appears in the Board's Seventh Annual Report to the International Joint Commission.

Though the Board has reviewed and approved the Subcommittee's report for publication, some of the specific conclusions and recommendations contained in this Appendix may not be supported by the Board.

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1 INTRODUCTION

The Radioactivity Subcommittee reports annually to the Implementation Committee of the Water Quality Board on the radiological status of the Great Lakes. This particular report presents information for calendar year 1978.

Figure 1 shows the geographical locations of all nuclear facilities in the Great Lakes Basin. The Cook 2 nuclear generating station, located at Benton Harbor, Michigan, came on line during 1978. The thirteen nuclear generating stations in the basin with their 22 reactors now have a total installed electrical generating capacity of 14,807 MW; Table 1 provides details of each facility. Stations currently under construction or planned to be in operation within the next decade have a designed electrical generating capacity of 23,861 MW; information regarding their location, generating capacity, and completion dates is given in Table 2.

The revised water quality objective for radioactivity was included in the 1978 Great Lakes Water Quality Agreement. Compliance with the objective, which is expressed in terms of dose, is determined by measuring the concentrations of specific radionuclides in the water, and converting to dose, using a procedure recommended by the International Commission on Radiological Protection (ICRP). In 1977, the ICRP changed the basis for converting between dose and concentration. At its July 1978 annual meeting, the International Joint Commission asked the Radioactivity Subcommittee to determine the significance of the changes introduced by ICRP for the water quality of the Great Lakes and to determine the adequacy of the radioactivity objective. Chapter 2 of this report describes the objective, explains the changes introduced by ICRP, and assesses the adequacy of the objective.

The International Joint Commission also asked the Radioactivity Subcommittee to describe the impact of nuclear fuel cycle activities on the Great Lakes Basin, with particular emphasis on the storage and disposal of high-level radioactive waste. Chapter 3 presents an overview of each step of the nuclear fuel cycle, with particular attention given to waste management, including the regulations and options for waste storage and disposal. The potential radiological impact on the Great Lakes Basin for each step of the nuclear fuel cycle, for both normal and abnormal operation, is considered to the extent possible. Radiological risk is also evaluated. Present fuel cycle activities in the basin, the specific impact of each, and their present waste management practices are described.

Chapter 4 tabulates releases of radionuclides from nuclear facilities in the Great Lakes Basin during 1978. Chapter 4 also presents the protocol developed for providing the International Joint Commission with information about unplanned releases of radionuclides within the basin.

Chapter 5 reports on radionuclides detected in the sludge and in the effluent of municipal sewage treatment plants.

TABLE 1

OPERATING NUCLEAR GENERATING STATIONS, 1978

LAKE	STATION	LOCATION	REACTOR TYPE	ELECTRICAL POWER, MW
MICHIGAN	Zion I & II	Zion, Illinois	PWR	2 X 1040
	Kewaunee	Carlton, Wisconsin	PWR	535
	Point Beach I & II	Manitowoc County, Wisconsin	PWR	2 X 497
	Palisades	Covert Township, Michigan	PWR	805
	Big Rock Point	Charlevoix County, Michigan	BWR	72
	Cook 1 and 2	Benton Harbor, Michigan	PWR	1054 & 1060
HURON	Douglas Point	Tiverton, Ontario	CANDU	220
	Bruce A	Tiverton, Ontario	CANDU	4 X 750
ERIE	Davis-Besse 1	Ottawa County, Ohio	PWR	906
ONTARIO	Pickering 1-4	Pickering, Ontario	CANDU	4 x 540
	Ginna	Ontario, New York	PWR	490
	Fitzpatrick	Oswego, New York	BWR	821
	Nine Mile Point 1	Oswego, New York	BWR	610

TABLE 2

NUCLEAR GENERATING STATIONS UNDER CONSTRUCTION OR PLANNED

LAKE	STATION	LOCATION	REACTOR TYPE	ELECTRICAL POWER, MW	ESTIMATED COMPLETION DATE
MICHIGAN	Bailly	Westchester Township, Indiana	BWR	645	1986
	Haven	Sheboygan, Wisconsin	PWR	900	1984
HURON	Midland 1 & 2	Midland, Michigan	PWR	460 & 811	1981-82
	Bruce B	Tiverton, Ontario	CANDU	4 X 750	1983-86
ST. CLAIR RIVER	Greenwood 2 & 3	St. Clair County, Michigan	PWR	2 X 1200	1987-89
ERIE	Fermi 2	Monroe County, Michigan	BWR	1093	1980
	Davis-Besse 2 & 3	Ottawa County, Ohio	PWR	2 X 906	1981-84
	Erie 1 & 2	Erie County, Ohio	PWR	2 X 1260	1985
	Perry 1 & 2	Lake County, Ohio	BWR	2 X 1205	1983
ONTARIO	Nine Mile Point 2	Oswego, New York	BWR	1100	1984
	Sterling 1	Cayuga, New York	PWR	1150	1989
	Pickering 5-8	Pickering, Ontario	CANDU	4 X 540	1981-83
	Darlington	Oshawa, Ontario	CANDU	4 X 850	1986-89

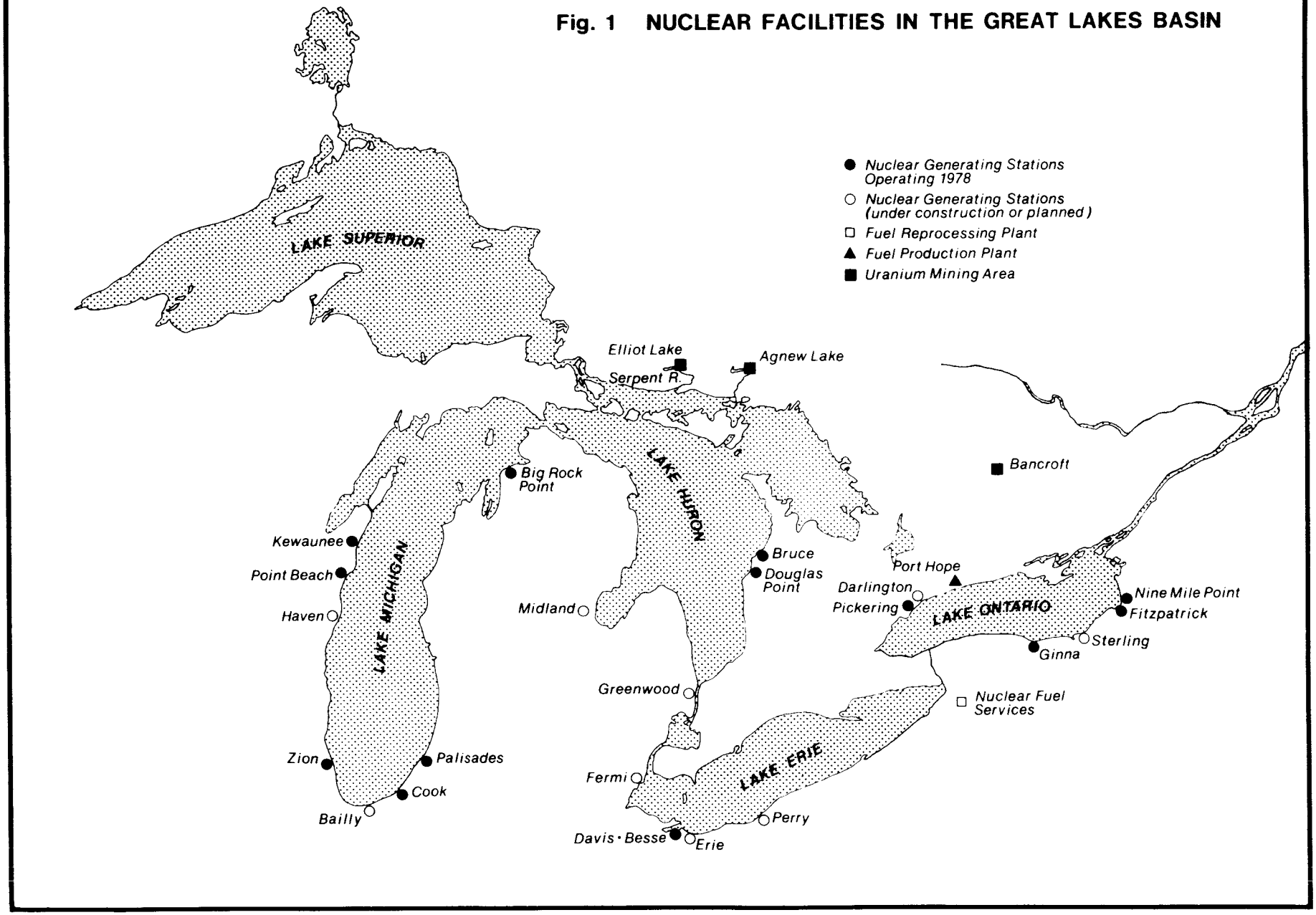
Fig. 1 NUCLEAR FACILITIES IN THE GREAT LAKES BASIN
Nuclear Generating Stations Operating 1978
Nuclear Generating Stations (under construction or planned)
Fuel Reprocessing Plant
Fuel Production Plant
Uranium Mining Area
LAKE SUPERIOR
Elliot Lake
Agnew Lake
Serpent R.
Big Rock Point
LAKE HURON
Bancroft
Kewaunee
Point Beach
Haven
LAKE MICHIGAN
Bruce
Douglas Point
Port Hope
Darlington
Pickering
LAKE ONTARIO
Nine Mile Point
Fitzpatrick
Sterling
Ginna
Midland
Greenwood
Nuclear Fuel Services
Zion
Palisades
Cook
Bailly
Fermi
LAKE ERIE
Perry
Davis-Besse
Erie

A radioactivity surveillance plan for the Great Lakes was presented in the Radioactivity Subcommittee's 1977 Appendix D. Chapter 6 summarizes the adequacy of present radioactivity surveillance activities and the extent of implementation of the Subcommittee's plan, in order to meet the requirements of the 1978 Water Quality Agreement.

Chapter 7 tabulates data on levels of radioactivity in water and biota samples collected during 1978.

The significance of the surveillance, monitoring, and release data are discussed in Chapter 8. Changes in the concentration of selected radionuclides with time are also considered, and compliance with the radioactivity objective is determined.

The Subcommittee's conclusions are presented in Chapter 9.

2 RADIOACTIVITY OBJECTIVE AND DOSE CALCULATION

RADIOACTIVITY OBJECTIVE

The specific radioactivity objective for the Great Lakes is given in Annex 1 to the 1978 Water Quality Agreement (1):

> The level of radioactivity in waters outside of any defined source control area should not result in a TED_{50} (total equivalent dose integrated over 50 years as calculated in accordance with the methodology established by the International Commission on Radiological Protection) greater than 1 millirem to the whole body from a daily ingestion of 2.2 litres of lake water for one year. For dose commitments between 1 and 5 millirem at the periphery of the source control area, source investigation and corrective action are recommended if releases are not as low as reasonably achievable. For dose commitments greater than 5 millirem, the responsible regulatory authorities shall determine appropriate corrective action.

The details of the objective were published in the Federal Register (2) and were also given in the Radioactivity Subcommittee's 1977 Appendix D (3).

The objective was developed to protect public health and the environment. It considers two major aspects:

1. Ambient water quality
2. Control of release of radioactive materials

Ambient concentrations of specific radionuclides must be considered so that contributions from all sources, including aerial deposition, are taken into account when total equivalent dose to man is calculated.

The license conditions for nuclear operations, such as power generation, mining, milling, and refining, permit the controlled release of radionuclides in the aqueous and gaseous discharges from these operations. The objective requires that both the concentrations and the quantities of radionuclides released via the aqueous effluent from each operation should be controlled so as to conform with the recommendation of the International Commission on Radiological Protection (ICRP) that "all doses be kept as low as is reasonably achievable economic and social considerations being taken into account" (4). For each identifiable source, the objective established a series of action levels, based on the total equivalent dose measured at the periphery of the source control area. The source control area was defined as the "area . . . bounded by a distance of 1 km radius from the point of release or, in those cases where the release point is to a narrow channel or river, the boundary shall be a point 1 km downstream from the source" (2, 3).

CALCULATION OF DOSE

The objective is expressed in terms of a total equivalent dose to a "reference man", integrated over fifty years (TED_{50}). "Reference man" has been defined by ICRP (5). This whole-body TED_{50} is calculated from the concentrations of the specific radionuclides measured in the water, in accordance with the procedure established by the ICRP (2, 3, 6). The term TED_{50} has now been replaced by "effective dose equivalent" (H_e).

The detailed objective requires that, for a single organ or tissue, the total equivalent dose "shall be in proportion to the dose limit recommended by the ICRP for that tissue" (2, 3). Most radionuclides of interest tend to concentrate in one or more "critical organs" or tissues. Under the former ICRP procedure, limits were set separately for each organ, and the various organ doses would have limited the ambient water concentrations.

In 1977, ICRP, in its Publication 26 (7), introduced basic changes in both the philosophy and the methodology of radiation protection. These changes give rise to a revised system of basic standards for radiation protection. The changes also directly affect the conversion from dose to concentration and, therefore, the corresponding maximum ambient water concentration for each radionuclide. Two distinct factors contribute to the change in the maximum concentration:

1. The use of improved metabolic parameters and dosimetric models.
2. Re-evaluation of the risk associated with a given organ dose.

As a result of these changes, at its July 1978 Annual Meeting, the International Joint Commission asked the Radioactivity Subcommittee:

> What is the significance for Great Lakes water quality of the change in the ICRP method to calculate dose from concentration for radionuclides?

The major change introduced in Publication 26 is that the concept of a "critical organ" has been replaced by a new concept in which the risk is equal "whether the whole body is irradiated uniformly or whether there is nonuniform irradiation" (7). Under the new method, the weighted products of all organ doses are summed to obtain a total dose; this "whole body" dose is used exclusively for risk comparison. However, the new method allows the calculation of implied organ limits, using the weighting factors promulgated in Publication 26, which correspond to the "whole body" limit. These implied organ limits may be compared with the previous "critical organ" limits. Both the implied and the critical organ limits must be scaled to correspond to the radioactivity objective action conditions, since the total equivalent dose to a single organ or tissue is to be in proportion to the dose limit previously recommended by the ICRP for that tissue.

A detailed example of the effects of the changes introduced in Publication 26 are given in Annex I, where the change in the allowable concentration is calculated for ^{90}Sr.

The general effect of the changes introduced by ICRP is to permit increased organ doses. However, the numerical differences cannot be accurately quantified until ICRP Committee 2 releases its new "annual limits of intake" for each radionuclide.

ADEQUACY OF THE OBJECTIVE

The changes recommended by ICRP, in general, raise the numerical dose limits to specific organs or tissues as compared to those allowed under the older "critical organ" concept. The changes therefore permit a higher concentration of most radionuclides in the Great Lakes. The ICRP changes reflect that organization's re-evaluation of both the risk and the dosimetric methodology associated with exposure to ionizing radiation. The Radioactivity Subcommittee concludes, however, that the objective should remain unchanged for the present since the net effect of these changes cannot be assessed until the new ICRP limits are published.

There are other principles imbodied in the 1978 Water Quality Agreement which act to limit ambient radionuclide concentrations. Maintenance or improvement of existing water quality (as set forth in Article IV, Item 1(c)), while difficult to achieve since a major input is via fallout, is still a fundamental principle. The principle of discharges from nuclear power plants being as low as reasonably achievable (ALARA) will also be utilized. ALARA also applies to other point-source inputs, such as from mining and low-level waste management sites, but does not apply to such inputs as fallout.

The radioactivity objective also bans dumping of radioactive waste.

Interpretation of the proposed objective and development of numerical secondary standards (concentrations for specific radionuclides) will be a future responsibility of the Radioactivity Subcommittee. This would be undertaken after ICRP Committee 2 publishes new dose-to-concentration conversion factors.

Regarding the permanent disposal of radioactive waste, any changes in dosimetric methodology given in Publication 26 should not alter the view of the Radioactivity Subcommittee, since the goal is no release whatsoever from any disposal site.

3 THE NUCLEAR FUEL CYCLE

INTRODUCTION

The International Joint Commission asked the Radioactivity Subcommittee to prepare a report on United States and Canadian nuclear fuel cycles with emphasis on how they may impact on the Great Lakes Basin. The Commission expressed particular concern as to the potential impact of the storage and disposal of high level radioactive waste on Great Lakes water quality.

The Subcommittee believes that a meaningful evaluation of nuclear fuel cycle impact is not possible at this time since the multitude of risk studies performed in this area, e.g. reactor accidents or breach of repository integrity, are not supported by an adequate data base. Estimates of radiological impact are most commonly made by assessing the risk, which is the product of the probability of an event and its consequence. In most critical areas, neither of these is known with any degree of certainty. In many instances, experts in various disciplines differ widely in their estimate of basic parameters. It should also be noted that identification of a potentially hazardous practice normally results in either the abandonment of that practice or the institution of remedial measures. As a consequence, the impact of "normal" fuel cycle activities is small and the risk associated with an "abnormal" event is reduced since the remedial measure is assumed to reduce its probability. The net effect of this approach is to sharply limit published estimates of fuel cycle impact.

This chapter has, therefore, attempted to respond to the Commission's request by presenting an overview of the nuclear fuel cycle, with emphasis on those aspects whose potential impact is greatest. This chapter has been separated into four sections.

In the first section, a brief description of each major step in the nuclear fuel cycle is given, except for waste management. Included here are the nature and types of radioactive materials involved in mining, milling, conversion (refining), enrichment, fabrication, power generation, and transportation.

The next section comprises a detailed discussion of waste management. Included here is a summary of present U.S. and Canadian regulations affecting waste storage and disposal, an outline of the classes of waste produced, and a description of the options under consideration for final waste disposal.

The third section attempts to delineate, or at least bound, the potential radiological impact on the Great Lakes Basin from each step in the fuel cycle, for both normal and abnormal operation. The values presented are taken from a variety of sources. Where a reliable data base exists, as in most normal cycle activities, the impact is small, and the magnitude of the numbers relatively unimportant. Where a potentially large impact is possible, the data base is virtually nonexistent. The various scenarios employed in the risk analysis do, however, serve to illustrate the types of impact which are conceivable.

The third section also includes a brief discussion of the quantities used in evaluating radiological risk. The presentation is, of necessity, quite simplified and, for additional background material, the reader is referred to an earlier report of the Radioactivity Subcommittee (12).

The fourth section of this chapter reviews existing fuel cycle activities located in the Great Lakes Basin, the impact of each, and their current waste management practices.

The Subcommittee's summary and conclusions about the nuclear fuel cycle are presented at the end of the chapter. The information presented in this chapter is from References (12-32).

FUEL CYCLE ACTIVITIES

Light-water-cooled nuclear reactors (LWR) in the United States use enriched uranium fuel to generate electricity. The heavy water Canadian (CANDU) reactors, which use natural uranium, operate on a similar fuel cycle but omit the enrichment step. The activities included in the nuclear fuel cycle are fuel supply, the reactors that "burn" the fuel, and the storage and reprocessing of spent fuel. A schematic diagram of a typical fuel cycle is given in Figure 2.

MINING

The term "uranium mine" includes any mine that produces ore or concentrate which at any stage of processing contains a minimum of 0.05% by weight of uranium. A variety of methods are employed to mine and process uranium ore. Most have several steps in common. The uranium-bearing ore is mined and transported to the processing facility. The ore is crushed and ground to expose the uranium minerals on the surface of the host-rock particles. The ground ore is pulped with water, and chemicals are added to dissolve the uranium. The dissolved uranium is separated from the leached residue, and the uranium-bearing liquor is treated by selective chemical techniques to yield a uranium-rich product liquor. The uranium is precipitated from this liquor, dried, and shipped to enrichment plants.

The release of radioactive material to the air and water occurs to a greater or lesser extent in all mining operations. Uranium ore contains naturally occurring isotopes of that element and a series of radioactive progeny which are formed by radioactive decay of the parent material. The radionuclides of principal concern are ^{238}U, ^{232}Th, ^{230}Th, ^{228}Th, ^{226}Ra, and ^{222}Rn gas and its daughters.

The abundance of these radionuclides depends primarily upon the geological and geochemical history of the ore deposit. The ore body, when exposed to the environment through mining, can serve as a source of radioactivity. Dissemination of radioactive material from an ore body may occur by three mechanisms: emanation of gases, erosion by precipitation and wind, and leaching of radionuclides into surface and ground water.

MILLING

The term "uranium mill" includes any plant which receives uranium ores as mined and converts these into a physical or chemical concentrate for further processing. The purpose of milling is to extract uranium from ore and prepare

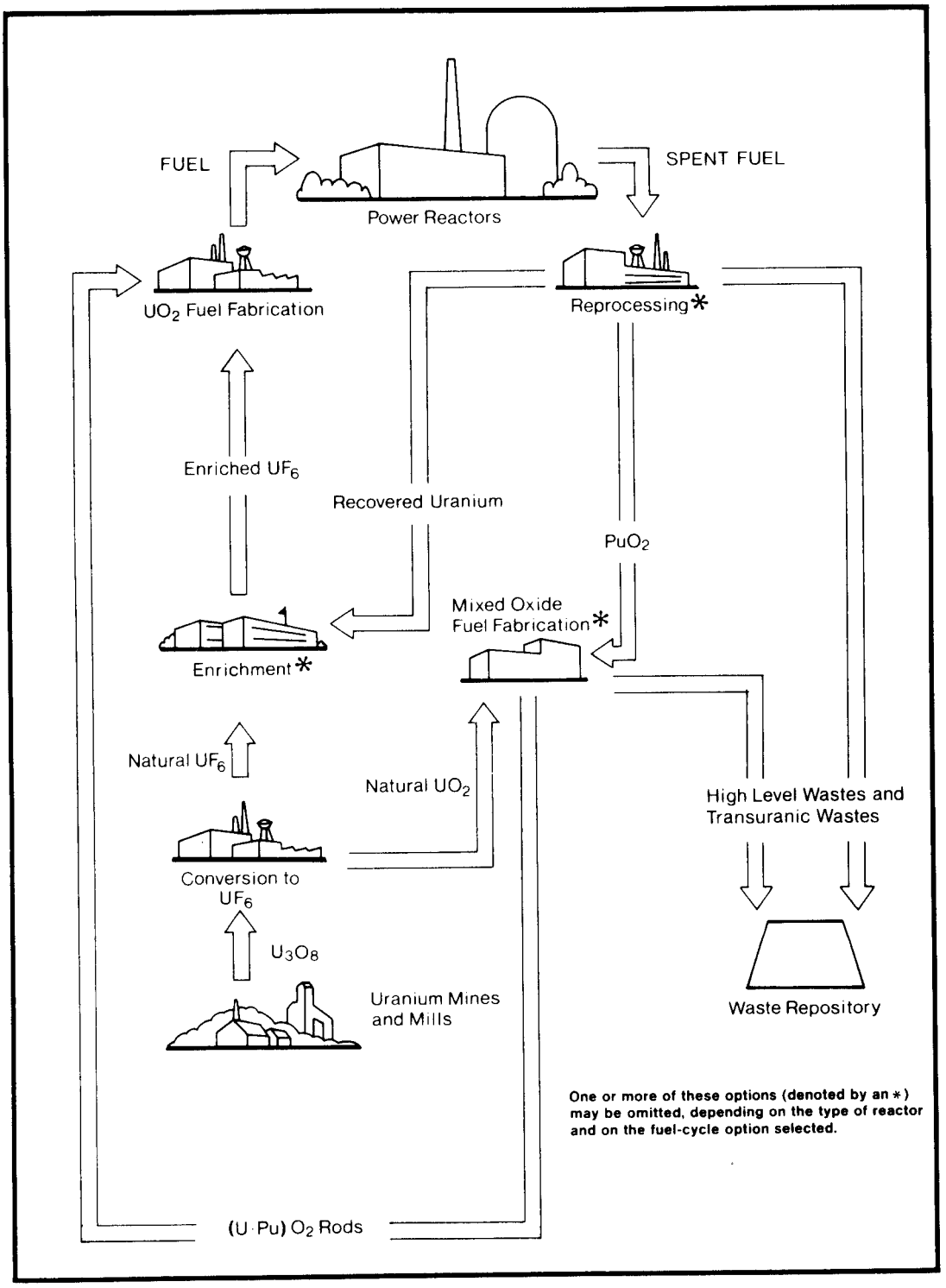

Fig. 2 TYPICAL NUCLEAR FUEL CYCLE

it into a semirefined form called "yellowcake", which is the feed material for the production of uranium hexafluoride (UF_6) and uranium oxides.

The radioactivity associated with uranium mill effluents comes from the natural uranium and its daughter products present in the ore. During the milling process, the bulk of the natural uranium is extracted from the ore, and more than 99% of the ore material becomes the mill wastes or tailings, a slurry of sandlike material. The tailings are pumped to an impoundment area where the solids settle out and accumulate to form a tailings pile. Each location where a mill is operating or has operated has an accumulation of tailings.

The "tailings pond" or "tailings pile" is of prime importance in estimating radiological impact because mining and milling remove only about 10-15% of the radioactive material from the ore; the remaining 85-90% remains in the tailings pile where it can be a long-term source of radon gas, which is readily dispersed and subsequently produces a series of radioactive decay products. In addition, non-stabilized tailings piles may allow radium and thorium to be blown or leached into surrounding areas.

Table 3 shows estimates of the wastes accumulated in both Canada and the U.S. from mining and milling operations. ^{222}Rn, a decay product of ^{226}Ra, emanates from these piles at an average rate of about 600 pCi/m^2s. Because of the presence in the tailings of ^{230}Th which, by its decay, maintains the radium inventory, the radioactivity in the tailings will remain for thousands of years.

CONVERSION

The conversion (refining) step purifies and converts yellowcake to UF_6, the chemical form in which uranium is fed to the enrichment plants, and also to uranium dioxide, a form of uranium used for fuel fabrication. The process employs a solvent extraction step to prepare high purity uranium feed prior to reduction, hydrofluorination, and fluorination of the purified feed.

Radionuclides present in the conversion facilities are isotopes of radium, thorium, uranium, and their decay products. Some of the decay products are delivered to the facility as impurities in the yellowcake and others recur there due to the continuing radioactive decay of the uranium. Uranium is present in the majority of the plant processes, appears in liquid effluents, and is essentially the only source of radioactivity in the gaseous effluents. The radium, thorium, and decay products are separated from the uranium in the conversion process and thus appear in the liquid effluents or solid waste associated with specific purifying procedures. 180 tonnes of uranium converted to 270 tonnes of uranium hexafluoride are required to support one gigawatt-year of electricity generated by light water reactors. Conversion of 10,000 tonnes of uranium per year to uranium hexafluoride produces an estimated 1,000 tonnes of solid waste (about 450 m^3) that must be shipped to a waste management site.

ENRICHMENT

At present, there are no enrichment plants in the Great Lakes Basin. However, enrichment is noted here since it comprises part of the nuclear fuel cycle for light-water nuclear power reactors, which utilize uranium that is enriched in ^{235}U to the range of 2-4%.

TABLE 3

ESTIMATES OF WASTE ACCUMULATED FROM MINING AND MILLING OPERATIONS

LOCATION OF TAILINGS	ESTIMATE OF DRY EXPOSED SURFACE AREA, in m^2	APPROXIMATE ^{226}Ra CONCENTRATION, in pCi/g
WITHIN BASIN		
Elliot Lake Area	35×10^5	500
Bancroft Area	3×10^5	500
OUTSIDE OF BASIN[a]		
Canada	26×10^5	500
United States	86×10^5	700

a. These tailings piles are not located in the Great Lakes Basin but will have an impact due to emanated gaseous radon.

TABLE 4

QUANTITIES AND TYPES OF WASTE PRODUCED BY NUCLEAR POWER REACTORS[a]

TYPE OF REACTOR	WET AND DRY WASTE		VOLUME m^3	TOTAL ACTIVITY, Ci
U.S. Light Water Reactors[b,c] (1000 MWe)	WET (such as resin and filters)		500	4,600
	DRY		120	
Canadian CANDU Reactor[d] (500 MWe)	WET	RESIN	11.9	550
		FILTERS	0.3	410
	DRY	COMBUS-TIBLE	228	1.1
		NON-COMBUS-TIBLE	1	0.015

a. Quantities of waste produced are for the size of the reactor given. It should be noted that a doubling of the electrical generating capacity does not necessarily result in an equivalent increase in the quantity of waste produced.

b. Average, based on 2/3 PWR's and 1/3 BWR's.

c. About 30 tonnes of spent fuel are produced each year.

d. About 65 tonnes of spent fuel are produced each year. To date, about 2,000 tonnes have been produced.

FABRICATION

Fuel for the U.S. light water power reactor is fabricated from uranium hexafluoride enriched to 2-4% in the ^{235}U isotope, while Canadian power reactors use natural (unenriched) uranium.

The only fuel fabrication facilities in the Great Lakes Basin are located on the Canadian side. Releases of radionuclides, primarily uranium, from these facilities are not considered significant. Specific facilities and their impact on the Great Lakes Basin are discussed later in this chapter.

POWER GENERATION

A nuclear power station operates on the same principle as a conventional fossil-fueled (oil or coal) power station except that the heat generation is by nuclear fission rather than combustion.

In the United States, two basic types of light-water-cooled nuclear reactor are used to generate electricity: the pressurized-water reactor (PWR) or indirect cycle and the boiling water reactor (BWR) which operates on a direct cycle. Pressurized-water reactors presently comprise approximately two-thirds of the light-water generating capacity committed through 1982. In Canada, CANDU reactors use natural uranium, heavy water as moderator and, in most cases, primary coolant, pressure tubes, and on-power refuelling. The types of reactors presently in operation, under construction, or planned in the Great Lakes Basin are given in Tables 1 and 2. Table 4 summarizes the quantities and types of waste produced by these reactors.

The nuclear power plant produces highly radioactive atoms from the fission of the uranium atoms (fission products) and also from the absorption of neutrons by the coolant and the structural materials (activation products). Among the more important radionuclides produced by uranium fissioning are isotopes of the noble gases krypton and xenon, the alkali metals cesium and rubidium, the alkaline earths barium and strontium, and the halogens iodine and bromine.

The capture of the neutrons liberated in fission by the nuclei of stable elements often results in the production of radioactive activation products. The radioactive coolant activation products are generally gases such as tritium, argon, fluorine, nitrogen, and oxygen which have relatively short half-lives. The induced activities in the structural materials may have considerably longer half-lives and comprise a much wider range of radioactive elements including zirconium, manganese, nickel, iron, carbon, chromium, cobalt, and copper.

TRANSPORTATION

Transportation of nuclear fuel material and waste products between U.S. facilities is currently made by rail and truck shipments with barge transportation being projected for the near future. In Canada, only road transportation is used at present, but rail and barge are being considered.

WASTE MANAGEMENT

REGULATORY FUNCTIONS

Primary responsibility for developing a waste management program in the United States is vested in the Interagency Nuclear Waste Management Review Group (IRG). The IRG is currently engaged in producing a comprehensive report, to be presented to the President, containing recommendations for the handling and disposition of spent fuel and other wastes produced in the nuclear fuel cycle (17). The present situation is complicated by the large number of technical options available and various political considerations. No firm estimates of the environmental effect of radioactive waste management can be attempted until such basic questions as repository form, waste type, and site location are specified.

There are, however, a number of present U.S. federal and state regulations which are applicable to one or more nuclear fuel cycle operations. These are summarized in Table 5. Several other United States federal agencies, including the Department of Labor's Mine Safety and Health Administration (uranium mining), and the Department of Health, Education and Welfare's Bureau of Radiological Health, are authorized by federal legislation to issue regulations on some aspect of radiation protection.

Radioactive waste management facilities in Canada are subject to the Atomic Energy Control Regulations. These were formulated by the Atomic Energy Control Board (AECB) under the authority of the 1946 Atomic Energy Control Act. Canadian federal and provincial regulations applicable to some portion of the nuclear fuel cycle are also summarized in Table 5.

Although the regulations cited will, where applicable, govern waste management practices, it seems assured that waste disposal operations will be the subject of more specific regulatory actions. The nature of these cannot, at present, be specified.

CLASSIFICATION OF WASTE

Although the terms "high-level" and "low-level" are much used, there is no generally accepted definition for either. Radioactive waste, however, falls naturally into three categories: low-level, medium-level, and high-level.

Low-level wastes are those which contain such low concentrations or quantities of radioactivity that they do not present any significant environmental hazards. Even if they were released from their packages in a transportation accident, they would not present much hazard to the public. Like any other freight spilled at the scene of an accident, they would have to be cleaned up because of their nuisance value. Under international regulations, they require only normal industrial packaging for shipment and require no special rail cars or other transport vehicles. Low-level wastes may include such things as residues or solutions from chemical processing; building rubble, metal, wood, and fabric scrap; glassware, paper, and plastic; solid or liquid plant waste, sludges, and acids; and slightly contaminated equipment or objects.

TABLE 5

PRESENT FEDERAL, STATE, AND PROVINCIAL REGULATIONS

TITLE	RESPONSIBLE AGENCY	CITATION	GENERAL APPLICABILITY
Atomic Energy Act	U.S. NRC	10 CFR 20	Sets limiting concentrations in air and water for most radionuclides. In general, based on a 5 rem per year dose in restricted areas and one-tenth that in unrestricted areas.
Uranium Fuel Cycle Standards	U.S. EPA	40 CFR 190	Sets an annual dose limit of 25 mrem to any member of the public from planned discharges. Does not apply to transportation or waste disposal sites but does apply to reprocessing where spent uranium fuel is to be reused.
Drinking Water Regulations	U.S. EPA	P.L. 93-523	Sets an annual dose limit of 4 mrem for the ingestion of finished drinking water containing man-made radionuclides.
Clean Air Act	U.S. EPA	P.L. 91-604 as amended	Not yet implemented - will set limits for all airborne pollutants, including radioactive emissions.
Atomic Energy Control Regulations	Canada AECB	-	0.5 rem per year is the limiting dose to an individual at the boundary of the exclusion zone for normal operation of a nuclear facility. A design and operating target of 1% of the derived release limits (based on 0.5 rem per year) is used for nuclear generating stations.
Canadian Drinking Water Standards and Objectives, 1968	Canada NH&W	-	Set objective concentrations of radionuclides in potable waters which correspond to an annual dose limit of 500 mrem. These are currently being revised.
Guidelines and Criteria for Water Quality Management in Ontario	Ontario MOE	-	Set permissible and desirable criteria for public water supplies for gross β and ^{226}Ra.
Fisheries Act	Canada DOE	1WP-77-1	Applies to effluents from uranium mines in Canada. Limits based on best practicable technology and on the principle of as low as reasonably achievable.

Medium-level wastes are predominantly beta-particle and gamma-ray emitters (e.g. ion exchange resins, industrial isotopes) and usually require some shielding materials as a part of the package. This waste may also be a combination of low-level, alpha, and beta-gamma types. Beta-gamma waste includes such things as irradiated reactor structural components, heavily contaminated objects, concentrated solidified sludges or evaporator bottoms, and nonrecoverable radioactive fuel scrap.

High-level wastes are spent reactor fuel or wastes from their reprocessing. Spent fuel is stored at the power plant site after removal from the reactor; a schematic of such a storage facility is shown in Figure 3. At the present time, reprocessing wastes are being stored in the Great Lakes Basin at the Nuclear Fuel Services (NFS) site near Buffalo. These reprocessing wastes have such a high radioactive content of long-lived isotopes that they require long-term storage in isolation. Eventually these liquid wastes will probably be solidified and shipped to a geologic disposal site. Figure 4 is a schematic for handling, storage, and ultimate disposal of spent fuel and reprocessing waste.

OPTIONS FOR WASTE MANAGEMENT

The objective of any waste management system is the isolation of the radionuclides until they have decayed to a safe level. This is obviously true for both Canadian and U.S. radioactive waste. While the U.S. incentive for reprocessing is greater, it cannot be ruled out as a Canadian option. For this reason, the Radioactivity Subcommittee has included three fuel cycle concepts in the ensuing discussion: the once-through (no reprocessing) cycle, the uranium-only cycle, and the uranium-plutonium cycle. These differ principally in that spent fuel is the only waste considered for the first, while the latter two produce chemically processed wastes which, in essence, are segregated into shorter half-life fission products and longer half-life trans- uranic isotopes. The waste management operations, therefore, depend strongly on the option chosen.

Waste management involves two major selections: the choice of waste form and the choice of repository. A multiple barrier approach has been proposed. As the first barrier, the chemical and thermal characteristics of the waste form can be varied in many ways. These include aging (cooling) prior to production of the disposal form, dilution of the radionuclides in a matrix material, transmutation and/or partitioning of certain isotopes, chemical design of the waste form, and adjustment of the waste material configuration. Canisters provide the next barrier. A selection of metals is available which gives various degrees of isolation depending on the particular disposal medium and exposure conditions. Absorptive overpack materials such as zeolites and bentonites are available as a further barrier. The disposal medium is a massive barrier to the intrusion of wastes into the biosphere. A number of choices range through stable, absorptive clays of the seabed; very deep hard rock formations; granite, shale, basalt, salt, and other rock formations; to outer space.

Options for low- and high-level waste management are given in Table 6. To the best of the Subcommittee's knowledge, both Canada and the United States are working toward some form of geologic waste disposal. Figure 5 is a schematic of a geologic disposal facility. To date, no specific sites have been chosen for the ultimate disposal of radioactive waste. In Canada,

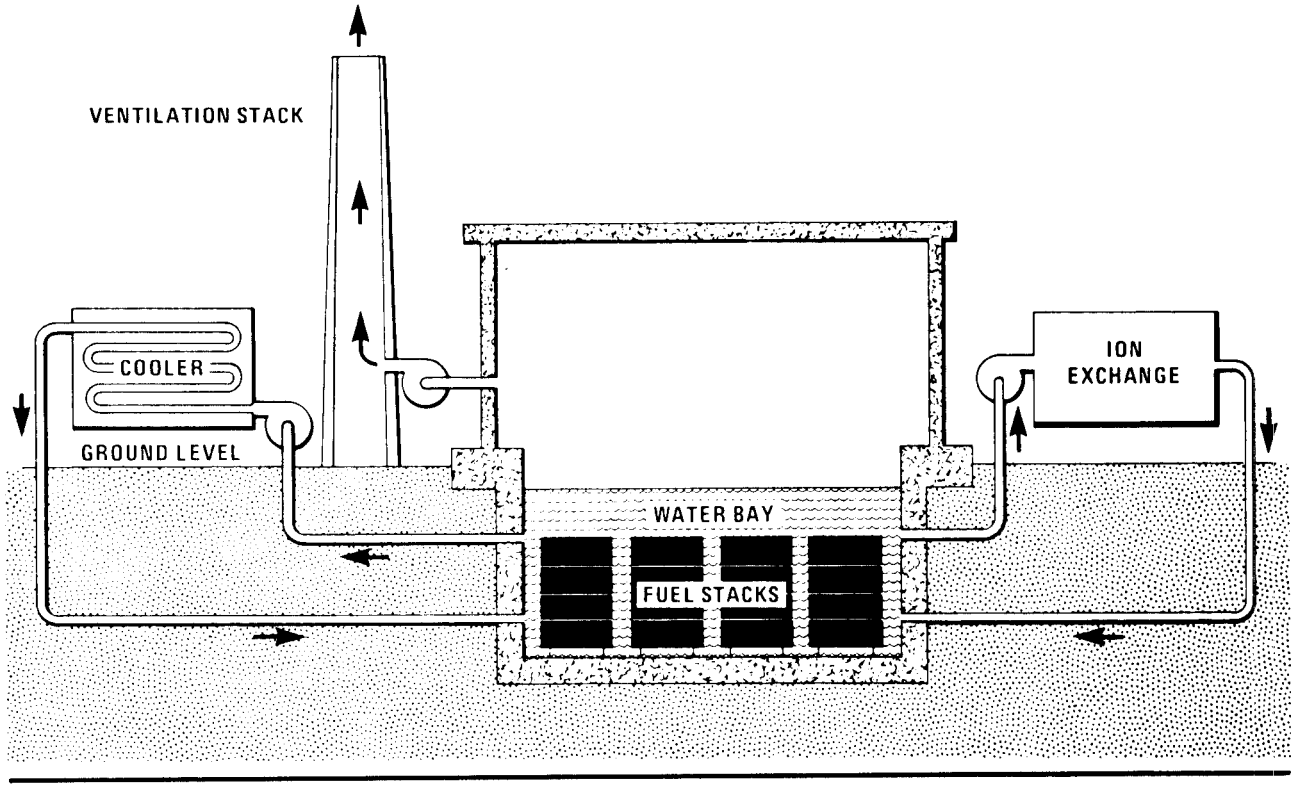

Fig. 3 SPENT FUEL STORAGE FACILITY

Figure from reference (46)

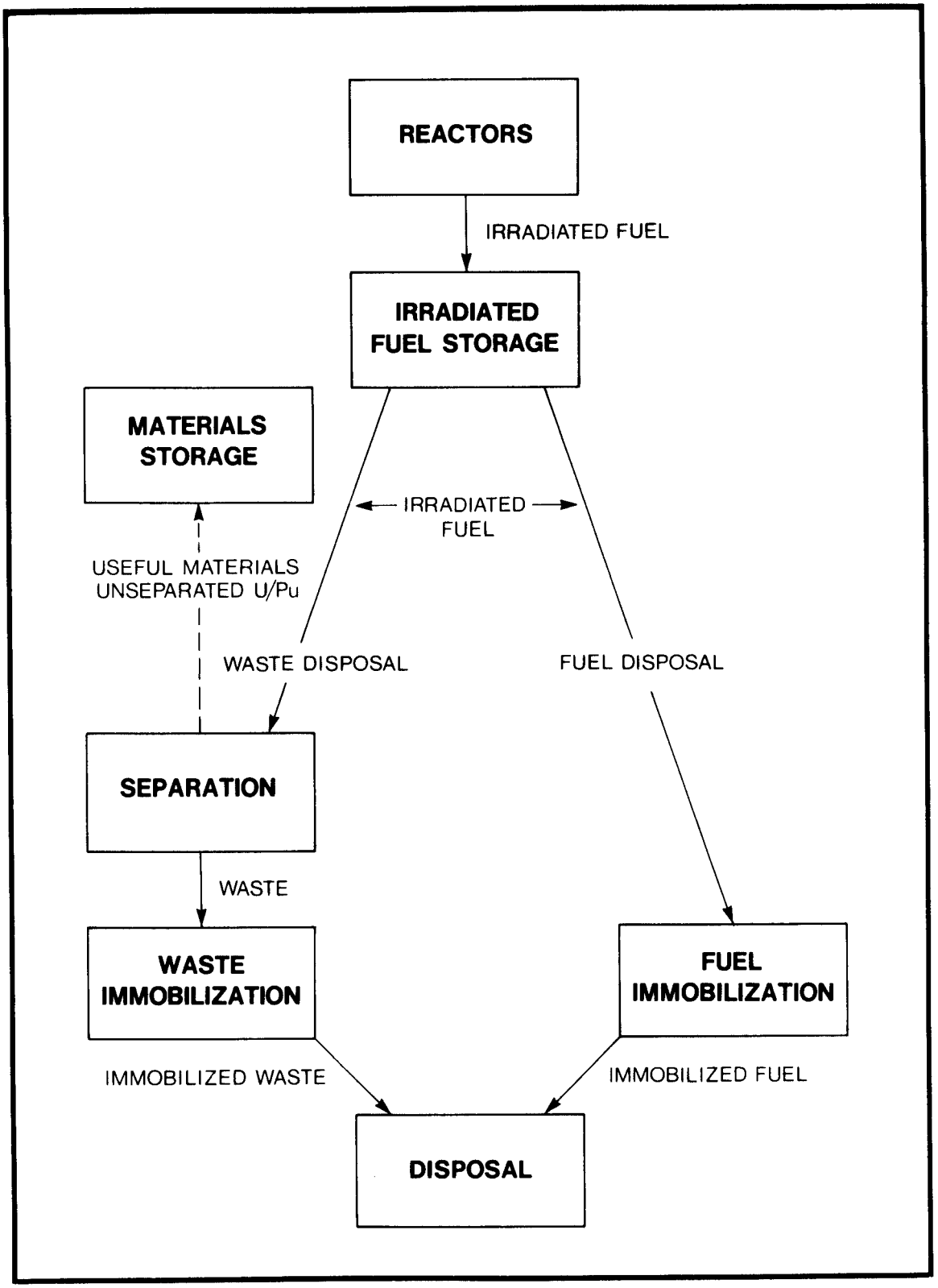

Fig. 4 OPTIONS FOR CLOSING THE URANIUM FUEL CYCLE

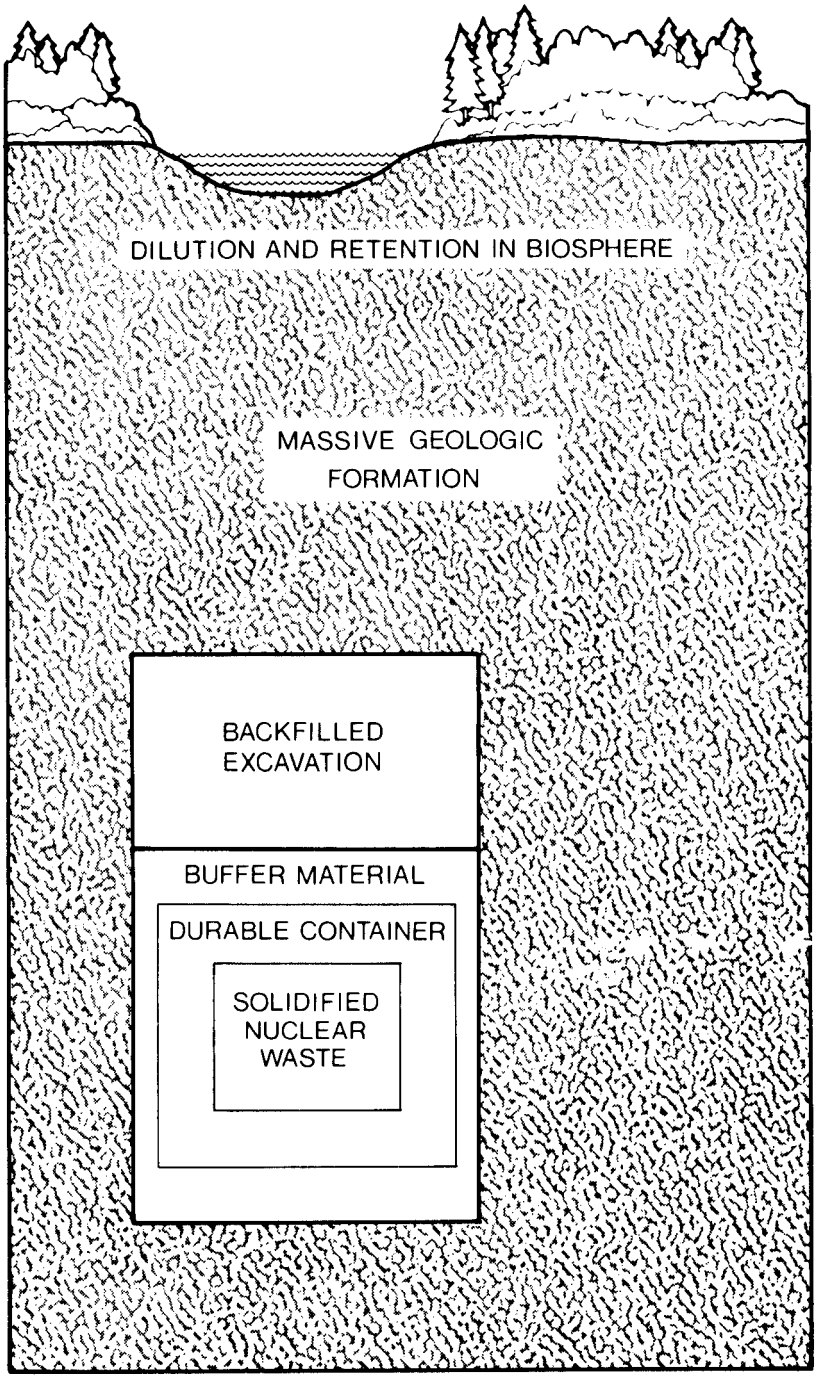

Fig. 5 FEATURES DESIGNED TO ISOLATE RADIOACTIVE WASTE

Figure adapted from reference (29)

TABLE 6

PROPOSED METHODS FOR DISPOSAL OF LOW- AND HIGH-LEVEL WASTES

LOW-LEVEL WASTE	HIGH-LEVEL WASTE
Shallow land burial, geologic barriers only	Conventional geologic disposal
Improved shallow land burial	Chemical resynthesis
Intermediate depth burial	Very deep hole concept
Deep well injection	Rock melting concept
Hydrofracturing	Island disposal
Emplacement in mined cavities	Sub-seabed geologic disposal
Ocean disposal, waste packaging and engineering barriers only	Icesheet disposal
Ocean disposal, waste form, packaging and geologic barriers	Reverse-well disposal
	Partitioning and transmutation
	Space disposal

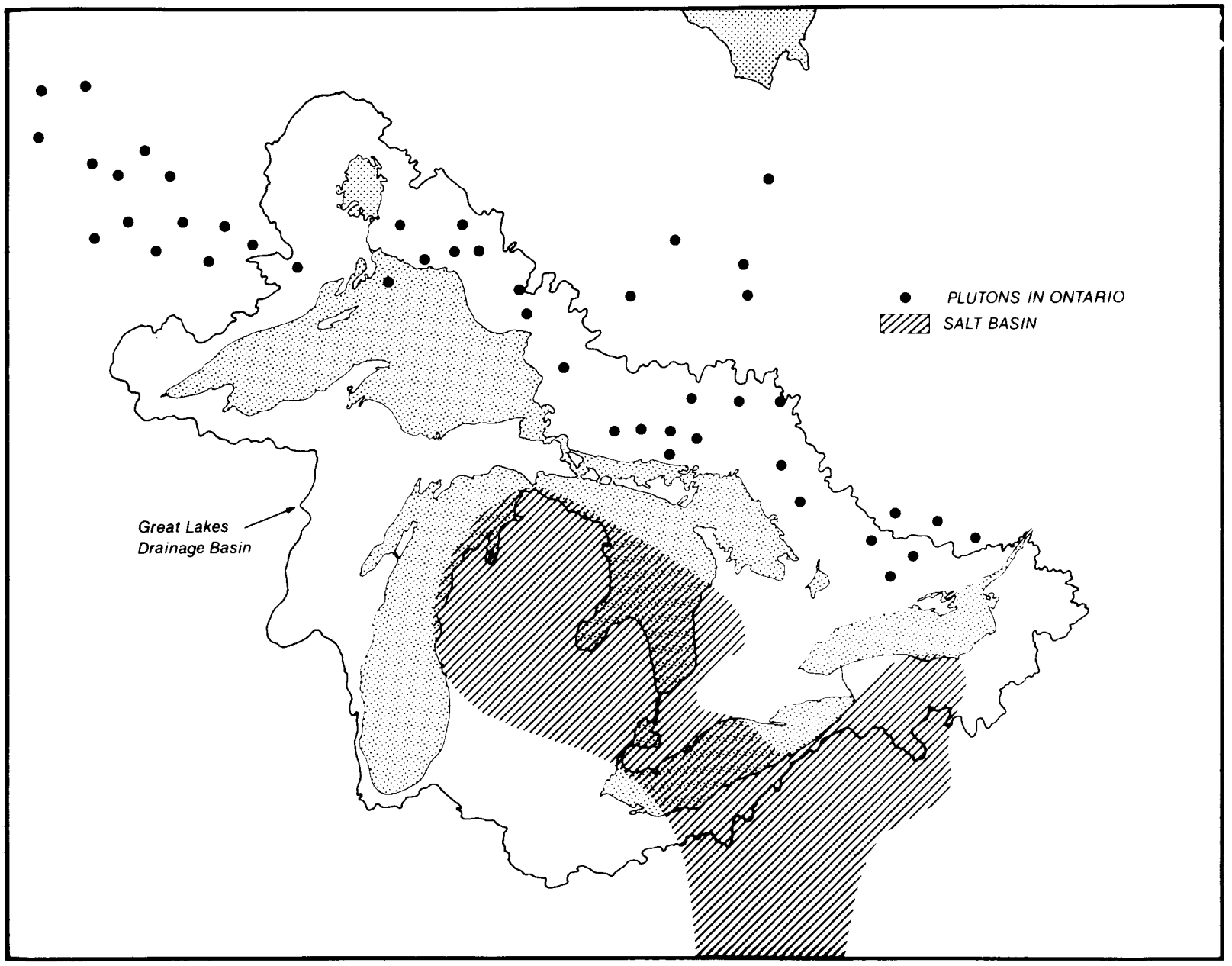

Fig. 6 LOCATION OF LARGE PLUTONS AND MAJOR SALT DEPOSITS IN THE GREAT LAKES BASIN

current AECB policy for waste management is "the indefinite retrievable storage of . . . wastes in solid forms in a limited number of government supervised, and preferably government operated, storage facilities". Specific waste management facilities and their impact on the Great Lakes Basin are discussed later in this chapter.

Of the various options for ultimate disposal of the high-level nuclear wastes, some form of geologic disposal is considered to be the most appropriate for both the U.S. and Canada.

CANADA

Current research in Canada is concentrating on disposal in hard, igneous rock. The Precambrian Shield has remained stable for over 900 million years, and there is no reason to expect that it will not remain stable for many more millions of years. It is intended that the waste be buried 500 to 1,000 metres deep inside rock plutons - masses of rock formed as single units from molten magma inside the earth's crust. There are over 1,500 plutons across Ontario (Figure 6) which will be the province where the initial disposal sites will be developed since this is where most of the benefit of nuclear generation has been obtained.

Atomic Energy of Canada Limited (AECL) has been given the lead role in Canada for research and development of disposal methods for high-level nuclear waste. AECL is also coordinating the work of other organizations involved in the program. The research and development will determine whether permanent disposal of radioactive waste in deep underground repositories in intrusive igneous rock is safe, secure, and desirable. Geological field studies began in 1978 to evaluate the effectiveness of barriers to prevent the release of radioactivity to the environment. The tentative program schedule is:

1978-1980	-	Geological survey work, experimental drilling, and accelerated research and development
1981-1983	-	Site selection for demonstration repository
1983	-	Site acquisition
1985-2000	-	Disposal demonstration
2000 and Beyond	-	Full scale facilities operational

Federal-provincial coordination involves a committee representing AECL, Ontario Hydro, Ontario Ministry of Energy, and the federal Department of Energy, Mines and Resources.

UNITED STATES

The U.S. Nuclear Regulatory Commission (NRC) has begun what will probably be a long rulemaking proceeding which will result in new regulations for shallow land burial of low-level radioactive wastes. Proposed regulations are not expected until 1980. The NRC will also propose regulations in 1981 for at least an alternative to shallow land burial. The NRC will prepare an environmental impact statement to provide information and a basis for reaching decisions on new criteria and rulemaking actions.

The NRC is addressing the following questions for storage and disposal of low-level wastes:

1. What should be considered significant enough to deal with in the environmental review; how to decide which alternatives to shallow land burial are viable; whether low-level waste should be divided into categories.

2. Whether explicit criteria should be developed for disposal and the format and content for any such criteria.

3. What to consider in criteria for waste performance, site suitability, design and operations, site monitoring and decommissioning, and post-operational maintenance and funding; whether criteria are needed in other areas.

4. The pros and cons of alternative disposal methods; which alternatives should be given priority in development of regulations; whether other viable alternatives exist and, if so, how they should be considered from technical, economic, social, and other standpoints.

5. The extent to which a state should be held responsible for waste generated within its borders.

Geologic disposal of high-level waste in salt deposits appears to be the preferred U.S. option. There are a large number of salt deposits, including several in the Great Lakes Basin (Figure 6).

The waste disposal schedules set in the United States were changed three times in 1978. The current aim is to have the Department of Energy apply for a waste disposal license in the early 1980's. A facility would then be licenced between 1988 and 1995. During this period, the overall waste management schedule is as follows:

1. The Department of Energy will develop one or more waste repositories, or intermediate scale facilities, probably allowing for spent fuel retrieval. The Department is also responsible for preparing relevant environmental impact statements.

2. EPA will develop overall standards governing public exposure.

3. The NRC will develop licencing criteria and procedures.

4. The environmental impact statements will be coordinated, probably by the Council on Environmental Quality.

5. The Department of Transportation will review transportation problems.

6. Legislation will be introduced clarifying the responsibilities of each federal agency.

IMPACT FROM TYPICAL FACILITIES

Any attempt to quantify the impact of nuclear fuel cycle activities on the Great Lakes Basin is subject to numerous reservations. Estimates of future

impact are even more uncertain since they depend on projections of nuclear capacity, choice of fuel cycle, specification of site, and the content of as yet unwritten standards and regulations.

While some phases of the nuclear industry, e.g. mining and milling, have not been controlled to the same extent as others, the current worldwide regulatory trend, particularly in the United States and Canada, has been in the direction of increasingly more stringent controls. In the future, it is unlikely that mine and mill operators will be allowed to abandon unstabilized tailings piles. With a few exceptions, the overall impact of normal operations related to the nuclear fuel cycle on the general environment and on public health may be expected to be small. The corollary to this statement is that most fuel cycle effects will result from abnormal releases. However, the probability of large-scale releases cannot be accurately predicted since no data base exists.

Having noted these reservations, an attempt has been made below to estimate the overall impact of present and future nuclear fuel cycle operations on the Great Lakes Basin. This section treats general classes of normal fuel cycle activity as they relate to the Great Lakes Basin. Accidental releases are covered in the next section, and the effects of specific basin facilities in the last section.

The sources of exposure from normal fuel cycle activity have been categorized by facility and effluent type as listed below:

1. Those facilities and effluents which act over substantial distances and, thus, affect the basin even though not necessarily sited therein. The major sources in this category are the radon emitted as a result of mining and milling operations, the ^{14}C produced in nuclear reactors, and the ^{85}Kr and ^{3}H which are released from reprocessing operations.

2. Those facilities which are sited in the basin and whose effluents, therefore, enter directly into the basin environment. This category includes local mines, mills, conversion facilities, and power reactors.

3. Facilities which could at some future time be sited within the basin. This category would comprise reprocessing plants and waste management facilities.

There is a certain amount of difficulty involved in choosing useful measures of radiation impact. The quantities cited in the literature are not always consistent and the health effects resulting from environmental radiation levels are imperfectly understood. In order to obtain some consistency in this presentation, a limited number of terms, which are discussed below, are employed. The definitions given are not intended to be rigorous but to allow comparison of the results given.

The quantity most commonly used in assessing radiation impact is the rem. The rem is basically a measure of the energy released in tissue, modified to indicate its biological effect. At environmental levels, a millirem, or mrem, is customarily used. While a variety of health effects may occur as a result

of exposure to radiation, it is thought that the most common, at environmental levels, is cancer. While it is possible for a person in the vicinity of a strong radiation source to be exposed externally, the most common environmental exposures are due to inhalation and ingestion. Most radionuclides are deposited preferentially in one or more internal organs or tissues. For example, strontium follows the chemistry of calcium and is deposited in bone. The health effects from internal exposures, therefore, depend on the sensitivity of the organ.

To convert doses to health effects, Table 7, adapted from the 1972 report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR Report), is used (15). The assumption is usually made that the number of health effects induced is proportional to the dose received, i.e. the number of health effects from a dose of 1 rem delivered to ten persons is the same as that from a dose of 10 rem to one person. This is not scientific fact but is an approximation used to estimate impact. One result of this assumption is that extremely small doses delivered to a large population may predict a large number of health effects. The unit of population dose used in this chapter is the person-rem, defined as the total dose delivered to a specified population, i.e. the product of the number of persons receiving a given dose and that dose. The number of health effects predicted is then the sum of the person-rem to each organ, or the person-rem to the total body, times the risk listed in Table 7.

The radiological impact of nuclear fuel cycle operations in the Great Lakes Basin has been presumed to be adequately described by specifying the dose and the number of health effects postulated to occur as a result of each type of operation. Where practical, an attempt has been made to relate these quantities with corresponding values for naturally present radionuclides or to compare the impact with that of non-cycle activities.

To put the doses involved into perspective, note that the average dose to an individual from exposure to natural background radiation is about 150 mrem per year. For a population of 30 million living in the Great Lakes Basin, the dose would be

$$(150 \times 10^{-3}\text{rem})\ (30 \times 10^{6}\ \text{persons}) = 4.5 \times 10^{6}\ \text{person-rem}$$

If this is assumed to be all total-body irradiation, the number of cancers would then be

$$(4.5 \times 10^{-6}\ \text{person-rem})\ (2 \times 10^{-4}\ \text{cancers/person-rem}) = 900\ \text{cancers}$$

Note that this is the number of cancers which would be expected, over the lifetime of this population, as a result of one-year's exposure to naturally occurring background radiation.

The impact of nuclear fuel cycle operations on the Great Lakes, to date, has been dwarfed by the effect of the residue from nuclear weapons testing. As an example, ambient levels of ^{90}Sr are currently about 1.0 pCi/L, but the ^{90}Sr contribution from reactor operations is projected to be less than 0.002 pCi/L through the year 2000.

The following section considers the impact that typical facilities could have on the Great Lakes Basin. The impact of specific nuclear facilities located in the basin is discussed later in this chapter.

TABLE 7

INDIVIDUAL RISK OF FATAL CANCER PER PERSON-REM[a,b]

ORGAN OR TISSUE	RISK
Total body[c]	2×10^{-4}
Red bone marrow (leukemia)	4×10^{-5}
Lung	4×10^{-5}
Breast (average for both sexes)	4×10^{-5}
Gastro-intestinal (except stomach)	2×10^{-5}
Stomach	2×10^{-5}
All other[d] (for each site)	1×10^{-5}
Thyroid[e]	1×10^{-6}

a. From Reference (15).
b. A quality factor of ten was assumed for alphas.
c. In addition, there is a genetic risk following gonadal irradiation.
d. Up to four sites other than those listed above.
e. Thyroid cancer incidence 1×10^{-5}.

TABLE 8

DOSES AND HEALTH EFFECTS TO A REGIONAL POPULATION WITHIN AN 80-KILOMETRE RADIUS OF A SPENT FUEL STORAGE FACILITY[a]

ORGAN	DOSE person-rem	HEALTH EFFECTS PER 10^6 PERSON-REM	HEALTH EFFECTS
Whole Body	8,598	400	3.4
Thyroid	44	60	0.0026
Bone	1,017	32	0.033
Lung	6	40	0.00024
Red Marrow	5	54	0.00027

a. The reference environment consists of two million people. Health effects are for the life of the facility plus one hundred years, and include non-fatal and genetic components.

NORMAL OPERATIONS

MINING AND MILLING

Uranium mills release small quantities of radon during processing but have, historically, created relatively large tailings piles which emit substantial quantities of gaseous radon. The radon, with a half-life of 3.8 days, is transported throughout the northern hemisphere. While the individual dose in the basin is small, the linear dose-effect model described above yields a non-negligible impact on the basin population.

The estimated dose to the average individual in the northern hemisphere resulting from one year's operation of a typical (100 hectare) tailings pile is about one-third mrem; the population dose in the Great Lakes Basin is then

$$1/3 \text{ mrem } (30 \times 10^6 \text{ persons}) = 10^4 \text{ person-rem}$$

This is an inhalation lung dose presumed to result in 4×10^{-5} lung cancers per person-rem (Table 7); there are no genetic effects from inhalation of radon daughters. Each year's operation, then, is projected to result in

$$(10^4 \text{ person-rem}) \left(4 \times 10^{-5} \frac{\text{health effects}}{\text{person-rem}}\right) = 0.4 \text{ health effects (lung cancers)}$$

As of 1970, there were 80 million tonnes of tailings occupying more than 850 hectares. This would give

$$\frac{850 \text{ hectares}}{100 \text{ hectares}} \left(0.4 \frac{\text{health effects}}{\text{uranium mill}}\right) = 3.4 \text{ health effects (lung cancers)}$$

these are population health effects for one year's exposure from all tailings piles. It is unlikely that newly created tailings piles will be unregulated. In addition, studies on the stabilizing of older piles are expected to result in drastically reduced emissions from those sources. If it is postulated that these piles remain untreated for 20 years, then the total result in the basin would be

$$20 \text{ years } \left(3.4 \frac{\text{health effects}}{\text{year}}\right) = 68 \text{ health effects (lung cancers)}$$

CONVERSION

The average individual within an 80-km radius of typical conversion facility would receive a lung dose of about 0.03 mrem per year. For a postulated population of two million living within the 80-km radius, the health effects would be

$$(0.03 \text{ mrem}) (2 \times 10^6 \text{ persons}) \left(4 \times 10^{-5} \frac{\text{health effects}}{\text{person-rem}}\right) = 0.002 \text{ health effects (lung cancers)}$$

Conversion facilities do not handle irradiated materials, and the release of naturally occurring radionuclides is so small as to make the impact on the Great Lakes Basin negligible.

FABRICATION

A typical fabrication facility has been estimated to result in a dose of 0.002 mrem per year to the lung of an individual within an 80-km radius of the facility. The number of health effects expected would be even less than the number from conversion facilities; therefore, impact on the basin is minimal.

NUCLEAR POWER GENERATION

The United States EPA conducted a detailed study on the impact of normal power reactor operation on the Great Lakes (14). The study was performed primarily as background in the development of the radioactivity objective included in the 1978 Water Quality Agreement.

The source terms used for United States and Canadian reactors are conservative in that, due to deferred and cancelled plants, the nuclear growth projected was higher than now appears realistic.

For United States reactors, the most important emissions are radioisotopes of tritium, cobalt, strontium, and cesium. For Canadian reactors, the largest contribution is from tritium. The source terms used in the study were based on actual releases. The total dose to an individual drinking water from the Great Lakes through the year 2000 is projected to be 0.25 mrem. If the highly conservative assumption is made that the entire year 2000 population of the basin receives the maximum dose, then the population dose would be

$$(30 \times 10^6 \text{ persons}) \left(\frac{250 \times 10^{-6} \text{ rem}}{\text{year}}\right) = 0.8 \times 10^4 \frac{\text{person-rem}}{\text{year}}$$

Since most of the dose is from tritium, a total body (body water) irradiator, the number of health effects per year would be

$$(0.8 \times 10^4 \text{ person-rem}) \left(2.0 \times 10^{-4} \frac{\text{health effects}}{\text{person-rem}}\right) = 1.6 \text{ health effects}$$

and, therefore, impact from the normal operation of nuclear power generators is small.

Spent fuel removed from a nuclear power reactor contains unfissioned nuclear fuel and radioactive wastes in the form of fission products. It is therefore highly radioactive and must be shielded and cooled for a considerable period of time. Due to the uncertainty surrounding ultimate disposal of this fuel, it may become necessary to construct facilities for the intermediate storage of this material. The population doses for a typical centralized storage operation have been estimated and are given in Table 8, along with the number of resulting health effects. These doses are for an assumed population of two million living within an 80-km radius of the storage facility. The doses are calculated over the period of operation of the facility, plus 100 years, to provide an assessment of the impact of persistent long-lived radionuclides. In terms of these health efects, the impact of spent fuel storage facilities is low.

TRANSPORTATION

During transportation of materials related to the nuclear fuel cycle, the primary mode of exposure of the population is from direct radiation resulting from the passage of the shipments. The United States Department of Transportation and the Canadian Transport Commission impose a dose limit of 10 mrem per hour at 2 metres from the surface of any shipping vehicle.

The population dose per kilometre for both U.S. and Canadian shipments can be estimated from the work of the (former) Atomic Energy Commission. Assuming a dose rate of 10 mrem per hour at 2 metres, and a uniform population density of 127.4 persons per square kilometre for the Great Lakes Basin, rail transportation gives 4.7×10^{-6} person-rem per kilometre and road truck transportation gives 1.6×10^{-6} person-rem per kilometre.

The total impact on the Great Lakes Basin depends on the somewhat uncertain growth of the nuclear industry. To remain consistent with the assumptions made in the reactor impact section, a total of 50 reactors on the lake in the year 2000 is used. In addition, it is assumed that transportation is 50% rail and 50% truck, although some travel may be made by barge or ship. Transportation of ore, refined uranium, and unused fuel are not considered since the direct dose rate from this would be far less than 10 mrem per hour at 2 metres. The total distance which the irradiated fuel would be transported for the above assumptions is estimated to be 2.7×10^{7} km. The total population dose per year due to normal transport would then be

$$(2.7 \times 10^{7} \text{ km})(0.5 \times 4.7 \times 10^{-6} + 0.5 \times 1.6 \times 10^{-6}) = 85 \text{ person-rem}$$

Considering these external doses to be to the whole body, the number of health effects per year would be

$$(85 \text{ person-rem})(2 \times 10^{-4} \text{ health effects/person-rem}) = 0.02 \text{ health effects}$$

ABNORMAL OPERATIONS

As is evident from the foregoing treatment, the calculated impact of normal operations in the nuclear fuel cycle is small. As previously implied, any large radiological impact will be the result of unplanned releases or significant abnormal occurrences.

It is difficult to postulate catastrophic events for that portion of the fuel cycle which deals with unirradiated fuel. The materials present prior to placement in the reactor are ones which occur in nature and which have low specific activities. While a tailings pile, for example, could be dispersed or a fabrication plant burned, the resulting releases, while substantially larger than normal, would not yield a significant number of health effects to the basin population. For this reason, only abnormal occurrences or accidents, pertaining to that part of the fuel cycle during and after power production, will be considered. Three major categories need to be considered: the reactor, transport of spent fuel, and waste disposal.

NUCLEAR POWER GENERATION

Abnormal events may range from, for example, the accidental release of the contents of a holdup tank, or the dropping of a spent fuel rod, to the melting

and dispersal of a reactor core. Based partially on experience, it is possible to establish a probability and consequence for some of the more common events. These are, for the most part, relatively low in consequences insofar as individual exposures are concerned. For the higher consequence-lower probability events, the estimates are largely guesswork.

Based on estimates of probability and consequence taken from American National Standards Institute documents, Nuclear Regulatory Commission (NRC) accident categories, and reactor manufacturer analyses, it has been estimated that, over the thirty-year plant life of a typical reactor, the higher probability abnormal occurrences may yield a total non-occupational dose of about 1,000 mrem at the plant boundary.

Using a suggested empirical relationship (dose $\propto r^{-1.5}$) for the dose variation with distance, r, the population dose to the two million inhabitants presumed to reside within an 80-kilometre radius is found to be about 10,000 person-rem. Since we assume 50 reactors in the basin,

$$(50 \text{ reactors}) \left(\frac{10{,}000 \text{ person-rem}}{\text{reactor}}\right) = 5 \times 10^5 \text{ person-rem}$$

and the number of associated health effects, conservatively assuming unlikely whole-body irradiation, would be

$$(5 \times 10^5 \text{ person-rem}) \left(\frac{2 \times 10^{-4} \text{ health effects}}{\text{person-rem}}\right) = 100 \text{ health effects}$$

Estimation of both the probability of occurrence and the consequences of a severe accident is extremely difficult. The only large-scale investigation in this area is the Reactor Safety Study (16), which has been subjected to a great deal of criticism and whose summary and conclusions were withdrawn by the NRC. The amount of experience with nuclear power plants is not sufficient to establish reliable bases for either type of accident or degree of consequence.

For want of other sources, however, the values used in the Reactor Safety Study are used here. The study was specific as to the type of reactor, site, and population distribution but extrapolation to the basin reactors and population are well within the uncertainties of the study. Construction details of the CANDU heavy water reactors are different enough from those of United States reactors that the type of analysis given in the Reactor Safety Study probably would not be applicable. In the absence of any other definitive study, however, the 50 reactors, both Canadian and United States, postulated to exist in the Great Lakes Basin are presumed to be equivalent to the typical reactor treated in the Reactor Safety Study.

The details of the study's treatment of reactor accidents are available in the literature (16). The basic features of the study are the identification of sequences of events leading to accidental releases and the estimation of the probabilities associated with each event. The product of probability and release, converted to health effects, is then defined as the risk.

The values associated with serious reactor accidents in the study are given in Table 9. Note that, while the consequences are far from negligible

TABLE 9

APPROXIMATE VALUES OF
EARLY ILLNESS, LATENT EFFECTS, AND RISK FOR ONE REACTOR[a]

PREDICTED CHANCE PER YEAR OF CORE MELT FOR ONE REACTOR	CONSEQUENCES			
	EARLY ILLNESS	LATENT CANCER FATALITIES[b] PER YEAR	THYROID ILLNESS[b] PER YEAR	GENETIC EFFECTS[c] PER YEAR
1 in 20,000	<1.0	<1.0	4	<1.0
1 in 1,000,000	300	170	1,400	25
1 in 10,000,000	3,000	460	3,500	60
1 in 100,000,000	14,000	860	6,000	110
1 in 1,000,000,000	45,000	1,500	8,000	170
Risk	0.0008	0.002	0.002	0.00008

a. From Reference (16).

b. This rate would occur approximately in the 10 to 40 year period after a potential accident.

c. This rate would apply to the generation born after the accident. Subsequent generations would experience effects at decreasing rates.

for more severe accidents, each consequence is intended to be multiplied by its corresponding probability to obtain the estimated risk. Table 9 also gives the product of the probability and consequence for each column.

If all these values are grouped together as "health effects", multiplied by 50 reactors assumed for the basin, and the effects arbitrarily presumed to occur for a 100-year period, then

$$50 \text{ reactors } (4.88 \times 10^{-3} \frac{\text{health effects}}{\text{reactor-year}}) \text{ (100 yrs)} \approx 25 \text{ health effects}$$

would be the total number of health effects due to accidents in nuclear power plants sited in the Great Lakes Basin.

TRANSPORTATION ACCIDENTS

From 1971 to 1975, only 144 transportation accidents involved radioactive materials, even though in 1975 alone 2 million radioactive packages were shipped in the United States.

Not all the accidents resulted in releases of contents or excessive radiation levels to people exposed. Depending on the severity of the accidents, loss of shielding efficiency of the packages or even dispersion of radioactive materials might occur, resulting in direct radiation exposure to people near the point of the accident.

Probability and consequence are the two factors considered in evaluating the impact of accidents involving radioactive shipments. The probability that an accident releasing radioactive material will occur is calculated using the expected number of accidents per year for each transport mode, the package response to these accidents, and the expected dispersal. The consequence of an accident is expressed in terms of the potential effects of the release of a specified quantity of dispersible radioactive material to the environment or the exposure resulting from damaged package shielding. The annual radiological risk for any shipment type, expressed in terms of the expected radiological consequences per year, is simply the product of the probability and the consequence. Considering only the most severe accidents involving transportation of spent fuel by both rail and truck, the estimated population dose commitment to the whole body is 1615 person-rem per year, based on the whole United States population of 225 million. For a population of 30 million in the Great Lakes Basin, the number of health effects per year is then

$$\frac{30}{225} \times 1615 \text{ person-rem} \times (2 \times 10^{-4} \frac{\text{health effects}}{\text{person-rem}}) = 0.04 \text{ health effects}$$

It should be remembered that this is a very rough estimate since it assumes a uniform distribution of the accident rate throughout the United States and Canada and also assumes that all exposures are to the whole body.

WASTE MANAGEMENT IMPACT

Several types of abnormal events subsequent to closure of the repository have been evaluated. Basically there are three kinds of accidents or events that could breach the repository and release any of its contents. These are:

1. Direct release of contents to the atmosphere or hydrosphere. Such release could follow volcanic activity, impact of a large meteorite or large nuclear weapon, and, on a much longer scale, denuding of the earth to the depth of the repository by erosion or glaciation.

2. Release via water. The water might enter the repository as a result of flooding or seepage following breach of overlying rock by such mechanisms as fracturing by faulting, nearby impact of meteorite or nuclear weapon, thermal stresses due to decay heat from the radioactive waste, mechanical stress resulting from adjustment of repository rock following excavations, or by such mechanisms as failure of shaft and/or bore hole seals.

3. Release via man-made intrusions. These might include exploratory drilling, archaeological exploration, solution mining of salt or phosphates, or cavern construction for storage of such materials as oil, industrial wastes, and compressed air.

Among these events several were chosen to provide a basis for assessing the risk of waste disposal in various geologic media. Those believed most representative of the above events and for which estimates of consequences were made are:

1. Fracturing through rock overlying the repository by faulting following by flooding

2. Exploratory drilling through a waste canister

3. In the case of a repository in salt, solution mining for the salt content.

The doses resulting from faulting, flooding, and extreme leaching have been estimated below. They represent the basic types of accident which could occur and, also, return the highest results. The scenarios leading to these events have not been reproduced, due to their length, but are available in the references.

The consequences of a repository breach by faulting and flooding are given in Table 10. The consequences of a hypothetical case in which the contents of the repository are leached into the biosphere within a one-year period are given in Table 11. Table 12 gives the doses for a hypothetical case in which the repository is struck by a meteorite. Note that the events described are not intended to represent actual occurrences but to demonstrate the impact of different, extreme repository breaches. Faulting and flooding and the meteorite strike, for example, are expected to result in relatively rapid release of radionuclides to the environment while leaching would cause more prolonged releases. For this reason, the doses are calculated over different time periods and the health effects would be expressed to different populations on a nonuniform time scale. Estimates of the resulting health effects are given in the summary.

IMPACT OF EXISTING FACILITIES

There are mines, mills, conversion, and fabrication facilities located in the Canadian portion of the Great Lakes Basin but none in the U.S. portion. No enrichment facilities are sited in the basin. There are 22 nuclear power

TABLE 10

REPOSITORY BREACH BY FAULTING AND FLOODING

	FIRST-YEAR TOTAL BODY DOSE (in rem) TO CRITICAL INDIVIDUAL		70-YEAR TOTAL BODY DOSE COMMITMENT TO THE REGIONAL POPULATION (in Person-rem)
	SALT	NONSALT MEDIA	
Year 2050			
Once-Through Spent Fuel	15	530	1.2×10^{8}
Reprocessing			
U and Pu Recycle	50	1700	3.6×10^{8}
U/Pu in high-level waste	50	1700	3.9×10^{8}
U/PuO_2 Stored	50	1700	3.9×10^{8}
+ 1,000 Years			
Once-Through Spent Fuel	0.0032	0.10	8.7×10^{4}
Reprocessing			
U & Pu Recycle	0.0081	0.019	1.7×10^{5}
U/Pu in high-level waste	0.014	0.37	2.9×10^{5}
U/PuO_2 Stored	0.0044	0.073	5.9×10^{4}
+ 100,000 Years			
Once-Through Spent Fuel	0.0066	0.17	1.4×10^{5}
Reprocessing			
U & Pu Recycle	0.0021	0.031	2.8×10^{4}
U/Pu in high-level waste	0.020	0.51	4.2×10^{5}
U/PuO_2 Stored	0.00066	0.14	1.4×10^{4}
+ 1,000,000 Years			
Once-Through Spent Fuel	0.0033	0.087	7.1×10^{4}
Reprocessing			
U & Pu Recycle	0.00049	0.010	1.0×10^{4}
U/Pu in high-level waste	0.0038	0.095	8.2×10^{4}
U/PuO_2 Stored	0.00035	0.0064	7.0×10^{3}

TABLE 11

ALL RADIONUCLIDES LEACHED OUT IN ONE YEAR-SPENT FUEL
REPOSITORY BREACH
YEAR 2050

YEAR SINCE BURIAL	50-YEAR ACCUMULATED TOTAL BODY DOSE (in rem) TO MAXIMUM INDIVIDUAL			
	SALT	GRANITE	SHALE	BASALT
1×10^2	34	90	46	40
1×10^3	75	200	100	200
1×10^4	1.5	4.1	2.1	4.1
1.1×10^5	1.4	0.38	0.19	0.38
1.4×10^6	55	140	70	140
	ESTIMATE OF 50-YEAR ACCUMULATED TOTAL BODY DOSE (in person-rem) TO THE REGIONAL POPULATION			
1×10^2	1×10^7	4×10^7	2×10^7	4×10^7
1×10^3	3×10^7	8×10^7	4×10^7	8×10^7
1×10^4	6×10^5	2×10^6	8×10^5	2×10^6
1.1×10^5	6×10^4	2×10^5	8×10^4	2×10^5
1.4×10^6	2×10^7	6×10^7	3×10^7	6×10^7

TABLE 12

REPOSITORY BREACH BY METEORITE STRIKE

	FIRST-YEAR TOTAL BODY DOSE (in rem) TO CRITICAL INDIVIDUAL		70-YEAR TOTAL BODY DOSE COMMITMENT (in person-rem) TO THE REGIONAL POPULATION	
	SALT	GRANITE	SALT	GRANITE
Year 2050				
Once-Through Spent Fuel	8.1×10^3	$22. \times 10^3$	6.9×10^7	1.8×10^8
Reprocessing				
U and Pu Recycle	$11. \times 10^3$	9.2×10^3	6.0×10^7	5.1×10^7
U/Pu in high-level waste	6.5×10^3	11×10^3	7.0×10^7	1.2×10^8
U/PuO_2 Stored	13×10^3	13×10^3	3.0×10^7	3.0×10^7
+ 1,000 Years				
Once-Through Spent Fuel	6.0	16.	1.6×10^7	4.2×10^7
Reprocessing				
U & Pu Recycle	6.0	5.1	6.0×10^6	5.1×10^6
U/Pu in high-level waste	4.8	8.0	1.3×10^7	2.1×10^7
U/PuO_2 Stored	2.5	2.5	2.3×10^6	2.3×10^6
+ 100,000 Years				
Once-Through Spent Fuel	4.4	12.	2.8×10^5	7.3×10^5
Reprocessing				
U & Pu Recycle	1.1	0.92	7.6×10^4	6.5×10^4
U/Pu in high-level waste	3.2	5.2	2.3×10^5	3.8×10^5
U/PuO_2 Stored	0.98	0.98	5.1×10^4	5.1×10^4
+ 1,000,000 Years				
Once-Through Spent Fuel	2.4	6.0	9.4×10^4	2.5×10^5
Reprocessing				
U & Pu Recycle	0.75	0.64	8.1×10^4	7.0×10^4
U/Pu in high-level waste	0.95	1.6	8.5×10^4	1.4×10^5
U/PuO_2 Stored	0.83	0.83	8.4×10^4	8.4×10^4

reactors (Figure 1), and the former reprocessing facility and waste disposal site is located at West Valley, New York. Existing facilities in both countries are discussed below, including a brief summary of their environmental impact. This impact is presented in terms of concentrations, which may be compared to jurisdictional criteria and the Agreement objective.

MINING AND MILLING

There are presently only four mining and milling operations in Ontario: Denison Mines Limited and Rio Algom Limited, both in the Elliot Lake area; Agnew Lake Mine in Espanola; and Madawaska Mines Limited, which began production near Bancroft in late 1976. Table 13 lists these operations and their licensed capacities.

THE ELLIOT LAKE AREA

Currently two major mines are active in the Elliot Lake area compared to a dozen that operated in the 1960's. From the standpoint of environmental impact, however, all uranium mines in the Serpent River Basin, both active and abandoned, contribute to the problem of acid mine drainage. At the active mine and mill locations, waste discharges are comprised of mill process wastes and mine waters, natural runoff and seepage from tailings sites, while polluted discharges from abandoned operations include runoff and seepage from the tailings areas. The acid mine waste flow can dissolve radioactive materials and carry them to downstream waters. The waste loadings from each of the tailings areas vary widely with the seasons and generally the higher loadings occur during periods of high streamflow.

The wastes from the uranium mining and milling industry in the Elliot Lake area have caused some impairment of the water quality in the Serpent River Basin. In 1978, the radiological loading of dissolved ^{226}Ra from the three operating mines in the area to the Serpent River was 72 mCi (34).

Serpent Harbour receives significant quantities of ^{226}Ra from the Serpent River and from Pronto Ditch; the Serpent River accounts for about 98% of the total annual ^{226}Ra load to the harbour (23). The largest proportion of the annual ^{226}Ra load ($\sim$50%) in Serpent River occurs annually in the months of April, May, and June, periods of snowmelt and highest river discharge. The quantity of radium flushed from tailings ponds at operating and non-operating sites is approximately proportional to the magnitude of flow and storm events. Significant decreases in ^{226}Ra levels and loadings from Serpent River have occurred from 1966 to 1974. Waste management strategies employed at both active and inactive mine, mill, and tailings areas are partially responsible for these trends. In 1978, the loading of ^{226}Ra to Serpent Harbour from the Serpent River was 1430 mCi, of which only 72 mCi was from the three active mines. The balance of the loading is probably due to naturally occurring inputs from the bedrock and also the result of leaching from the tailings piles at abandoned mines. It may also reflect the long retention time of the river system. Levels of ^{226}Ra at the mouth of the Serpent River generally average above 3 pCi/L, the Ontario permissible criterion for public surface water supply.

Considerable quantities of the thorium isotopes also enter the waters of the Serpent River Basin, but the fate of these isotopes is not known. At the present time, waste treatment is limited to reduction of radium found in mine waste discharges.

TABLE 13

STATUS OF URANIUM MINE AND MILL FACILITIES
IN THE GREAT LAKES BASIN

FACILITY NAME, LOCATION, AND LICENSEE	LICENSED CAPACITY
Agnew Lake Mine Espanola, Ontario (Agnew Lake Mines Ltd.)	1,700 kg/day uranium concentrate
Denison Mines Elliot Lake, Ontario (Denison Mines Ltd.)	uranium ore - 6,450 tonnes/day mill feed
Madawaska Mine Bancroft, Ontario (Madawaska Mines Ltd.)	2,400 kg/day uranium concentrate
Quirke Mine Elliot Lake, Ontario (Rio Algom Ltd.)	6,350 tonnes/day mill feed
Panel Mine Elliot Lake, Ontario (Rio Algom Ltd.)	Authorization given to proceed with the underground exploration and with mill rehabilitation work.

TABLE 14

FUEL FABRICATION AND CONVERSION
FACILITIES IN THE GREAT LAKES BASIN

LICENSEE	OPERATION	LICENSED CAPACITY
Canadian General Electric Co. Ltd., Toronto, Ontario	Fuel pellet manufacture	500 tons/year U
Canadian General Electric Co. Ltd., Peterborough, Ontario	Fuel bundle manufacture	500 tons/year U
Westinghouse Canada Limited Port Hope, Ontario	Fuel pellet and bundle manufacture	500 tons/year U
Westinghouse Canada Limited Hamilton, Ontario	Research and development	a
Eldorado Nuclear Limited (Port Hope Refinery)	Uranium refinery and chemical conversion	5,000 tonnes/year UF_6 2,000 tonnes/year UO_2

a. Small quantities as required.

The Ontario Environmental Assessment Board has conducted a public hearing into uranium mine expansion as it affects the environment in the Elliot Lake area. A report entitled "Environmental Assessment of the Proposed Elliot Lake Uranium Mines Expansion" (28) presents data on radionuclide analyses of aqueous effluents, suspended particulates in air, samples collected in dust-fall jars, vegetation, and fish samples.

THE BANCROFT AREA

Madawaska Mines Limited completed rehabilitation of the former Faraday mine and mill in August 1976. The property, located 8 km west of the town of Bancroft, Ontario, ceased production in 1964, but was reactivated.

Liquid effluents from Madawaska Mines are allowed to stand in concrete settling ponds before their discharge into a sand pit. The concentration of dissolved ^{226}Ra going to the sand pit varies from 10-15 pCi/L. In 1978, 10 mCi of dissolved ^{226}Ra entered Bentley Creek from the sand pit (34). The creek flows to Bow Lake, where measurements made in 1976 showed an average dissolved ^{226}Ra level of 7 pCi/L and, in 1977, 4 pCi/L. Bow Lake is a part of the Trent River system, which discharges into Lake Ontario. In view of the geographical remoteness of Brancroft from Lake Ontario, it is reasonable to conclude that there are no identifiable radioactive loadings from the Bancroft area to Lake Ontario.

THE ESPANOLA AREA

Mine development in the Espanola area started in the late 1960's but was discontinued after a short period due to the drop in demand for uranium. Since 1976, however, mining at the Agnew Lake Mine has been carried out by the bacterial leaching method, which produces no surface tailings.

The radium activities in John Creek and in Agnew Lake, into which the creek runs, are continually at background levels (about 1 pCi/L). The radium activity in Ministic Creek is also usually at about 1 pCi/L but has reached 3 pCi/L due to spring runoff overflowing the precipitate pond. Agnew Lake and Ministic Creek both discharge to the Spanish River, where the radium concentration is at background levels.

CONVERSION

Eldorado Nuclear Limited operates a uranium hexafluoride refinery in Port Hope, Ontario. This plant is designed to process 5000 tonnes of uranium per year from mine concentrates to UF_6, which is Eldorado's principal product (Table 14). Prior to 1962 raw ores were also processed at the Port Hope Refinery.

The process and cooling waters are taken from and returned back to Port Hope harbour. Cooling water and other process streams from the refinery enter an on-site lagoon system and are treated, if necessary, before being returned to the harbour. The discharge has a negligible effect on the receiving water quality.

To keep up with the expanding Canadian uranium mine production, Eldorado is proposing to build a second refinery with the capacity to produce 9000 tonnes of uranium from mine concentrates to UF_6. The new refinery would triple Eldorado's current UF_6 capacity and is proposed to be located in one of the three proposed sites of Hope Township, Sudbury, or Blind River, all of which are in the Great Lakes Basin.

Eldorado Nuclear Ltd. operates a waste management facility at Port Granby. The site is located adjacent to Lake Ontario about 13 kilometres west of the Town of Port Hope. In 1978, the dissolved ^{226}Ra loading from this facility was 0.12 mCi. The concentration of ^{226}Ra in the adjacent area of Lake Ontario is less than 1 pCi/L; as a result, no detectable deterioration in water quality has been found.

Welcome disposal site, located near the Town of Port Hope, was used for the disposal of refinery residues from the late 1940's until the late 1950's. In 1978, the dissolved ^{226}Ra loading from the Welcome site was 1.4 mCi (34). In 1978, the concentration of ^{226}Ra in Lake Ontario waters in the vicinity of the outfall was generally less than 1 pCi/L. No deterioration in the quality of Lake Ontario as a result of the discharge from the Welcome disposal area has been detected.

FABRICATION

The two fuel fabrication facilities in the Great Lakes Basin and their capacities are listed in Table 14. The Canadian General Electric Company Limited (CGE) currently produces nuclear fuel for CANDU reactors with the work being carried out at two sites. The Peterborough operation of CGE does not have any emission points to the environment. Westinghouse Canada Limited operates a fuel pellet and bundle manufacturing unit at Port Hope, Ontario. Trace quantities of uranium are released to the air and water from CGE's Lansdowne plant in Toronto and from Westinghouse's Port Hope operations, but quantities are below minimum detectable levels.

POWER GENERATION

A list of nuclear generating stations and their gaseous and aqueous releases are given in Chapter 4 in Tables 19 and 20, respectively. Plant operators are required to monitor and control the radioactivity in effluents and to measure doses at the site boundary. Beyond the site boundary federal, state, and provincial health and environmental agencies conduct monitoring programs as final checks that the releases are within the limits.

The radioactivity in gaseous and liquid effluents from normal operation averages less than a few percent of the limits stipulated in the operating licenses. In Canada, with the cooperation of the licensees, the Atomic Energy Control Board has established a design and operating target for new nuclear power plants which is 1% of the license limit. In the U.S., the Nuclear Regulatory Commission establishes operating limits for power reactors. The magnitude of the releases is consistent with the principle stated by the ICRP that doses from radiation should be kept as low as is reasonably achievable, social and economic factors taken into consideration.

WASTE MANAGEMENT

Facilities in the Great Lakes Basin where wastes from the nuclear fuel cycle are presently managed are listed in Table 15. Waste management practices for mining, milling, and conversion activities, and the environmental impact of wastes resulting from these activities, were described above. Waste management practices and the impact of waste produced as a result of power generation and of fuel reprocessing are described below.

CANADA

The low-level, solid wastes arising from nuclear power generation consist generally of protective clothing and boots, rubber gloves, and miscellaneous cleaning utensils and materials. Such wastes are transported from the generating station of origin to Bruce Generating Station where the combustible material is incinerated. The resulting ash is classified as medium-level waste. Other medium-level wastes are ion-exchange resins, special filter media, and solidified liquid concentrates. In general, the low-level waste is stored in concrete trenches and the medium-level waste in more elaborate concrete structures called "tile holes" and "quadricells".

On average, the waste (excluding tritium) has an activity less than 1 mCi/m^3. Incineration causes some activity to be released to the atmosphere. The distribution of activity following incineration is shown in Table 16. All of the radioiodine and tritium and about 0.4% of the total particulate activity is emitted via the stack. The final distribution of the incinerated radionuclides depends on their physical and chemical properties, as shown in Table 17.

Spent fuels are regarded as high-level wastes. Most of the spent fuel which has been produced is stored in water-filled, double-walled, concrete tanks at the station of origin (Figure 3). The storage volume is about 2 m^3 per tonne of fuel. The fuel can be stored in this manner for up to 30 years.

Another storage practice being tested is the concrete canister. This is a dry method of storage, consisting of three inner containment cans inside an outer can, all within the cylindrical concrete vessel. The present design is for fuel that has been stored and cooled for five years in the station water bays.

Use of the abovementioned storage facilities allows time for a decision to be made on whether or not to reprocess the fuel. Whatever the decision, the fuel waste will have to be disposed of, i.e. contained without the provision or intention of retrieval. Disposal will be conducted with the aim that the integrity of the waste will be maintained without continued human intervention whether in the form of treatment, monitoring, or restriction of access.

UNITED STATES

In October 1977, a U.S. Presidential policy on interim management of spent fuel was announced. Under this policy, the United States federal government would offer to take title and provide interim storage for the power reactors' spent fuel.

TABLE 15

RADIOACTIVE WASTE MANAGEMENT FACILITIES
IN THE GREAT LAKES BASIN[a]

LOCATION AND LICENSEE	PURPOSE
Bruce Nuclear Power Development Tiverton, Ontario - Site 1 (Ontario Hydro)	Wastes from Bruce, Douglas Point, and other Ontario Hydro nuclear generating stations
Bruce Nuclear Power Development Tiverton, Ontario - Site 2 (Ontario Hydro)	Waste volume reduction facility with waste compactor, radioactive and clean waste incinerators. Also trenches and tile holes for medium and low-level waste from nuclear generating stations.
Waste Management Area, Port Granby, Ontario (Eldorado Nuclear Ltd.)	Wastes from Eldorado refinery at Port Hope, Ontario
Waste Management Area, Welcome, Ontario (Eldorado Nuclear Ltd.)	Wastes from Eldorado refinery at Port Hope, Ontario
Agnew Lake Mine, Espanola, Ontario (Agnew Lake Mines Ltd.)	Process waters
Denison Mines, Elliot Lake, Ontario (Denison Mines Ltd.)	Mine and mill tailings (stanrock and canmet)
Madawaska Mine, Bancroft, Ontario (Madawaska Mines Ltd.)	Mine and mill tailings (bicroft)
Quirke Mine and Panel Mine, Elliot Lake, Ontario (Rio Algom Ltd.)	Mine and mill tailings
Nuclear Fuel Services, Inc. West Valley, New York	Waste from U.S. atomic energy program and some from commercial processing.
Lake Ontario Ordnance Works, Lewiston, New York	Refinery and conversion waste from operations conducted at sites outside of the Great Lakes Basin.

a. In addition to those listed, there are a number of abandoned tailings areas in the Elliot Lake and the Bancroft regions.

TABLE 16

LOW-LEVEL WASTE INCINERATION - "TYPICAL"

	PARTICULATE ACTIVITY		^{131}I	^{3}H
	µCi/burn	Percent	µCi/burn	µCi/burn
Incinerator Ash	19,000	90	-	-
Baghouse Ash	2,000	9.6	-	-
Stack Effluent	75	0.4	50	5×10^{6}

TABLE 17

RADIONUCLIDE DISTRIBUTION IN PARTICULATES FROM INCINERATION

RADIONUCLIDE	INCINERATION ASH, PERCENT	BAGHOUSE ASH, PERCENT	STACK EFFLUENT PERCENT
^{144}Ce	15.1	<1	1.7
^{124}Sb	a	10	a
^{51}Cr	4.5	a	a
^{103}Ru	3.0	<1	4.3
^{134}Cs	1.8	10	11.7
^{106}Ru	5.2	7	<1
^{137}Cs	5.6	49	54.8
^{95}Zr	9.1	<1	<1
^{95}Nb	16.0	<1	a
^{65}Zn	5.0	20	25.1
^{60}Co	14.8	3	<1
^{140}La	15.2	a	a
Others[b]	4.7	1	2.4
	100	100	100

a. Not detectable

b. ^{153}Gd, ^{141}Ce, ^{113}Sn, ^{125}Sb, ^{54}Mn, ^{59}Fe, ^{140}Ba

Storage of spent fuel using a water basin (Figure 3) at either the reactor site or the centralized away-from-reactor storage will have similar operations in regard to effluent control. The only difference would be the quantity of spent fuel stored at either type of site.

While a small amount of commercial U.S. spent fuel has been shipped to private storage facilities, the vast majority is still retained at the generating stations. Generic radioactive releases, both normal and accidental, from these storage pools were discussed earlier in this chapter.

NUCLEAR FUEL SERVICES

Several existing U.S. facilities contain varying amounts and types of radioactive waste. The best known of these is Nuclear Fuel Services, Inc. (NFS), which operated the only commercial reprocessing facility in the U.S. The facility, located in West Valley, New York, about 65 km upstream of Lake Erie, reprocessed 624.5 tonnes of uranium from 1966 to 1972. NFS ceased reprocessing activities in 1972 in order to modify and expand the facility but, in 1976, chose not to pursue expansion due to the new more stringent NRC seismic requirements for reprocessing facilities.

As a result of reprocessing activities, the site contains high-level liquid-waste tanks, a high-level solid waste disposal area, and a spent fuel storage pool, as well as the reprocessing plant. In 1962, New York State, under agreement with NRC, licensed NFS to accept low-level radioactive waste. Low-level waste burial activities ceased in 1975 when water was found seeping from some of the northern low-level waste trenches. Table 18 shows the type and the amount of radioactive wastes at the NFS site.

The NRC is in the process of evaluating NFS's plans for decommissioning the site. In 1979, the NRC may initiate studies to assess the NRC-licensed high-level solid waste burial area. Along with EPA, the NRC is funding the New York Geological Survey to evaluate the surface water pathway and erosion problem at the low-level burial area; results of this work will be incorporated into the EPA-funded modelling project.

In February 1978, the U.S. Congress authorized the Department of Energy (DOE) to consider future disposition of the NFS site. Among the options being considered by DOE are federal aid in support of decommissioning the high-level waste disposal operation, federal operation during decommissioning, permanent federal ownership and responsibility for the site, and other uses (radiological and nonradiological) for the site. A report entitled "Western New York Nuclear Service Center (WNYNSC) Study" on the costs and radiological impact of these options was issued in November 1978.

Low-Level Site Impact

The options identified by the WNYNSC Study for decommissioning the low-level waste burial area range from permanent closing of the site with provisions for monitoring and burial area maintenance to complete exhumation of the wastes with reclamation of the burial area. The low-level waste burial area is presently maintained in a shut down status with annual or semiannual pumpouts of the trenches to prevent seepage. The liquid is collected in lagoons, treated, and released into Cattaraugus Creek. While the site can be maintained in this manner, such a planned discharge program is not to be

TABLE 18

RADIOACTIVE WASTES AT NUCLEAR FUEL SERVICES SITE, WEST VALLEY, NEW YORK

FACILITY	CAPACITY	AMOUNT OF MATERIAL	ACTIVITY, curies
Spent Fuel Storage Facility	240 tonnes	164 tonnes uranium	
High-Level Liquid Storage Facility	a) 2,840,000 litre acid tanks	2,120,000 litres liquid 470,000 litres sludge	3.9×10^6 (short-lived) 2.3×10^4 (long-lived)
	b) 57,000 litre neutral tanks	45,000 litres liquid thorium-based waste	2.4×10^6 (short-lived) 3.6 (long-lived)
NRC-licensed Waste Burial Facility	2.4 hectares	3,900 m^3 of spent fuel hardware, encased defective rods	5.5×10^7 (short-lived) 5.50×10^2 (long-lived)
NYS-licensed Waste Burial Facility	8.9 hectares	66,000 m^3	7.1×10^5 (short-lived) 1.42×10^2 (long-lived)

regarded as a permanent solution, however. From 1973 to 1977, some of the discharges were 4,311 Ci of ^{3}H, 0.119 Ci of ^{90}Sr, 0.130 Ci of ^{137}Cs, and 1.84 Ci of ^{106}Ru. As a result of their controlled release, the average concentration of ^{3}H in 1978, measured at Springville Dam on Cattaraugus Creek, about 30 km downstream of NFS, was 2770 pCi/L, and the average concentration of ^{90}Sr was 1 pCi/L (35). During the summer 1978, the caps on the northern trenches were increased to 2.4 metres by NFS, in order to reduce water infiltration.

High-Level Site Impact

Evidence of former reprocessing activities at West Valley has been found in sediment samples from Cattaraugus Creek. Fish samples from the creek showed highest concentrations of radionuclides in samples collected nearest the plant.

In December 1978, the NRC was informed that a defect in a metal annulus pan between the high-level liquid waste tanks and the concrete vault was found during a test. Apparently the pan was unable to hold water placed in it. The waste tanks have maintained their integrity. The NRC is investigating the pan defect.

The WNYNSC study evaluated the range of decommissioning options possible for the high-level liquid waste tanks, the NRC-licensed burial area, the reprocessing facility, and the spent fuel storage pool. The options ranged from extended care and/or on-site stabilization to complete dismantlement and/or exhumation.

OTHER FACILITIES

Lake Ontario Ordnance Works is located in Lewiston, New York about 8 km east of the Niagara River and 8 km south of Lake Ontario. It is owned by the U.S. Department of Energy (DOE) and was used by the U.S. Atomic Energy Commission, predecessor agency of DOE, for storage of uranium mill tailings. DOE and African Metals, Inc. own radioactive residual materials stored at the site. These materials are potential sources of additional minerals. As such, both owners are reluctant to dispose of them. However, because of the nature of these materials, ground and surface water monitoring programs have been maintained by DOE. In addition, EPA has encouraged the initiation of an air monitoring program for radon measurements. Radon concentrations ranged from 0.1 to 20 pCi/L.

Niagara Mohawk intends to build an incineration system to reduce radioactive waste volume at the Nine Mile Point nuclear station. The NRC has made no decision on approving the incineration system. Any emissions from this incineration system must meet EPA's Uranium Fuel Cycle Standards (40 CFR 190; see Table 5).

SUMMARY

In order to reply to the request from the International Joint Commission concerning the possible impact of the Canadian and the U.S. nuclear fuel cycles on the Great Lakes Basin, the Radioactivity Subcommittee prepared an overview comprising fuel cycle activities, with emphasis on waste management; impact from typical facilities for both normal and abnormal operation; and impact of existing facilities.

The preceeding analysis has assumed that the impact of nuclear fuel cycle operations on the Great Lakes Basin is adequately described by estimating the number of human health effects involved. While this is not entirely true, since some flora or fauna could be more adversely affected by bioconcentration of certain radioisotopes, a basic tenet in radiation protection has long been that protection of humans would also protect other life forms.

Even with this over-simplification, quantification of impact is difficult. The radiation doses and associated health effects presented above demonstrate that the impact of "normal" operation in the fuel cycle is small. As an illustration, roughly 20% of the deaths in the general population is ascribed to cancer. This equates to about six million fatal cancers for the basin population. The total number of cancers, as a result of exposure to natural background radiation, is about nine hundred. The total number of cancers from normal operations, as discussed above, is on the order of one hundred.

In the area of abnormal operations, it is obvious that there can be accidents, particularly in reactor operation and waste management, which result in substantial numbers of health effects. The worst reactor accident in Table 9, for example, might cause

$$(1{,}500\ \frac{\text{fatal cancers}}{\text{year}})\ (30\ \text{years}) = 45{,}000\ \text{fatal cancers}$$

without considering other health effects or additional health effects from residual contamination due to a large release. The frequency of such events, however, is assumed to be so low that the total risk is small. There is not, however, sufficient operating experience to verify either the types of accidents postulated or the probability of occurrence. The same situation arises when waste management is considered.

Although the doses given in Tables 10-12 do not readily lend themselves to the calculation of health effects, an upper bound may be estimated by using the largest total-body doses in the tables. If the 70-year dose commitment to a typical (two million persons within an 80-km radius) regional population from a repository breach is taken to be 5×10^8 person-rem, then

$$(5 \times 10^8\ \text{person rem})\ (\frac{2 \times 10^{-4}\ \text{health effects}}{\text{person-rem}}) = 100{,}000\ \text{health effects}$$

This scenario envisions a large, one-time release of the contents of a repository. The consequences would diminish, according to the tables, if the accident were to occur at later periods. An alternate scenario would be the leaching out of the entire repository contents over a one-year period. Should this occur 100 years after burial, for example, Table 11 indicates that, for salt, there would be

$$(1 \times 10^7\ \text{person-rem})\ (\frac{2 \times 10^{-4}\ \text{health effects}}{\text{person-rem}}) = 2{,}000\ \text{health effects}$$

Additional calculations show that smaller releases would, of course, yield a smaller number of health effects, but that these would extend over increased periods of time. In general, the net impact would be similar but diminish with increasingly large periods of time after closure of the repository.

All of the above scenarios are based on postulates which can be neither proven nor disproven. Alteration of the many assumptions built into the background calculations could substantially affect the estimated impact.

The foregoing analysis of the impact is based on calculations from a number of sources and is intended to be representative rather than accurate. Furthermore, the classes of accident used herein for illustrative purposes have been extreme ones whose probability, without precise specification, must be low.

The Subcommittee, therefore, believes that it is impossible, at present, to accurately quantify the impact of nuclear fuel cycle activities on the Great Lakes Basin. From a waste disposal standpoint, the problem is basically one of isolating potentially hazardous materials from the biosphere. The results cited previously indicate that the consequences from certain types of event, while not negligible, are not so catastrophic as sometimes is envisioned. It is, however, possible to conceive scenarios which would lead to unacceptable effects. Certainly, a severe reactor accident or high-level waste respository breach in the basin would significantly impact on the Great Lakes. We do not believe, however, that the probability of such occurrences can be established at this time. It is quite possible that the most significant impact on the lakes area will be from "abnormal" occurrences or less severe accidents which release smaller amounts of radioactive material but which may occur more frequently. This opinion is based on the fact that "normal" operation of fuel cycle activities will be rigidly controlled and that every effort will be made to prevent catastrophic events. Present impact on the basin is largely due to past activities, i.e. mining and reprocessing, which would not be permitted to operate in similar fashion under current regulations. The impact of these activities, while of concern, has not been major.

The rapid growth formerly envisioned for commercial nuclear power has not come to pass. Projections of the number of reactors in the Great Lakes Basin by the year 2000 have been lowered in recent years; present estimates would indicate that about fifty are still planned. This much less rapid growth will permit closer scrutiny of the actual operation of commercial reactors and reduce the number of waste disposal sites necessary. It should be noted, in summary that decisions on the acceptability of nuclear power should not be made in vacuuo, but should carefully consider the impact of available alternative energy sources.

4 RADIONUCLIDE DISCHARGES FROM NUCLEAR FACILITIES IN 1978

RELEASES FROM NUCLEAR GENERATING STATIONS

As a condition of its license, a nuclear generating station must report annual releases of radionuclides to the responsible federal regulatory agency. Gaseous and aqueous releases for 1978 are tabulated in Tables 19 and 20, respectively.

RELEASES FROM NUCLEAR FUEL REPROCESSING PLANTS

Although the Nuclear Fuel Services, Inc. fuel reprocessing plant at West Valley, New York, has not processed irradiated fuel since 1972, radionuclides are continuously discharged to Cattaraugus Creek, which drains to Lake Erie. The quantities of radionuclides discharged during 1978 from NFS were 1.67 mCi of gross α, 193 mCi of gross β, 774.1 Ci of ^{3}H, and 11.9 mCi of ^{90}Sr.

RELEASES FROM URANIUM MINING, MILLING, AND REFINING

The sources of radioactivity to the Serpent River are natural inputs from the bedrock and surface-water leaching of radium and thorium from uranium mine tailings at both active and abandoned sites in the Elliot Lake area (see Chapter 3). Much of the radioactivity at active mines is precipitated in settling ponds, but the remainder reaches the Serpent River and ultimately the North Channel by direct flow over, and seepage through, the tailings pond dams.

In 1978, dissolved ^{226}Ra discharges to the Serpent River from the tailings ponds at the three active mines in the river basin totalled 72 mCi (Table 21). The loading of ^{226}Ra for 1978 from the Serpent River to Serpent Harbour on the North Channel was 1430 mCi; this value was calculated from the weighted average annual concentration of ^{226}Ra measured near the river mouth and the average annual flow for 1978 (Table 25).

Table 21 also gives the dissolved ^{226}Ra discharge from the Madawaska Mine, located in the Lake Ontario Basin, as well as the quantity of ^{226}Ra discharged to Lake Ontario from Eldorado Nuclear Ltd.'s Port Hope facility and from their waste management sites at Port Granby and at Welcome. The two creeks which drain the Port Granby site are dammed, and a treatment facility removes ^{226}Ra before discharging runoff to the lake. A waste treatment facility became operational at the Welcome site in December 1978, so discharges for 1979 and future years should be considerably reduced from the value reported for 1978.

UNPLANNED RELEASES OF RADIONUCLIDES

The International Joint Commission asked the Water Quality Board to establish a procedure to receive and assess information on unplanned releases of

TABLE 19

GASEOUS DISCHARGES FROM NUCLEAR GENERATING STATIONS - 1978[a]

STATION	ANNUAL RELEASE IN CURIES			
	PARTICULATES	^{131}I	NOBLE GASES	^{3}H
Big Rock Point	0.006	0.003	18,900	8.32
Bruce A	0.0037	0.0029	42,000	13,000
Cook 1 and 2[b]	0.10	0.012	48,500	20
Davis-Besse 1	0	0.0002	<600	34
Douglas Point	0.00024	0.00092	9,800	16,000
Fitzpatrick	0.06	0.22	5,880	7.54
Ginna	0.00015	0.027	971	44
Kewaunee	0.0016	0.004	443	12
Nine Mile Point 1	0.03	0.11	3,020	85
Palisades	0.006	0.02	323	5.5
Pickering	0.0028	0.0015	4,100	26,000
Point Beach 1 & 2	0.01	0.018	518	169
Zion 1 & 2	0.043	0.08	49,900	0

a. Information from References (33) and (34).

b. Went on line March 10, 1978.

TABLE 20

AQUEOUS DISCHARGES FROM NUCLEAR GENERATING STATIONS - 1978[a]

STATION	ANNUAL RELEASE IN CURIES	
	FISSION AND ACTIVATION PRODUCTS	^{3}H
Big Rock Point	0.27	4.04
Bruce A	4.7	4,150
Cook 1 and 2[b]	1.48	626
Davis-Besse 1	0.09	215
Douglas Point	0.20	1,170
Fitzpatrick	0.06	0.16
Ginna	0.06	242
Kewaunee	0.70	296
Nine Mile Point 1	0	0
Palisades	0.10	101
Pickering	0.65	32,100
Point Beach 1 & 2	0.77	1,286
Zion 1 & 2	0.95	726

a. Information from References (33) and (34).
b. Went on line March 10, 1978.

TABLE 21

DISCHARGES FROM OTHER NUCLEAR FACILITIES, 1978[a]

LAKE BASIN	SOURCE	DISCHARGE IN 1978	
		DISSOLVED ^{226}Ra, Ci	U, kg
Huron-North Channel	Rio Algom - Quirke Mine[c]	0.058	-
	- Panel Mine[c,e]	0.0000135	-
	Denison Mines[c]	0.014	-
	Serpent River, to Serpent Harbour	1.43[b]	-
Ontario	Eldorado Nuclear Ltd.[d]	-	948
	Port Granby Waste Management Area	0.00012[b]	5.57
	Welcome Waste Management Area	0.0014[b]	87.5
	Madawaska Mine - Bancroft[c]	0.010	-

a. Information from References (34) and (44).
b. Total radium.
c. Measured at facilities' final point of control.
d. Atmospheric release of uranium was 250 kg in 1978.
e. Operated for the last 6 months of 1978.

radionuclides into the Great Lakes. In response, representatives from the U.S. Nuclear Regulatory Commission (NRC) and the Canada Atomic Energy Control Board (AECB) met with the Water Quality Board in Toronto on December 14, 1976. Both the NRC and the AECB agreed to provide timely advice to the Water Quality Board about unplanned releases of radionuclides into the Great Lakes.

In the U.S., an arrangement was developed whereby the NRC will notify the Environmental Protection Agency (EPA), through their appropriate regional offices, about unplanned releases from NRC licencees for the following situations:

1. Nuclear power plants exceeding radiological effluent technical specifications reporting requirements;

2. Other NRC licensees exceeding 10 CFR Part 20 reporting requirements or other effluent reporting requirements contained in license conditions; or

3. Any occurrence of a lesser release to the environs which has a perceived public interest, such that the NRC or the licensee plans to issue a press release describing the occurrence.

These reporting requirements will in due time reflect the uranium fuel cycle standards that EPA has established. By extension, EPA has agreed that its regional representative will inform the Secretary of the Radioactivity Subcommittee of the Water Quality Board of any such events.

In Canada, the representative of the AECB on the Radioactivity Subcommittee will provide similar information to the Secretary about:

1. Nuclear power plants exceeding their operating target of 1% of the derived release limit, calculated on a weekly or a monthly basis;

2. Other AECB licensees exceeding any operating targets contained in their license conditions; or

3. Any occurrence of a lesser release (either atmospheric or aqueous) to the Great Lakes or its tributaries which has a perceived public interest, such as when the AECB or the licensee plans to issue a press release describing the occurrence.

After receipt of information about a given incident, the Secretary of the Radioactivity Subcommittee will notify the appropriate agency representatives on the Subcommittee who will, in turn, assess the available information. A report would be provided to the Water Quality Board. If the incident is significant, the Board would be informed immediately. All unplanned releases after January 1, 1979, as described above, will be reported by the Radioactivity Subcommittee through its Appendix D.

5 INPUTS TO THE GREAT LAKES FROM MEDICAL AND INDUSTRIAL USES OF RADIONUCLIDES

The possibility exists that radionuclides could reach the Great Lakes from other than the various stages of the nuclear fuel cycle. Many laboratories in the Great Lakes Basin are licensed by either the Atomic Energy Control Board or the U.S. Nuclear Regulatory Commission to use radionuclides. Examples of such usage would be for diagnostic and therapeutic purposes in hospitals, for teaching and research studies in universities and governmental laboratories, and for process development in industry. The levels of radioactivity pertaining to such usage are usually not very high so that the normal disposal method is by dilution and flushing into the sanitary sewage system of the municipality in which the laboratory is located. Radionuclides discharged to a sanitary sewer would then pass through the sewage treatment plant where they would either settle out with the sludge in the digestor or remain in solution and pass out with the effluent to the receiving waters.

In order to assess the importance of such possible discharges to the Great Lakes, the Radioactivity Subcommittee requested its members involved in surveillance activities on the Great Lakes to include major sewage treatment plants in their 1978/1979 monitoring programs. Three studies were carried out for selected municipal sewage treatment plants in the Lake Ontario Basin.

One study undertaken by Environment Canada (36) involved the Hamilton and the Dundas sewage treatment plants, both of which discharge into Burlington Bay, at the extreme western tip of Lake Ontario. Samples of the effluent and dried digestor sludge from each plant were analyzed for γ-ray emitting radionuclides. The radionuclides identified and the concentrations obtained from these analyses are given in Table 22.

Radionuclides entering the sewage treatment plants are more readily detected in the sludge than in the effluent because of the chemical scavenging by the sludge solids. The majority of radionuclides identified in the Hamilton and the Dundas sludges are either of natural origin or arise from fallout from nuclear weapons testing.

Radionuclides which do not arise from fallout or weapons testing, and therefore are due to local use, are ^{51}Cr, ^{75}Se, and ^{131}I. The half lives of these radionuclides are 27.8 days, 120.4 days, and 8.07 days, respectively. All three radionuclides are used in nuclear medicine for research, diagnosis, and therapeutic purposes and are voided by patients to the sanitary sewage system. ^{51}Cr is the only one of these radionuclides reaching Lake Ontario, which it does in the effluent from the Hamilton sewage treatment plant, although at a very low concentration.

From the data in Table 22 and from operating data on annual sludge production and effluent volume which were supplied by the Hamilton-Wentworth Regional Engineering Department, about 115 mCi per year of ^{51}Cr enter the lake with the effluent and 33 mCi per year accompany the incinerated sludge to

TABLE 22

CONCENTRATIONS OF RADIONUCLIDES IN ONTARIO SEWAGE SLUDGE AND EFFLUENT[b]

RADIONUCLIDE	HAMILTON STP		DUNDAS STP	
	DRIED SLUDGE pCi/kg	EFFLUENT pCi/kg	DRIED SLUDGE pCi/kg	EFFLUENT pCi/kg
^{144}Ce	1248 ± 52	a	676 ± 53	a
^{141}Ce	145 ± 10	a	a	a
^{51}Cr	2705 ± 132	1.24 ± 0.06	a	a
^{131}I	45 ± 10	a	185 ± 19	a
^{125}Sb	143 ± 29	a	a	a
^{7}Be	2227 ± 139	0.23 ± 0.05	827 ± 140	a
^{103}Ru	229 ± 15	a	a	a
^{106}Ru	951 ± 113	a	a	a
^{95}Zr	254 ± 27	a	a	a
^{95}Nb	364 ± 22	a	a	a
^{137}Cs	210 ± 17	0.025± 0.005	100 ± 20	a
^{228}Th	236 ± 14	a	284 ± 20	0.02 ± 0.01
^{226}Ra	1024 ± 106	a	643 ± 97	a
^{75}Se	a	a	133 ± 12	a

a. Not detected.

b. Information from Reference (36).

TABLE 23

RADIONUCLIDES IN NEW YORK STATE SEWAGE TREATMENT PLANT EFFLUENTS, 1978[a]

LOCATION	SAMPLE DATE	CONCENTRATION IN pCi/L				
		^{131}I	^{137}Cs	^{106}Ru	^{95}Zr	^{3}H
Syracuse	February 28	-	<6	<20	<7	<300
	June 6	147 ± 9	<7	<30	<9	<400
	July 17	-	<6	<20	<7	220 ± 165
Buffalo	January 26	-	<6	<20	<7	<300
	March 31	-	47 ± 13	<4	<15	500 ± 400
	April 27	-	<4	<14	<5	<300
	May 26	-	<6	<20	<8	400 ± 270
	July 31	-	<6	<19	<6	330 ± 190
	August 31	-	<4	<13	<5	<200

a. Information from Reference (35)

land disposal. This estimate of the annual input of ^{51}Cr to the sewage treatment plant is in excellent agreement with the annual usage of about 200 mCi ^{51}Cr estimated by the McMaster University Department of Nuclear Medicine.

A parallel study of the radiological quality of effluents from the four Toronto sewage treatment plants (North Toronto, Main, Highland Creek, and Humber) discharging to Lake Ontario was carried out by the Ontario Ministries of the Environment and Labour (44). Monthly composite samples of the effluents of each plant were collected during May, June, and July of 1978 and analyzed for γ-emitters. The levels of ^{60}Co, ^{134}Cs, and ^{137}Cs were all below the minimum detectable concentration, which was 30 pCi/L for each.

The study by the New York Department of Environmental Conservation (35) involved analyses of several treated effluent samples from municipal sewage treatment plants at Syracuse and at Buffalo. The former discharges to Lake Ontario via the Oswego River and the latter via the Niagara River. One sample of the Syracuse effluent showed a measurable concentration of ^{131}I (147$\pm$9 pCi/L) which would have arisen from the medical use of the radioisotope; all other radionuclides were at or below the laboratory's minimum detection limit (Table 23).

The Buffalo effluent samples, with one exception, were at or below the detection levels for the radionuclides which were determined. The exception was a higher-than-normal result for ^{137}Cs (47$\pm$13 pCi/L) in the March 31, 1978 sample, which may be attributable to other than fallout sources.

In summary, the results of these studies show that medical and industrial discharges of radionuclides through municipal sewage treatment plants have little effect on radioactivity levels in the Great Lakes. Most of the radionuclides reaching the plants are either naturally occurring or due to fallout from weapons testing, although small quantities of short-lived radionuclides used in nuclear medicine are present. Most of the radioactivity is removed with the sludge in the treatment of the sewage, and concentrations in the sludge are similar to those found in normal soils. The level of radioactivity remaining in the effluent is less than that found in rainfall.

6 RADIOACTIVITY SURVEILLANCE

The Great Lakes radioactivity surveillance plan was developed by the Radioactivity Subcommittee as a component of the Great Lakes International Surveillance Plan developed under the direction of the Surveillance Subcommittee. The radioactivity surveillance plan consists of five general areas for surveillance. These are:

1. Source control areas
2. Ambient waters
3. Potable water supplies
4. Biota
5. Sediments

Details of the plan, including radionuclides to be measured, sampling locations and frequency, and analytical requirements, are presented in the 1977 Appendix D (3). The adequacy of present radioactivity surveillance activities and the extent of implementation of the plan developed by the Radioactivity Subcommittee, in order to meet the requirements of the Great Lakes Water Quality Agreement, are given below.

SOURCE CONTROL AREAS

Monitoring at the periphery of a source control area determines the action required by the regulatory agency, as specified in the radioactivity objective given in the 1978 Water Quality Agreement (see Chapter 2).

The Radioactivity Subcommittee concludes that the present monitoring programs are adequate to determine the action level to be followed by the regulatory agency. However, more frequent sampling and more specific analyses would be required in order to adequately assess the contribution of radionuclides to the Great Lakes from controlled sources.

AMBIENT WATERS

Monitoring of the radionuclide concentrations of the open waters of the Great Lakes determines compliance with the radioactivity objective as well as trends in radiological water quality. In past years, radiological surveillance of the ambient waters was not conducted on a routine basis.

For the 1979 field year, agreement was reached between the Canada National Water Research Institute (NWRI) and the U.S. Environmental Protec- tion Agency (EPA) for the conduct of this program. For Lake Superior, Lake Michigan, and Lake Huron, NWRI will provide sampling equipment, EPA will collect the samples, and NWRI will perform the analyses. For Lake Erie and Lake Ontario, NWRI will conduct the entire program.

In general, at least one sample will be collected each year from each sub-basin of each of the Great Lakes. Based on data from past years, this program should be adequate to provide the desired annual assessment.

Since the expanded activities described above are being incorporated into existing programs, the additional costs should be minimal.

PUBLIC WATER SUPPLIES

Radiological monitoring of public water supplies under the Water Quality Agreement is designed to determine the radiological dose to man from ingesting water from the Great Lakes. Sampling and radiological analysis of finished drinking water would provide a direct measure of the human uptake of radionuclides from consumption of the water. The analysis of raw water collected at the water supply intake would provide a companion estimation of radiological quality of the lake water. In addition, paired raw and finished water samples would provide an estimate of the efficiency of the finishing process to remove radionuclides.

Drinking water sampling programs are conducted by various jurisdictional authorities. From the concentrations of the specific radionuclides routinely monitored as part of the Canadian program conducted by the Department of National Health and Welfare, the dose to an individual drinking water from the Great Lakes can be calculated, and compliance with the objective determined.

The data produced in some state programs are also adequate in determining compliance with the radioactivity objective. However, the purpose of many state screening programs is different from the purpose of radioactivity surveillance under the Agreement. Data collected as part of these latter programs are often limited to gross α and gross β, or the concentrations of specific radionuclides are reported as "less than" values; such data indicate whether or not jurisdictional health protection criteria are being met. However, such data are of little value in determining radiological dose to man, and hence compliance with the objective, since the concentrations of specific radionuclides are required. The data collected are, however, adequate to determine if the dose commitment to an individual is greater than 1 mrem and, therefore, whether or not source investigation and corrective action at a point source, as specified in the radioactivity objective, are recommended.

In the U.S., the Safe Drinking Water Act requires radiological monitoring of public water supplies. Coordination of monitoring require- ments under the Act and under the Water Quality Agreement is being investigated.

FISHERY

Food (primarily fish) harvested from the Great Lakes and consumed by man is another pathway of radionuclides to man. The radioactivity objective, however, does not include the dose equivalent to man from consumption of Great Lakes fish, since this pathway for ingestion of radionuclides is considered insignificant. Programs to measure the concentration of specific radionuclides in fish have been undertaken primarily in Lake Ontario, to determine whether radionuclides released from nearby point sources are detectable in fish.

SEDIMENT

The sediment can act as a sink for radionuclides of interest in the water column. However, because of the spatial variability of radionuclides in the

sediment, a large number of samples would be required. Therefore, no major effort, other than research, has been undertaken to implement this portion of the program.

CONCLUSION

Present radioactivity surveillance activities on the Great Lakes and the data they generate are generally adequate to determine compliance with the radioactivity objective and to determine trends in the radiological quality of the water. The programs are, however, not adequate to determine total intake of radionuclides by man from drinking water and eating fish from the lake, nor are the present programs adequate to determine the dispersion and fate of radionuclides in the biota and the sediment. Radioactivity surveillance activities in the Great Lakes Basin are expected to improve in the next few years as the radioactivity surveillance plan is implemented and as drinking water monitoring requirements are strengthened.

7 MONITORING DATA FOR 1978

The radiological monitoring data for water and biota samples obtained during 1978 are reported in Tables 24-35.

TABLE 24

OPEN LAKE DATA, 1978[a]

LAKE	STATION		SAMPLING DATE	DEPTH IN METRES	CONCENTRATION IN pCi/L		
	NORTH LATITUDE	WEST LONGITUDE			^{137}Cs	^{125}Sb	^{90}Sr
SUPERIOR	47°26'00"	89°43'00"	June 16	1	0.037±0.005	0.028±0.013	$0.3^{+0.2}_{-0.1}$
				185	0.070±0.007	0.040±0.013	$0.3^{+0.2}_{-0.1}$
	47°46'00"	87°27'00"	June 16	1	0.053±0.006	0.023±0.013	$0.3^{+0.2}_{-0.1}$
				162	0.037±0.006	0.031±0.010	-
	47°04'30"	85°37'18"	June 16	1	0.054±0.007	0.028±0.014	-
				145	0.059±0.007	0.023±0.013	-
HURON	45°40'30"	83°31'36"	June 17	1	0.029±0.006	0.042±0.016	$0.5^{+0.5}_{-0.1}$
				144	0.043±0.007	0.023±0.013	$0.5^{+0.5}_{-0.1}$
	44°57'00"	82°37'15"	June 17	1	0.032±0.006	0.015±0.013	$0.5^{+0.5}_{-0.1}$
				115	0.034±0.007	0.040±0.017	$0.6^{+0.5}_{-0.1}$
	43°37'42"	82°18'00"	June 18	1	0.043±0.005	0.029±0.012	1.0±0.1
				60	0.019±0.005	0.050±0.015	$0.6^{+0.5}_{-0.1}$
GEORGIAN BAY	45°19'00"	81°00'00"	September 7	1	0.036±0.006	0.035±0.013	$0.6^{+0.5}_{-0.1}$
ST. CLAIR	42°25'18"	82°45'02"	September 7	1	0.031±0.006	0.038±0.014	$0.6^{+0.5}_{-0.1}$
ERIE	42°52'00"	82°44'00"	July 20	1	0.015±0.005	0.064±0.013	$0.5^{+0.5}_{-0.1}$
				10	0.004±0.004	0.030±0.011	$0.6^{+0.5}_{-0.1}$
	42°34'28"	79°36'34"	July 13	1	0.025±0.007	0.048±0.013	$0.5^{+0.5}_{-0.1}$
				53.5	0.013±0.005	0.040±0.016	$0.6^{+0.5}_{-0.1}$
	42°01'15"	81°30'48"	July 14	1	0.013±0.006	0.056±0.016	$0.6^{+0.5}_{-0.1}$
				24	0.036±0.005	0.072±0.014	0.6±0.1
ONTARIO	43°25'06"	79°24'12"	July 8	1	0.025±0.005	0.031±0.012	$0.6^{+0.5}_{-0.1}$
				101	0.034±0.006	0.049±0.018	$0.6^{+0.5}_{-0.1}$
	43°35'30"	78°00'48"	July 5	1	0.019±0.005	0.035±0.013	$0.6^{+0.5}_{-0.1}$
				181	0.020±0.005	0.035±0.012	$0.6^{+0.5}_{-0.1}$
	43°36'24"	76°42'36"	July 6	1	0.029±0.007	0.019±0.013	$0.6^{+0.5}_{-0.1}$
				188	0.085±0.007	0.037±0.013	$0.6^{+0.5}_{-0.1}$

a. Information from Reference (37).

TABLE 25

DRINKING WATER INTAKES, 1978[a]

LAKE	NEARBY FACILITY	SAMPLING LOCATION[b]	MEAN CONCENTRATION IN pCi/L				
			GROSS α	GROSS β	^{3}H	^{90}Sr	^{137}Cs
MICHIGAN	Big Rock Point	Charlevoix[c]	<3	2.8 ± 2	-	1.2 ± 0.7	-
		Petoskey[c]	<2	1.9 ± 1	-	1.4 ± 0.8	-
	Donald Cook	New Buffalo[c]	<2	2.5 ± 2	-	1.4 ± 0.8	-
		Lake Township[c]	<2	1.6 ± 1	-	1.3 ± 0.8	-
		Bridgman[c]	<2	2.4 ± 1	-	1.1 ± 0.8	-
	Palisades	South Haven[c]	<2	2.5 ± 1	-	0.9 ± 0.8	-
		Benton Harbor[c]	<2	2.3 ± 2	-	1.2 ± 0.9	-
		St. Joseph[c]	<2	2.6 ± 1	-	1.9 ± 0.9	-
	Zion	Lake County	0.7 ± 0.6	2.8 ± 1.1	360 ± 260	-	-
		Waukegan	0.6 ± 0.6	3.0 ± 1.0	290 ± 260	-	-
HURON	Bruce	Kincardine	-	-	-	0.67	0.03
		Port Elgin	-	-	-	0.69	0.08
ERIE	Davis-Besse	Port Clinton					
		Raw	-	2 ± 3	200 ± 1200	-	g
		Finished	-	5 ± 3	1400 ± 1000	-	g
		Erie Ind. Park					
		Raw	-	<2	600 ± 1000	-	3 ± 6
		Finished	-	<2	g	-	8 ± 7
		Put-In-Bay					
		Raw	-	<2	300 ± 1200	-	g
		Finished	-	<2	800 ± 1200	-	2 ± 11
		Toledo					
		Raw	-	3	430 ± 1200	4 ± 1	g
		Finished	-	2	700 ± 1200	g	g
	Fermi 1 & 2	Flat Rock[c,h]	<2	<2	-	0.9 ± 0.7	-
		Monroe[c,h]	<2	4 ± 2	-	1.8 ± 0.8	-
	Nuclear Fuel Services	Angola	<2.3	<2.6	<270	0.84 ±0.05	-
		Sturgeon Point	<2.3	<3.3	320	-	-
		Dunkirk	<2.7	<3.6	310	<1.2	-
ONTARIO	Eldorado Nuc. Ltd.	Port Hope[f]	-	-	-	-	-
	Pickering	Pickering	-	-	-	0.82	0.04
		Ajax	-	-	-	0.78	0.05
		Toronto	-	-	-	0.86	0.04
	Ginna	Ontario[d]	<9.3	<6.9	<400	0.87	-
	Fitzpatrick and Nine Mile Point	Oswego[c]	<2.3	3.2	<310	-	-
		Demster Beach[e]	<2.6	<3.7	350	-	-

a. Information from References (35, 38, 39, 45, and 47).
b. Raw water unless indicated.
c. Finished water.
d. ^{131}I <0.23 pCi/L and ^{89}Sr <0.11 pCi/L.
e. Not a drinking water intake.
f. ^{226}Ra ◘ 0.20 pCi/L, ^{210}Pb = 0.20 pCi/L, U = 0.50 µg/L.
g. Not detected.
h. Station discontinued May 31, 1978.

TABLE 26

LAKE MICHIGAN INSHORE SURFACE WATERS, 1978[a]

NEARBY FACILITY	SAMPLING LOCATION	STATION NUMBER	CONCENTRATION IN pCi/L[b]		
			GROSS α	GROSS β	^{3}H
Big Rock Point	Mt. McSauba Point	SB-1	<1.6	2.7 ± 1.8	420 ± 200
	0.8 km south	SB-2	<3	3 ± 2	400 ± 200
	BRP Plant	SB-3	<1.4	3.2 ± 1.8	380 ± 200
	0.8 km north	SB-4	<1.5	3.0 ± 1.8	400 ± 200
	Nine Mile Point	SB-5	<1.2	3.0 ± 1.8	330 ± 200
Donald Cook	Weko Beach	SC-1	-	3.2 ± 1.6	360 ± 200
	0.8 km south	SC-2	-	3.3 ± 1.7	370 ± 200
	Cook Plant-Unit I	SC-3	-	2.8 ± 1.4	440 ± 200
	Cook Plant-Unit II	SC-3a	-	3.0 ± 1.5	410 ± 200
	0.8 km north	SC-4	-	3.0 ± 1.8	430 ± 200
	Chalet on Lake	SC-5	-	4.2 ± 1.6	380 ± 200
Palisades	Covert Twp. Park	SP-2	-	4.4 ± 1.6	420 ± 200
	Palisades Plant	SP-3	-	2.5 ± 1.5	470 ± 200
	Van Buren St. Park	SP-4	-	4.0 ± 1.6	500 ± 200
	South Haven	SP-5	-	3.6 ± 1.8	500 ± 200
	Roadside Park	SP-6	-	5.0 ± 1.6	340 ± 200
Zion	Unit 1 & 2 Intake	030201	0.5 ± 0.5	2.8 ± 1.0	<270
	0.6 km north	030203	0.7	3.7 ± 1.4	330 ± 260
	2.1 km north	030205[c]	0.7 ± 0.6	2.8 ± 1.1	360 ± 260
	0.1 km south	030207	2.0 ± 1.2	8.4 ± 2.0	830 ± 270
	9.6 km south	030206[c,d]	0.6 ± 0.6	3.0 ± 1.0	290 ± 260
Bailly (proposed)	Burns Ditch	BD-0	-0.39	4.2	-
	Indiana Harbor Canal	IHC-1	-0.16	5.2	-

a. Information from References (45, 47, and 48).
b. 2σ counting error.
c. Public water supply intake.
d. ^{89}Sr <1 pCi/L, ^{90}Sr <0.8 pCi/L.

TABLE 27

NORTH CHANNEL - SERPENT RIVER SURFACE WATER, 1978[a]

SAMPLING LOCATION	DATE	FLOW (m^3/s)	CONCENTRATION IN pCi/L			U ($\mu g/L$)
			GROSS α	GROSS β	^{226}Ra	
On Serpent River at Hwy. 17 bridge, 8.4 km upstream from harbour. Station number 14-019-1	April 28	53.2	15	15	2	<10
	May 24	53.8	14	13	3	<10
	June 27	11.7	11	13	2	<10
	Dec. 29	15.8	15	17	2	<10
	Average for 1978	18.7	-	-	2.43[b]	<10

a. Information from Reference (44).
b. Weighted average, taking into account the variable stream flow.

TABLE 28

NORTH CHANNEL INSHORE SURFACE WATER SERPENT HARBOUR, 1978[a]

STATION LOCATION		DATE	DISTANCE FROM SOURCE (km)	CONCENTRATION IN pCi/L					
NORTH LATITUDE	WEST LONGITUDE			^{228}Ra	^{226}Ra	^{232}Th	^{230}Th	^{228}Th	^{210}Pb
46°12'15"	82°37'36"	June 6	0.4	<2	6	<1	<1	<1	<1
		Sept 9			6	<1	<1	<1	<1
46°12'12"	82°38'22"	June 6	1.4	<2	6	<1	<1	<1	<1
		Sept 9			3	<1	<1	<1	<1
46°12'11"	82°39'00"	June 6	2.2	<2	4	<1	<1	<1	<1
		Sept 9			2	<1	<1	<1	<1
46°11'45"	82°40'00"	June 6	3.7	<2	3	<1	<1	<1	<1
		Sept 9			3	<1	<1	<1	<1
46°11'38"	82°41'04"	June 6	5.3	<2	3	<1	<1	<1	<1
		Sept 9			<1	<1	<1	<1	<1
46°10'53"	82°42'24"	June 6	7.0	<2	<1	<1	<1	<1	<1
		Sept 9			<1	<1	<1	<1	<1

a. Information from Reference (44).

TABLE 29

LAKE HURON SURFACE WATER
DOUGLAS POINT AND BRUCE "A" NUCLEAR GENERATING STATIONS
JUNE 15, 1978[a]

STATION LOCATION		CONCENTRATION IN pCi/L			
NORTH LATITUDE	WEST LONGITUDE	^{60}Co	^{134}Cs	^{137}Cs	^{3}H
Douglas Point N.G.S.					
44°20'09"	81°35'42"	<30	<30	<30	<270
44°19'33"	81°36'50"	<30	<30	<30	<270
44°20'02"	81°36'45"	<30	<30	<30	<270
44°19'33"	81°36'27"	<30	<30	<30	<270
44°19'11"	81°36'34"	<30	<30	<30	350±130[b]
44°19'38"	81°36'18"	<30	<30	<30	<270
44°19'46"	81°36'13"	<30	<30	<30	<270
44°20'09"	81°36'07"	<30	<30	<30	<270
Bruce "A" N.G.S.					
44°20'36"	81°35'12"	<30	<30	<30	<270
44°20'54"	81°35'21"	<30	<30	<30	<270
44°20'30"	81°35'29"	<30	<30	<30	<270
44°20'51"	81°34'44"	<30	<30	<30	<270
44°21'04"	81°34'26"	<30	<30	<30	<270
44°21'04"	81°35'03"	<30	<30	<30	<270
44°21'07"	81°34'44"	<30	<30	<30	<270
44°20'55"	81°34'10"	<30	<30	<30	980±130[b]

a. Information from Reference (44).
b. 1σ counting error

TABLE 30

LAKE ERIE - CATTARAUGUS CREEK WATER
1968 - 1978[a,b]

YEAR	AVERAGE ANNUAL CONCENTRATION IN pCi/L			
	GROSS α	GROSS β	^{90}Sr	^{3}H
1968	-	123	25	22,000
1969	-	214	47	17,600
1970	-	222	69	19,600
1971	c	208	37	31,000
1972	c	169	9	2,200
1973	c	19	4	<500
1974	<4	15	<3	<800
1975	<4	11	<3	6,200
1976	<5	10	<2	8,400
1977	<5	7	1	1,800
1978	<4	7	1	2,770
Maximum Permissible Concentrations:[h]				
NRC Technical Specifications for Nuclear Fuel Services[d]	-	-	30	300,000
EPA Drinking Water Standard	15[g]	50[f]	8[e]	20,000[e]

a. Information from Reference (35).
b. Measured at Springville Dam (Site 042).
c. Not detected.
d. 10% of 10 CFR 20.
e. 4 mrem, from 40 CFR 141.
f. If gross β >50 pCi/L, then analysis for specific radionuclides must be performed.
g. Combined ^{226}Ra and ^{228}Ra = 5 pCi/L maximum.
h. If sole source of radioactivity.

TABLE 31

LAKE ERIE INSHORE SURFACE WATER, 1978[a]

NEARBY FACILITY	SAMPLE LOCATION	STATION NUMBER	MEAN CONCENTRATION IN pCi/L			
			GROSS α	GROSS β	^{3}H	^{137}Cs
Fermi 1 & 2	Fermi Plant	SE-9	-	3.3 ± 1.8[b]	450 ± 200[b]	-
Nuclear Fuel Services	Niagara River	-	<2.60	3.35	<280	-
Davis-Besse	Intake Canal	-	-	6 ± 3	200 ± 800	6 ± 8
	Sand Beach	-	-	3 ± 3	500 ±1100	6 ± 7

a. Information from References (35, 38, and 45).
b. 2σ counting error.

TABLE 32

LAKE ONTARIO INSHORE SURFACE WATER
PICKERING "A" NUCLEAR GENERATING STATION, 1978
SOURCE CONTROL AREA[a]

STATION LOCATION		DATE	CONCENTRATION IN pCi/L					
NORTH LATITUDE	WEST LONGITUDE		GROSS α (DISSOLVED)	GROSS β (DISSOLVED)	^{3}H	^{60}Co	^{137}Cs	^{134}Cs
43°48'33"	79°04'40"	May 2	<1	3	<260	<30	<30	<30
		Nov. 14	2	7	15,560 ± 200			
43°48'25"	79°04'32"	May 2	<1	4	<260	<30	<30	<30
		Nov. 14	<1	4	10,160 ± 180			
43°48'35"	79°05'03"	May 2	3	5	<260	<30	<30	<30
		Nov. 14	<1	4	4,270 ± 150			
43°48'25"	79°05'00"	May 2	1	5	<260	<30	<30	<30
		Nov. 14	1	6	2,750 ± 140			
43°48'15"	79°04'51"	May 2	1	4	<260	<30	<30	<30
		Nov. 14	<1	4	3,650 ± 150			
43°48'09"	79°04'40"	May 2	<1	4	<260	<30	<30	<30
		Nov. 14	<1	4	10,120 ± 180			
43°48'07"	79°04'08"	May 2	<1	3	<260	<30	<30	<30
		Nov. 14	<1	4	10,010 ± 180			
43°48'19"	79°03'52"	May 2	<1	4	<260	<30	<30	<30
		Nov. 14	5	10	4,060 ± 150			

a. Information from Reference (44)
b. 1σ counting error

TABLE 33

LAKE ONTARIO SURFACE WATER NEAR PORT HOPE
AND OFF WELCOME AND PORT GRANBY DUMPS, 1978[a]

GENERAL AREA	SAMPLING LOCATION	DATE	CONCENTRATION IN pCi/L			
			GROSS α (DISSOLVED PLUS UNDISSOLVED)	GROSS β (DISSOLVED PLUS UNDISSOLVED)	^{226}Ra	U (µg/L)
Inside Port Hope Harbour	Stormwater discharge	May 18	185	50	<1	100
		June 23	1274	178	3	780
		July 20	112	19	<1	79
		Sept. 11	330	33	2	200
		Oct. 12	271	46	(55)[b]	160
	50 metres opposite discharge	May 18	122	38	2	65
		June 23	70	14	<1	40
		July 20	191	7	<1	130
		Sept. 11	300	40	1	170
		Oct. 12	356	46	2	210
	100 metres opposite discharge	May 18	133	38	1	65
		June 23	72	16	<1	40
		July 20	130	5	<1	93
		Sept. 11	252	39	2	140
		Oct. 12	357	60	4	220
	UO_2 cooling water discharge	May 18	182	55	-	-
		June 23	651	440	<1	75
		July 20	292	9	<1	220
		Sept. 11	1304	184	1	850
		Oct. 12	253	36	2	150
	50 metres opposite cooling water discharge	May 18	103	35	-	-
		June 23	71	15	<1	45
		July 20	26	6	<1	17
		Sept. 11	292	40	1	170
		Oct. 12	359	55	2	210
	Middle of channel at entrance to turning basin	May 18	113	33	-	-
		June 23	70	13	<1	40
		July 20	3	5	<1	<10
		Oct. 12	357	55	2	210
	50 metres south of crane dock	May 18	62	23	-	-
		June 23	2	<1	<1	<10
		July 20	1	3	1	<10
		Sept. 11	1	6	<1	<10
		Oct. 12	33	7	<1	20
Outside Port Hope Harbour	50 metres west of harbour mouth	May 18	1	5	<1	<10
		June 23	<1	<1	<1	<10
		July 20	5	2	4[c]	<10
		Sept. 11	<1	4	<1	<10
	50 metres east of harbour mouth	May 18	<1	4	<1	<10
		June 23	<1	<1	<1	<10
		July 20	10	3	9[c]	<10
		Sept. 11	<1	3	<1	<10
	100 metres south of harbour mouth	May 18	1	5	<1	<10
		June 23	<1	<1	<1	<10
		July 20	1	3	<1	<10
		Sept. 11	<1	3	<1	<10

(Table continued on next page.)

TABLE 33 (CONT'D.)

LAKE ONTARIO SURFACE WATER NEAR PORT HOPE
AND OFF WELCOME AND PORT GRANBY DUMPS, 1978[a]

GENERAL AREA	SAMPLING LOCATION	DATE	CONCENTRATION IN pCi/L			U (µg/L)
			GROSS α (DISSOLVED PLUS UNDISSOLVED)	GROSS β (DISSOLVED PLUS UNDISSOLVED)	^{226}Ra	
Off Welcome Dump	50 metres south of Welcome effluent discharge	May 18	10	5	6	<10
		June 23	<1	<1	<1	<10
		July 20	<1	3	<1	<10
		Sept. 11	<1	2	<1	<10
	100 metres southeast of Welcome effluent discharge	May 18	<1	5	<1	<10
		June 23	<1	<1	<1	<10
		July 20	<1	2	<1	<10
		Sept. 11	2	5	<1	<10
	100 metres southwest of Welcome effluent discharge	May 18	<1	5	<1	<10
		June 23	<1	<1	<1	<10
		July 20	<1	3	<1	<10
		Sept. 11	<1	3	<1	<10
Off Port Granby Dump	50 metres south of Port Granby East Gorge	May 18	<1	5	<1	<10
		June 23	2	<1	<1	<10
		July 20	<1	2	<1	<10
		Sept. 11	2	4	<1	<10
	100 metres southeast of East Gorge	May 18	<1	3	<1	<10
		June 23	<1	<1	<1	<10
		July 20	<1	<3	<1	<10
		Sept. 11	<1	4	<1	<10
	50 metres south of West Gorge	May 18	35	35	<1	<10
		June 23	<1	<1	<1	<10
		July 20	<1	4	<1	<10
		Sept. 11	<1	3	<1	<10

a. Information from Reference (44).
b. This result is considered to be erroneous; there was no abnormal discharge prior to the sampling.
c. These results may be due to disturbance of the harbour sediment on July 18 and 19, during a core sampling operation.

TABLE 34

^{137}Cs IN GREAT LAKES FISH

LAKE	TYPE OF FISH	COLLECTION DATE	MASS OF WHOLE FISH, kg	SEX	^{137}Cs CONCENTRATION pCi/kg (wet weight)
SUPERIOR	Siscowet lake trout	June 21	7.69	F	280 ± 10
		August 9	5.24	F	310 ± 9
		August 23	4.61	M	480 ± 10
ERIE	White bass	May 18	0.054	Immature	60 ± 6
	White bass	May 18	0.053	Immature	56 ± 10
	Small mouth bass	July 8	1.23	M	59 ± 10
	Walleye	November 9	2.22	M	27 ± 3
		November 9	2.35	F	23 ± 3
		November 15	2.10	F	31 ± 3
ONTARIO	Rainbow trout	April 27	-	F	57 ± 5
			-	F	63 ± 6
			-	F	91 ± 7
			-	F	35 ± 5
			-	F	46 ± 4
			-	F	71 ± 5

a. Information from Reference (37).

TABLE 35

LAKE ONTARIO FISH AND AQUATIC VEGETATION IN THE VICINITY OF NUCLEAR GENERATING STATIONS IN NEW YORK, 1978[a]

NEARBY FACILITY	TYPE OF SAMPLE	SAMPLING LOCATION	COLLECTION DATE	CONCENTRATION IN pCi/kg (wet weight)				
				^{137}Cs	^{134}Cs	^{106}Ru	^{90}Sr	^{40}K
Nine Mile Point	Bottom feeder	300 metres offshore	Oct. 11	56 ± 9.5	<7	5 ± 3.7	25 ± 2.5	2620 ± 157
	Bottom feeder	Vicinity of discharge	Oct. 4	54 ± 4.3	12 ± 3.4	<15	<1.9	1840 ± 92
	Aquatic Vegetation[b]	Demster Beach	Sept. 12	32 ±15.7	<12	170 ± 53	-	1500 ± 270
Ginna	Top feeder	Vicinity of discharge	March 14	67 ± 5.4	<4	<20	14 ± 2.0	2410 ± 96
	Top feeder	Vicinity of discharge	June 1	64 ± 7.7	<6	<60	12 ± 2.3	2140 ± 150
	Bottom feeder	Vicinity of discharge	June 8	44 ± 7.5	<6	<30	51 ± 2.6	2360 ± 140
	Top feeder	Vicinity of discharge	June 8	114 ± 4.6	20 ± 3.2	<15	121 ± 8.5	2190 ± 88
	Aquatic Vegetation[c]	Shoreline behind sewage treatment plant	Sept. 12	<8	<7	<30	-	2600 ± 160

a. Information from reference (35)
b. ^{60}Co <19 pCi/kg
c. ^{144}Ce = 83 ± 17.4 pCi/kg, ^{131}I <7 pCi/kg, and ^{54}Mn <10 pCi/kg.

8 SIGNIFICANCE OF MONITORING DATA

The surveillance and monitoring data presented in Chapter 7 are discussed below. Five radionuclides in particular are considered: ^{3}H, ^{90}Sr, ^{137}Cs, ^{125}Sb, and ^{226}Ra; the first two are the major contributors to the radiological dose resulting from the ingestion of water from the Great Lakes. In accordance with the changes introduced by the International Commission on Radiological Protection (ICRP), discussed in Chapter 2, the "doses" presented below are implied values incorporating the weighting (risk) factors promulgated in ICRP Publication 26 (7). These doses are calculated, using the dose-to-concentration conversion factors presented in the Radioactivity Subcommittee's 1977 Appendix D (3).

In general, the open waters of all of the Great Lakes are homegeneous with respect to the concentrations of ^{90}Sr, ^{137}Cs, and ^{125}Sb. Trends in radionuclide concentration are discussed below.

WATER

LAKE SUPERIOR

The average concentration of ^{90}Sr in the open waters of Lake Superior in 1978 was 0.3 pCi/L (Table 24). Ingestion of 2.2 litres of Lake Superior water per day for one year would result in an annual dose to man of 0.02 mrem. The objective is 1 mrem.

The average open-water concentration of ^{137}Cs in 1978 was 0.05 pCi/L, which is similar to the average level reported for 1976 (43) and slightly lower than the average level of 0.08 pCi/L reported for 1973 and 1974 (12, 42). The annual dose from ingestion of water containing ^{137}Cs at the level observed for 1978 is about 0.001 mrem.

The concentration of ^{125}Sb reported for 1978 (0.03 pCi/L) is essentially unchanged from values reported for 1973-74 (12, 42). This concentration is equivalent to an annual dose of about 0.00003 mrem.

LAKE MICHIGAN

Tables 25 and 26 give radiological monitoring data collected during 1978 at source control areas of nuclear generating stations and at selected drinking water intakes located on Lake Michigan. The average ^{3}H concentration was 400 pCi/L and the average ^{90}Sr concentration was 1.3 pCi/L. These levels are about the same as the average values reported for 1977 (330 and 1.1 pCi/L, respectively). The primary source of the ^{90}Sr and the ^{3}H is fallout from atmospheric testing of nuclear weapons. For 1978, the doses due to ingestion of ^{3}H and ^{90}Sr in water from Lake Michigan were 0.03 and 0.10 pCi/L, respectively.

The average gross β level in 1978 is essentially unchanged from 1977. The observed values do not indicate any major release of radionuclides from the nuclear generating stations.

LAKE HURON

The concentrations of ^{90}Sr, ^{137}Cs, and ^{125}Sb reported for Georgian Bay and for Lake St. Clair are similar to those reported for the open water of Lake Huron (Table 24). The average open water concentration of ^{90}Sr reported for Lake Huron in 1978 is about 0.61 pCi/L. This is in close agreement with the average raw water concentration of 0.68 pCi/L (Table 25) reported for the Kincardine and the Port Elgin public water intakes. These intakes are in the vicinity of the Bruce nuclear power and heavy water complex. The observed ^{90}Sr concentrations are equivalent to an annual dose of about 0.05 mrem.

The average concentrations of ^{137}Cs measured in the open water and at the Port Elgin and the Kincardine public water intakes in 1978 are similar (0.03 and 0.05 pCi/L, respectively).

To determine changes with time in the ^{90}Sr, ^{137}Cs, and ^{125}Sb concentrations in Lake Huron, public water intake and open water data from 1963 to 1978 were compiled (Table 36). The major source of the radionuclides to the water is from nuclear weapons testing. The water intake data for ^{90}Sr indicate an apparent concentration maximum in 1965 and essentially no change since 1967; the open water data corroborate these findings. The average annual dose over this 16-year period due to ingestion of Lake Huron water containing ^{90}Sr is about 0.06 mrem, and the maximum 0.08 mrem (for the Port Elgin water intake in 1965).

The concentration of ^{137}Cs decreased almost tenfold from 1963 to 1978; this can be attributed to sedimentation or sorption of ^{137}Cs onto sedimenting particles. The maximum dose due to ^{137}Cs was 0.01 mrem in 1963. The average concentration reported in 1978 would result in an annual dose of 0.001 mrem.

The concentration of ^{125}Sb observed in 1978 was about 0.03 pCi/L, which is generally lower than levels reported for previous years. The corresponding annual dose is about 0.00003 mrem.

The average annual concentration of ^{226}Ra measured at the mouth of the Serpent River has been steadily decreasing each year as a result of a decrease in mine activity, reuse of process waters, and the use of barium chloride treatment. In 1966, the mean concentration of ^{226}Ra was 11.7 pCi/L (42) and, by 1977, the mean concentration was 4.8 pCi/L (3). These mean values are all in excess of the Ontario criterion of 3 pCi/L for public surface water supplies. In 1978, the mean concentration reported at the mouth of the Serpent River was 2.4 pCi/L (Table 27), which is better than the criterion; this converts into an annual dose equivalent of 1.0 mrem to the whole body.

Since the river mouth is considered as a source control area, the concentration at the 1-km boundary is the critical value. Data in Table 28 indicate that the concentration at this distance from the river mouth is greater than 3 pCi/L. The frequency of sample collection and the amount of data produced at both the sampling station near the Serpent River mouth (Table 27) and in Serpent Harbour (Table 28) are insufficient for further interpretation of the data.

TABLE 36

^{90}Sr, ^{137}Cs, AND ^{125}Sb IN LAKE HURON WATER

1963 - 1978[a,b]

YEAR	CONCENTRATION IN pCi/L								
	KINCARDINE		PORT ELGIN		AVERAGE		OPEN WATER		
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{125}Sb
1963	0.60	0.37	0.75	0.40	0.68	0.38	-	-	-
1964	0.80	0.30	0.76	0.28	0.78	0.29	-	-	-
1965	0.96	0.19	1.06	0.19	1.01	0.19	-	-	-
1966	0.85	0.18	0.94	0.09	0.90	0.14	-	-	-
1967	0.76	0.11	0.84	0.06	0.80	0.08	-	-	-
1968	0.70	0.08	c	c	-	-	-	-	-
1969	0.66	0.06	c	c	-	-	-	-	-
1970	0.66	0.06	c	c	-	-	-	-	-
1971	0.75	<0.10	0.84	<0.10	0.80	<0.10	-	-	-
1972	0.71	<0.10	0.74	<0.10	0.72	<0.10	-	-	-
1973	0.70	<0.10	0.80	<0.10	0.75	<0.10	0.86	0.04	0.08
1974	0.75	0.07	0.79	0.04	0.77	0.05	-	0.05	0.07
1975	0.72	0.04	0.76	0.03	0.74	0.03	-	0.04	0.06
1976	0.71	0.06	0.74	0.09	0.72	0.07	-	0.02	0.04
1977	0.64	0.03	0.68	0.02	0.66	0.02	0.84	0.04	0.06
1978	0.67	0.03	0.69	0.08	0.68	0.05	0.61	0.03	0.03
AVERAGE	0.73	0.11	0.80	0.11	0.77	0.11	0.77	0.04	0.06

a. Raw water.

b. Information from References (3, 12, 37, 39-43).

c. Not sampled.

Since the dose from ^{226}Ra, in any event, is greater than 1 mrem, the radioactivity objective requires source investigation and correction action if releases are not as low as reasonably achievable. Loading data presented in Table 21 indicate that, in 1978, 72 mCi of ^{226}Ra entered Serpent River from the three active mines but that the 1978 loading from Serpent River to Serpent Harbour was 1430 mCi; the loading in 1977 was 1420 mCi (3). The major sources of radioactivity to the Serpent River are probably natural inputs from the bedrock and also the result of leaching from tailings piles at abandoned mines upstream in the river basin.

The monitoring data collected in the vicinity of the Bruce "A" and the Douglas Point nuclear generating station source control areas (Table 28) show no measurable releases at the time of sampling. The average ^{3}H level (<270 pCi/L) for 1978 is equivalent to an annual dose of less than 0.02 mrem.

LAKE ERIE

The average concentration of ^{90}Sr for 1978 in the open waters of Lake Erie (Table 24) was lower than the level observed in 1977 (0.57 vs. 0.81 pCi/L). The average 1978 concentration of ^{137}Cs (0.02 pCi/L) is unchanged from levels reported in 1973 (12) and 1977 (3). The average concentrations of ^{125}Sb reported in 1977 and 1978 are similar (0.04 and 0.05 pCi/L, respectively), but are lower than the 1973 level of 0.09 pCi/L (3). The observed 1978 average concentrations of ^{90}Sr, ^{137}Cs, and ^{125}Sb are equivalent to annual doses of 0.05, 0.0004, and 0.00005 mrem, respectively.

The average raw water concentration of ^{3}H in Lake Erie in 1978 was about 330 pCi/L, which is equivalent to an annual dose of about 0.02 mrem.

Table 30 summarizes the average annual concentrations of ^{3}H, ^{90}Sr, gross α, and gross β measured from 1968 through 1978 in Cattaraugus Creek at Springville Dam, which is about 30 km upstream from the mouth of the creek and about 30 km downstream from Nuclear Fuel Services (NFS).

The observed concentrations of ^{90}Sr and ^{3}H are within the Nuclear Regulatory Commission's technical specifications for NFS and also meet EPA's drinking water standard. The highest reported average concentration of ^{3}H was 31,000 pCi/L in 1971, which was equivalent to a dose of 2.0 mrem; and the highest reported average concentration of ^{90}Sr, 69 pCi/L, was equivalent to a dose of 5.45 mrem. In 1978, the doses from ingestion of water from this location in Cattaraugus Creek were 0.18 and 0.08 mrem, respectively. The observed concentration of ^{3}H in Lake Erie in the vicinity of the mouth of Cattaraugus Creek is <280 pCi/L (Table 31), which is equivalent to a dose of less than 0.02 mrem.

The increase in ^{3}H concentrations in 1975 through 1978 is the result of the controlled release of water pumped from the trenches at the low-level waste burial site at NFS. This trench water was treated in the low-level waste treatment facility at NFS prior to its release.

LAKE ONTARIO

The average 1978 concentration of ^{90}Sr reported (Table 24) for the open waters of Lake Ontario is lower than the average reported (Table 25) for raw

water samples collected at the Pickering, Ajax, Toronto, and Ontario (New York) public water supplies (0.60 vs. 0.83 pCi/L, respectively). These concentrations are equivalent to an annual dose of about 0.06 mrem.

The average 1978 open water concentration of ^{137}Cs is about the same as the average reported for the Pickering, Ajax, and Toronto public water supplies (0.03 vs. 0.04 pCi/L, respectively); for both, the equivalent annual dose is less than 0.001 mrem.

^{90}Sr, ^{137}Cs, and ^{125}Sb data for the period 1971-1978 were compiled (Table 37) to determine trends in the radiological water quality of Lake Ontario. The ^{90}Sr concentration shows essentially no change between 1971 and 1978. The average annual dose due to ingestion of ^{90}Sr contained in Lake Ontario water for this period is about 0.07 mrem; both the maximum and the minimum doses (0.10 and 0.06 mrem, respectively) were recorded at the Toronto public water supply.

In general, the average ^{137}Cs concentrations are comparable for each year at the three water intakes and in the open waters (Table 37) and, as for Lake Huron, the average yearly concentration has decreased with time. The reason for this decrease, as for Lake Huron, is sedimentation or sorption of ^{137}Cs onto sedimenting particles. Nonetheless, even for the highest average annual ^{137}Cs concentration reported (0.37 pCi/L), the annual dose was still less than 0.01 mrem.

Open water ^{125}Sb concentrations are similar for 1976-78 (about 0.03 pCi/L) and, like ^{137}Cs, are considerably lower than the level reported (0.09 pCi/L) for 1973. The average annual dose due to ^{125}Sb ingestion is about 0.00003 mrem.

The waters of Port Hope Harbour receive waste from the Eldorado Nuclear Ltd. uranium refinery. The average ^{226}Ra concentration in the harbour (Table 33) in 1978 was below the Ontario criterion of 3 pCi/L for public surface water supplies; in 1977, some of the samples collected had shown ^{226}Ra levels of 4 pCi/L (3). In general, the concentrations of gross α, gross β, and uranium were higher in Port Hope Harbour in 1978 than in 1977 (3).

The 1978 data (Table 33) for ^{226}Ra, gross α, gross β, and uranium in Lake Ontario outside Port Hope Harbour and off the Port Granby and the Welcome waste management sites show levels near to or less than the detection limits; these are comparable to data collected in 1977 (3).

In 1978, the concentration of ^{226}Ra in Lake Ontario water in the vicinity of Port Hope was 0.20 pCi/L (39); this is equivalent to a dose of 0.09 mrem.

In general, the concentration of ^{3}H is below the detection limit of 260 pCi/L (Table 32; see also Table 25). This is equivalent to a dose of less than 0.02 mrem. On one sampling date, however, elevated levels of ^{3}H were reported in the vicinity of the Pickering "A" nuclear generating station. If the highest concentration reported (15,560 pCi/L) had been maintained for a full year, the dose to the whole body would have been 1.0 mrem.

TABLE 37

^{90}Sr, ^{137}Cs, AND ^{125}Sb IN LAKE ONTARIO WATER

1971 - 1978[a,b]

YEAR	CONCENTRATION IN pCi/L										
	PICKERING		AJAX		TORONTO		AVERAGE		OPEN WATER		
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{125}Sb
1971	0.80	-	0.83	-	1.04	-	0.89	-	-	-	-
1972	0.82	0.31	0.93	0.24	1.30	0.22	1.01	0.26	-	-	-
1973	0.85	0.06	0.88	0.15	0.94	0.08	0.89	0.10	1.26	0.05	0.09
1974	0.95	0.37	0.85	0.11	0.87	0.07	0.89	0.18	-	-	-
1975	0.82	0.12	0.95	0.04	0.91	0.04	0.89	0.07	-	-	-
1976	0.82	0.04	0.82	0.09	0.84	0.05	0.83	0.06	-	0.02	0.02
1977	0.91	0.05	0.96	0.08	0.95	0.04	0.94	0.06	0.93	0.02	0.04
1978	0.82	0.04	0.78	0.05	0.86	0.04	0.82	0.04	0.60	0.03	0.03
AVERAGE	0.85	0.14	0.88	0.11	0.96	0.08	0.89	0.11	0.93	0.03	0.04

a. Raw water.

b. Information from References (3, 12, 37, 39-43).

FISH

Reasonably low levels of ^{137}Cs are reported as present in samples of whole Great Lakes fish (Table 34). Of the species collected, the ^{137}Cs concentration is highest in siscowet lake trout from Lake Superior, but these levels are sufficiently low so as to not be of any environmental or health concern. The average ^{137}Cs concentration reported in samples of whole rainbow trout from Lake Ontario show little change with time. The observed average values are 64, 53, and 60 pCi/kg for 1976, 1977, and 1978, respectively (3).

Analyses of fish collected in the vicinity of the Ginna and the Nine Mile Point nuclear generating stations average 66 pCi/kg for ^{137}Cs (Table 35) which agrees with the values reported for whole rainbow trout (Table 34). The appearance of ^{134}Cs at just above the detection limit in two of the six fish samples suggests that some of the bioaccumulated cesium may have come from the nuclear station effluent.

SUMMARY

The overall radiological quality of the Great Lakes remains essentially unchanged from 1977. Differences in the reported levels of radioactivity for the open lakes are not large and not consistent enough to support attempts at long-term projections.

The annual dose to man from the ingestion of ^{90}Sr in water from the Great Lakes is 0.02, 0.10, 0.05, 0.05, and 0.06 mrem for water from Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario, respectively; these doses are similar to those reported for previous years. The average concentration of ^{3}H in each of the Great Lakes ranges from less than 260 to 400 pCi/L, which is equivalent to an annual dose of about 0.03 mrem or less. Thus, the maximum annual dose due to ingestion of raw lake water (except from the Serpent Harbour area and in the vicinity of Port Hope) would come from drinking water from Lake Michigan; this dose (0.13 mrem) is considerably less than the objective of 1 mrem per year.

The average 1978 concentration of ^{226}Ra at the mouth of the Serpent River was 2.4 pCi/L, which is less than the Ontario criterion of 3.0 pCi/L for public surface water supplies. This average concentration is equivalent to an annual dose of 1.0 mrem. The data indicate that the major sources of radioactivity are probably natural inputs from the bedrock and also the result of leaching from tailings piles at abandoned mines in the Serpent River Basin.

In the Port Hope area, the ingestion of raw water containing ^{226}Ra would result in an additional dose of 0.09 mrem.

Elevated levels of ^{3}H were reported well upstream in Cattaraugus Creek, which drains the area surrounding the Nuclear Fuel Services site, but levels reported in the vicinity of the creek mouth in Lake Erie are below the detection limit.

9 SUMMARY & CONCLUSIONS

RADIOACTIVITY OBJECTIVE AND DOSE CALCULATION

In response to a question from the International Joint Commission, the Radioactivity Subcommittee assessed the changes introduced by the International Comission on Radiological Protection (ICRP) and their significance for Great Lakes water quality. The changes recommended by ICRP, in general, raise the numerical dose limits to specific organs or tissues as compared to those allowed under the older "critical organ" concept. The changes therefore permit a higher concentration of most radionuclides in the Great Lakes. The ICRP changes reflect that organization's re-evaluation of both the risk and the dosimetric methodology associated with exposure to ionizing radiation. The Radioactivity Subcommittee concludes, however, that the objective should remain unchanged for the present since the net effect of these changes cannot be assessed until the new ICRP limits are published.

There are other principles imbodied in the 1978 Water Quality Agreement which act to limit ambient radionuclide concentrations. Maintenance or improvement of existing water quality (as set forth in Article IV, Item 1(c)), while difficult to achieve since a major input is via fallout, is still a fundamental principle. The principle of discharges from nuclear power plants being as low as reasonably achievable (ALARA) will also be utilized. ALARA also applies to other point-source inputs, such as from mining and low-level waste management sites, but does not apply to such inputs as fallout.

NUCLEAR FUEL CYCLE

In response to a request from the International Joint Commission concerning the possible impact of the Canadian and the U.S. nuclear fuel cycles on the Great Lakes Basin, the Radioactivity Subcommittee prepared a report on fuel cycle activities, with emphasis on waste management; impact from typical facilities for both normal and abnormal operation; and impact of existing facilities.

The Subcommittee concludes that an accurate evaluation of the impact is not possible at this time since the multitude of risk studies performed in this area, e.g. reactor accidents or breach of repository integrity, are not supported by an adequate data base. Estimates of radiological impact are most commonly made by assessing the risk, which is the product of the probability of an event and its consequence; in most critical areas, neither of these is known with any degree of certainty. The Subcommittee concludes that the radiation dose and the consequent health effects resulting from "normal" operations in the fuel cycle would be small.

In the area of "abnormal" operations, accidents are possible, particularly in power generation and in waste management, which might have a substantial impact. There has not been sufficient operating experience in these areas, however, to estimate the probability of such incidents with any degree of certainty.

The impact of existing facilities on the Great Lakes Basin has, to date, been small. Some problem areas, most notably active and abandoned mill tailings piles in northern Ontario and commercial reprocessing waste in western New York state, are however apparent. While some remedial actions have been taken, as described in Chapter 3, future activities in these areas should be closely monitored. An additional factor which warrants consideration is the spent fuel produced by power reactors. Although both Parties are currently studying waste management options, the large amount of spent fuel and the limited storage capacity at reactor sites dictate accelerated efforts in the waste management area.

UNPLANNED RELEASES OF RADIONUCLIDES

The International Joint Commission asked the Water Quality Board to establish a procedure to receive and assess information on unplanned releases of radionuclides into the Great Lakes. In response, the U.S. Nuclear Regulatory Commission and the Canada Atomic Energy Control Board agreed to provide timely advice to the Water Quality Board, through its Radioactivity Subcommittee, about unplanned releases of radionuclides into the Great Lakes.

Beginning in 1979, the date of implementation of this procedure, the reporting of unplanned releases will be treated as follows: After receipt of information about a given incident from the NRC or the AECB, the Secretary of the Radioactivity Subcommittee will notify the appropriate agency representatives on the Subcommittee who will, in turn, assess the available information. A report would be provided to the Water Quality Board. If the incident is significant, the Board would be informed immediately. All unplanned releases, as described above, will in the future be reported by the Radioactivity Subcommittee through its Appendix D.

INPUTS FROM MEDICAL AND INDUSTRIAL USES OF RADIONUCLIDES

Medical and industrial discharges of radionuclides through municipal sewage treatment plants have little effect on radioactivity levels in the Great Lakes. Most of the radionuclides reaching the plants are either naturally occurring or due to fallout from weapons testing, although small quantities of short-lived radionuclides used in nuclear medicine are present. Most of the radioactivity is removed with the sludge in the treatment of the sewage, and concentrations in the sludge are similar to those found in normal soils. The level of radioactivity remaining in the effluent is less than that found in rainfall.

SURVEILLANCE

Present radioactivity surveillance activities on the Great Lakes and the data they generate are generally adequate to determine compliance with the radioactivity objective and to determine trends in the radiological quality of the water. The programs are, however, not adequate to determine total intake of radionuclides by man from drinking water and eating fish from the lake, nor are the present programs adequate to determine the dispersion and fate of radionuclides in the biota and the sediment. Radioactivity surveillance activities in the Great Lakes Basin are expected to improve in the next few years as the radioactivity surveillance plan is implemented and as drinking water monitoring requirements are strengthened.

LAKE ASSESSMENT

In accordance with the changes introduced by ICRP, discussed in Chapter 2, the "doses" presented here are implied values incorporating the weighting (risk) factors as promulgated in ICRP Publication 26.

The overall radiological quality of the Great Lakes remains essentially unchanged from 1977. Differences in the reported levels of radioactivity for the open lakes are not large and are not consistent enough to support attempts at long-term projection. ^{90}Sr is still the most important contributor to the annual dose to man. The ingestion of ^{90}Sr in water from the Great Lakes would yield doses of 0.02, 0.10, 0.05, 0.05, and 0.06 mrem for water from Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario, respectively; these doses are similar to those reported for previous years. The average concentration of ^{3}H in each of the Great Lakes ranges from less than 260 to 400 pCi/L, which is equivalent to an annual dose of 0.03 mrem or less. The maximum annual dose due to ingestion of lake water (except from the Serpent Harbour area and in the vicinity of Port Hope) would come from drinking water from Lake Michigan; this dose (0.13 mrem) is considerably less than the objective of 1 mrem per year.

The average 1978 concentration of ^{226}Ra at the mouth of the Serpent River was 2.4 pCi/L, which is less than the Ontario criterion of 3.0 pCi/L for public surface water supplies. This average concentration is equivalent to an annual dose of 1.0 mrem. The data indicate that the major sources of radioactivity are probably natural inputs from the bedrock and also the result of leaching from tailings piles at abandoned mines in the Serpent River Basin.

Ingestion of raw water in the Port Hope area would result in an additional dose of 0.09 mrem because of the presence of ^{226}Ra in the water.

Although elevated levels of ^{3}H were reported well upstream in Cattaraugus Creek, which drains the area surrounding the Nuclear Fuel Services site, the average levels reported in the vicinity of the creek mouth in Lake Erie are below the detection limit.

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MEMBERSHIP LIST

RADIOACTIVITY SUBCOMMITTEE

Dr. R. E. Sullivan (Chairman)
Bioeffects Analysis Branch
Criteria and Standards Division
(ANR-460)
U.S. Environmental Protection Agency
Washington, D.C. 20460

Dr. D. A. Marsden
Consultant, Environmental Radioactivity
Radiation Protection Service
Ontario Ministry of Labour
400 University Avenue
Toronto, Ontario M7A 1T7

Dr. Jean-Marc Légaré
Quebec Environment Protection Service
9310 St. Lawrence Blvd.
Montreal, Quebec H2N 1N4

Mr. Alun W. James
Ontario Ministry of the Environment
4375 Chesswood Drive
Toronto, Ontario M3J 2C2

Dr. J. Ferman
Minnesota Pollution Control Agency
1935 W. County Road B2
Roseville, Minnesota 55113

Mrs. D. P. Meyerhof
Environmental Radiation Hazards Division
Radiation Protection Bureau
Health & Welfare Canada
Brookfield Road
Ottawa, Ontario K1A 1C1

Dr. L. K. Cohen
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Mr. D. E. Van Farowe
Chief, Division of Radiological Health
Michigan Department of Public Health
P. O. Box 30035
Lansing, Michigan 48909

Mr. P. Tedeschi
U.S. EPA, Region V
230 South Dearborn Street
Chicago, Illinois 60604

Dr. R. W. Durham
Applied Research Division
National Water Research Institute
Department of Environment
P. O. Box 5050
Burlington, Ontario L7R 4A6

Dr. Margaret A. Reilly
Chief, Division of Nuclear Reactor
Review and Environmental Surveillance
Bureau of Radiological Health
Department of Environmental Resources
P. O. Box 2063
Harrisburg, Pennsylvania 17120

Mr. Thomas J. Cashman
Director, Bureau of Radiation
Dept. of Environmental Conservation
50 Wolf Road
Albany, New York 12233

Mr. V. E. Niemela
Chief, Program Evaluation and
Co-ordination
Water Pollution Programs Branch, EPS
Department of Environment
Place Vincent Massey, 13th Floor
Ottawa, Ontario K1A 1C8

Mr. James C. Wynd
Director, Radiological Health Program
Radiological Health Unit
Ohio Department of Health
P. O. Box 118
Columbus, Ohio 43216

Mr. Gary N. Wright
Chief, Division of Radiological Health
Illinois Department of Public Health
Suite 450, 545 West Jefferson St.
Springfield, Illinois 62761

Dr. R. M. Chatterjee
Atomic Energy Control Board
P. O. Box 1046
Ottawa, Ontario K1P 5S9

CONTACTS

Mr. Laurence J. McDonnell
Chief, Section of Radiation Protection
Wisconsin Department of Health and Social Services
Division of Health
P. O. Box 309
Madison, Wisconsin 53701

Mr. Oral H. Hert
Technical Secretary
Indiana Stream Pollution Control Board
1330 West Michigan Street
Indianapolis, Indiana 46206

Mr. H. S. Stocks
Chief, Radiological Health Section
Department of Industrial Hygiene & Radiological Health
Indiana State Board of Health
1330 West Michigan Street
Indianapolis, Indiana 46206

SECRETARY

Dr. M. P. Bratzel, Jr.
Great Lakes Regional Office
International Joint Commission
100 Ouellette Avenue, 8th Floor
Windsor, Ontario N9A 6T3

ANNEX I

CALCULATION OF ALLOWABLE CONCENTRATION OF ^{90}SR

To calculate the numerical value for the annual dose equivalent limit, $H_{wb,L}$, for uniform irradiation to the whole body, the dose equivalents to the individual organs or tissues are summed, using the equation:

$$\Sigma_T \, W_T H_T \leq H_{wb,L}$$

where W_T is a weighting factor applied to each tissue, and H_T is the annual dose equivalent, expressed in rems, in tissue (T). The values of W_T recommended by ICRP are given in Table 38. H_T, at a point in a tissue is given by:

$$H_T = DQN$$

where D is the absorbed dose, Q is the quality factor applicable to the absorbed radiation, and N is the product of all other modifying factors.

Radioactivity in the Great Lakes is mainly a residual from nuclear weapons testing. In addition, nuclear facilities and naturally-occurring radioactive material make small contributions to the total equivalent dose. ^{90}Sr, which entered as fallout from weapons debris, is the major contaminant. The concentration of ^{90}Sr in the ambient waters of the Great Lakes is about 1 pCi/L.

^{90}Sr is a bone seeker. Under the former ICRP procedure (1), bone was considered as one organ. In the new treatment, introduced in Publication 26 (7), bone is separated into several components, e.g. red bone marrow and bone surfaces. Each has its own weighting factor (Table 38) and its own implied dose limit. Therefore, the dose to each component must be summed to obtain the whole body dose.

For the former ICRP methodology, the bone-to-whole-body dose ratio was thirty rem to five rem. The objective is 1 mrem, and this translates to a bone dose of 6 mrem. The ingestion of water containing ^{90}Sr at 1 pCi/L, at the ICRP rate of 2.2 L/d for a one-year period gives an annual intake, I, of:

$$I = (1 \text{ pCi/L}) \, (2.2 \text{ L/d}) \, (365.25 \text{ d/a})$$

$$= 803 \text{ pCi/a}$$

The resultant fifty year dose, D_{50}, may be calculated from the equation:

$$D_{50} = \frac{51.2 \, \varepsilon I}{m} \int_0^{50} R(t) d^t$$

where ε is the effective energy release per disintegration in bone, m is

TABLE 38

WEIGHTING FACTORS[a]

TISSUE	WEIGHTING FACTOR, W_T
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder (other tissues or organs)[b]	0.30

a. From Reference (7).

b. The remainder (0.30) is allocated equally to the five other organs or tissues receiving the highest dose equivalent. When the gastrointestinal tract is irradiated, the stomach, small intestine, upper large intestine, and lower large intestine are treated as four separate organs.

the bone mass, and R(t) is the retention function for ^{90}Sr in bone. Using values for these parameters and the integral given in ICRP 10 (6), the fifty-year dose resulting from a one year's intake, I, of 803 pCi is:

$$D = \left(\frac{51.2 \text{ dis}\cdot g\cdot rad}{d\cdot\mu Ci\cdot Mev}\right)\left(\frac{(5.5 \text{ Mev/dis})(rem/rad)}{7000 \text{ g}}\right)(803 \times 10^{-6} \mu Ci)(0.3)\left(\frac{709 \mu Ci\cdot d}{\mu Ci}\right)$$

$$= 6.88 \text{ mrem}$$

The new ICRP methodology requires that separate weighted doses to the target organs, red marrow (m) and bone surfaces (endosteum cells, e), be summed to obtain the total bone dose. For ^{90}Sr, the source and target organs differ, with the source organs considered to be cortical bone (c) and trabecular bone (t). In addition, while the effective energy release, ε, used in the previous calculation is adjusted to account for energy released by the ^{90}Sr decay products, the new method requires that the specific effective energy (SEE) of each be calculated separately. Performing this step using ICRP SEE values calculated by the method of Spiers, and ICRP values for ^{90}Sr in bone provided by the Ontario Ministry of Health (8), the results for the endosteal cells, e, are:

$$SEE\ (e \leftarrow c) = 2.5 \times 10^{-5}\ \frac{Mev}{g\cdot dis} \qquad \text{Parent } ^{90}Sr$$

$$SEE\ (e \leftarrow c) = 1.4 \times 10^{-4}\ \frac{Mev}{g\cdot dis} \qquad \text{Daughter } ^{90}Y$$

$$SEE\ (e \leftarrow t) = 4.6 \times 10^{-5}\ \frac{Mev}{g\cdot dis} \qquad \text{Parent } ^{90}Sr$$

$$SEE\ (e \leftarrow t) = 1.6 \times 10^{-4}\ \frac{Mev}{g\cdot dis} \qquad \text{Daughter } ^{90}Y$$

For red bone marrow, m, the results are:

$$SEE\ (m \leftarrow c) = 6.17 \times 10^{-7}\ \frac{Mev}{g\cdot dis} \qquad \text{Parent } ^{90}Sr$$

$$SEE\ (m \leftarrow c) = 1.5 \times 10^{-5}\ \frac{Mev}{g\cdot dis} \qquad \text{Daughter } ^{90}Y$$

$$SEE\ (m \leftarrow t) = 4.5 \times 10^{-5}\ \frac{Mev}{g\cdot dis} \qquad \text{Parent } ^{90}Sr$$

$$SEE\ (m \leftarrow t) = 2.7 \times 10^{-4}\ \frac{Mev}{g\cdot dis} \qquad \text{Daughter } ^{90}Y$$

These values must then be multiplied by the fifty-year integral of the retention functions, U, for ^{90}Sr in bone. The integral values may be found in Table 34(b) of ICRP Publication 20 (9):

$$U_c = 399\ \mu Ci \text{ days}$$

$$U_t = 158\ \mu Ci \text{ days}$$

The fifty-year doses per unit intake are found to be:

$$D_{50}^{e} = 51.2\ [(399)(1.6 \times 10^{-4}) + (158)(2.0 \times 10^{-4})]$$
$$= 4.9\ \text{rem}/\mu\text{Ci} \qquad \text{(blood)}$$

$$D_{50}^{m} = 51.2\ [(399)(1.6 \times 10^{-5}) + (158)(3.2 \times 10^{-4})]$$
$$= 3\ \text{rem}/\mu\text{Ci} \qquad \text{(blood)}$$

Then, using the ICRP value of 0.3 for the ingestion-to-blood fraction and the weights given in Table 38 for red bone marrow and for endosteal cells, the fifty-year dose from one year's intake of water with a ^{90}Sr concentration of 1 pCi/L is found to be:

$$D_{50} = (8.03 \times 10^{-4}\ \mu\text{Ci})(0.3)\ [(0.03)(4.9\ \text{rem}/\mu\text{Ci}) + (0.12)(3.0\ \text{rem}/\mu\text{Ci})]$$
$$= 0.12\ \text{mrem}$$

In summary, then, the former ICRP method returns a bone dose of 6.88 mrem, and the newer a dose of 0.12 mrem, from the annual ingestion of lake waters containing 1 pCi/L of ^{90}Sr. In terms of the radioactivity objective, the old ICRP treatment would equate a 1 mrem whole body dose to a 6 mrem bone dose, and the water concentration required to reach the 1 mrem objective would be:

$$(1\ \text{pCi/L})\left(\frac{6\ \text{mrem}}{6.88\ \text{mrem}}\right) = 0.87\ \text{pCi/L} \qquad \text{(old ICRP)}$$

The new ICRP treatment would equate the sum of the weighted red blood marrow and endosteal doses to a 1 mrem whole body dose and the resulting objective concentration would be:

$$(1\ \text{pCi/L})\left(\frac{1\ \text{mrem}}{0.12\ \text{mrem}}\right) = 8.33\ \text{pCi/L} \qquad \text{(new ICRP)}$$

Utilization of the new ICRP methodology, therefore, allows an increase in ^{90}Sr water concentration by about a factor of 10.

Other radionuclides would, of course, yield different ratios, although the general trend is to allow higher concentrations. As a point for reference, it might be noted that the new, larger value (8.33 pCi/L) for ^{90}Sr is very close to the concentration allowed (8.0 pCi/L) for finished drinking water under the U.S. National Interim Primary Drinking Water Regulations (10).

International Joint Commission
Great Lakes Regional Office
100 Ouellette Avenue
Eighth Floor
Windsor, Ontario
N9A 6T3