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Environmental Monitoring Program Design for Uranium Refining and Conversion Operations

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August 1984

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ENVIRONMENTAL MONITORING PROGRAM DESIGN FOR URANIUM REFINING AND CONVERSION OPERATIONS

L Report (Canada Environmental Protection Service)

by

SENES Consultants Limited

for the

Environmental Protection Service
Environment Canada

EPS 3/HA/1
August 1984

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ABSTRACT

The objective of this study was to develop recommendations for the design of environmental monitoring programs at Canadian uranium refining and conversion operations. In order to develop monitoring priorities, chemical and radioactive releases to the air and water were developed for reference uranium refining and conversion facilities. The relative significance of the radioactive releases was evaluated through a pathways analysis which estimated dose to individual members of the critical receptor group. The effects of chemical releases to the environment were assessed by comparing predicted air and water contaminant levels to appropriate standards or guidelines.

For the reference facilities studied, the analysis suggested that environmental effects are likely to be dominated by airborne releases of both radioactive and nonradioactive contaminants. Uranium was found to be the most important radioactive species released to the air and can serve as an overall indicator of radiological impacts for any of the plants considered. The most important nonradioactive air emission was found to be fluoride (as hydrogen fluoride) from the uranium hexafluoride plant. For the uranium trioxide and uranium dioxide plants, air emissions of oxides of nitrogen were considered to be most important.

The study recommendations for the design of an environmental monitoring program are based on consideration of those factors most likely to affect local air and water quality, and human radiation exposure. Site- and facility-specific factors will affect monitoring program design and the selection of components such as sampling media, locations and frequency, and analytical methods.

RÉSUMÉ

Cette étude a été réalisée en vue d'élaborer des recommandations concernant la conception de programmes de surveillance de l'environnement à des installations canadiennes d'affinage et de transformation de l'uranium. Pour établir les priorités de surveillance, on a étudié les dégagements de produits chimiques et de matières radioactives dans l'air et l'eau à des installations de référence. On a évalué l'importance relative des dégagements de matières radioactives par une analyse des cheminements consistant à estimer l'exposition pour des membres particuliers du groupe des récepteurs critiques. Quant aux effets des dégagements de produits chimiques dans l'environnement, ils ont été déterminés par comparaison des niveaux prévus des contaminants dans l'air et dans l'eau avec les normes ou lignes directrices appropriées.

Aux installations de référence, l'analyse a indiqué que les dégagements dans l'atmosphère de matières radioactives et non radioactives étaient probablement responsables des principaux effets sur l'environnement. L'uranium était le plus important élément radioactif libéré dans l'atmosphère; il pourrait servir d'indicateur général de l'incidence en ce qui concerne les matières radioactives pour toutes les installations examinées. Le fluorure (sous forme de fluorure d'hydrogène) provenant de l'installation de l'hexafluorure d'uranium constituait le plus important produit non radioactif émis dans l'atmosphère. Dans les cas des installations du bioxyde et du trioxyde d'uranium, les émissions atmosphériques d'oxydes d'azote ont été considérées comme les plus importantes.

Les recommandations formulées concernant la conception d'un programme de surveillance de l'environnement tiennent comptent des facteurs les plus susceptibles d'influer sur la qualité de l'air et de l'eau dans la région et sur l'exposition de l'homme aux rayonnements. La conception du programme de surveillance ainsi que le choix de ses composantes telles que les milieux, emplacements et fréquences d'échantillonnage ainsi que les méthodes d'analyse pourront varier en fonction des facteurs particuliers à chaque emplacement et à chaque installation.

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1 INTRODUCTION

This study develops recommendations for the design of environmental monitoring programs at Canadian uranium refining and conversion operations. Chemical and radioactive releases to the air and water from a reference facility were derived from an examination of the existing uranium refining operations and consideration of the engineering design of proposed facilities.

The effects of chemical releases to the environment were assessed by comparing predicted air and water contaminant levels to appropriate standards or guidelines. The effects of radioactive releases to the environment were assessed through a radiation exposure pathways analysis using generally accepted models reported in the literature.

2 PLANT EMISSIONS

2.1 Introduction

The chemical and radiological releases to air and water associated with the normal process operations and pollution controls of the refining and conversion facilities described in Appendix A are summarized here. The magnitude of normal variability in release rates associated with process variations, scheduled maintenance operations, and other factors, is also noted where data are available. Accidental releases are beyond the scope of the present study and are not discussed.

The major processing steps involved in uranium refining and conversion are illustrated in Figure 1. The first step, the uranium trioxide (UO_3) circuit, is the actual refining stage where yellowcake from uranium mills is purified. The uranium hexafluoride (UF_6) circuit converts the uranium trioxide feed material to uranium hexafluoride destined for the export market. The uranium dioxide (UO_2) circuit converts an intermediate product from the uranium trioxide circuit to reactor-grade uranium dioxide for use in CANDU fuel. The uranium metal plant produces uranium metal (U) from an intermediate product, uranium tetrafluoride (UF_4), drawn from the uranium hexafluoride circuit.

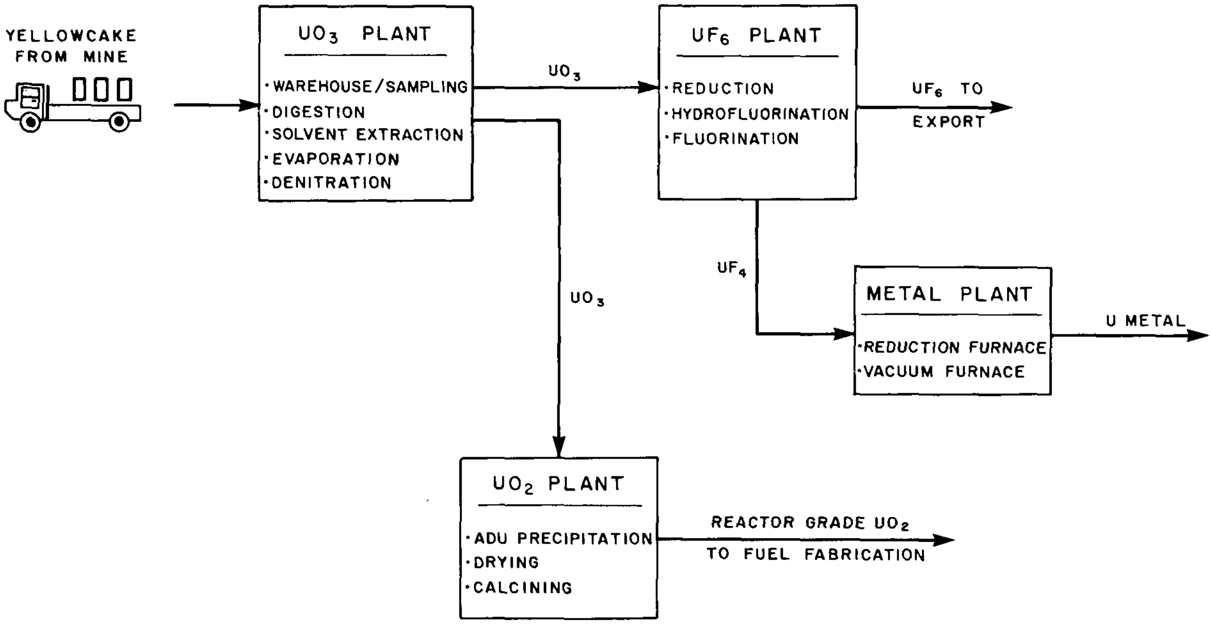

FIGURE 1 REFERENCE FACILITY SCHEMATIC FOR URANIUM REFINING AND CONVERSION

Releases to the air or water associated with the operation of plant utilities are not considered in this report. It should be noted that, with the possible exception of the incinerator, all process emissions are released through vents and stacks and are assumed to be entrained in the building wake.

2.2 Existing Facilities

The existing Eldorado Nuclear Limited (ENL) facility in Port Hope includes all of the circuits shown in Figure 1. Published data concerning emissions from these facilities are summarized below. These data are a mixture of engineering estimates and the results of source emission tests.

2.2.1 Releases from the UO_3 Plant. The existing UO_3 plant in Port Hope has a nominal production capacity of 5500 tonnes per year of uranium as UO_3.

2.2.1.1 Air emissions. The major process air emissions from the UO_3 plant are summarized in Table 1. Warehouse emissions are associated with the weighing, sampling and calcining of the incoming yellowcake before it enters the UO_3 circuit (ENL, 1980b). All dust emissions from the warehouse are reported to pass through bag filters followed by HEPA filters except for the yellowcake dryer exhaust (yellowcake preparation), which passes through a sintered metal filter.

TABLE 1 AVERAGE AIR EMISSION RATES FROM EXISTING PORT HOPE UO_3 FACILITY AND WAREHOUSE MATERIALS HANDLING

Type of Emission	Warehouse* (g/h)	UO_3 Plant* (g/h)
Uranium (U)	0.4**	11**
Ammonia (NH_3)	1 000	1 100
Nitrate (NO_3)	3	240
Oxides of Nitrogen (NO_x)	-	4 500

* Data from ENL (1980b).
** Data from ENL (1982a).

The major releases of uranium from the UO_3 plant include emissions from the ammonium diuranate (ADU) scrubber and from the UO_3 plant ventilation air exhaust.

In addition to the uranium emissions noted in Table 1, releases of thorium-232, thorium-230, radium-226 and radon-222 can be expected. Monitoring data for these species are not available; however, release rates can be estimated on the basis of the radionuclide composition of yellowcake reported by Eldorado Nuclear Limited (ENL, 1978a). The radionuclide compositions relative to uranium of the two major yellowcake feed materials are:

Radionuclide	Ammonium Diuranate (ADU)	Magnesium Diuranate (MDU)
Natural Uranium	1 g	1 g
Radium-226	5.18 Bq	0.518 Bq
Thorium-232	0.01 g	0.003 g
Thorium-230	407 Bq	12.21 Bq

The composition of yellowcake is variable and will be discussed later in this report. For the purposes of the present study, all uranium compounds released to the air are assumed to be in an insoluble form.

Radon-222 is released from the process point where radium-bearing materials are present in unsealed containers. The following assumptions were made for the present study: a) one equilibrium quantity of radon is released from the yellowcake feed during sampling; b) the feed is then stored for later processing when a second equilibrium quantity of radon is released. A reference facility processing 1000 tonnes of U_3O_8 per year will thus release radon at the following average rate:

Feed	Average Radon Release Rate
100% ADU	0.5 Bq/h
100% MDU	0.05 Bq/h

Radon will also be released from the yellowcake and circuit inventories. Both sources are highly dependent on the nature of the particular facility and have not been estimated for this study. Published estimates suggest that these sources could contribute about 20% of the overall radon release (ENL, 1980a).

Air emission rates vary even for normal operating conditions. As illustrated in Table 2, the release rates from some air emission sources deviate by more than an order of magnitude from the average value reported in Table 1.

TABLE 2 VARIATION IN AIR EMISSION RATES FOR SELECTED UO_2/UO_3 OPERATIONS

Source		Release Rate* (g/h)	
		Average	Maximum
Warehouse			
Dryer Exhaust (Variable)	NO_3	3	12
	NH_3	1 000	1 700
UO_2/UO_3 Plant			
ADU Scrubber (Variable)	U	7(7)**	34(39)**
	NO_3	20	100
	NH_3	1 000	3 600
ADU Dust Collector (Intermittent)	U	-	90

* Data from Appendix 3.1 of ENL (1980b).
** Data in brackets from ENL (1982a).

2.2.1.2 Water emissions. The UO_3 plant circuit entails extensive process water recycling to maximize uranium recovery and minimize chemical consumption. Process water release from the circuit is limited to that required to prevent continued build-up of impurities in the recycled waters.

The main sources of water emissions include the in-plant sump treatment system (which serves to segregate plant losses for recycle), the uranyl nitrate evaporate overheads, the nitric acid recovery concentrator overheads, and the process condensate transfer tank. These waste streams are directed to a neutralization sump where potassium hydroxide is added to raise the pH prior to release. At the Port Hope facility, the treated process wastewater is released to the once-through cooling water return.

Average hourly emission rates for the four chemical constituents monitored routinely by ENL on the cooling water discharge from the UO_3 plant in Port Hope are summarized in Table 3. The principal constituent, nitrate resulting from losses of nitric acid in the UO_3 process, has been found to be the least variable of the constituents monitored; the standard deviation of annual means for the past five years of operation equals approximately 25% of the combined mean. Uranium, the next most prevalent constituent, has been found to be more variable. The effluent monitoring data suggest that, under normal plant operating conditions, the uranium emission rate is less than 50% of the long-term mean value reported in Table 3. Trace amounts of ammonia and fluoride have also been found in the UO_3 plant cooling water return.

TABLE 3 AVERAGE WATER EMISSION RATES* FROM THE EXISTING PORT HOPE UO_3 FACILITY

Type of Emission	Mean Annual Emission Rate (g/h)**
Uranium (as U)	130 ± 130
Nitrate (as N)	2 600 + 620
Ammonia (as N)	30 ± 45
Fluoride (as F)	15 ± 10

* Based on Eldorado Nuclear Limited monitoring program data for the period 1977 through 1981 inclusive.

** Mean ± Std. Deviation.

Monitoring of radium-226 in the UO_3 plant cooling water discharge indicates consistently low levels, with the exception of an odd spillage in the plant which resulted in elevated radium levels. Available data do not permit the determination of an emission rate. No data were found on levels of other radionuclides.

2.2.2 Releases from the UF_6 Plant. The existing Port Hope UF_6 plant has a nominal conversion capacity of 5500 tonnes per annum of uranium as UF_6.

2.2.2.1 Air emissions. The average air emission rates for major contaminants from the existing UF_6 plant are summarized in Table 4. Uranium release rates are based on emission measurements (ENL, 1982a, 1982b). Consequently, an intermediate value of 20 g/h is assumed to be a reasonable estimate of the long-term uranium emission rate. Uranium compounds released from the UF_6 plant are assumed to be equally split between soluble (class W) and insoluble (class Y) compounds.

TABLE 4 AVERAGE AIR EMISSION RATES FROM EXISTING PORT HOPE UF_6 OPERATIONS

Type of Emission	Average Emission Rate (g/h)
Uranium (U)	28[a] (17)[b]
Fluoride (F)	200[c] (100)[d]
Nitrate (NO_3)	1.2[c]

[a] Data derived from ENL (1982a).
[b] Data from ENL (1982b).
[c] Data derived from ENL (1980a).
[d] ENL is upgrading the fluoride controls, which is expected to reduce the fluoride emission rate by about a factor of 2.

ENL is upgrading fluoride emission controls through improved collection and scrubbing at fluoride air release points. This is expected to reduce fluoride emissions by about a factor of 2. An intermediate fluoride release rate of about 150 g/h was assumed for this study.

As for the UO_3 plant, the air release rates for individual sources can vary, on an intermittent basis, by more than an order of magnitude from the long-term average shown in Table 4. This variability is illustrated by the air emission data shown in Table 5 for selected UF_6 plant operations.

The principal air pollution control devices used in the UF_6 facility are baghouses and KOH scrubbers.

2.2.2.2 **Water emissions.** The UF_6 plant features extensive process water recycling, with only a limited quantity of water being bled from the circuit to control build-up of impurities. Process wastewater sources from the UF_6 plant include the reduction reactor seal pots, scrubber solutions from plant gas effluent treatment and HF recovery systems, and the UF_6 uranium recovery system which is used to treat various process water streams for recovery of uranium. Process water from the seal pots is discharged directly to the cooling water return. Lime is added to the other process waters in the plant sump treatment system to precipitate fluoride prior to releasing excess water to the cooling water return.

Monitoring of the existing Port Hope UF_6 cooling water discharge has shown an increase in uranium and fluoride levels above the background levels in the plant water supply. Average emission rates for these contaminants, based on the most recent five years of monitoring data collected by ENL, are summarized in Table 6.

TABLE 5 VARIATION IN AIR EMISSION RATES FOR SELECTED UF$_6$ OPERATIONS

Source		Emission Rate* (g/h)	
		Average	Maximum
UO$_3$ Dust Collector 75-6-54 (Baghouse)	U	2.7(0.1)	4.3(1.4)
Hydrofluorination Reactor Offgas Scrubber 75-D-3	U	1.3(0.8)	3.7(7)
	F	2	7
UF$_4$ Dust Collector 80-6-33 (Baghouse and KOH Scrubber)	U	0.8(2.9)	8.7(2.1)
	F	49	330
UF$_6$ Tail Gas Scrubber 85-D-10 and 85-D-18 (2 Scrubbers in Series)	U	5.6(3.5)	81(50)
	F	1.9	42
Ventilation Stack (Building Ventilation)	U	49(3)	520(24)
	F	32	160
Blow Fan 85-6-113 (Lime Bed Scrubber)	U	0.3(0.05)	1.3(0.3)
	F	29	230
Dust Collection System 75-D-13 (KOH Scrubber)	U	1.4(0.74)	3.6(12)
	F	7	51
Super Stack	U	1.9(3.9)	14(38)
	F	76	680

* Data from Appendix 3.1 of ENL (1980b).
Data in brackets from ENL (1982a).

The uranium emission rate from the UF$_6$ plant seems quite low and is consistent (standard deviation is less than 30% of the five-year mean annual value). The slightly greater variability of the fluoride emission rate has been attributed to washoff water from the scrubbers located on the roof of the UF$_6$ plant reaching parts of the roof drainage system which are connected to the cooling water return. Once provisions are completed for housing the scrubbers, all scrubber water will be treated in the plant sump treatment system prior to recycle or wastage and the fluoride emission rate from the UF$_6$ plant is expected to be considerably reduced.

TABLE 6 AVERAGE WATER EMISSION RATES FROM THE EXISTING PORT HOPE UF_6 PLANT

Type of Emission	Mean Annual Emission Rate (g/h)[a]
Uranium[b]	6 ± 2
Fluoride[c]	40 ± 20

[a] Mean ± Std. Deviation.
[b] Data derived from ENL (1982b).
[c] Data derived from ENL monitoring program for 1977 to 1981.

2.2.3 Releases from the UO_2 Plant.

The existing UO_2 plant has a nominal production capacity of 2500 tonnes per annum of uranium as UO_2.

2.2.3.1 Air emissions. The average air emission rates for major contaminants from the existing UO_2 plant are shown in Table 7. Estimates of the uranium release rate (ENL, 1982a) are based on measurements made by ENL; an average rate of 3.8 g/h was assumed in this study. All uranium released to the air is assumed to be in an insoluble form (class Y). While no data on the variability of air releases are available, it is expected that normal process variations will result in a variable release rate.

TABLE 7 AVERAGE AIR EMISSION RATES FROM EXISTING UO_2 OPERATIONS

Type of Emission	Emission Rate* (g/h)
Uranium (U)	3.8**
Ammonia (NH_3)	8 700
Nitrate (NO_3)	140
Oxides of Nitrogen (NO_x)	260

* Data derived from ENL (1980b).
** Data from ENL (1982a).

During operation, the incinerator at Port Hope, which is adjacent to the UO_2 plant, emits about 1.4 g/h of uranium to the air (ENL, 1982a). Two-thirds of the incinerator emissions are assumed to be in soluble form (class W), with the remainder in insoluble form (class Y).

2.2.3.2 Water emissions. The existing UO_2 plant has been shown to be a very minor source of waterborne contaminants; only uranium is present at levels above background in the cooling water return (ENL, 1982b). Monitoring data on this plant indicate a uranium release rate of 0.8 g/h. The plant was not found to be a source of radium.

2.2.4 Releases from the Uranium Metal Plant

2.2.4.1 Air emissions. Uranium metal is produced intermittently at the Port Hope refinery. The daily average air emission rates of uranium (U) and fluoride (F) from the metals plant are 0.7 g/h (ENL, 1982a) and 3.8 g/h (ENL, 1980b), respectively. Emissions from the metal plant are intermittent and occur during the reaction cycle, during which time the release rates are substantially higher than the average value noted previously. Reported data indicate that uranium releases during the reaction cycle are nearly constant; fluoride releases may vary by a factor of 2 to 3.

Approximately 60% of the uranium compounds released from the metal plant are assumed to be soluble (class W), with the remainder in an insoluble form (class Y).

2.2.4.2 Water emissions. The existing metals plant has not been identified as a source of waterborne contaminants. This aspect is therefore not considered further in this report.

2.3 Facilities Under Construction

2.3.1 Releases from the Blind River Refinery. The new Blind River refinery will have the capacity to convert 18 000 tonnes per annum of uranium from yellowcake to UO_3 (U basis). The emission estimates reported below are based on engineering design criteria.

2.3.1.1 Air emissions. Air emissions from the new UO_3 refinery in Blind River will be discharged from three major process areas: the warehouse vent, the calciner flue vent, and the absorber stack. All streams potentially contaminated with uranium will pass through control devices prior to being discharged to the atmosphere.

Normal air emissions are summarized in Table 8. The efficiency of the control devices incorporated in the UO_3 plant design have been reported by Eldorado (ENL, 1980a).

2.3.1.2 Water emissions. The design of the new UO_3 plant provides for a number of internal recycle stages to minimize both freshwater requirements and chemical consumption. Process water bleed streams and process area sumpages will be collected and treated with sodium carbonate, potassium hydroxide and nitric acid in the plant sump

TABLE 8 ESTIMATED EMISSIONS TO THE ATMOSPHERE FOR THE NEW BLIND RIVER REFINERY

Type of Emission	Emission Rate (g/h) Plant Systems[a]	Incinerator[b]	Total
NH_3	19 000	-	19 000
NO_x	190	240	260
SO_2	10	1200	1 200
HNO_3	41	-	41
U	22	10	32
Radon-222[c]	9.99 GBq/h	-	9.99 GBq/h

[a] Adapted from ENL (1980a).

[b] For 520 h/annum (note: incinerator auxiliary fuel is No. 6 fuel oil).

[c] Estimated on basis that i) yellowcake is sampled upon receipt and then stored until processing, hence permitting radon ingrowth (thus, two equilibrium quantities of radon-222 are assumed to be released); and ii) the circuit inventory equals 5 days production during which period 50% of the radon produced will be released.

treatment system for chemical recovery. To prevent the build-up of impurities in the recycle streams, process water will be bled from three main areas: the UO_3 plant sump treatment system, denitrator evaporator overheads, and the nitric acid recovery concentrator overheads. These process waste streams (with an estimated flow of 24.4 m^3/h) will be directed through a two-stage nitrate wastewater neutralization system where sodium carbonate will be added for pH control (MacLaren, 1981). Intermittent flows resulting from washdown of the process condensate transfer tank and precipitation on the chemical storage tank area will also be treated in the nitrate wastewater neutralization system.

The treated process wastewater will be combined with utility wastewater streams in an effluent monitoring lagoon. If found to be of satisfactory quality, the lagoon contents will be pumped out daily through the outfall into the North Channel. Provision has also been made to treat the lagoon contents in a separate lagoon if necessary prior to release to the environment. In contrast to the Port Hope uranium refinery complex, the Blind River plant will incorporate a recycle cooling water system complete with cooling towers.

Chemical losses from the new UO_3 refinery are predicted to be considerably less than those reported for the Port Hope UO_3 refinery due to improvements incorporated into the plant design. A nitrate emission rate of 405 g/h as N has been reported (MacLaren, 1981). The uranium loss is predicted to be minimal.

2.3.2 Releases from the Expanded Port Hope UF_6 Facility.

2.3.2.1 Air emissions. Average air emission rates for major contaminants released from the new UF_6 plant are summarized in Table 9. The overall atmospheric emission control strategy and the proposed control devices for the new plant are described in ENL's site application (ENL, 1980b). Briefly, there are four emission points: the vent stack which handles most UF_6 plant air emissions; the cooling air exhaust vent which handles the cooling air exhaust from the reduction reactor cooling enclosures; the reduction reactor off-gas seal pot vent which handles the reduction reactor off-gas; and the H_2 seal pot vent which handles the hydrogen generated in the fluorine cells.

TABLE 9 ESTIMATED AIR EMISSION RATES FOR THE EXPANDED PORT HOPE UF_6 PLANT

Type of Emission	Average Continuous Release Rate (g/h)
Uranium (U)	19*
Hydrogen Fluoride (HF)	100**
Oxides of Nitrogen (NO_x)	2800**
Potassium Hydroxide (KOH)	3400**

* From ENL (1982b).
** Derived from ENL (1980b).

Hydrogen fluoride emissions have historically been a primary concern. In the new plant, air streams containing fluorides will be treated in the HF recovery system which consists of two venturi water scrubbers and two KOH scrubbers. Entrained HF in the hydrogen stream from the electrolytic cells is treated separately in a water scrubber/seal pot system. Similarly, exhaust from the UF_4/fluorination dust collection system is directed to a KOH scrubber prior to release.

The design for the UF_6 plant gas effluent treatment system incorporates three large potassium hydroxide scrubbers designed to handle continuous, intermittent and emergency flows. Continuous KOH scrubbing capacity is provided to handle vents and purges from the fluorine cell area. A second KOH scrubber is provided to handle fluorine cell maintenance ventilation air. A third KOH scrubber is provided to handle UF_6 safety process releases and to provide additional capacity in the event large ventilation air streams become contaminated with F_2 or HF.

2.3.2.2 Water emissions. As with the existing UF_6 plant, the new facility includes provisions for treatment of various process waters for uranium recovery and extensive water recycle to minimize chemical consumption. A process wastewater flow rate of 310 L/min has been predicted for the plant, comprising process water from the reduction reactor seal pots and effluent from the plant sump treatment system (ENL, 1980b). Various process water streams will be treated in the sump system for removal of fluorides and recovery of potassium hydroxide, including scrubber solutions from the plant gas effluent treatment system and the HF recovery system, filtrate from the uranium recovery system, and sumpage from F_2 cell maintenance. The seal pot and sump treatment system wastewaters will be discharged to the once-through cooling water return as currently practiced at Port Hope.

Uranium and fluoride emissions from the new UF_6 refinery have been estimated at 11.25 and 0.125 g/h, respectively (ENL, 1980b). These rates were established taking into consideration both operating experience with the existing UF_6 plant and equipment design efficiencies. The uranium emission rate for the new plant is consistent with actual operating experience. The fluoride emission rate is three orders of magnitude less than that experienced at the existing plant. The predicted emission rate was based on housing the scrubber system in the new plant, thus ensuring that all scrubber solution is collected for treatment. Experience at the existing plant has demonstrated that inadvertent losses of scrubber solution from the scrubbers mounted on the roof of the plant gain access to the roof drainage network, which is connected to the cooling water return outfall sewer.

2.4 Reference Facilities

2.4.1 Characteristics. For the purpose of this report, uranium refining operations are considered to include the following major process steps:

1) Uranium Trioxide (UO_3) Plant - In this plant, yellowcake from uranium mills is purified and converted to UO_3.

2) Uranium Hexafluoride (UF_6) Plant - Using UO_3 as feed, this plant converts uranium trioxide to UF_6, which is destined for export.

3) Uranium Dioxide (UO_2) Plant	-	Using an intermediate product from the UO_3 circuit as a feed material, this plant produces reactor-grade UO_2 destined for the fabrication of CANDU reactor fuel.
4) Uranium Metal Plant	-	This plant produces specialized castings of uranium metal using uranium tetrafluoride (UF_4) as the feed material on an as-required basis.

The following characteristics were assumed for the reference facility:

i) The reference facility handles only natural (or depleted) uranium feeds. The processing of enriched uranium and the use of advanced nuclear fuels were not considered.

ii) Since the final fate of radioactive solid wastes is unclear at this time, the recycle practices currently used by Eldorado Nuclear Limited were also assumed for the reference facility.

iii) Monitoring requirements for normal operating conditions, i.e., average rates of release to air and water, were the principal focus of this study. However, the effect of normal variations associated with any process operation, e.g., scheduled maintenance and plant upset conditions, were also considered. The monitoring requirements for potential accidental releases (e.g., storage tank rupture, etc.) were outside the scope of the study.

iv) The nominal capacities for the reference facilities were selected to be representative of both existing facilities and those under construction.

2.4.2 Releases. The major releases to air and water are associated with the operation of the UO_3, UO_2 and UF_6 plants. Average emission rates to the air and water for major contaminants from process sources are summarized in Table 10 for the reference facilities. The atmospheric emission rates were derived by averaging the unit release rates observed at existing facilities and those expected in the new facilities as reported in previous sections and prorating to the indicated nominal capacity.

The water emission rates for nitrate (UO_3 plant) and fluoride (UF_6 plant) were taken as those expected from new facilities and prorated to the reference facility capacity. The waterborne release rates for UO_2 and UF_6 plants were derived from experience at existing facilities and prorated on a plant capacity basis. Finally, the water

TABLE 10 AVERAGE AIR AND WATER EMISSION RATES FOR PROCESS RELEASES FROM REFERENCE FACILITIES

Reference Facility	Nominal Capacity (tonnes/a U)	Average Emission Rates (g/h) U	F	NH_3	NO_3	NO_x	Rn*
1) Air Emissions							
UO_3 Plant**	10 000	18	-	7 200	230	4 200	3.9
UO_2 Plant	2 500	4	-	8 700	140	260	-
UF_6 Plant	10 000	27	190	-	2	3 100	-
2) Water Emission							
UO_3 Plant**	10 000	12	-	-	225	-	-
UO_2 Plant	2 500	0.8	-	-	-	-	-
UF_6 Plant	10 000	12.5	0.14	-	-	-	-

* In Bq/h.

** Other radionuclides are assumed to be released in proportion to their presence in the yellowcake feed material.

emission rate for uranium from the UO_3 plant was taken to be present in direct proportion to the unit nitrate emission rates predicted for the new facility versus that experienced at the existing facility.

The metal plant has not been identified as a source of waterborne contaminants. The air emissions of both uranium and fluoride are also very small compared to air emissions of uranium and fluoride from the other reference facilities. Consequently, the metal plant is not specifically discussed in later sections of this report.

In the case of the UO_3 plant, radionuclides other than uranium are assumed to be present in releases to the air and water in proportion to their presence in yellowcake feed (assumed to be 30% ADU and 70% MDU). While radionuclides other than uranium are likely to be present in releases from other plants, available data do not justify incorporating these nuclides in the pathways analysis (see Section 3.4). Nonetheless, the proposed monitoring programs recognize that radionuclides other than uranium may be present in plant releases (see Chapter 4).

3 ENVIRONMENTAL ASSESSMENT

3.1 Introduction

Both radioactive and nonradioactive materials are released to the air and water from uranium refining operations as discussed in Chapter 2 and Appendix A. The assessment method for the environmental effects of these normal process releases is described in this section. The reader is cautioned against using the environmental analysis described in this report for purposes other than to provide the basis for developing recommendations for the design of an environmental monitoring program.

The potential radiation exposures associated with releases of radioactive materials are estimated through an environmental pathways analysis. The exposures predicted for a representative member of the critical group are compared to the public exposure limit. The relative effects of releases of nonradioactive contaminants are assessed by comparing the predicted air or water concentrations with respective air or water quality standards.

3.2 Characteristics of the Reference Site and Critical Receptor

The reference site is assumed to be in a rural setting on the shore of a large lake which provides an abundant supply of drinking water, and process and cooling water for the facility. The nearest permanent residence is assumed to be 500 m downwind from the plant.

Man may be exposed to radioactive materials released to the environment through various physical, chemical and biological processes. Such processes, which are site-specific and vary widely, include the movement and dispersion of contaminants released to the air or water, concentration or bioaccumulation processes, and the exposure conditions and habits of man.

Public exposure to radionuclides can occur through various environmental pathways. However, experience indicates that in many situations it is not necessary to evaluate all of the pathways, since the total dose for all pathways differs very little from that calculated by examining the most relevant radionuclides and their associated exposure pathways. Depending on site conditions and individual characteristics, the presence of a particular nuclide in a critical pathway will result in varying doses to different members of the public. For dose estimation purposes, it is usual to identify the critical groups (people who, on average, are likely to receive higher doses than other groups of the public); this requires consideration of plant releases, local environmental conditions and an individual's characteristics (e.g., living habits, eating habits, residence location, etc.).

In this report, the average member of the critical group is assumed to be an adult male who lives just outside the facility boundary in the direction of the prevailing wind. Fifty percent of his annual fruit and vegetable intake is assumed to be home-grown. All of his drinking water and 50% of his fish intake is assumed to be taken from the lake at the edge of the mixing zone. The major exposure pathways for this average individual from the critical group are illustrated in Figure 2. The methods and parameters used to calculate this individual's exposure are discussed later in this Chapter and in Appendices A, C and D.

External gamma radiation levels have been reported for locations adjacent to the yellowcake and the UF_6 cylinder storage area at ENL's existing Port Hope facility (ENL, 1980b). Average exposure rates adjacent to storage areas are reported to be in the order of 50-100 μR/h. The exposure rate at 500 m from the source has been estimated to be less than 10 μR/h. This rough calculation does not consider shielding, either man-made or natural.

While this aspect is not considered further in this chapter, the public can be exposed to direct radiation from on-site inventories of radioactive materials. The monitoring recommendations in Chapter 4 consider this source of exposure.

3.3 Air Quality

Air emissions from uranium refining operations are normally exhausted to the atmosphere through roof vents and short stacks located on building roofs. For the present study it has been assumed that all air emissions are entrained in the building wake. Consequently, all air emissions were modelled as area sources. The UO_3 and UO_2 plants were modelled as area sources 50 m on a side, with an effective release height of 10 m. The UF_6 plant was modelled as an area source 50 m on a side, with an effective release height of 20 m. The atmospheric emission rates used in model calculations are those presented in Chapter 2.

The Climatological Dispersion Model (CDM) used to estimate average annual concentrations of suspended particulate (U.S. EPA, 1973, 1977), calculates average long-term concentrations at a given receptor using a Gaussian plume model. The calculation incorporates a joint frequency of 6 stability classes, 16 wind directions, and 6 wind speed categories, for a total of 576 meteorological conditions. This wind stability array (STAR)

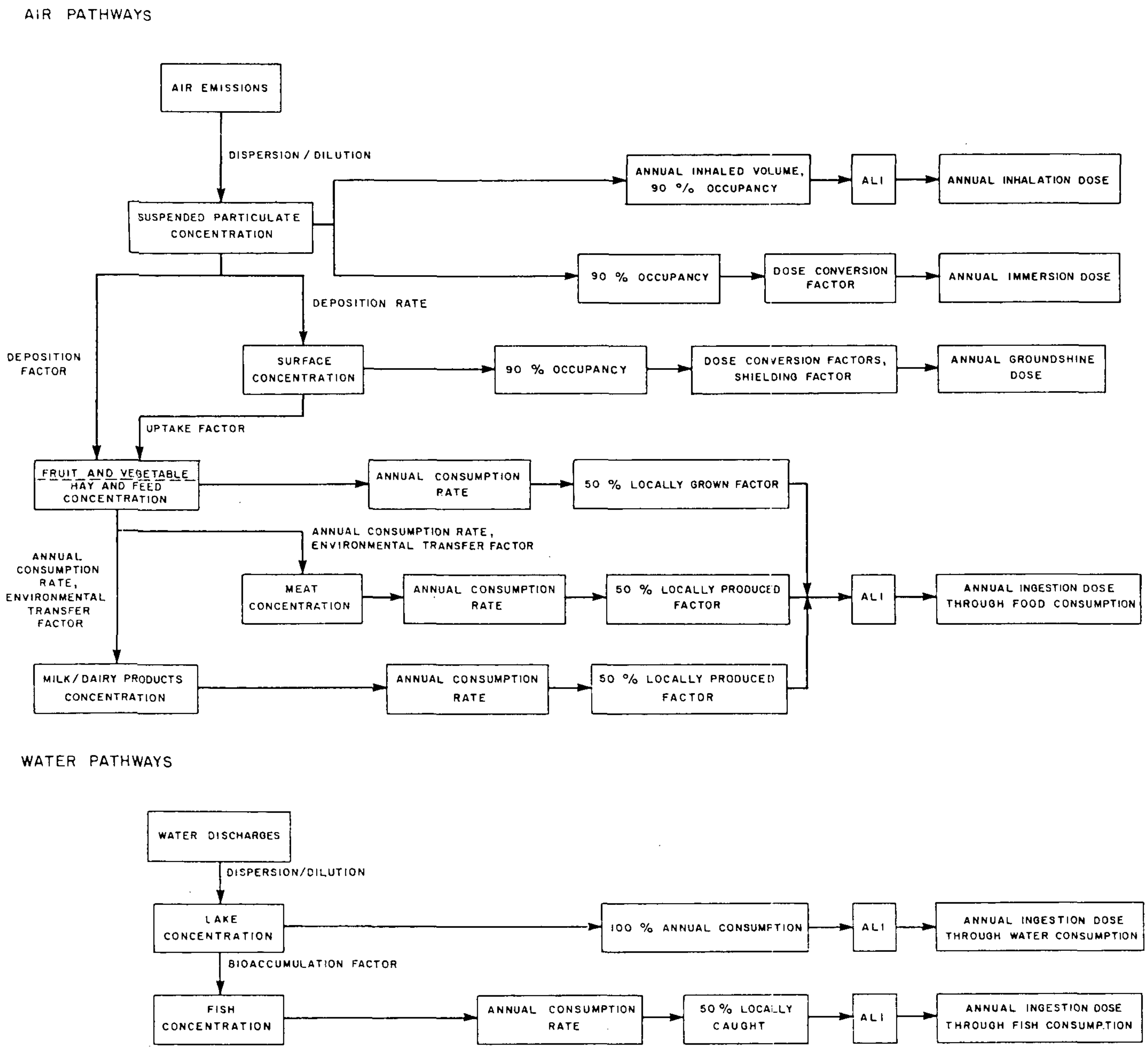

FIGURE 2 EXPOSURE PATHWAYS DIAGRAM FOR AN AVERAGE INDIVIDUAL IN THE CRITICAL GROUP

was derived from meteorological observations made at the Trenton, Ontario, airport from 1976 to 1980, and exhibits the following distribution of atmospheric stability:

Stability Class		Fraction of Year (%)
unstable	A	1
unstable	B	4
unstable	C	10
neutral	D	56
stable	E	11
stable	F	18

The CDM model also requires mixing height data. Mean nocturnal and afternoon mixing heights of 300 and 1300 m, respectively, taken from data published by the U.S. and Canadian weather services, were input to the model.

The rate at which particulate airborne material is deposited on the ground was estimated by multiplying the predicted air concentration by an effective settling velocity. The removal of particulate from the air is generally described in terms of dry deposition and washout (wet deposition). Literature values for dry deposition parameters vary widely; in the absence of site-specific data, a value of 10^{-2} m/s is often assumed (Sehmel, 1980). Literature values for wet deposition parameters also vary widely; McMahon and Denison (1979) suggest that local measurements should be utilized where available. In this study, a value of 2×10^{-2} m/s has been assumed for an overall deposition velocity which takes into account both dry and wet deposition processes.

Atmospheric emissions and the predicted air concentrations are summarized in Table 11 for each plant. The predictions represent estimates of the average annual contaminant air concentration at a receptor 500 m downwind from the source. The relative importance of uranium (and other particulate airborne radionuclides) and radon-222 are discussed in Section 3.5.

Canadian annual air quality objectives do not exist for the nonradioactive species listed in Table 11. However, for the present purposes, the maximum predicted NO_x level of 8.1 $\mu g/m^3$ can be compared to the annual federal criterion of 100 $\mu g/m^3$ for NO_2. The predicted HF level of 0.29 $\mu g/m^3$ falls below the Ontario growing season criterion of 0.34 $\mu g/m^3$ (30 days). Although no long-term criteria exist for ammonia,

TABLE 11 ESTIMATED ANNUAL AVERAGE AIR CONCENTRATIONS FOR MAJOR PROCESS AIR EMISSIONS FROM REFERENCE FACILITIES

	Estimated Annual Average Air Concentrations					
Reference Facility	U (μg/m^3)	HF (μg/m^3)	NH_3 (μg/m^3)	NO_3 (μg/m^3)	NO_x (μg/m^3)	R_{n3} (Bq/m^3)
UO_3 Plant	0.035*	NA	14	0.45	8.1	0.008
UO_2 Plant	0.008	NA	17	0.27	0.5	NA
UF_6 Plant	0.042	0.29	NA	0.0031	4.8	NA
U Metal Plant	0.0014	NA	NA	NA	NA	NA

* Radionuclides other than uranium are assumed to be present in proportion to their presence in yellowcake feed (assumed to be 30% ADU and 70% MDU). See Sections 2.2.1 and 2.4.

Ontario's half-hour point of impingement criterion for ammonia is 3600 μg/m^3, well above predicted levels. Thus, on a comparative basis, HF releases have the greatest potential to affect air quality.

The predicted radon concentration of 0.008 Bq/m^3 in air is within the natural range of variation in radon levels.

3.4 Water Quality

For the reference facilities, it was assumed that treated process wastewater would be combined with once-through cooling water and released through a submerged outfall to the nearshore waters of a large lake. Incremental environmental concentrations of waterborne contaminants from the reference facilities were evaluated by taking into consideration process wastewater dilution in the cooling water return, and dilution and dispersion of the combined effluent in the nearshore waters.

Cooling water requirements for the individual plants were derived from the usage at the existing ENL refinery in Port Hope and design cooling water requirements for new facilities and prorated for the reference facility capacity (ENL, 1980b, 1982b). Cooling water requirements and estimated contaminant concentrations in the plant effluents are summarized in Table 12. The contaminant emission rates presented previously in Table 10 were used in calculating the concentration levels in the water discharges.

TABLE 12 ESTIMATED ANNUAL AVERAGE WATER CONCENTRATIONS DUE TO DISCHARGES FROM REFERENCE FACILITIES

Reference Plant	Average Cooling Water Requirement (m^3/min)	Reference Facility Cooling Water Discharge Contaminant Concentrations U (µg/L)	F (µg/L)	NO_3 as N (µg/L)	Reference Town Water Supply Intake Incremental Contaminant Levels U (µg/L)	F (µg/L)	NO_3 as N (µg/L)
UO_3 Plant	9.0	22*	NA	420	0.22*	NA	4.2
UO_2 Plant	0.5	27	NA	NA	0.27	NA	NA
UF_6 Plant	10.0	21	0.2	NA	0.21	0.002	NA

* Radionuclides other than uranium are assumed to be present in proportion to their presence in yellowcake feed (assumed to be 30% ADU and 70% MDU). See Sections 2.2.1 and 2.4.

Dilution of heated effluents in a lake occurs through initial dilution and additional dilution. Initial dilution accounts for the velocity component of the discharge and the buoyancy effect of the heated water. Additional dilution takes into consideration dispersion in lake currents, reversals, upwellings and downwellings. For a submerged outfall, initial dilution is measured at the surface near the outfall, while additional dilution is estimated at some distant point of interest (e.g., a water supply intake).

Respecting the reference facilities, it was assumed that the water supply for the reference population is drawn from the lake nearshore waters. The water supply intake was taken to be located at a distance of 1 km from the plant outfall.

Evaluation of effluent dilution was based on the results of an environmental impact assessment undertaken for a similar-sized refinery with a once-through cooling water discharge of 24.7 m^3/h to the nearshore waters of Lake Ontario (ENL, 1977). For an outfall located approximately 1 km offshore, at a depth of approximately 9 m and equipped with a multiport diffuser, initial dilution ratios for critical isothermal conditions and average normal conditions of 33:1 and 40:1 were estimated. The additional dilution expected at a distance of 1 km from the outfall was predicted to vary from about 1:1-5:1 under conditions of prolonged longshore currents, to approximately 25:1-40:1 under semi-stagnant conditions. Large-scale shifts in current direction occurred frequently. Over the long term, the additional dilution realized within 1 km of the outfall was conservatively assumed to vary from 5:1 to 10:1. Based on the ratios given above for both initial dilution and additional dilution, the total available dilution would vary from 165:1 to 400:1.

Predictions of the incremental levels of uranium, fluoride and nitrate in the reference water supply were made using a conservative total dilution ratio of 100:1 and are reported in Table 12. All predicted levels are very low. The maximum uranium level due to an individual plant discharge is approximately 100 times less than the federal drinking water criterion of 20 µg/L (Health and Welfare Canada, 1978). The fluoride level attributable to the UF_6 plant is several orders of magnitude below the federal drinking water objective of 1.0 mg/L (Health and Welfare Canada, 1978). The nitrate level due to the UO_3 plant is also several orders of magnitude less than the maximum acceptable drinking water concentration of 10 mg/L (Health and Welfare Canada, 1978). Specific water quality criteria for the protection of aquatic life have not been established for these contaminants.

3.5 Radiological Assessment

Figure 2 summarizes the potential exposure pathways and assumptions used to assess the radiological impact of each of the reference facilities. The selection of the critical group and the air and water quality modelling were described in Sections 3.2, 3.3 and 3.4. The models used to predict radionuclide concentrations in other environmental media are described in Appendix C. The methods used for dose estimation are given in Appendix D.

The estimated annual dose (effective committed dose equivalent) for each facility is summarized in Table 13, which suggests that the most significant exposure pathway is likely to be the inhalation of airborne uranium for all of the plants. For the UO_3 plant, the uptake of thorium by ingestion of foodstuffs contaminated by airborne releases contributes the second largest dose.

A number of factors could change the relative importance of a radionuclide and/or exposure pathway. Table 13 is only appropriate within the context of the generic situation described in this report. Included in these factors are the following:

i) Emission Rates: these are facility dependent, and are affected by feed material, plant size, emission controls, process variations and other factors.

ii) Air and Water Dispersion Characteristics: these may be affected by the plant design (stack height, exit velocity, etc.) and site characteristics (meteorology, terrain, lake or river site, climate and other factors).

iii) Environmental Characteristics: such as local biota, environmental transfer factors, bioaccumulation factors, and other aspects vary from one situation to another.

TABLE 13 ESTIMATED ANNUAL DOSE BY EXPOSURE PATHWAY

		Air (mSv/a)			Water (mSv/a)
			Internal		Internal
Plant	Radionuclide	External	Inhalation	Ingestion	Ingestion
UO_3	U-nat	9.7×10^{-4}	2.5×10^{-1}	9.5×10^{-4}	2.5×10^{-4}
	Th-230	1.2×10^{-6}	2.4×10^{-3}	1.2×10^{-2}	3.6×10^{-4}
	Ra-226	1.4×10^{-7}	1.2×10^{-6}	3.8×10^{-6}	9.2×10^{-8}
	Rn-222	4.2×10^{-9}	5.6×10^{-4}	--	--
	Pb-210	2.3×10^{-8}	--	7.0×10^{-7}	--
	Th-nat*	7.4×10^{-7}	2.5×10^{-3}	1.3×10^{-2}	3.8×10^{-4}
UO_2	U-nat	2.2×10^{-4}	5.6×10^{-2}	2.2×10^{-4}	3.2×10^{-4}
UF_6	U-nat	1.2×10^{-3}	1.3×10^{-1}	2.7×10^{-3}	2.4×10^{-4}
U Metal	U-nat	3.9×10^{-5}	4.4×10^{-3}	8.8×10^{-5}	--

* For the purpose of dose estimates, Th-232 was assumed to be in equilibrium with Th-228. See Appendix D for further details.

iv) Demography: the location of residents, their occupations, habits and housing, the amount and type of food they eat, the local production of food, the source of the drinking water supply, and other factors affect the exposures predicted through pathways analysis.

3.6 Monitoring Priorities

The foregoing analysis suggests that environmental effects are likely to be dominated by airborne releases for both radioactive and nonradioactive constituents. Uranium is the most important radioactive species released to the air and can serve as an overall indicator of radiological impacts for any of the plants considered. The most important nonradioactive air emission is fluoride (as HF) for the UF_6 plant and NO_x for the UO_3 and UO_2 plants.

4 ENVIRONMENTAL MONITORING

4.1 General

Objectives considered in the design and operation of an environmental monitoring program would normally include:

i) identification of trends in contaminant levels (radioactive and nonradioactive) and environmental radiation dose rates;

ii) collection of data for estimation of potential dose to man;

iii) reassurance of the general public and regulatory agencies with regard to compliance with environmental and public health criteria;

iv) scientific investigation (typically related to movement and accumulation of contaminants in the air, water or biosphere).

Ideally, the monitoring program would be designed to accomplish several objectives simultaneously. Normally, environmental monitoring programs associated with scientific research would be government-sponsored activities; compliance monitoring is company-oriented.

Data collected through different programs may not be readily comparable. For example, as noted in Appendix B, the uranium water quality data collected by the Ontario Ministry of the Environment (MOE) and those collected by the Radiation Protection Bureau (RPB) are not comparable. Either data set provides a suitable measure of compliance with the drinking water criteria of 20 µg/L; however, all of the RPB data are below the lower limit of detection of 10 µg/L reported by the MOE. The potential bias associated with the incautious use of such water quality data should be recognized. Other considerations related to the use and interpretation of monitoring data are discussed in later sections.

This chapter discussed various factors related to the design (and operation) of environmental programs for operating unranium refining facilities, focusing principally on the monitoring of air and water quality. The selection of biological monitoring media is highly site-specific and requires detailed knowledge of a specific site (and facility).

4.2 Preoperational Studies

The preoperational monitoring program is similar in many respects to the monitoring that will be carried out during the operational period of the facility, taking into account the same objectives and endpoint uses of the data. Data obtained from preoperational studies are used to determine the preoperational radiation dose rates and levels of radioactive and nonradioactive contaminants in the environment, thus providing the basis for assessing any incremental effect of the facility. Preoperational monitoring should be initiated well in advance, typically one or more years before the facility goes into operation.

The preoperational survey provides an excellent opportunity to evaluate the following factors: sample availability, sample types, sampling locations, sampling procedures, equipment, personnel requirements (including any necessity for training), analytical techniques and laboratory capabilities, documentation procedures, data interpretation, reporting formats and procedures, quality control and assurance, and costs. This allows time to identify and correct potential problems and may suggest modifications to the proposed operational monitoring program.

4.3 Design Considerations for Operational Monitoring Programs

4.3.1 Selection of "Critical" Contaminants and Exposure Pathways. Experience has shown that certain contaminants and pathways of radiation exposure to man are often much more significant than other pathways.

Estimates of the dose to members of the public arising from releases from each of the reference facilities are summarized in Table 14. Estimates of direct radiation from stored radioactive materials are not included.

The major source of exposure is seen to be related to emission of uranium to the air; inhalation accounts for most of the predicted exposure. Overall, the next most significant exposure pathway is the ingestion of radionuclides deposited from the air on various foodstuffs. (Although the dose from water pathways is relatively very small, this aspect would require further consideration for a once-through cooling option on a river site.) Uranium is the major radioactive contaminant released to the air from all of the reference facilities.

For the reference UO_3 and UO_2 plants, the major nonradioactive contaminants released to the air are oxides of nitrogen and ammonia, respectively; however, the predicted environmental levels are very low. For the reference UF_6 plant, the major air emissions are fluorides and oxides of nitrogen. While the mass emission rate of fluoride is lower than that of NO_x, the levels of fluoride in ambient air were predicted to be substantially more significant than the NO_x levels.

TABLE 14 ESTIMATED ANNUAL EFFECTIVE COMMITTED DOSE EQUIVALENT BY EXPOSURE PATHWAY (expressed as a percentage of the maximum permissible dose to a member of the public)*

		Air (mSv/a)			Water (mSv/a)
			Internal		Internal
Plant	Radionuclide	External	Inhalation	Ingestion	Ingestion
UO_3	U-nat	0.02	5	0.02	0.005
	Th-230	0.00002	0.05	0.2	0.007
	Ra-226	0.000003	0.00002	0.00008	0.000002
	Rn-222	0.00000008	0.01	-	-
	Pb-210	0.0000005	-	0.00001	-
	Th-nat	0.00001	0.05	0.3	0.008
UO_2	U-nat	0.004	1	0.004	0.006
UF_6	U-nat	0.02	2.6	0.05	0.005
U Metal	U-nat	0.0008	0.09	0.002	-

* Numbers emphasize the relative significance of the exposure pathways.

Uranium and nitrate discharges to wastewater streams from the reference UO_3 facility are of prime significance; radium-226 releases are relatively less important. Uranium is the only contaminant of interest discharged from UO_2 operations. Both uranium and fluorides are present in wastewater streams discharged from the reference UF_6 facility.

The relative significance of the various radionuclides and potential exposure pathways and predicted levels of nonradioactive contaminants were considered in developing the monitoring design recommendations discussed in Section 4.4.

4.3.2 **Monitoring Locations.** The number and location of monitoring stations for each environmental medium depend on many site-specific variables.

4.3.2.1 **Air quality monitoring.** The key variables influencing the siting of air quality monitoring stations are local meteorological conditions, population distribution and local land use (e.g., agricultural activities) and topography. Monitoring locations would logically include the point(s) of estimated maximum annual average ground level concentration. This station(s) would usually be supplemented with monitoring upwind of the plant to provide information on background levels; stations at downwind locations would provide information on the rate at which concentrations decrease with distance.

Factors such as proximity to population centres and agricultural activities need to be considered with regard to the location of the upwind and downwind sites. The siting of monitoring stations will be influenced by other factors such as topography, accessibility, types of suspended particulates, the location of a suitable power supply, etc. Stations monitoring suspended particulates, dustfall, and ambient radon levels would often be located in close proximity, thereby increasing operating efficiency and also assisting in data interpretation.

4.3.2.2 **Water quality monitoring.** The following key variables influence the siting of water quality monitoring stations: the physical characteristics of the receiving water body, the location(s) of other water users, drainage characteristics of the site and, in some cases, the habitat, migration pattern and spawning behaviour of fish.

Monitoring should be done both at the edge of the mixing zone and further away from the plant discharge. The location of this second statioin would be determined largely by site-specific factors. Monitoring of background water quality should also be considered.

4.3.2.3 **Biological pathways.** Sampling of vegetation susceptible to fluoride damage would be a logical adjunct to air quality monitoring near UF_6 operations.

In order to determine the dose to man, the selected biological media should include those portions of an organism which form man's diet. Edible portions of produce should be measured in both washed and unwashed states (following preparation in the same manner in which it would be used by the local population). Composite samples of locally grown produce are preferred to individual grab samples. The location of biological media is site-specific and should take into account the characteristics of the critical group(s).

The design of such a biological monitoring program is largely dependent on site characteristics and the species selected. Estimation of doses to lower biota is outside the scope of this study. For further discussion of this topic the reader is referred to the literture (e.g. LeClare et al., 1975; Ophel, 1979; Blaylock and Trabalka, 1978).

4.3.3 **Monitoring Frequency.** Once the environmental pathways and sampling locations have been established, the monitoring frequency must be determined. The selection of the most appropriate frequency depends on many factors including:

i) objective(s) of the monitoring program;
ii) characteristics of releases from the plant;
iii) characteristics of a particular contaminant or exposure pathway;
iv) detection limits;
v) type and characteristics of available monitoring equipment and procedures;
vi) location of the monitoring sites;
vii) sample analysis requirements;
viii) seasonal variations of climate;
ix) budgetary constraints;
x) experience (Environmental monitoring should be more frequent on plant start-up or following major modifications to the plant process. Trend analysis may indicate that it would be desirable to change the type and number of samples collected and analyzed, or perhaps the location of sample collection as well);
xi) reporting requirements, regulatory agencies and the public involvement; and
xii) degree of variability in background levels, both from natural sources and as a result of man's activity in the vicinity of the plant.

Statistical analysis of the variability of background levels obtained through preoperational monitoring can indicate the number of stations and sampling frequency required to detect long-term trends during plant operations. Factors such as the spatial and temporal variability in the background, the trend size in background mean concentrations (perhaps selected as some fraction of the concentration required to produce maximum permissible dose to the public), and the required confidence level (for example, 90% probability of detecting trend size in the mean background level given a distribution around the mean) all affect this type of analysis.

4.4 Design Recommendations for Model Monitoring Programs

The environmental monitoring program design considerations discussed below are oriented towards evaluating those factors most likely to affect local air and water quality and human radiation exposure. The model monitoring programs were developed for the reference site located on the edge of a large lake. Comments concerning how such a program might be modified for other locations are also noted where appropriate.

Table 15 lists the various types of emissions from uranium processing operations and identifies the environmental media to be monitored. The basic components of environmental monitoring programs for the reference UO_3, UO_2 and UF_6 plants are

TABLE 15 ENVIRONMENTAL MEDIA FOR RADIOLOGICAL AND NONRADIOLOGICAL MONITORING

Emission Type	Exposure Pathway	Media Monitored
Radionuclides emitted to air	inhalation	suspended particulate and ambient radon
	ingestion	deposition from air (dustfall) on foodstuffs and on surface soil
	external	suspended particulate
Radionuclides emitted to water	ingestion	water quality and fish
Direct radiation	external	thermoluminescence dosimeter
Fluorides released to air	N/A	ambient air levels, lime candles, and vegetation
NO_x/NH_3 released to air	N/A	ambient air levels
Fluoride/NO_3 released to water	N/A	water quality

outlined in Tables 16, 17 and 18, respectively. The types of environmental samples and monitoring priorities for both radiological and nonradiological monitoring components are based on the analysis presented earlier in this report. The species and release pathways for routine plant upset conditions would be the same as those during normal operations. The monitoring frequency might have to be adjusted depending on release history. Water quality monitoring at a site well out of the influence of the plant is also desirable to identify regional trends not associated with facility operation.

Site-specific considerations, regulatory requirements and other factors all need to be considered in the design of a monitoring program and in the selection of monitoring locations, frequency, sampling methods, detection limits, reporting requirements (including statistical treatment of data) and other factors. The program design should allow for modifications as experience from ongoing programs indicate a need.

A few general comments are provided below to assist the reader in interpreting the programs set out in Tables 16 to 18.

TABLE 16 MODEL OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM FOR THE REFERENCE UO_3 PLANT

Sample Type	Station Location	Sample Frequency	Analysis Required	Comments
RADIOLOGICAL				
Suspended Particulate	3 stations	1 per 6 days for high volume; continuous for low volume	Total dust, natural uranium	Periodic analysis of particle size, and composite samples for Th-230, Th-232, Ra-226
Dustfall	Located at suspended particulate stations	Monthly	Total dust, natural uranium	Periodic analysis of composite for Th-230, Th-232, Ra-226
Direct radiation	Facility perimeter and suspended particulate stations	Quarterly	Yes	TLD*
Radon-222	Suspended particulate stations	Bi-monthly	Yes	Passive
Surface water	Area of discharge	Monthly grab	Natural uranium, radium-226	Periodic analysis for Th-230, Th-232, Pb-210
	Town water supply	Daily sample, monthly composite for analysis	Natural uranium, radium-226	Periodic analysis for Th-230, Th-232, Pb-210
Foodstuffs	As appropriate	Annual	Uranium	-
Soil	In areas where vegetation is collected	Annual	Uranium	-
NONRADIOLOGICAL				
NH_3/NO_x in air	Several locations	Periodic survey	Yes	-
NO_3 in water	Area of discharge/ town water supply	Monthly grab	NO_3 as N	-

* Thermoluminescence dosimeter

TABLE 17 MODEL OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM FOR THE REFERENCE UO_2 PLANT

Sample Type	Station Location	Sample Frequency	Analysis Required	Comments
RADIOLOGICAL				
Suspended particulate	3 stations	1 per 6 days for high volume; continuous for low volume	Total dust, natural uranium	Periodic analysis of particle size and composite samples for Th-230, Th-232
Dustfall	Located at suspended particulate stations	Monthly	Total dust, natural uranium	Periodic analysis of composite for Th-230, Th232
Direct radiation	Facility perimeter and suspended particulate stations	Quarterly	Yes	TLD*
Surface water	Area of discharge	Monthly grab	Natural uranium	-
	Town water supply	Daily sample, monthly composite for analysis	Natural uranium	-
Foodstuffs	As appropriate	Annual	Uranium	-
Soil	In areas where vegetation is collected	Annual	Uranium	-
NONRADIOLOGICAL				
NH_3/NO_x in air	Several locations	Periodic survey	Yes	-

* Thermoluminescence dosimeter

TABLE 18 MODEL OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM FOR THE REFERENCE UF_6 PLANT

Sample Type	Station Location	Sample Frequency	Analysis Required	Comments
RADIOLOGICAL				
Suspended particulate	3 stations	1 per 6 days for high volume; continuous for low volume	Total dust, natural uranium	Periodic analysis of particle size and composite samples for Th-230, Th-232
Dustfall	Located at suspended particulate stations	Monthly	Total dust, natural uranium	Periodic analysis of composite for Th-230, Th232
Direct radiation	Facility perimeter and suspended particulate stations	Quarterly	Yes	TLD*
Surface water	Area of discharge	Monthly grab	Natural uranium	-
	Town water supply	Daily sample, monthly composite for analysis	Natural uranium	
Foodstuffs	As appropriate	Annual	Uranium	-
Soil	In areas where vegetation is collected	Annual	Uranium	-
NONRADIOLOGICAL				
Fluoride in air (HF)	Suspended particulate stations	Monthly fluoridation rate	Yes	Periodic ambient fluoride surveys
NOx in air	Several locations	Periodic survey	Yes	-
Fluoride in water	Area of discharge/ town water supply	Monthly grab	As F	-
Vegetation	Near fluoridation stations plus other locations as appropriate	End of growing season	Fluoride content	Phytotoxic effects

* Thermoluminescence dosimeter

4.4.1 Ambient Air Sampling. Source geometry, wind characteristics, changes to airflow caused by abrupt changes in terrain, height above ground for the sampler, and atmospheric stability will affect values recorded at any given time. Practical considerations such as availability, cost, and accessibility of the site, together with the cost of providing electrical power, must also be considered.

Suspended particulate matter is usually monitored by high-volume air samplers. Particle size analysis of suspended dust is also possible using various types of modified high-volume samplers if size analysis is required for assessing inhalation dose. High-volume samplers normally operate on a 24-hour period but can be operated for longer periods if required. Low-volume air samplers can also be used to collect suspended particulate matter samples over extended time periods, such as a month.

Dustfall is usually determined by the use of dustfall jars. The standard sampling duration is one month; however, dustfall jars can be left in the field for longer periods if required. Both suspended dust and dustfall would be analyzed for total weight of collected material and appropriate chemical/radiological parameters.

Ambient radon levels are best monitored in environmental situations using passive devices. Experience suggests that environmental levels are normally so low that long exposure periods (e.g., two months) are required to provide a satisfactory low detection level.

An indication of the ambient fluoride levels can be obtained by measuring fluoridation rates using limed filter paper. These measurements should be supplemented by periodic determinations of ambient fluoride levels in order to provide a basis for correlation with plant releases.

The prediction of air quality at various locations requires wind direction and speed statistics, information on atmospheric stability, and other parameters such as precipitation during the observation periods, to establish source-receptor relationships. If suitable data are not available from nearby weather stations, consideration should be given to an on-site meteorological station.

4.4.2 Surface Waters. Grab samples are taken at designated sites using standard sampling techniques, preferably on a monthly, but at least on a quarterly (seasonal), basis.

In the absence of on-site waste storage, there is no requirement for routine monitoring of groundwater contaminant levels.

4.4.3 Terrestrial Biota/Produce/Crops. To estimate the radiological impact, terrestrial biota and food are sampled on the basis of their significance in the local diet. In general, samples should be selected on the basis of local conditions such as meteorology, prevalence of various local food crops, and local eating habits.

Produce samples should be collected at harvest time in order to accurately assess the maximum levels to radiological components. Samples should be analyzed both unwashed and washed (e.g., prepared in the same manner the local population would prepare its food).

Radionuclides deposited on soil may be taken up by food crops. Soil samples should therefore be collected from locations adjacent to sampled food crops, preferably at the location of the highest estimated annual deposition.

Vegetation surveys should be carried out (annually) in the vicinity of UF_6 operations. These may include both visual surveys and sample collection for subsequent fluoride assay.

4.4.4 Sample Variability. Long-term average levels may differ from short-term (e.g., hourly) values by more than a factor of 10, whether as a consequence of a short-term dispersion condition or of a plant upset. Short-term variations in environmental radionuclide levels associated with normal operating conditions would not likely have a significant effect on the annual dose to a member of the critical group. However, very high levels of chemical constituents could have a significant effect even for short exposure periods.

4.4.5 Effluent Monitoring. Effluent monitoring, although not part of the environmental monitoring program, provides the data necessary to characterize the releases from the facilities. It can also be used as a basis for the prediction of contaminant levels at environmental receptors. Monitoring points are selected such that the results are representative of actual discharges (normally downstream of effluent treatment systems). The effluent data are an essential component of any environmental analysis in that they provide confirmation of the type and quantity of radionuclides released from the facility.

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APPENDIX A

PROCESS DESCRIPTIONS

Introduction

Eldorado Nuclear Limited (ENL), which operates the only existing uranium refinery in Canada, is the only known proponent of new refining capacity. Once ENL's expansion plans are complete, Canadian refining operations will consist of the following major operations:

i) UO_3 - 18 000 tonnes per year of uranium (new facility at Blind River, Ontario, expected completion 1983);
ii) UF_6 - 5 500 tonnes per year of uranium (existing facility at Port Hope);
iii) UF_6 - 9 000 tonnes per year of uranium (new facility at Port Hope, expected completion 1983);
iv) UO_2 - 2 500 tonnes per year of uranium (existing facility at Port Hope).

The following general process descriptions are derived largely from published data on ENL refining processes (ENL 1978a, b, 1980a,b; MacLaren 1978). Where data are available, the currently used or proposed technology for controlling releases to the air or to the water is also indicated.

The UO_3 Process

Process Steps. A simplified schematic of the process proposed for ENL's Blind River Ontario refinery (ENL, 1980a) is shown in Figure 3 and includes the process steps listed below.

Warehousing and sampling. Uranium concentrate from uranium mills (yellowcake) is received at the refinery in 45 gallon (205 L) steel drums; it is weighed, sampled and analyzed for uranium and impurity content. A typical analysis of yellowcake is shown in Table 19. The principal feed to ENL's existing refinery is ammonium diuranate (ADU). An increasing proportion of future feed materials is anticipated to be in the form of magnesium diuranate. This is due to environmental concerns with the nitrification of receiving waters at uranium mill sites where ammonium diuranate is the end product. After sampling, the yellowcake is stored until sent to nitric acid digestion.

Feed transfer points and hoppers in the yellowcake sampling area have baghouse dust control. Feed preparation dusts are controlled by a series of sintered metal filters. Recovered yellowcake is returned to digestion.

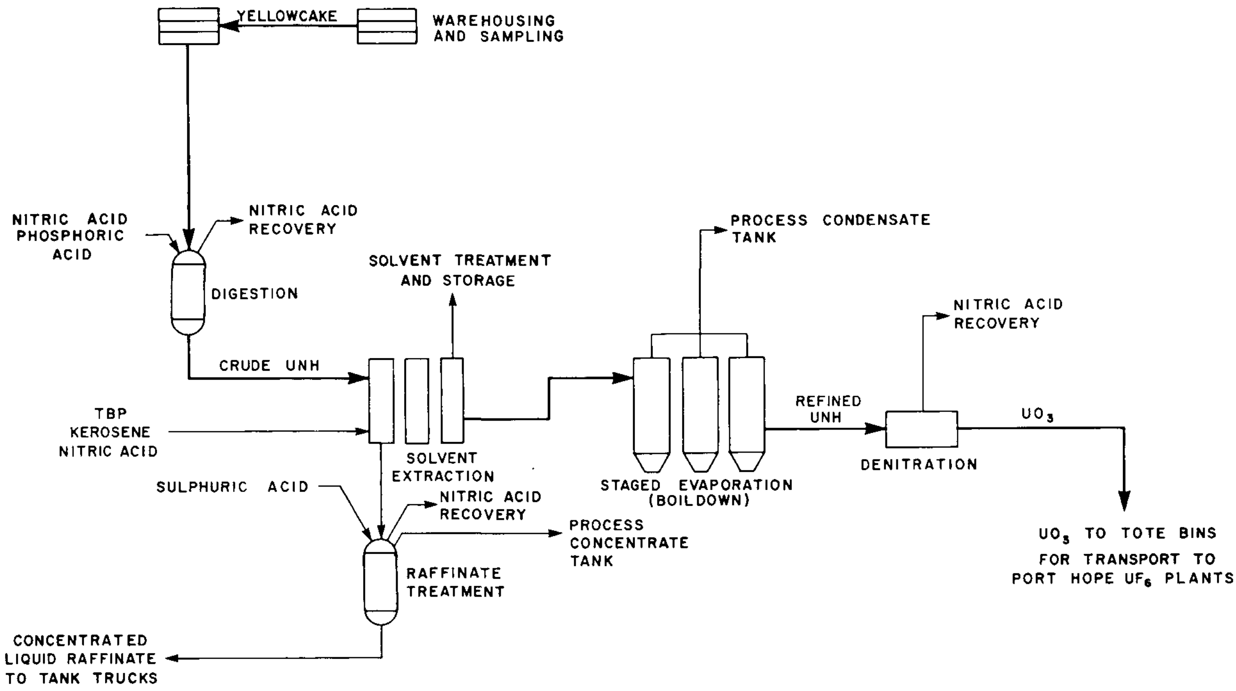

FIGURE 3 UO_3 PROCESS SCHEMATIC

Digestion. Yellowcake is treated with nitric acid in a staged digestion process to produce a crude uranyl nitrate. Phosphoric acid is also added to complex the impurities. The aqueous solution of crude uranyl nitrate then proceeds to solvent extraction.

Off-gases from digestion pass through a venturi scrubber. Scrubber liquors are recycled to the digestion vessels. Off-gas is sent to nitric acid recovery followed by a catalytic convertor. Sumpage from the digestion area and a bleed stream from the digestor flume scrubber are directed to the UO_3 plant sump treatment system for recycling.

Solvent extraction. The actual purification of the yellowcake feed is carried out by a solvent extraction process. The uranyl nitrate solution and associated impurities are contacted with the solvent (tributyl phosphate (TBP) in a kerosene equivalent) in a countercurrent flow system. Uranium transfers to the organic phase, leaving the majority of the yellowcake impurities in the aqueous phase. This aqueous waste stream is called

TABLE 19 TYPICAL YELLOWCAKE COMPOSITION[a]

PARAMETER	Wt % of Yellowcake[b] ADU[c]	MDU[d]
Natural uranium (U)	70	70
Water (H_2O)	5	--
Sulphate (SO_4)	4	0.4
Ammonium (NH_4)	1.8	--
Nitrate (NO_3)	0.9	--
Magnesium (Mg)	--	1.4
Calcium (Ca)	0.3	1.4
Aluminum (Al)	0.02	0.4
Iron (Fe)	0.4	0.8
Thorium (Th-232)	0.7	0.02
Radium (Ra-226)	3.7 Bq/g	0.37 Bq/g

[a] Data taken from ENL (1978a).
[b] Other impurities which are present at less than 0.5% by weight include Cd, Cr, Mn, Na, Pb, Cl, CO_3, F, P and SO_2.
[c] Ammonium diuranate.
[d] Magnesium diuranate.

raffinate. The uranium-bearing organic phase is washed with a small volume of recycled water (process condensate) to remove residual impurities. The aqueous wash stream is then recycled to digestion.

Following the washing, a larger volume of recycled water is used to re-extract the uranyl nitrate back to the aqueous phase. The aqueous uranyl nitrate solution is then passed through an organic skimmer to reduce solvent carry-over. Stripped solvent is treated with sodium carbonate to remove solvent breakdown products prior to solvent recycle. Aqueous wastes from this treatment operation and general area sumpage are treated in the UO_3 plant sump treatment system for recycling.

Water vapour and fumes from the raffinate drying step pass through a scrubber and then a nitric acid recovery system. Dusts collected from local collectors in the raffinate treatment system pass through baghouses for dust control.

Evaporation (Boildown). The aqueous uranyl nitrate solution from solvent extraction is concentrated by evaporation. Vapours are condensed and sent to the process condensate tank for recycling.

Denitration. The concentrated uranyl nitrate hexahydrate (UNH) solution is thermally decomposed to UO_3 in denitrators. The off-gas from this process is passed through a scrubber and the discharged to the nitric acid recovery system.

Packaging. The UO_3 from denitration is shipped to the Port Hope, Ontario, conversion facilities. Dusty airstreams from UO_3 sampling and loading are directed to baghouses for dust control. The UO_3 product is approximately 79% natural uranium by weight. Various amounts of other radionuclides, including thorium-232, thorium-230 and lead-210, are also present.

Process chemicals. Chemicals used in the refining of yellowcake include ammonia, kerosene (or equivalent), magnesium oxide, nitric acid, phosphoric acid, soda ash, sulphuric acid, tributyl phosphate, and yellowcake.

Internal Recycle. To minimize emissions to the air and water, the production of solid waste and the consumption of chemicals in the plant, ENL has incorporated several internal recycling systems at the Blind River refinery. A 100% recycle is not possible due to impurity build-up in the recycle streams. In addition, small fugitive releases can be expected. The major recycle streams planned for the Blind River refinery include those listed below.

$\underline{UO_3\text{ plant sump treatment system}}$

This system is designed to recycle sumpage from the UO_3 process area, contaminated water from equipment decontamination, and other contaminated water streams. Magnesium oxide will be used to precipitate uranium as MDU which will be recycled to the digestion circuit for uranium recovery, the magnesium will be discharged with the raffinate.

Nitric acid recovery system

This system will be used to recover nitric acid from various process air streams such as those associated with the scrubbing of fumes from digestion, denitration and raffinate drying.

Process condensate recycle system

This system reduces the freshwater make-up requirement by recycling the process condensate from boildown.

The UF_6 Process

Process Steps. Two processes are used in UF_6 refining: a dry hydrofluorination process and the wet chemical process as employed at ENL's existing refinery. The major difference in the two processes is in the method of separating the impurities contained in the yellowcake feed. In the dry hydrofluorination method, these impurities are separated from the final product by a UF_6 distillation method; in the wet chemical method, the impurities are separated in the UO_3 process stage by nitric acid dissolution of the yellowcake and solvent extraction. Both processes use hydrofluoric acid and fluorine to produce UF_6.

At an early stage in the planning of additional refining capacity, ENL undertook detailed studies of both refining processes and the individual methods employed by other producers, and finally selected a version of the wet refining process. The following wet process description is based on information found in ENL (1980b). A schematic layout of the conversion process is shown in Figure 4.

Reduction. In the first stage of conversion to UF_6, the UO_3 is reduced to uranium dioxide (UO_2) by reaction with hydrogen. The hydrogen is produced by dissociation of anhydrous ammonia.

Uranium trioxide and uranium dioxide feed, transfer and preparation steps have baghouses for dust control. Reduction reactor off-gases first pass through sintered metal filters to remove particulates and then through a seal pot prior to discharge.

Hydrofluorination. In the hydrofluorination stage, uranium dioxide is converted to uranium tetrafluoride (UF_4) by reaction with hydrogen fluoride (HF). Reactor off-gas is treated for hydrogen fluoride recovery. Uranium tetrafluoride (UF_4) is 71% natural uranium by weight. Thorium-232 and thorium-230 are also present.

Fluorine generation. Fluorine for the final step in the conversion process is produced by electrolysis of hydrogen fluoride. The hydrogen fluoride is fed to the electrolytic cells and forms an electrolyte with potassium bifluoride (KFHF). Fluorine is produced at the anodes and hydrogen is produced at the cathodes. Prior to use in the flame reactor, the fluorine stream is treated to recover and recycle any entrained electrolyte to the cells. The hydrogen stream is scrubbed to remove HF before being vented to the atmosphere through a KOH seal pot.

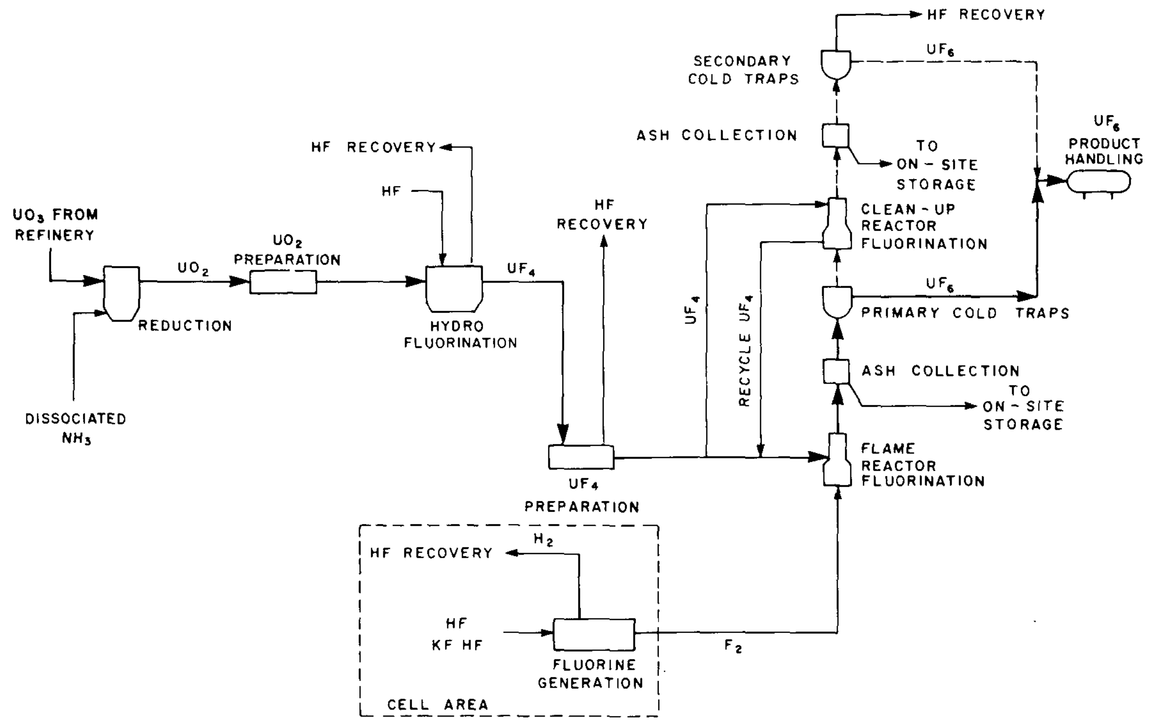

FIGURE 4 UF_6 PROCESS SCHEMATIC

The electrolytic cells are cleaned and maintained in a separate area. Sumpage from this area is transferred to the UF_6 plant sump treatment system for fluoride removal and KOH recycling. Ventilation air is scrubbed for hydrogen fluoride removal.

In case of an accidental release of fluorine or hydrofluoric acid in the cell area, emergency ventilation scrubbing with potassium hydroxide can be activated in the UF_6 plant gas effluent treatment system.

Fluorination. Uranium tetrafluoride is fed both to a flame reactor and to a cleanup reactor. Fluorine gas is introduced in the flame reactor to convert the uranium tetrafluoride (UF_4) to uranium hexafluoride (UF_6). The resulting gas stream containing UF_6 vapour, unreacted fluorine gas and entrained UF_4 solids is filtered to recover and recycle the unreacted UF_4. The flame reactor ash containing any residual impurities is collected in a series of filters and stored. The reslting stream of unreacted fluorine gas and UF_6 vapours is then passed through chilled primary cold traps to recover UF_6.

Excess fluorine from the primary UF_6 cold traps is then fed to the cleanup reactor where it reacts with excess UF_4, ensuring complete utilization of fluorine.

Unreacted UF_4 solids are then recycled to the flame reactor. The UF_6 vapour is recovered in a series of chilled secondary cold traps, and the resulting secondary cold trap off-gas is finally treated for HF recovery prior to release.

The fluorination reactors (flame reactor and cleanup reactors) are surrounded by air cooling shrouds for temperature control. Fluorine-contaminated air streams from this area are diverted to the UF_6 plant gas effluent treatment system for KOH scrubbing prior to discharge. Emissions from UF_4 transfer points are controlled by baghouse dust collectors, followed by a KOH scrubber. Emissions from UF_4 preparation are controlled by sintered metal filters or baghouses, followed by the venturi scrubbers and the KOH scrubbing system in the HF recovery system.

Product packaging. Thick-walled, steel shipping cylinders, holding either 9 or 13 tonnes of UF_6, are filled with liquid UF_6 which gradually solidifies as it returns to room temperature. Emergency ventilation scrubbing with KOH can be activated for the UF_6 product handling area to control accidental releases.

Process chemicals. The major chemicals used in the conversion of UO_3 to UF_6 include hydrofluoric acid, ammonia, caustic potash, quicklime, potassium carbonate and potassium bifluoride.

Internal Recycle. To minimize emissions to the air and water, the production of solid wastes, and to reduce the consumption of chemicals in the plant, ENL have incorporated a number of internal recycling stages in the plant design. The need to prevent the continual buildup of impurities in recycled streams via recycle bleed streams precludes 100% recovery. A number of these internal recycling systems are described in the following paragraphs.

Uranium recovery system

This system is used to recover uranium from various process streams in the UF_6 plant, such as the waste water from equipment decontamination and scrubber solution from the UF_6 plant gas effluent treatment system.

UF_6 plant sump treatment system

This system is used to remove fluorides from various process water streams, including streams from the UF_6 plant gas effluent treatment system, the HF recovery system and the F_2 cell maintenance sump. The UF_6 plant sump treatment system also recovers potassium hydroxide for recycling. The major solid waste from the UF_6 process, calcium fluoride solids, result from this process.

HF recovery system

This system is used to recover hydrogen fluoride from various treated process air streams in the UF_6 plant.

The UO_2 Process

Reactor-grade uranium dioxide is a specially prepared UO_2 suitable for pelletizing, sintering and subsequent preparation as nuclear fuel for CANDU-type reactors. To produce reactor-grade UO_2, ENL uses the ammonium diuranate UO_2 process which includes the following steps: ADU precipitation, filtration, drying and calcining.

ADU Precipitation/Filtration. Concentrated uranyl nitrate solution from the UO_3 circuit is mixed with ammonium hydroxide to precipitate ammonium diuranate (ADU). The resulting slurry mixture is dewatered by vacuum filtration, producing a wet cake for drying, and a liquid aqueous waste stream of ammonium nitrate for disposal. This liquid stream contains trace amounts of uranium.

Drying/Calcining. The wet ADU precipitate (containing entrained ammonium nitrate) is dried, then thermally decomposed to UO_3 which in turn is reduced to UO_2. The final process is performed in a gas-heated calciner in the presence of H_2, in a manner similar to the reduction step in the UF_6 circuit. Before shipment, all uranium dioxide is pulverized and blended.

The UO_2 process generates the following waste streams: ammonium nitrate aqueous waste, which contains trace amounts of unrecovered ADU from solid/liquid separation equipment; and dust from ADU drying/UO_3 thermal decomposition, UO_2 calcination, and UO_2 pulverization. Process modifications developed in the last few years by ENL have lead to the sale of non-contaminated liquid ammonium nitrate waste as fertilizer.

Uranium Metal

Uranium metal is produced intermittently at ENL's Port Hope refinery. This process involves the reduction of uranium tetrafluoride from the UF_6 circuit with magnesium. The UF_4/Mg mixture is fed to a reduction furnace in steel reactor vessels. The reaction produces an ingot of uranium metal and a magnesium fluoride slag containing residual amounts of uranium. The crude ingot is then remelted and cast into billets, or alternatively can be machined as is.

APPENDIX B

HISTORICAL ENVIRONMENTAL MONITORING DATA

Air Quality Data

Introduction. Air quality data are or have been collected in the Port Hope area by the Ontario Ministry of the Environment (MOE), the Atomic Energy Control Board (AECB), the Radiation Protection Branch of Health and Welfare Canada (RPB), and Eldorado Nuclear Limited (ENL). This section is a compilation of data (excluding phytotoxicology studies) collected by these organizations through 1981; 1982 data have been included where they are available. The following acronyms are used in Tables 20 to 42:

N - Number of samples
AM - Arithmetic mean of N sample
ASD - Arithmetic standard deviation of N sample
GM - Geometric mean of N sample
GSD - Geometric standard deviation of N sample
NX - Number of samples exceeding provincial criteria

Annual summaries are generally presented; however, monthly summaries are presented in certain instances of short periods of record.

Total Suspended Particulate. Total suspended particulate (TSP) measurements were carried out by ENL and MOE, and are presented in Tables 20 and 21, respectively. Annual geometric mean TSP levels range from 33 to 59 $\mu g/m^3$, and from 14 to 76 $\mu g/m^3$ at MOE and ENL stations, respectively. No significant long-term trends are apparent in the MOE data. The ENL data for the Crane Building suggest elevated TSP levels in 1979 through 1981, with a decrease during the first half of 1982. Whether this is a true decrease or a bias resulting from the use of a partial year of data is not known. This behavior may also be associated with local construction activities.

Uranium in TSP. Uranium in TSP is being or has been monitored at 14 locations in the Port Hope area by MOE, ENL and RPB. Summaries of these data are presented in Tables 22, 23 and 24. No significant temporal pattern is apparent in either MOE or ENL data, even with the elevated uranium emissions that occurred in the first quarter of 1981. The 1981/82 RPB data for stations comparatively remote from ENL operations suggest background uranium levels in TSP in the order of 0.003 to 0.01 $\mu g/m^3$. It should be noted

TABLE 20 TOTAL SUSPENDED PARTICULATE - SUMMARY OF MOE DATA

	TSP ($\mu g/m^3$)		
Date	58027 51 Shuter Street	58028 2 Choate Street	58029 66 Queen Street
1975 - June to Dec.			
N	65	60	62
AM	48	64	57
ASD	-	-	-
GM	42	51	52
GSD	1.69	1.92	1.54
1976 - Jan. to June			
N	61	61	62
AM	45	65	54
ASD	-	-	-
GM	39	55	47
GSD	1.67	1.81	1.71
1977	- NO DATA AVAILABLE-		
1978 - Sept. to Nov.			
N	38	38	38
AM	39	60	52
ASD	-	-	-
GM	34	53	47
GSD	1.83	1.66	1.62
1979 - June to October			
N	49	38	43
AM	58	64	64
ASD	-	-	-
GM	53	59	58
GSD	1.53	1.58	1.57
1980 - Oct. to Nov.			
N	41	41	39
AM	37	43	43
ASD	-	-	-
GM	33	37	39
GSD	1.55	1.71	1.55
1981 - May to October			
N	117	99	119
AM	41	55	47
ASD	-	-	-
GM	34	47	41
GSD	1.81	1.79	1.70

TABLE 21 TOTAL SUSPENDED PARTICULATES - SUMMARY OF ENL DATA

	TSP (µg/m^3)		
Date	Waterworks	Crane Building	Shuter Street
1977			
N		4	
AM		14	
ASD	N/A	3.7	N/A
GM		14	
GSD		1.3	
1978			
N		41	
AM		34	
ASD	N/A	20	N/A
GM		29	
GSD		1.8	
1979			
N		64	
AM		61	
ASD	N/A	48	N/A
GM		48	
GSD		2.0	
1980			
N		84	
AM		51	
ASD	N/A	57	N/A
GM		38	
GSD		2.0	
1981			
N	39	161	141
AM	81	102	90
ASD	54	79	58
GM	61	76	73
GSD	2.6	2.2	2.0
1982			
N	51	59	75
AM	80	74	77
ASD	61	44	46
GM	65	59	62
GSD	1.8	2.2	2.1

that the RPB reports uranium levels to lower values than other groups whose practical lower limit of detection for normal monitoring is about 0.01 μg/m^3. Although the AECB do not routinely monitor air quality during June, July and August 1981 they operated 12 high-volume sampling stations in Port Hope, in proximity to ENL operations. These monthly data are summarized in Table 25.

TABLE 22 URANIUM IN TOTAL SUSPENDED PARTICULATE - SUMMARY OF MOE DATA

	U in TSP (μg/m^3)		
Date	58027 51 Shuter Street	58028 2 Choate Street	58029 66 Queen Street
1979 - June to September			
N	26	26	26
AM	0.069	0.141	0.038
ASD	0.097	0.183	0.059
GM	0.032	0.059	0.013
GSD	3.89	4.11	4.81
1980 - October to November			
N	37	39	39
AM	0.14	0.18	0.156
ASD	0.24	0.39	0.263
GM	0.036	0.029	0.034
GSD	5.95	6.59	6.88
1981 - May to October			
N	108	83	116
AM	0.067	0.112	0.037
ASD	0.084	0.185	0.076
GM	0.025	0.035	0.013
GSD	5.09	5.38	4.39

Other Parameters in TSP. The MOE also monitors for levels of sulphate and nitrate contained in TSP. Summary statistics of these data (as calculated by the MOE) are presented in Tables 26 and 27. The highest nitrate levels occurred in 1979. Sulphate levels show no apparent trend.

TABLE 23 URANIUM IN TOTAL SUSPENDED PARTICULATES - SUMMARY OF ENL DATA

	U in TSP (μg/m^3)		
Date	Crane	Shuter Street	Waterworks
1977 - Nov. and Dec.			
N	4		
AM	0.024		
ASD	0.012	no data	no data
GM	0.021		
GSD	1.70		
1978 - Jan., Mar., Apr., Aug., Oct. and Nov.			
N	42		
AM	0.067		
ASD	0.072		
GM	0.040	no data	no data
GSD	2.98		
1979 - Feb., Apr., June and Aug. to Dec.			
N	64		
AM	0.208		
ASD	0.332		
GM	0.093	no data	no data
GSD	3.67		
1980 - full year except Sept. and Oct.			
N	80		
AM	0.409		
ASD	1.316		
GM	0.106	no data	no data
GSD	4.69		
1981 - full year except April			Oct. to Dec.
N	168	148	39
AM	0.223	0.141	0.073
ASD	0.472	0.467	0.087
GM	0.088	0.047	0.039
GSD	3.73	3.57	3.14
1982 - January to June			January to June except May
N	60	73	53
AM	0.106	0.090	0.141
ASD	0.126	0.151	0.196
GM	0.053	0.039	0.054
GSD	3.46	3.45	4.30

TABLE 24 URANIUM IN TOTAL SUSPENDED PARTICULATE - SUMMARY OF RPB DATA

	U in TSP (µg/m^3)							
Year	Greenwood Motel	Sunshine Heights	Dr. Hawkins School	Dr. Powers School	Penryn Park	Shuter Street	Water Works	Car Wash
1981	June - October	June - August	June - August	June - August	June - Oct.	Sept - Dec.	Sept - Dec.	Sept - Dec.
N	8	5	6	4	11	8	8	10
AM	0.011	0.006	0.005	0.009	0.010	0.021	0.067	0.017
ASD	0.006	0.002	0.003	0.003	0.007	0.015	0.051	0.017
GM	0.010	0.006	0.005	0.009	0.007	0.016	0.050	0.012
GSD	1.66	1.59	1.69	1.54	2.49	2.18	2.48	2.30
1982	Feb - June				March - April	Jan - June	Jan - June	Jan - June
N	18				7	20	19	18
AM	0.019				0.034	0.043	0.14	0.017
ASD	0.020	no	no	no	0.032	0.041	0.13	0.014
GM	0.012	data	data	data	0.020	0.028	0.077	0.011
GSD	2.81				3.89	2.56	3.57	3.11

Total Dustfall. Total dustfall is monitored by both the MOE and ENL. Summaries of these data are presented in Table 28 and 29. Neither set of data exhibit any significant trends. Annual arithmetic mean dustfalls ranging from 1.4 to 8.3 g/m^2/30 days have been recorded by the MOE; values ranging from 2.9 to 8.7 g/m^2/30 days have been observed by ENL. By way of comparison, the Ontario ambient air quality criterion is 4.6 g/m^2/30 days averaged over one year.

Uranium in Dustfall. Uranium in dustfall has been routinely monitored by the MOE and ENL. Summaries of these data are presented in Tables 30, 31 and 32. These data all show highest uranium levels occurring in 1981. This is consistent with the elevated uranium releases which occurred in the first quarter of 1981. The AECB dustfall data for the summer of 1981 are also summarized in Table 32.

Fluoride in Dustfall. Fluoride in dustfall is monitored by both MOE and ENL at a total of 12 stations. Summaries of these data are presented in Tables 33 and 34. With the possible exception of the ENL warehouse data, there is no discernible trend in the MOE data; however, the ENL data show a steady rise until 1981, with an apparent decline thereafter.

TABLE 25 URANIUM IN TOTAL SUSPENDED PARTICULATE - SUMMARY OF AECB DATA

	U in TSP (µg/m³)											
	1	2	3	4	5	6	7	8	9	10	11	12
Date	Shuter	Peter	Hayward	Dynaflex	Thomas	Town Hall	Hope + William	Dorset	Smith	Cavan	Walton	Bramley
1981 - June												
N	27	27	27	26	25	27						
AM	0.076	0.074	0.074	0.16	0.067	0.084						
ASD	0.056	0.068	0.085	0.21	0.069	0.104						
GM	0.057	0.053	0.051	0.077	0.046	0.054						
GSD	2.3	2.3	2.4	3.5	2.3	2.4						
1981 - July												
N	31	27	27	30	27	27	28	28	28	28	28	24
AM	0.12	0.057	0.065	0.078	0.019	0.030	0.028	0.050	0.030	0.024	0.025	0.021
ASD	0.14	0.043	0.056	0.12	0.023	0.026	0.028	0.044	0.027	0.021	0.026	0.019
GM	0.060	0.044	0.046	0.032	0.012	0.023	0.19	0.36	0.020	0.019	0.018	0.016
GSD	3.5	2.2	2.3	4.0	2.6	2.2	2.2	2.3	2.3	1.9	2.2	2.0
1981 - August												
N	30	30	30	30	30	30	30	29	30	29	27	30
AM	0.039	0.032	0.037	0.19	0.019	0.022	0.029	0.033	0.022	0.020	0.012	0.021
ASD	0.036	0.022	0.035	0.45	0.016	0.016	0.021	0.027	0.021	0.013	0.004	0.016
GM	0.027	0.024	0.026	0.049	0.015	0.018	0.023	0.024	0.016	0.017	0.012	0.017
GSD	2.4	2.1	2.3	4.0	1.9	1.9	2.0	2.3	2.0	1.8	1.4	1.9

TABLE 26 NITRATE IN TOTAL SUSPENDED PARTICULATE - SUMMARY OF MOE DATA

	NO_3 in TSP ($\mu g/m^3$)		
Date	58027 51 Shuter Street	58028 2 Choate Street	58029 66 Queen Street
1975 - June to December			
N	55	48	53
AM	4.0	6.7	2.8
ASD	-	-	-
GM	2.6	3.6	1.8
GSD	2.9	3.1	3.1
1976 - January to June			
N	63	61	63
AM	5.0	6.0	4.7
ASD	-	-	-
GM	3.6	4.1	3.2
GSD	2.4	2.5	2.5
1977	- NO DATA AVAILABLE -		
1978 - September to November			
N	38	38	37
AM	5.7	5.0	5.3
ASD	-	-	-
GM	3.6	3.9	3.6
GSD	2.9	2.2	2.6
1979 - June to October			
N	49	38	43
AM	6.8	7.7	6.4
ASD	-	-	-
GM	4.5	5.5	3.8
GSD	2.8	2.7	3.2
1980 - October to November			
N	41	42	39
AM	4.3	5.6	3.8
ASD	-	-	-
GM	2.7	3.3	2.6
GSD	3.0	3.1	2.6
1981 - May to October			
N	109	97	119
AM	3.8	6.2	3.9
ASD	-	-	-
GM	2.5	3.9	2.5
GSD	2.8	3.0	2.9

Nitrate in Dustfall. Both MOE and ENL monitor nitrate levels in dustfall. Summaries of these data are presented in Tables 35 and 36. There are no readily discernible long-term or spatial trends in these data.

Fluoridation Rate. The fluoridation rate is probably the most extensive (and perhaps the most controversial) of the monitoring programs in the Port Hope area. Table 37 presents a summary of the MOE data. In addition to the normal means and deviations presented on the previous tables, the number of months of exceedance of the MOE criteria is also presented. The most critical MOE criteria for fluoridation rate are based on the growing season, defined as 15 April to 15 October. For the purpose of counting number of exceedances, the period from 1 April to 30 October (which is tabulated) has been used to construct this table from monthly data. There is generally no apparent long-term trend; certain individual stations do show peak years.

Nitrogen Oxides. For a short period in 1979 and 1980, the MOE maintained a nitrogen oxides analyser in Port Hope. The data collected during this period are presented in Tables 38, 39 and 40.

Water Quality Data

Introduction. Water quality monitoring in the vicinity of the Port Hope uranium refinery has been undertaken for several years by MOE, RPB and ENL. The main thrust of the MOE and ENL programs has been related to monitoring of the water supply intake and cooling water returns, all of which are located inside the Port Hope harbour. MOE annually also carries out several surveys in the harbour and out into the nearshore waters of Lake Ontario. Because the harbour acts as a mixing basin for the refinery effluents, and since a substantial fraction of the effluent water is recycled through the plant water supply intake, the water quality data collected inside the harbour are not considered to be indicative of environmental data. Only the data collected on Lake Ontario outside the mouth of the harbour entrance are discussed.

The monitoring programs also include analyses of water samples collected from the Town of Port Hope treated water supply. The town draws its water from Lake Ontario through either of two intakes located approximately 570 m and 750 m southwest of the entrance to the harbour. The most comprehensive and informative program has been that carried out by the RPB. This program has analyzed monthly composite samples prepared from daily sampling of the treated water supply since it was first initiated in mid-1978. The analytical techniques employed at the RPB laboratory for uranium and

TABLE 27 SULPHATE IN TOTAL SUSPENDED PARTICULATE - SUMMARY OF MOE DATA

Date	Sulphate in TSP (µg/m³) 58027 51 Shuter Street	 58028 2 Choate Street	 58029 66 Queen Street
1975	NO DATA AVAILABLE		
1976 - January to June			
N	54	60	61
AM	9.2	11.0	9.3
ASD	-	-	-
GM	7.8	9.5	8.4
GSD	1.7	1.7	1.6
1977	NO DATA AVAILABLE		
1978 - September to November			
N	38	38	38
AM	7.5	7.7	7.2
ASD	-	-	-
GM	6.7	7.1	6.6
GSD	1.7	1.6	1.6
1979 - June to October			
N	49	38	43
AM	11.8	11.2	11.8
ASD	-	-	-
GM	10.2	9.2	10.1
GSD	1.7	1.9	1.8
1980 - October to November			
N	41	42	39
AM	7.9	8.8	7.1
ASD	-	-	-
GM	7.5	8.1	6.9
GSD	1.4	1.5	1.3
1981 - May to October			
N	117	99	119
AM	8.4	9.1	8.6
ASD	-	-	-
GM	7.0	7.5	7.1
GSD	1.8	1.9	1.9

TABLE 28 DUSTFALL - TOTAL SOLIDS - SUMMARY OF MOE DATA

	Dustfall (g/m^2/30 days)						
Date	58026 Eldorado Warehouse	58027 51 Shuter Street	58028 2 Choate Street	58029 68 Queen Street	58033 Walton & Pine Street	58035 Lakeshore Rd. Granby	58036 Lakeshore Rd. R.R. No. 3
1975							
N	5	7	7	7			
AM	2.6	2.3	2.2	4.0			
ASD	0.7	1.0	0.6	1.1		N/A	
GM	2.5	2.1	2.1	3.8			
GSD	1.4	1.7	1.4	1.4			
1976							
N	10	12	12	12			
AM	3.0	2.9	2.4	5.4			
ASD	1.1	1.0	0.8	2.5		N/A	
GM	2.8	2.7	2.3	4.8			
GSD	1.5	1.4	1.4	1.7			
1977							
N	11	10	12	12	3	3	3
AM	3.0	3.5	3.5	6.0	3.4	4.5	1.4
ASD	1.1	1.1	1.7	2.8	0.2	4.8	0.3
GM	2.8	3.3	3.3	5.6	3.4	3.1	1.4
GSD	1.4	1.3	1.5	1.5	1.1	2.8	1.3
1978							
N	7	12	12	12	12	12	12
AM	3.3	3.0	2.4	4.9	4.2	6.4	2.0
ASD	2.1	2.2	1.1	2.9	2.0	11	1.6
GM	2.8	2.4	2.2	4.3	3.7	3.1	1.5
GSD	1.8	1.9	1.6	1.8	1.6	3.3	2.3
1979							
N	11	11	12	12	12	11	12
AM	2.5	3.3	2.9	4.6	3.1	3.9	3.0
ASD	1.0	1.1	1.0	2.7	1.8	3.7	3.1
GM	2.2	2.1	2.7	4.0	2.7	2.7	2.0
GSD	1.8	1.6	1.4	1.7	1.8	2.5	2.5
1980							
N	12	11	12	12	12		
AM	3.2	2.5	3.1	8.3	4.4		
ASD	1.6	0.8	1.2	7.1	1.6	N/A	N/A
GM	2.9	2.4	2.9	6.3	4.1		
GSD	1.5	1.4	1.5	2.1	1.5		
1981							
N	12	11	12	12	12		
AM	2.4	2.2	2.8	3.7	3.8		
ASD	1.0	1.2	1.9	2.2	1.8	N/A	N/A
GM	2.2	1.9	2.3	3.2	3.5		
GSD	1.5	1.9	2.2	1.8	1.5		

TABLE 29 DUSTFALL - TOTAL SOLIDS - SUMMARY OF ENL DATA

	Dustfall ($g/m^2/30$ days)				
Date	Port Hope Waterworks Roof	Analytical Laboratory Roof	Crane Jetty Warehouse Roof	Fenceline at SE Corner of Refinery	Shuter Street Substation
1976			NO DATA		
1977			NO DATA		
1978			NO DATA		
1979					
N	10	11	11	10	
AM	5.3	5.1	6.5	8.1	
ASD	4.8	4.3	6.1	7.4	N/A
GM	3.9	3.7	4.4	5.6	
GSD	2.2	2.4	2.5	2.6	
1980					
N	12	12	12	11	
AM	2.9	4.6	4.0	4.3	N/A
ASD	2.1	3.6	2.3	2.2	
GM	2.4	3.5	3.5	3.8	
GSD	1.8	2.3	1.8	1.7	
1981*					
N	25	21	26	26	4
AM	5.8	3.8	7.0	8.7	5.9
ASD	9.6	2.9	10.0	13.0	6.8
GM	2.4	3.0	3.7	4.3	3.5
GSD	3.5	2.1	3.0	3.2	3.3
1982*					
N	18	19	19	19	7
AM	6.0	8.6	6.1	6.4	4.3
ASD	3.4	3.9	4.1	6.7	3.9
GM	4.9	7.7	4.9	3.9	3.3
GSD	2.0	1.7	2.0	2.8	2.2

* In 1981 and 1982 data are presented for a composite of twice-monthly and monthly sampling campaigns.

radium-226 analyses also have historically allowed measurement to much lower levels than the techniques used by either of the other laboratories. For example, uranium is measured to a detection limit of 0.1 µg/L at the RPB laboratory, as compared with a limit of 10 µg/L at the MOE and ENL laboratories. Similarly, radium-226 is measured to 5 mBq/L (0.135 pCi/L) at the RPB laboratory versus 37 mBq/L (1 pCi/L) at the MOE and ENL laboratories.

Ontario Ministry of Environment. Water quality data collected on Lake Ontario between May 1977 and September 1980 by the MOE are summarized in Table 41 for two of the contaminants associated with the refinery operation. The summary of uranium data indicates that nearly all of the measurements were below the detection limit of 10 µg/L. On two sets of observations, the uranium levels were measured to a detection limit of 1 µg/L. Only 4 observations out of the total of 55 individual measurements had levels greater than the detection limit of 10 µg/L.

Nitrate levels varied considerably at all three stations, as indicated by the large standard deviations. Inorganic nitrogen forms are typically found to be highly variable in nature; this observation is therefore not unexpected. The mean nitrate values reported in Table 41 correspond with levels measured by the MOE on the nearshore waters of Lake Ontario (MOE, 1980). Consequently, it appears that the Port Hope refinery has minimal impact on nitrate levels in the immediate area of Lake Ontario outside the entrance to Port Hope harbour.

The MOE program also includes routine monitoring of fluoride and radium levels on samples collected from the lake stations. Of a total of 57 fluoride analyses, 55 samples measured 0.1 mg/L while the remaining 2 samples recorded a level of 0.2 mg/L. Again, the water quality data do not suggest a measurable impact from the Port Hope refinery. A total of 54 measurements of radium-226 levels were made over the monitoring period. Of these, 42 samples measured <37 mBq/L, 9 samples measured 37 mBq/L and the remaining three samples recorded levels of 74, 148 and 222 mBq/L.

TABLE 30 URANIUM IN DUSTFALL - SUMMARY OF MOE DATA

	U in Dustfall ($mg/m^2/30$ days)			
Date	58026 Eldorado	58027 51 Shuter St.	58028 2 Choate St.	58029 66 Queen St.
1978	July to Nov.	Jan., July to Sept., Nov., Dec.	July to Oct. & December	Jan., Aug., Oct. & Dec.
N	5	6	5	4
AM	6.2	1	1.8	2
ASD	4.7	0	0.8	1.2
GM	5.1	1	1.6	1.7
GSD	1.9	1	1.6	1.9
1979	full year except Mar.	Oct. & Dec. missing	full year except Jul.	Jan. to Apr. Sept. & Nov.
N	11	10	11	6
AM	4.9	1.4	3.4	1.5
ASD	3.2	0.7	2.8	0.5
GM	4.1	1.3	2.5	1.4
GSD	1.9	1.5	2.2	1.5
1980	Apr. to June missing	Apr. to July missing	Apr. to June missing	Aug. to Dec.
N	9	8	9	5
AM	23	5.4	11	8.6
ASD	34	7.2	21	9.6
GM	8.9	2.5	3.3	4.5
GSD	4.2	3.5	4.0	3.8
1981 - full year				
N	12	12	12	12
AM	86	56	46	21
ASD	160	96	92	33
GM	9.1	3.7	3.9	2.4
GSD	13	16	12	12
1982	Jan. to June	Jan. to June	Jan. to June	Feb. to June
N	6	6	6	5
AM	3.3	1.3	2.0	0.7
ASD	0.8	0.7	0.8	0.4
GM	3.2	1.1	1.8	0.6
GSD	1.3	1.8	1.5	1.7

NOTE - no values reported as 0 were included in this analysis.

TABLE 31 URANIUM IN DUSTFALL - SUMMARY OF ENL DATA

	U in Dustfall ($mg/m^2/30$ days)		
Date	Crane	Shuter Street	Waterworks
1977	November & December		
N	2		
AM	8.70		
ASD	1.27	no data	no data
GM	8.65		
GSD	1.16		
1978	January, March, April August, October & November		
N	6		
AM	11.64		
ASD	8.84	no data	no data
GM	9.29		
GSD	2.04		
1979	February, April, June & August to December		
N	8		
AM	5.51		
ASD	5.69	no data	no data
GM	3.91		
GSD	2.27		
1980	full year except September & October		
N	10		
AM	25.4		
ASD	45.7	no data	no data
GM	12.1		
GSD	3.06		
1981	full year except April	June to December	October to December
N	11	8*	3
AM	103.5	12.2	4.67
ASD	189.6	11.4	2.08
GM	26.1	6.86	4.38
GSD	5.72	3.6	1.54
1982	January to June	January to June	January to June except May
N	6	6	5
AM	8.83	5.83	13.6
ASD	3.06	3.71	7.67
GM	8.14	5.10	11.1
GSD	1.65	1.72	2.24

* One abnormal data point was excluded from this analysis.

TABLE 32 URANIUM IN DUSTFALL - SUMMARY OF AECB DATA (1981)

	U in Dustfall (mg/m^2/30 days)			
	Durham Motors	Dynaflex Plastics	Crane Building	Selvigs Garage
Number of Samples	6	7	5	7
Arithmetic Mean	4.6	8.0	19	7.4
Arithmetic Standard Deviation	2.3	7.6	16	4.9
Geometric Mean	4.0	5.2	10	6.2
Geometric Standard Deviation	2.0	2.8	5.5	1.9

NOTE: AECB's dustfall sampling campaign was only carried out over 3 months (June, July and August 1981).

Radiation Protection Branch. A summary of the uranium concentration data reported by the RPB on the treated water supply for the Town of Port Hope is given in Table 42. Radium levels measured by the RPB on the town water supply over the 3.5-year monitoring period were reported to be consistently below the detection limit of 5 mBq/L.

The uranium data summary presented in Table 42 indicates the uranium level was variable although consistently below the federal maximum acceptable drinking water concentration of 20 µg/L. An overall mean value of 1.25 ± 0.69 µg/L was calculated for the entire data set. In contrast, the basin-wide mean uranium concentration for the open waters of Lake Ontario has been reported to equal 0.50 ± 0.08 µg/L (Durham et al., 1982). While the nearshore waters of Lake Ontario may have a higher uranium level than reported for the open water, the level measured in the town water supply could be interpreted as suggesting that the ENL refinery has some impact on the water supply. Because the monitoring program data of the MOE on the nearshore lake waters are not measured to the same level of accuracy, the two data sets cannot be easily interpreted in this instance in assessing the effect, if any, of the Port Hope refinery on local water quality. This example suggests a need for establishing consistency in monitoring program methodologies.

TABLE 33 FLUORIDE IN DUSTFALL - SUMMARY OF MOE DATA

	Fluoride in Dustfall (mg/m^2/30 days)						
Date	58026 Eldorado Warehouse	58027 51 Shuter Street	58028 2 Choate Street	58029 68 Queen Street	58033 Walton & Pine Street	58035 Lakeshore Rd. Granby	58036 Lakeshore Rd. R.R. No. 3
1975							
N	4	5	6	5			
AM	61	14	33	18			
ASD	66	2.5	27	17		N/A	
GM	43	14	27	13			
GSD	2.4	1.2	1.9	2.4			
1976							
N	9	12	12	11			
AM	19	15	17	8.1			
ASD	3.9	14	23	6.9		N/A	
GM	19	11	8.8	6.5			
GSD	1.2	2.3	3.4	1.9			
1977							
N	4	2	4	4			
AM	28	6	5.3	3.5			
ASD	22	-	1.0	2.1		N/A	
GM	23	5	5.2	2.9			
GSD	2.1	-	1.8	2.2			
1978							
N	7	12	12	12	11	12	11
AM	22	10	13	9.6	4.6	4.6	2.6
ASD	23	9.0	21	12.2	6.2	5.8	2.6
GM	16	7.3	5.6	6.2	3.1	2.7	2.0
GSD	2.5	2.2	3.9	2.5	2.2	2.6	2.1
1979							
N	11	12	12	12	11	11	12
AM	14	6.3	13	3.4	3.3	2.5	2.8
ASD	8.8	3.6	9.3	4.3	2.5	2.2	2.2
GM	12	5.2	9.6	2.3	2.5	1.8	2.1
GSD	1.8	2.1	2.4	2.5	2.2	2.2	2.2
1980							
N	12	11	12	12	5		
AM	13	9.8	11	4.1	1.4		
ASD	9	9.1	17	2.7	0.9	N/A	N/A
GM	9	6.4	5.8	3.1	1.2		
GSD	2.6	2.8	3.0	2.4	1.6		
1981							
N	10	10	10	10	12		
AM	11	5.2	4.9	4	1.7		
ASD	11	5.0	4.9	3.9	1.4	N/A	N/A
GM	5.8	3.3	2.8	2.6	1.4		
GSD	4.0	2.9	3.2	2.6	1.8		
1982							
N	2	2	2	1	1		
AM	8	3	8	2	2		
ASD	-	-	-	-	-	N/A	N/A
GM	6	2	8	2	1		
GSD	-	-	-	-	-		

TABLE 34 FLUORIDE IN DUSTFALL - SUMMARY OF ENL DATA

	Fluoride in Dustfall (mg/m^2/30 days)				
Date	Port Hope Waterworks Roof	Analytical Laboratory Roof	Crane Jetty Warehouse Roof	Fenceline at SE Corner of Refinery	Shuter Street Substation
1976					
N	10	11	10	10	
AM	14	9.0	28	21	
ASD	10	7.1	34	19	N/A
GM	12	7.4	18	15	
GSD	1.8	1.8	2.6	2.3	
1977					
N	10	11	11	11	
AM	31	11	21	28	
ASD	14	5.7	15	19	N/A
GM	29	9.9	18	22	
GSD	1.6	1.6	1.9	2.3	
1978					
N	8	7	7	8	
AM	23	18	36	38	
ASD	21	11	28	38	N/A
GM	18	16	29	28	
GSD	2.0	1.8	1.9	2.1	
1979					
N	12	11	12	11	
AM	40	27	24	35	
ASD	26	12	13	15	N/A
GM	35	24	19	32	
GSD	1.6	1.7	2.2	1.5	
1980					
N	11	11	11	11	
AM	30	32	46	38	
ASD	25	27	59	21	N/A
GM	23	26	28	34	
GSD	2.0	1.9	2.7	1.7	
1981*					
N	17	16	17	17	3
AM	65	39	62	42	9
ASD	88	30	52	41	-
GM	34	29	45	31	8
GSD	3.1	2.2	2.3	2.1	-
1982*					
N	15	15	16	16	6
AM	30	23	19	19	11
ASD	18	8.7	7.5	6.9	1.9
GM	25	21	18	17	11
GSD	1.9	1.5	1.5	1.5	1.2

* 1981 and 1982 data are composites of twice-monthly and monthly sampling campaigns.

TABLE 35 NITRATE IN DUSTFALL - SUMMARY OF MOE DATA

Date	Nitrate in Dustfall ($g/m^2/30$ days) 58026 Eldorado Warehouse	58027 51 Shuter Street	58028 2 Choate Street	58029 68 Queen Street	58033 Walton & Pine Street	58035 Lakeshore Rd. Granby	58036 Lakeshore Rd. R.R. No. 3
1975							
N	4	6	6	6			
AM	0.27	0.22	0.22	0.25			
ASD	0.22	0.13	0.12	0.14	N/A		
GM	0.16	0.16	0.18	0.19			
GSD	4.3	2.6	2.1	2.6			
1976							
N	10	12	12	12			
AM	0.42	0.38	0.42	0.35			
ASD	0.16	0.15	0.14	0.17	N/A		
GM	0.40	0.35	0.39	0.32			
GSD	1.4	1.5	1.4	1.6			
1977							
N	2	2	4	4			
AM	0.37	0.33	0.34	0.26			
ASD	-	-	0.08	0.09	N/A		
GM	0.36	0.32	0.33	0.25			
GSD	-	-	1.3	1.4			
1978							
N	6	11	11	11	10	11	
AM	0.55	0.32	0.31	0.36	0.28	0.37	
ASD	0.18	0.12	0.15	0.25	0.14	0.43	N/A
GM	0.52	0.30	0.24	0.29	0.21	0.18	
GSD	1.4	1.6	2.6	2.1	3.1	4.2	
1979							
N	11	12	12	12	12	11	
AM	0.53	0.34	0.41	0.37	0.32	0.30	
ASD	0.30	0.12	0.16	0.17	0.11	0.10	N/A
GM	0.46	0.32	0.38	0.33	0.30	0.29	
GSD	1.8	1.5	1.5	1.6	1.4	1.4	
1980							
N	12	11	12	12	5		
AM	0.42	0.33	0.37	0.31	0.29		
ASD	0.16	0.10	0.14	0.13	0.14	N/A	N/A
GM	0.39	0.31	0.34	0.29	0.25		
GSD	1.5	1.5	1.5	1.6	1.8		
1981							
N	12	12	12	12	12		
AM	0.38	0.33	0.40	0.30	0.27		
ASD	0.13	0.14	0.32	0.14	0.14	N/A	N/A
GM	0.36	0.31	0.34	0.28	0.25		
GSD	1.4	1.5	1.7	1.5	1.5		
1982							
N	1	1	1		1		
AM	0.54	0.27	0.25		0.18		
ASD	-	-	-	N/A	-	N/A	N/A
GM	0.54	0.27	0.25		0.18		
GSD	-	-	-		-		

TABLE 36 NITRATE IN DUSTFALL - SUMMARY OF ENL DATA

	Nitrate in Dustfall (g/m^2/30 days)			
Date	Port Hope Waterworks Roof	Analytical Laboratory Roof	Crane Jetty Warehouse Roof	Fenceline at SE Corner of Refinery
1976		NO DATA		
1977		NO DATA		
1978				
N	8	7	7	8
AM	0.074	0.17	0.10	0.061
ASD	0.047	0.05	0.050	0.036
GM	0.064	0.16	0.092	0.046
GSD	1.7	1.4	1.6	2.6
1979				
N	12	12	12	11
AM	0.10	0.24	0.099	0.090
ASD	0.10	0.17	0.072	0.054
GM	0.07	0.16	0.062	0.074
GSD	2.5	2.9	3.4	2.0
1980				
N	8	9	8	7
AM	0.31	0.86	0.36	0.81
ASD	0.27	0.65	0.32	1.3
GM	0.15	0.58	0.18	0.40
GSD	5.1	3.2	5.1	3.1

NOTE: No data were collected during 1981 and 1982.

TABLE 37 FLUORIDATION RATE - SUMMARY OF MOE DATA

		Fluoridation (μg/100 cm^2/month)												
Station		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
58005 49 Shuter	N	12	12	12	12	12	12	12	12	12	12	12	12	12
	AM	13	26	98	51	51	55	47	56	45	37	47	189	77
	ASD	9	17	81	55	21	45	38	77	25	18	19	156	44
	GM	10	18	68	28	47	44	37	22	40	34	43	121	65
	GSD	2.2	2.8	2.7	3.4	1.6	1.9	2.0	4.5	1.6	1.6	1.7	3.0	1.9
	NX	0	3	7	5	6	5	4	2	3	1	5	9	9
58006 8 College Street	N	12	12	12	12	11	12	10	11	12	12	12	12	12
	AM	5	10	16	12	24	15	8	4	10	14	14	18	13
	ASD	2.7	9.1	11	9.3	22	17	8.2	3.9	4.1	6.8	16	15	2.8
	GM	5	6	13	8	18	10	6	3	9	13	9	14	13
	GSD	1.9	3.2	2.1	2.7	2.2	2.9	2.2	2.5	1.7	1.5	2.5	2.0	1.3
	NX	0	0	1	0	1	0	0	0	0	0	1	1	0
58007 Victoria Street Highland Drive	N	12	12	12	12	10	12	11	11	12	12	12	12	12
	AM	11	21	19	26	26	12	9	5	12	16	14	21	16
	ASD	5.3	11	7.3	25	21	6.3	10	4.1	6.8	6.8	7.1	12	4.5
	GM	9	19	18	17	21	11	5	3	10	15	12	18	16
	GSD	2.0	1.6	1.5	2.9	1.9	1.9	3.5	2.4	1.8	1.5	1.6	1.8	1.3
	NX	0	1	0	1	1	0	0	0	0	0	0	1	0
58008 377 Lakeshore Road	N	11	12	12	12	11	12	6		2	12	12	12	12
	AM	15	31	35	31	33	12	8		23	17	17	29	24
	ASD	6.1	33	13	17	21	5	6.7		0.7	6.8	8.1	21	12
	GM	14	23	32	26	28	11	5		22	16	15	24	22
	GSD	1.6	2.2	1.5	1.9	1.8	1.6	3.1		1.0	1.4	1.6	1.9	1.6
	NX	0	2	3	2	3	0	0		0	0	0	2	1
58009 3.7 miles west of ENL	N	9	11	12	12									
	AM	10	12	19	19									
	ASD	4.8	7.0	10	11									
	GM	9	9	16	16									
	GSD	1.7	2.6	1.8	2.1									
	NX	0	0	0	0									
58010 2.3 miles northwest of ENL	N	7	9	12	12									
	AM	9	18	19	20									
	ASD	4.9	16	7.2	14									
	GM	8	10	17	15									
	GSD	1.7	4	1.6	2.5									
	NX	0	0	0	0									
58011 3.1 miles northeast of ENL	N	12	12	12	12									
	AM	11	16	20	20									
	ASD	5.0	8.7	8.1	12									
	GM	10	14	19	16									
	GSD	1.6	1.7	1.6	2.0									
	NX	0	0	0	0									
58012 3.3 miles east of Eldorado	N	8	11	12	12									
	AM	8	13	18	16									
	ASD	4.2	11	10	8.6									
	GM	7	11	15	13									
	GSD	1.7	1.9	1.8	2.3									
	NX	0	1	0	0									
58013 Golf and Country Club	N				8	12	12	11	12	12	12	4	3	
	AM				14	30	18	17	14	17	15	25	8	
	ASD				8.2	19	6.0	16	24	8.7	6.6	37	8.6	
	GM				10	26	17	12	5	15	14	9	5	
	GSD				2.9	1.6	1.5	2.5	4.1	1.6	1.4	6.2	4.2	
	NX				0	1	0	2	1	0	0	0	0	

TABLE 37 FLUORIDATION RATE - SUMMARY OF MOE DATA (Cont'd)

		Fluoridation (μg/100 cm^2/month)												
Station		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
58014	N				8	11	11	10	11	12	12	12	10	12
28 Sullivan Street	AM				13	27	15	12	8.0	11	14	14	16	16
	ASD				8.3	24	6.4	9.8	11	5.9	6.3	11.5	10	4.6
	GM				10	21	13	8	5	10	13	11	13	16
	GSD				2.3	1.9	1.9	2.5	3.4	1.6	1.5	2	1.8	1.3
	NX				0	1	0	0	0	0	0	1	0	0
58015	N				8	12	12	12	12	12	12	12	12	12
4 Ward Street	AM				13	23	15	14	11	17	18	20	45	29
	ASD				4.8	23	7.7	12	11	7.4	9.6	13	53	18
	GM				12	18	11	10	7	15	16	18	28	25
	GSD				1.5	1.9	2.8	2.3	2.9	1.6	1.5	1.7	2.7	1.7
	NX				0	1	0	0	0	0	1	1	2	1
58016	N					11	12	12	11	11	12	11	11	11
Rose Glen Road	AM					31	19	22	12	22	21	21	69	32
CNR Tracks	ASD					25	13	21	14	15	15	10	77	17
	GM					25	13	15	6	18	18	19	34	28
	GSD					1.9	3.1	2.6	3.8	2.1	1.6	1.7	3.8	1.7
	NX					1	1	2	0	1	1	0	5	3
58017	N					10	12	12	10	12	12	12	12	12
Spur Gas Station	AM					39	35	40	29	30	25	31	120	49
south of Hwy. 2	ASD					23	23	37	26	16	16	15	130	30
	GM					34	29	29	20	27	22	27	63	41
	GSD					1.7	2.0	2.3	2.7	1.7	1.6	1.6	3.6	1.9
	NX					3	4	3	1	2	1	2	7	5
58026	N							7	11	10			12	12
Eldorado Storage	AM							180	100	230			330	180
Building	ASD							210	84	230			540	120
	GM							100	73	157			197	140
	GSD							3.3	2.4	2.4			2.4	2.1
	NX							5	7	8			11	11
58027	N									3	12	12	11	12
51 Shuter Street	AM									42	53	65	340	110
	ASD									23	42	24	290	57
	GM									36	41	60	190	100
	GSD									2.1	2.1	1.7	3.6	1.7
	NX									1	3	7	8	10
58028	N							7	12	12	12	12	12	12
2 Choate Street	AM							140	36	76	69	110	260	180
	ASD							110	37	39	64	79	250	300
	GM							110	19	66	49	89	160	100
	GSD							2.2	3.9	1.8	2.3	1.9	3.2	2.6
	NX							6	3	7	5	9	8	9
58029	N							7	12	12	12	12	12	12
68 Queen Street	AM							42	12	36	32	21	68	40
	ASD							27	7.4	23	16	11	91	29
	GM							33	9	29	29	19	41	33
	GSD							2.3	2.4	2.0	1.6	1.6	2.5	1.8
	NX							3	0	3	2	1	4	2
58035	N										2	11		
Lakeshore Road	AM										16	9.0		
Port Grandby	ASD										-	5.6		
	GM										16	7		
	GSD										-	1.7		
	NX										0	0		
58036	N										2	12		
Opp. Roy Res.	AM										14	10		
R.R. No. 3	ASG										-	3.5		
Lakeshore Road	GM										14	9		
	GSD										-	1.5		
	NX										0	0		

TABLE 38 NITROGEN OXIDES - SUMMARY OF MOE DATA (Station 58030, 132 King Street, Port Hope)

	Level (µg/g)							
	1979				1980			
Date	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading
January	-	-	-	-	31	0.018	0.040	0.18
February	-	-	-	-	5	0.008	0.020	0.040
March	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-
August	6	0.025	0.030	0.10	-	-	-	-
September	29	0.025	0.050	0.20	-	-	-	-
October	31	0.026	0.070	0.016	-	-	-	-
November	30	0.035	0.080	0.020	-	-	-	-
December	31	0.028	0.050	0.021	-	-	-	-
Annual	127	0.028	0.080	0.021	36	0.016	0.040	0.18

TABLE 39 NITROGEN DIOXIDE - SUMMARY OF MOE DATA (Station 58030, 132 King Street, Port Hope)

	Level (µg/g)							
	1979				1980			
Date	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading
January	-	-	-	-	31	0.013	0.020	0.030
February	-	-	-	-	5	0.008	0.010	0.030
March	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-
August	6	0.016	0.020	0.050	-	-	-	-
September	29	0.018	0.030	0.060	-	-	-	-
October	31	0.019	0.040	0.070	-	-	-	-
November	30	0.022	0.040	0.050	-	-	-	-
December	31	0.019	0.040	0.060	-	-	-	-
Annual	127	0.020	0.040	0.070	36	0.012	0.020	0.030

TABLE 40 NITRIC OXIDE - SUMMARY OF MOE DATA (Station 58030, 132 King Street, Port Hope)

	Level (µg/g)							
	1979				1980			
Date	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading	No. of days	Average Conc.	24-Hour Maximum	Maximum Reading
January	-	-	-	-	31	0.005	0.020	0.16
February	-	-	-	-	5	0.001	0.000	0.001
March	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-
August	8	0.008	0.010	0.090	-	-	-	-
September	30	0.007	0.020	0.15	-	-	-	-
October	31	0.007	0.040	0.13	-	-	-	-
November	30	0.012	0.060	0.17	-	-	-	-
December	31	0.009	0.030	0.19	-	-	-	-
Annual	130	0.009	0.060	0.19	36	0.004	0.020	0.16

TABLE 41 URANIUM AND NITRATE LEVELS IN LAKE ONTARIO OPPOSITE THE ENTRANCE TO PORT HOPE HARBOUR

	Uranium (μg/L)			Nitrate (mg/L)		
	No. of Observations					
Lake Station Locations	Total	Less Than 10 μg/L	Range of Measured Concentrations	No. of Observations	Mean Value	Standard Deviation
50 m west of Harbour entrance	19	18	1 - 41	19	0.24	0.13
50 m east of Harbour entrance	18	16	1 - 25	19	0.31	0.33
100 m south of Harbour entrance	18	17	1 - 160	19	0.33	0.21

Sources: Ontario Ministry of the Environment Monitoring Program Data Summary Sheets for the Port Hope's Welcome and Port Granby areas for the period May 1977 to September 1980.

TABLE 42 TOWN OF PORT HOPE TREATED WATER SUPPLY QUALITY - SUMMARY OF URANIUM CONCENTRATION DATA REPORTED BY HEALTH AND WELFARE CANADA

	Uranium Concentration (μg/L)			
	1978	1979	1980	1981
Minimum Recorded Value	0.17	0.76	0.5	0.4
Maximum Recorded Value	0.90	2.44	2.9	2.6
Mean Annual Concentration	0.50	1.39	1.1	1.6
Standard Deviation	0.24	0.48	0.7	0.7
Number of Observations	6	12	12	12

Source: Environmental Radiation Hazards Division, Radiation Protection Branch, Health and Welfare Canada: Data Summary Dated July 1982. (Tracey, 1982).

APPENDIX C

MODELLING RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL MEDIA

Introduction

Radionuclide concentrations in certain environmental media due to plant emissions must be modelled for use in calculating the dose for the typical individual in the critical group. The models used for this purpose in this report are largely based on data published in U.S. NRC Regulatory Guides (U.S. NRC, 1976, 1982).

Annual average air and water concentrations are required as input data for use in the equations that follow (see Sections 3.3 and 3.4). These equations yield resulting concentrations in environmental media of interest, including total ground surface concentrations, and concentrations in edible vegetation, meat, milk, eggs, poultry, and fish. Calculations are performed for all radionuclides of interest.

The calculated air concentrations are used to obtain total deposition rates onto vegetation (resuspension losses of activity deposited on vegetation are assumed to be accounted for by the application of a weathering half-life). Total deposition rates and ground concentrations are used to compute concentrations in various vegetation types, including hay and forage. Radionuclide concentrations in hay and animal forage are initial inputs for the calculation of radionuclide concentrations in meat, milk, poultry, and eggs ingested by man. Radionuclide concentrations in water are used to compute concentrations in fish.

Ground Concentrations

Radionuclide ground concentrations are computed from the calculated airborne particulate concentrations arising directly from on-site sources. Resuspended particulate concentrations are not considered for evaluating ground concentrations. The deposition rate of radionuclides is calculated using the following relationship:

$$D_i = C_{ai}V \tag{1}$$

where: C_{ai} is the calculated air concentration of radionuclide, i, in Bq/m^3 or $\mu g/m^3$;

D_i is the resulting deposition rate of radionuclide, i, in $Bq/m^2 \cdot s$ or $\mu g/m^2 \cdot s$;

V is the deposition velocity, in m/s (see Section 3.4).

The concentration of radionuclide i on the ground surface due to constant deposition at the rate D_i over time t is obtained from:

$$C_{gi}(t) = D_i \frac{(1 - \exp(-\lambda_i + \lambda_e)t)}{\lambda_i + \lambda_e} \tag{2}$$

where:
$C_{gi}(t)$ is the calculated ground surface concentration of radionuclide i at time t, in Bq/m^2 or $\mu g/m^2$;
t is the time interval over which deposition has occurred, in seconds;
λ_e is the assumed rate constant for environmental loss, in s^{-1};
λ_i is the radioactive decay constant for radionuclide i, in s^{-1}.

The environmental loss constant λ_e corresponds to an assumed half-time for loss of environmental availability of 50 years. This parameter accounts for downward migration in soil and loss of availability due to chemical binding. It is assumed to apply to all radionuclides deposited on the ground. Ingrowth of Pb-210 from Ra-226 can be significant, with large deposition rates of Ra-226. This is equal to:

$C_g(Ra \rightarrow Pb) = D_{Ra} \times 3.04 \times 10^8$ (see U.S. NRC, 1982).

where:
$C_g\ (Ra \rightarrow Pb)$ is the incremental lead-210 concentration resulting from the decay of the radium-226 deposited over the lifetime of the facility (30 years).

It should be noted that this is not a significant source of Pb-210 in dietary intake, as uptake from the soil by vegetation is insignificant compared to surface deposition.

Vegetation Concentrations

Vegetation concentrations are derived from ground concentrations and the deposition rate. The deposition rate (D_i) was defined previously.

Concentrations of airborne materials can be enrivonmentally transferred to the edible portions of vegetables or to hay or pasture grass consumed by animals by two mechanisms: direct foliar retention and root uptake. Five categories of vegetation are considered here: edible above-ground vegetables, potatoes, other edible below-ground vegetables, pasture grass, and hay. Vegetation concentrations are computed using the following equation:

$$C_{vi} = D_i\, F_r\, E_v\ \frac{(1 - \exp(-\lambda_w t_v))}{Y_v \lambda_w} + C_{gi} \frac{B_{vi}}{p} \tag{3}$$

where: B_{vi} is the soil-to-plant transfer coefficient for radionuclide i for vegetation type v (μg/kg (wet) plant per μg/kg (dry) soil) (see Table 43);

C_{vi} is the resulting concentration in vegetation v, in μg/kg or Bq/kg (wet weight);

E_v is the fraction of the foliar deposition retained on edible portions of vegetation, dimensionless;

F_r is the fraction of the total deposition retained on plant surfaces, 0.2, dimensionless;

p is the assumed soil areal density for surface mixing, 240 kg (dry weight)/m^2;

t_v is the assumed duration of exposure while vegetation v is growing, in s;

Y_v is the assumed yield density of vegetation v in kg (wet weight)/m^2; and

λ_w is the decay constant accounting for weathering losses (equivalent to a 14-day half-life), 5.73×10^{-7} s^{-1}.

The value of E_v is assumed to be 1.0 for all above-ground vegetation and 0.1 for all below-ground vegetables. The value of t_v is taken to be 60 days, except for pasture grass, for which a value of 30 days is assumed. The yield density Y_v is taken to be 2.0 kg/m^2, except for pasture grass, for which a value of 0.75 kg/m^2 is applied.

Meat and Milk, Poultry and Egg Concentrations

Radioactive materials can be deposited on grasses, hay, or silage that are eaten by meat animals and that are in turn eaten by man. The equation used to estimate the radionuclide concentration in meat is:

$$C_{bi} = QF_{bi} (F_{pg}C_{pgi} + F_hC_{hi}) \qquad (4)$$

where: C_{bi} is the resulting average concentration of radionuclide i in meat, in μg/kg or Bq/kg;

C_{hi} is the concentration of radionuclide i in hay (or other stored feed), in μg/kg or Bq/kg (wet weight);

C_{pgi} is the concentration of radionuclide i in pasture grass, in μg/kg or Bq/kg (wet weight);

TABLE 43 ENVIRONMENTAL TRANSFER COEFFICIENTS

	Transfer Coefficient				
	U	Th	Ra	Pb	Reference
Plant/Soil (B_{vi})					
(µg/kg plant - wet weight)/(µg/kg soil - dry weight) or (Bq/kg plant - wet weight)/(Bq/kg soil - dry weight)					U.S. NRC (1982)
Edible Above Ground	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}	
Potatoes	2.5×10^{-3}	4.2×10^{-3}	3.0×10^{-3}	4.0×10^{-3}	
Other Below Ground	2.5×10^{-3}	4.2×10^{-3}	1.4×10^{-2}	4.0×10^{-3}	
Pasture Grass	2.5×10^{-3}	4.2×10^{-3}	1.8×10^{-2}	2.8×10^{-2}	
Stored Feed (Hay)	2.5×10^{-3}	4.2×10^{-3}	8.2×10^{-2}	3.6×10^{-2}	
Beef/Feed (F_{bi})					
(µg/kg per µg/day) or (Bq/kg per Bq/day)	3.4×10^{-4}	2.0×10^{-4}	5.1×10^{-4}	7.1×10^{-4}	U.S. NCR (1982)
Milk/Feed (F_{mi})					
(µg/L per µg/day) or (Bq/L per Bq/day)	6.1×10^{-4}	5.0×10^{-6}	5.9×10^{-4}	1.2×10^{-4}	U.S. NCR (1982)
Poultry/Feed (F_{pi})					
(µg/kg per µg/day) or (Bq/kg per Bq/day)	1.2×10^{-3}	4.0×10^{-3}	9.9×10^{-4}	9.9×10^{-4}	Soldat et al. (1974)
Eggs/Feed (F_{ei})					
(µg/kg per µg/day) or (Bq/kg per Bq/day)	3.4×10^{-1}	2.0×10^{-3}	2.0×10^{-3}	9.9×10^{-4}	Soldat et al. (1974)
Fish/Water (B_{fi})					
(µg/kg per µg/L) or (Bq/kg per Bq/day)	2.0	3.0×10^{1}	5.0×10^{1}	1.0×10^{2}	U.S. NCR (1976)

F_{bi} is the feed-to-meat transfer coefficient for radionuclide i ingested, in µg/kg per µg/day (or Bq/kg per Bq/day) (see Table 43);

F_{pg}, F_h are the fractions of the total annual feed requirement assumed to be satisfied by pasture grass or locally grown stored feed (hay) respectively, dimensionless (assumed to be 0.5 and 0.5);

Q is the assumed feed ingestion rate, 50 kg (wet weight)/day.

The equation used to estimate milk concentrations from cows ingesting contaminated feed is:

$$C_{mi} = QF_{mi} (F_{pg}C_{pgi} + F_hC_{hi}) \tag{5}$$

where: C_{mi} is the resulting average concentration of radionuclide i, in µg/L or Bq/L;

F_{mi} is the feed-to-milk transfer coefficient for radionuclide i, in µg/L per µg/day ingested (or Bq/L per Bq/day) (see Table 43).

The equation to estimate the radionuclide concentration in poultry is:

$$C_{pi} = QF_{pi}C_{hi} \tag{6}$$

where: C_{pi} is the resulting average concentration of radionuclide i in poultry meat, in µg/kg or Bq/kg;

C_{hi} is the concentration of radionuclide i in stored feed, in µg/kg or Bq/kg (wet weight);

F_{pi} is the feed-to-meat transfer coefficient for radionuclide i in µg/kg per µg/day ingested (or Bq/kg per Bq/day) (see Table 43);

Q is the assumed feed ingestion rate, 0.12 kg/day.

The equation used to estimate concentrations in eggs from poultry ingesting contaminated feed is:

$$C_{ei} = Q\ F_{ei}\ C_{hi} \tag{7}$$

where:

C_{ei} is the resulting average concentration of radionuclide i in eggs, in µg/kg or Bq/kg;

F_{ei} is the feed-to-egg transfer coefficient of radionuclide i, in µg/kg per µg/day ingested (or Bq/kg per Bq/day) (see Table 43).

Fish Concentrations

Fish concentrations are derived from water concentrations using the following equation:

$$C_{fi} = C_{wi}B_{fi} \tag{8}$$

where:

B_{fi}	is the water-to-fish transfer coefficient for radionuclide i for fish, in µg/kg (wet) per µg/L (or Bq/kg per Bq/L) (see Table 43);
C_{wi}	is the water concentration of radionuclide i, in µg/L or Bq/L;
C_{fi}	is the resulting concentration of radionuclide i in fish, in µg/kg or Bq/kg.

It should be noted that the values shown in Table 43 are generic. Where sound site-specific values exist, consideration should be given to their use.

APPENDIX D

DOSE CALCULATION METHODOLOGY

Introduction

This appendix details the methods used to calculate the radiation exposure of a typical member of the critical group due to releases from the reference facility. Radiation protection limits and the methodology for the application of these limits are outlined, followed by a documentation of the dose calculation model.

Radiation Protection Limits and Dose Calculation Methodology

The radiation exposure regulations implemented in Canada by the AECB are generally based on the recommendations of the ICRP. The present regulations limit the whole-body exposure for members of the public to 5 mSv/a (AECB, 1974, 1978). Dose limits for individual tissues or organs are also prescribed. The AECB is understood to be revising its regulations, in accordance with the latest recommendations of the ICRP (ICRP, 1977).

For stochastic effects, the dose limitation is based on the principle that the risk should be equal whether the whole body is irradiated uniformely or whether there is non-uniform irradiation. This is accomplished if doses received are expressed as whole-body effective dose equivalents, $H_E = \sum_T w_T H_T$, which are given by the sum of the weighted dose equivalents H_T to relevant tissues T. Weighting factors for individual organs or tissues are provided in the recommendations (ICRP, 1977).

H_E must be less than or equal to 5 mSv/a for members of the public. As noted by the ICRP, the application of this limit to individual members of the public is likely to result in average doses of less than 0.5 mSv/a, provided that the practices exposing the public are few and cause little exposure outside the critical groups. In fact, due to the maximizing assumptions usually made in selecting critical groups (see Section 3.3), the doses actually received by the most highly exposed individuals will, in most cases, be considerably lower than the doses postulated for the critical group.

Since it is difficult, especially for internal exposure, to measure directly the dose limits described above, derived limits referring to quantities that can be measured are required. The ICRP (ICRP, 1979) provides tabulations of Annual Limits of Intake (ALI) for inhalation and ingestion of selection radionuclides for adult radiation workers.

An individual who ingests or inhales, in one year, an intake equivalent to an ALI for a particular radionuclide, would be exposed over 50 years to a risk equivalent to the 0.05 Sv/a limit (or to the 0.5 Sv/a individual tissue limit if the ALI is based on a non-stochastic effect). The calculation of the ALI considers several factors such as organ mass, fractional uptake of the radionuclide (i.e., soluble or insoluble) radioactive decay energies, etc.

To cover the cases of intake for a wide range of age groups (infants and adults), Johnson et al. (1979) calculated effective dose equivalent conversion factors based on the ICRP recommendations. The annual dose limit of 5 mSv/a for members of the public can be divided by these dose conversion factors to give the ALI for inhalation and ingestion. The ALIs for adults for the radionuclides of interest to this study are given in Table 44 for various solubility classifications. The solubility classification of several compounds are given in Table 45. Yellowcake is a generic term referring to the products from uranium mills. As a consequence of different processing histories, the term "yellowcake" includes a wide variety of materials with different properties, including different solubilities in lung fluids. Various authors have indicated that yellowcake commonly includes both soluble (class D) and insoluble (class Y) fractions (Kalkwarf, 1979; Eidson and Mewhinney, 1980; Dennis et al., 1982). However, for the purpose of this study, in the absence of facility-specific data, yellowcake was assumed to be entirely class Y material.

As noted by Palmer (1981), Johnson's calculations differ slightly from those of the ICRP because of two main considerations. Firstly, the aerosol diameter used in his calculations for inhalation exposure was 0.3 μm, which is thought to be more appropriate for routine releases to the environment form uranium refineries than the 1.0 μm used by the ICRP. Secondly, Johnshon has reviewed the value used for the fraction of a radionuclide ingested that is absorbed into the blood (f_1) and has included calculations for absorption fractions he considers more appropriate for use with environmentally incorporate radionuclides than the occupational factors used by the ICRP.

Differences in age do affect the doses received by individual members of the public. It has been customary to calculate doses for both infants and adults when assessing releases of radionuclides to the environment (e.g., Palmer, 1981; Ontario Hydro, 1981). However, for the radionuclides of interest in the present study, the combination of age-dependent dose conversion factors and intake rates (food, water, air) would likely result in male adults being the maximally exposed group. Illustrative calculations of age-dependent doses are given in Table 46. The estimates of annual doses for adults are larger

TABLE 44 ANNUAL LIMITS ON INTAKE FOR ADULT MEMBERS OF THE PUBLIC FOR SELECTED RADIONUCLIDES IN THE URANIUM DECAY CHAIN

	ALI (Bq)*	
Radionuclide	Inhalation	Ingestion
Uranium-natural	7.4×10^3 (D)** 2.2×10^3 (W) 1.3×10^2 (Y)	6.4×10^4 (5×10^{-2}) 7.4×10^5 (2×10^{-3})
Thorium-230	6.3×10 (W) 6.2×10 (Y)	2.4×10^2 (3×10^{-2}) 3.6×10^4 (2×10^{-4})
Radium-226	1.9×10^3 (W)	1.6×10^4 (0.2)
Lead-210	1.4×10^3 (D)	3.1×10^3 (0.2)
Polonium-210	2.2×10^3 (D) 2.0×10^3 (W)	9.4×10^3 (0.1)
Thorium-natural	1.1×10 (W) 1.0×10 (Y)	4.0×10 (3×10^{-2}) 5.8×10^3 (2×10^{-4})

* All values are derived from Johnson (1979). Natural thorium is assumed to consist of equal activities of thorium-232 and thorium-228.

** Values in parenthesis refer to ICRP solubility classifications (inhalation) and the fraction (f_1) entering the GI tract that is transferred to blood (ingestion). The ALIs for inhalation assume a 0.3 µm particle size.

than for infants except for the cases of ingestion of foods containing thorium, radium or lead where the largest infant/adult dose ratio is 2.5. It should, however, be noted that these estimates are based on the 50-year dose commitment which results in very conservative dose estimate for infants. On the basis of these calculations, male adults were selected as the critical age group for detailed dose estimation.

The ALI's given in Table 44 are based on the stochastic limit of 5 mSv/a since the nonstochastic limits will not be approached as a result of normal releases to the environment. Also, the ALIs are based on the 50-year effective committeed dose equivalent, i.e., the integral to 50 years of the doses to all body organs following an intake of radioactive material. This means that for radionuclides having a long residence time in the body, such as the bone-seeking uranium compounds, the actual dose received in the early years of a chronic 50-year intake at the ALI would be much less than the annual dose limit. In the case of infants, their changing metabolism (as they grow to adulthood) further reduces to actual dose received.

TABLE 45 SOLUBILITY CLASSES AND f_1 VALUES FOR SELECTED COMPOUNDS*

Compound	f_1**	Inhalation Class
UF_6	5×10^{-2}	D
UO_3	5×10^{-2}	W
UF_4	5×10^{-2}	W
UO_2, U_3O_8	2×10^{-3}	Y
Yellowcake	2×10^{-3}	Y
Thorium oxides and hydroxides	2×10^{-4}	Y
All radium compounds	0.2	W
All lead compounds	0.2	D
Polonium oxides, hydroxides and nitrates	0.1	W

* Data from Johnson et al. (1979) and ICRP (1979).
** Fraction of the ingested activity that reaches the blood.

The ALI for a particular radionuclide is based on the assumption that exposure to radiation results from either ingestion or inhalation of that radionuclide alone. In practice, workers or members of the public are exposed to more than one radionuclide through more than one pathway (e.g., external exposure, ingestion, or inhalation). In such circumstances, the ALI cannot be used directly since the combined doses from external exposure and the intake of radionuclides (each at their ALI) will be greater than the recommended limits. In such instances, the recommended limits will be met if:

$$\frac{\Sigma I_i}{ALI_i} + \frac{E}{5} \leq 1$$

where: I_i is the annual intake of radionuclide i;
E is the annual external exposure (mSv);
5 is the annual stochastic dose limit (mSv).

Dose Calculations

Effective committed dose equivalents (herein referred to as doses) to the typical individual are calculated for inhalation, external exposure to air and ground contamination, and ingestion of vegetables, milk, meat, poultry, eggs, fish and water. Physiological data and dose coversion factors for an adult male are documented on the following pages.

TABLE 46 COMPARISON OF INFANT AND ADULT ANNUAL DOSES FOR REFERENCE RADIONUCLIDE CONCENTRATIONS

Inhalation[a]			Uranium	Thorium-230	Radium-226	Lead-210	Th-nat[d]
Dose Conversion Factor (Sv/Bq):	Infant	(D)	1.4×10^{-6}	-	-	1.6×10^{-5}	-
		(W)	6.8×10^{-6}	2.1×10^{-4}	-	-	1.1×10^{-3}
		(Y)	1.9×10^{-4}	3.1×10^{-4}	8.2×10^{-6}	-	1.7×10^{-3}
	Adult	(D)	6.8×10^{-7}	-	-	3.5×10^{-6}	-
		(W)	2.3×10^{-6}	7.9×10^{-5}	2.6×10^{-6}	-	4.8×10^{-4}
		(Y)	4.0×10^{-5}	8.1×10^{-5}	-	-	4.8×10^{-4}
Annual Dose (Sv/a):	Infant	(D)	1.9×10^{-3}	-	-	2.2×10^{-2}	-
		(W)	9.4×10^{-3}	2.9×10^{-1}	-	-	1.5
		(Y)	2.6×10^{-1}	4.3×10^{-1}	1.1×10^{-2}	-	2.4
	Adult	(D)	5.7×10^{-3}	-	-	2.9×10^{-2}	-
		(W)	7.9×10^{-2}	6.6×10^{-1}	-	-	4.0
		(Y)	3.4×10^{-1}	6.8×10^{-1}	2.2×10^{-2}	-	4.0
Ingestion[b]							
Dose Conversion Factor (Sv/Bq)[c]:	Infant		1.3×10^{-7}	5.5×10^{-5}	1.2×10^{-6}	7.3×10^{-6}	2.8×10^{-4}
			1.0×10^{-8}	3.7×10^{-7}	-	-	1.9×10^{-6}
	Adult		7.8×10^{-8}	2.1×10^{-5}	3.2×10^{-7}	1.6×10^{-6}	1.3×10^{-4}
			6.8×10^{-9}	1.4×10^{-7}	-	-	8.6×10^{-7}
Annual Dose (Sv/a)[c]:	Infant		8.7×10^{-5}	3.8×10^{-2}	8.2×10^{-4}	5.0×10^{-3}	1.9×10^{-1}
			6.7×10^{-6}	2.5×10^{-4}	-	-	1.3×10^{-3}
	Adult		9.7×10^{-5}	2.6×10^{-2}	4.0×10^{-4}	2.0×10^{-3}	1.6×10^{-1}
			8.4×10^{-6}	1.7×10^{-4}	-	-	1.1×10^{-3}

[a] Based on air concentration of 1 Bq/m^3 per radionuclide and inhalation rates of 3.8 m^3/d for infants and 23 m^3/d for adults (ICRP, 1975).

[b] Based on water and milk concentrations of 1 Bq/L, food concentration of 1 Bq/kg, fluid intakes of 1.4 L/d for infants and 2.0 L/d for adults (ICRP, 1975) and food intakes of 0.44 kg/d for infants and 1.4 kg/d for adults (Nutrition Canada, nd).

[c] Multiple values refer to relatively soluble (top line) and insoluble intakes.

[d] 1 Bq of Th-nat assumed to contain 1 Bq each of Th-232 and Th-238.

Inhalation Doses. Inhalation doses are calculated using the following equation:

$$d(inh) = 5 \left[\sum_i \frac{C_{ai} V}{ALI\ (inh)_i} + \frac{C_{Rn}\, E\, f}{0.48} \right]$$

where:		
	$ALI\ (inh)_i$	is the ALI for inhalation or radionuclide i, in µg or Bq;
	C_{ai}	is the air concentration or radionuclide i, in $\mu g/m^3$ or Bq/m^3;
	V	is the volume of air inhaled in one year;
	C_{Rn}	is the air concentration of radon, in mBq/L;
	E	is the factor used to convert radon concentrations to WLM, here taken to be 0.26 WLM/a per mBq/L of radon-222 (see below);
	f	is the fraction of time spent at a receptor location (0.9);
	5	is the annual dose limit, in mSv/a;
	0.48	is the annual limit of exposure to radon daughters, WLM/a;
	d(inh)	is the annual inhalation dose, in mSv/a.

The assessment of dose from exposure to radon daughters assumes that the risk from a radon daughter exposure of 0.48 WLM/a is equal to the risk from a 5 mSv/a whole-body dose. Since the radon daughter risk factor is derived from occupational exposure data, it may overestimate the risk for members of the public (Evans et al., 1981).

External Doses. External doses resulting from exposure to air and ground contamination are computed using dose conversion factors and occupancy factors. The following equation is used to calculate external doses:

$$D(ext) = \sum_i \left(C_{ai}\ DCF_i\ (imm) + C_{gi}\ DCF_i(gnd)\right) OF$$

where:		
	C_{ai}	is the air concentration of radionuclide i, in $\mu g/m^3$ or Bq/m^3;
	C_{gi}	is the ground concentration of radionuclide i, in $\mu g/m^2$ or Bq/m^2;
	d(ext)	is the external whole body dose, in mSv/a;
	$DCF_i(imm)$	is the dose conversion factor for radionuclide i for immersion, in mSv/a per $\mu g/m^2$ (or mSv/a per Bq/m^3)
	$DCF_i(gnd)$	is the dose conversion factor for radionuclide i for ground exposure, in mSv/a per $\mu g/m^2$ (or mSv/a per Bq/m^2);
	OF	is the occupancy factor which accounts for the fraction of the year spent at the location of interest and the shielding of buildings when indoors.

Ingestion Doses. Ingestion doses are based on environmental concentrations established in Appendix C, and ingestion rates and dose conversion factors given in Appendix D.

Ingestion doses from vegetable consumption are calculated assuming that an average of 50% of the initial radioactivity will be lost in food preparation, usually involving washing, peeling, boiling, etc. The following equation is used to compute the annual radionuclide intake via ingestion:

$$I_i = (U_m C_{mi} + U_b C_{bi} + 0.5 \sum_v U_v C_{vi} + U_e C_{ei}) + (U_p C_{pi} + U_f C_{fi} + U_w C_{wi})$$

where:	I_i	is the ingestion rate of radionuclide i, in µg/a or Bq/a;
	$U_m, U_b, U_e, U_p, U_f, U_w$	are milk (L/a), meat (kg/a), eggs (kg/a), poultry (kg/a), fish (kg/a) and water (L/a) ingestion rates adjusted for percent locally grown or obtained;
	U_v	is the ingestion rate of locally grown vegetable category v, in kg(wet weight)/a;
	0.5	is the fraction of vegetable activity remaining after food preparation, dimensionless.

Ingestion doses are then computed by:

$$d\,(\text{ing}) = 5 \sum_i \frac{I_i}{\text{ALI (ing) } i}$$

where:	d (ing)	is the dose for ingestion in mSv/a;
	ALI (ing) i	is the appropriate ALI for ingestion of radionuclide i for the sources considered.

Individual Dose Totals. Total doses to individuals are calculated using the following equation, which sums the dose contributions from inhalation, external exposure, and ingestion:

$$d(\text{tot}) = d(\text{inh}) + d(\text{ing}) + d(\text{ext})$$

where: d(tot) is the total dose, in mSv/a.

Physiological Data for an Adult Male

Annual Inhaled Volume. Annual breathing rates where taken from ICRP 23 (ICRP, 1975) as follows:

8 h working light activity		9.6 m3
8 h nonoccupational activity		9.6 m3
8 h resting		3.6 m3
	daily	23 m3
	annual	8395 m3

It is assumed that this individual spends 90% of his time at the location of highest potential exposure. The remaining 10% is assumed to be at a location(s) with less than 10% of the air concentrations of the critical location and at which the resultant exposures can be neglected.

Annual Water Intake. Annual water intake was also taken from ICRP 23 (ICRP, 1975) as follows:

Daily Tap Water		0.15 L
Daily Other		1.50 L
	Daily	1.65 L
	Annual	600 L

100% of the annual water intake is assumed to be from the town water supply.

Annual Food Consumption Rates. All annual food consumption rates for an adult male living in Ontario were taken from a Nutrition Canada report (Nutrition Canada, nd):

Dairy Products (milk equivalent)	175 L
Meat	79 kg
Fish	8 kg
Eggs	18 kg
Poultry	11 kg
Above-Ground Vegetables (including fruit)	157 kg
Potatoes	64 kg
Other Below-Ground Vegetables	6 kg

The annual intake of dairy products (milk, milk products and cheese, excluding butter) was 415 kg. This was converted to litres using the conversion factor of 420 g equal to 2.1 cups of milk (Nutrition Canada, nd) and 1 cup equal to 0.23 L. The relative percentages of above- versus below-ground vegetables (excluding potatoes) were taken from the U.S. NRC Regulatory Guide (U.S. NRC, 1982). It is assumed that 50% of the above foods are grown at the critical location. Fish are assumed to be 50% local (from the area of the town water intake).

Dose Conversion Factors

Annual limits of intake for inhalation and ingestion were used to convert estimated intakes of each pertinent radionuclide to a predicted dose. Table 47 documents the ALIs used for each plant in the dose calculations.

The variable ALIs used to assess releases of uranium to the air are due to the differing percentages of total emissions in each solubility class assumed for each plant. The following assumptions were made for uranium:

		Assumed Solubility Class	
Plant	Major Air Emissions Type	Inhalation Class	Ingestion (f_1)
UO_3	yellowcake, U_3O_8	Y	2×10^{-3}
UF_6	UO_3, UF_4 (60%)	W	5×10^{-2}
	UO_2 (40%)	Y	2×10^{-3}
UO_2	UO_2, ADU*, U_3O_8	Y	2×10^{-3}
Metals	UF_4 (60%)	W	5×10^{-2}
	other (40%)	Y	2×10^{-3}

* Assumed to be insoluble for this study.

The ALI for the mot restrictive solubility class was selected for assessing releases of other radionuclides to the air for either the inhalation or ingestion pathways. For assessing releases to the water, the ALI for ingestion of the nuclide in its most restrictive solubility class was used.

Table 48 lists the immersion and groundshine dose conversion factors used to estimate external doses. An effective reduction factor of 0.7 due to structural shielding for indoor exposure was used to adjust these factors as appropriate (U.S. NRC, 1982). It was assumed that an individual spends 14 hours a day indoors.

TABLE 47 ANNUAL LIMITS OF INTAKE USED IN THIS STUDY

	Plant			
Radionuclide	UO_3	UF_6	UO_2	Metals
Inhalation				
U-nat (µg)	5.3×10^3	1.2×10^4	5.3×10^3	1.2×10^4
Th-230 (Bq)	6.2×10^1	6.2×10^1	6.2×10^1	NA
Ra-226 (Bq)	1.9×10^3	NA	NA	NA
Pb-210 (Bq)	NA	NA	1.4×10^3	NA
Th-nat* (Bq)	1.0×10^1	1.0×10^1	1.0×10^1	1.0×10^1
Ingestion				
U-nat (µg):				
Air Releases	2.9×10^7	1.3×10^7	2.9×10^7	1.3×10^7
Water Releases	2.6×10^6	2.6×10^6	2.6×10^6	2.6×10^6
Th-230 (Bq)	2.4×10^2	2.4×10^2	2.4×10^2	NA
Ra-226 (Bq)	1.6×10^4	NA	NA	NA
Pb-210 (Bq)	NA	NA	3.1×10^3	NA
Th-nat* (Bq)	4.0×10^1	4.0×10^1	4.0×10^1	4.0×10^1

NA = not applicable.

* These are expressed as Bq of Th-232, assuming Th-228 is in equilibrium.

TABLE 48 EXTERNAL DOSE CONVERSION FACTORS (Kocher, 1982)

Radionuclide	Immersion (mSv/a per µg or Bq/m^3)	Groundshine (mSv/a per µg or Bq/m^2)
U-nat (µg)	9.0×10^{-8}	2.4×10^{-9}
Th-230 (Bq)	5.4×10^{-7}	2.6×10^{-8}
Ra-226 (Bq)	9.4×10^{-6}	2.1×10^{-7}
Rn-222 (Bq)	5.3×10^{-10}	-
Pb-210 (Bq)	1.9×10^{-6}	8.5×10^{-8}
Th-nat* (Bq)	3.0×10^{-6}	9.6×10^{-8}

* These are expressed as Bq of Th-232, assuming Th-228 is in equilibrium.