1998 ANNUAL REPORT OF RADIOLOGICAL MONITORING RESULTS FOR THE CHALK RIVER AND WHITESHELL LABORATORIES SITES

VOLUME 3 – ENVIRONMENTAL MONITORING

1. INTRODUCTION

1.1 Purpose and Scope

This report summarizes the results of environmental monitoring for AECL's Chalk River Laboratories (CRL) site located on the Ottawa River shore near Chalk River, Ontario, and for AECL's Whiteshell Laboratories (WL) site located on the Winnipeg River shore near Pinawa, Manitoba. These laboratories operate under the terms of the Nuclear Research and Test Establishment Licences granted by the Atomic Energy Control Board (AECB) [1, 2].

The CRL and WL licences require that AECL submits to the AECB annual reports for each calendar year summarizing the results of monitoring of radiation dose to personnel at the sites, the results of monitoring of radioactive materials in airborne and liquid effluents from the sites, and the results of environmental monitoring at the sites and surrounding areas. AECL reports the monitoring results in a three volume report entitled "Annual Report of Radiological Monitoring Results for the Chalk River Laboratories and Whiteshell Laboratories Sites", AECL-MISC-362. This report, Volume 3 of AECL-MISC-362, addresses the licence requirement regarding environmental monitoring for the CRL and WL sites for the calendar year 1998. Results of personnel dose monitoring and effluent monitoring for 1998 are reported in Volumes 1 and 2 of AECL-MISC-362-98, respectively.

1.2 Site Environmental Monitoring Programs

AECL maintains comprehensive Site Environmental Monitoring Programs for both CRL and WL to ensure that radiation doses as a result of releases of radioactive material in site effluents remain well below the annual dose limits for members of the public specified in the Atomic Energy Control (AEC) Regulations[2] and, as low as reasonably achievable, economic and social factors being taken into account (ALARA). The primary objectives of the CRL and WL site Environmental Monitoring Programs are:

- to provide a quantitative record of radioactive contaminants in the environment resulting from operation of the site(s), which will permit assessment of actual or potential radiation doses to critical groups and populations;
- to provide data to confirm compliance with regulatory limits and other guidelines, and to provide public assurance of compliance;
- to provide verification of the effectiveness of facility operation and control of emissions, and the adequacy of effluent monitoring; and
- to provide data to verify or refine the assumptions and models used in DRL calculations for the site(s), where applicable.

The following secondary objectives are also considered in the design of the site Environmental Monitoring Programs:

- to provide data for trend analysis;
- to provide baseline data and capability for monitoring and assessment in the event of emergency conditions; and
- to provide information and assurance to the public about radiological hazards involved in site operations.

The designs of the monitoring programs for the CRL and WL sites are generally consistent with guidelines in the National Standard of Canada, CAN/CSA-N.288.4 [7]. The programs take into account the facilities and processes at the sites, actual emissions from the sites, the environmental pathways leading to radiation dose to the most highly exposed members of the public (i.e., critical group[3]) as identified by the Derived Release Limits (DRLs)[4] calculations

---

[2] The regulatory limit in Canada for radiation dose to members of the public from operations and products involving ionizing radiation (excluding medical procedures and occupational doses) is 5 mSv per year. The Atomic Energy Control Board has proposed to reduce this limit to 1 mSv per year, to bring Canada in line with 1990 recommendations by the International Commission on Radiological Protection (ICRP publication 60 [13]).

[3] A critical group is an identifiable, relatively homogeneous group of people expected to receive the highest radiation dose as a result of radioactive emissions from a given facility or site [7].

[4] Derived release limits (DRLs) are the upper limits, approved by the Regulatory Authority (AECB in Canada), for releases of radioactive materials in emissions from a nuclear facility or site, derived on the basis of the dose limits for members of the public

for personnel at the sites and outside the sites, past monitoring results, as well as various historic, public and scientific considerations. Because the monitoring programs for CRL and WL have evolved somewhat separately, and because of differences in the types of site facilities and processes, types and quantities of radioactive emissions, and site histories, the programs at the two sites differ in various aspects. Specific designs of the programs for both sites may change from time to time in response to changes in these various factors.

The Site Environmental Monitoring Programs for both CRL and WL operate under the direction of AECL's Environmental Protection Program, as defined in the AECL Environmental Protection Program Manual, RC-2000-021 [8]. Monitoring is conducted by groups independent of the direct line management of the CRL and WL facilities.

1.3 CRL and WL Facilities, Operations and Radioactive Emissions

AECL's CRL and WL sites are broad-based installations for nuclear research, development and demonstration, and operate a variety of nuclear facilities. The respective Nuclear Research and Establishment Licences [1, 2] list the main nuclear facilities at each site. In addition, there is a variety of smaller research, development and analytical laboratories at both CRL and WL. The main facilities contributing radioactive emissions from the CRL site are the NRU Research Reactor, the Molybdenum-99 Radioisotope Production Facility, the Heavy Water Upgrading Plant, the Universal Cells, the Fuels and Materials Cells (FMC), the Waste Treatment Centre and the Waste Management Areas. The main facilities contributing radioactive emissions from the WL site are the Shielded Facilities that include the Hot Cell Facility and the Immobilized Fuel Test Facility, and the Active Liquid Waste Treatment Centre. There are no longer any operating nuclear reactors at the WL site.

Detailed results of the monitoring of radioactive material in airborne and liquid effluents from the CRL and WL sites are in Volume 2 of AECL-MISC-362-98 [3]. The following Tables 1 to 4 contain a brief summary of airborne and liquid releases from CRL and WL during 1998. The releases are expressed as average quantities per monitoring periods (in becquerels (Bq)) and as percentages of the applicable Derived Release Limit (DRL) [4, 6] based on most heavily exposed members of the public outside the site boundaries (this is, critical groups). Tables 1 to 4 also indicate the critical groups outside the sites, and the dominant exposure pathways to the critical groups, as identified by the DRL calculations, using the methodology of the National Standard of Canada, CAN/CSA N288.1 [7]. For practical purposes, the sum of site releases during the year, as percent of the DRLs, represents a generally conservative upper bound radiation dose (as a percent of the regulatory dose limit for members of the public, 5 mSv in a year) to the most heavily exposed members of the public, due to emissions from the site.

Table 1: CRL Air Emissions – Average Releases in 1998 and Dominant Environmental Pathways

Radionuclide	DRL[1] (Bq/wk)	1998 Avg. Releases [3] Bq/week	% DRL_b	Dominant Dose Pathway [4]	Critical Group [4]
Argon-41	1.5E+16	3.6E+14	2.4E+00	Air Immersion	Infants at Balmer Bay
Mixed Noble Gas	7.4E+15	7.8E+12	1.1E-01	Air Immersion	Infants at Balmer Bay
Tritium (HTO)	3.1E+16	4.6E+12	1.5E-02	Milk Ingestion	Infants at Sheenboro
Tritium (Elemental)	1.4E+18	5.7E+10	4.0E-06	Milk Ingestion	Infants at Sheenboro
Carbon-14 (CO_2)	1.9E+14	1.3E+10	6.6E-03	Milk Ingestion	Infants at Sheenboro
Iodine -131	1.4E+11	2.5E+08	1.8E-01	Milk Ingestion	Infants at Sheenboro
Iodine -125	9.0E+10	2.1E+07	2.3E-02	Milk Ingestion	Infants at Sheenboro
Gross Beta Particulates assuming all Sr-90	4.3E+11	4.7E+06	1.1E-03	Exposure to Contaminated Ground	Adults and Infants at Balmer Bay
Gross Alpha Particulates assuming all Pu-239	5.2E+09	9.1E+03	1.8E-04	Air Inhalation	Adults at Balmer Bay
assuming all U-234	1.9E+10	3.0E+01	1.5E-07	Air Inhalation	Adults at Balmer Bay
Site Total			2.8E+00		

1) DRL in effect as of 1998 November 01 [1, 4], superseding the earlier DRLs defined in [5].

by means of environmental pathway analysis. The DRLs in effect for the CRL and WL sites are given in references [4] and [6], respectively. The DRLs for CRL [4] came in effect on 1998 November 01, as a condition of the renewed CRL Nuclear Research and Test Establishment Licence [1], superseding the DRL values defined in [5]. The new CRL DRLs have been calculated for the most heavily exposed members of the public outside the site boundaries.

Table 2: CRL Liquid Effluents -- Average Releases in 1998 and Dominant Dose Pathways

Radionuclide	DRL (Bq/month)	1998 Average Release [3] (Bq/month)	% DRL	Dominant Pathway [4]	Critical Group [4]
Releases to Ottawa River					
Phosphorus-32	2.13E+12	1.40E+09	6.57E-02	Fish Ingestion	Adults at Ft. William
Caesium-137	6.80E+12	3.13E+09	4.60E-02	Fish Ingestion	Adults at Ft. William
Tritium Oxide	6.65E+17	1.17E+13	1.75E-03	Water Ingestion	Infants, Ft. William
Strontium-90	3.54E+13	3.44E+08	9.72E-04	External Exposure from Ground Deposits	Adults and Infants at Ft. William
Cobalt-60	3.85E+13	2.41E+09	6.26E-03	External Exposures from Ground Deposits	Infants at Ft. William
Caesium-134	5.08E+12	1.91E+08	3.76E-03	Fish Ingestion	Adults at Ft. William
Sodium-24	4.85E+15	1.39E+11	2.87E-03	Fish Ingestion	Adults at Ft. William
Arsenic-76	2.95E+14	8.01E+09	2.72E-03	Fish Ingestion	Adults at Ft. William
Iodine-131	2.60E+13	2.67E+08	1.03E-03	Water Ingestion	Adults at Ft. William
Cerium-144	1.80E+14	3.97E+08	2.21E-04	Water Ingestion	Adults at Ft. William
Gross Alpha (as americium-241)	2.60E+12	2.80E+08	1.08E-02	Fish Ingestion	Adults at Ft. William
Gross Beta (as strontium-90)	3.54E+13	2.31E+09	6.53E-03	External Exposure from Ground Deposits	Adults at Ft. William
Other Nuclides		1.02E+10	4.55E-03	Fish and Water Ingestion, Beach Exposure	Adults and Infants at Ft. William
		TOTAL	1.53E-01		
Releases to Maskinonge Lake					
Tritium Oxide	2.38E+16	1.08E+12	4.54E-03	Water Ingestion	Adults at Sturgeon (Chalk) Lake
Gross Alpha (as americium-241)	1.13E+10	2.29E+06	2.03E-02	Fish Ingestion	Adults at Sturgeon (Chalk) Lake
Gross Beta (as strontium-90)	2.60E+11	9.90E+07	3.81E-02	Fish Ingestion	Adults at Sturgeon (Chalk) Lake
		TOTAL	6.29E-02		
CRL SITE TOTAL			2.16E-01		

Table 3: WL Air Effluents -- Average Releases in 1998 and Dominant Dose Pathways

Source	Average Release [3] (Bq/week)	(% DRL $_b$)*	Dominant Dose Pathway [6]	Critical Group [6]
Tritium:	1.9E+09	1.9E-05	Inhalation	Adult at boundary
Gross Beta Particulates -assuming all Sr-90	4.5E+04	1.5E-04	Vegetable Ingestion Contaminated Ground	Infant at boundary Adult at boundary
Iodine-131	9.6E+04	1.3E-03	Vegetable Ingestion	Infant at boundary
Site Total - Airborne		1.5E-03		

*DRL_b = DRL based on critical group at site boundary

Table 4: WL Liquid Effluents -- Average Releases in 1998 and Dominant Dose Pathways

Source	Average Release [2] (Bq/month)	(% DRL)	Dominant Dose Pathway [6]	Critical Group [6]
Caesium-137	4.2E+07	2.7E-03	Fish Ingestion	Adult at downstream boundary
Strontium-90	1.5E+07	3.7E-04	Vegetable Irrigation/Ingestion	Infant at downstream boundary
Cobalt-60	8.2E+04	2.6E-06	Fish Ingestion	Adult at downstream boundary
Gross Alpha (assuming Am-241)	9.1E+04	2.8E-05	Vegetable Irrigation/Ingestion	Infant at downstream boundary
Site Total - Liquid		9.6E-03		

2. CRL ENVIRONMENTAL MONITORING PROGRAM AND RESULTS FOR 1998

2.1 CRL Site Location

AECL's CRL site is located in Ontario on the south shore of the Ottawa River, about 200 km Northwest of Ottawa. Nearby communities include Chalk River, Deep River, Petawawa and Pembroke. A map of the CRL site and surrounding areas is in Appendix 1.

2.2 CRL Environmental Monitoring Program and Results

For CRL, the Environmental Monitoring Program includes the following:

a) Monitoring of airborne effluent exposure pathways:
- meteorological conditions;
- ambient gamma radiation;
- ambient tritium in air;
- atmospheric deposition of radioactive material;
- land gamma radiation;
- radioactivity in milk; and
- radioactivity in vegetation.

b) Monitoring of liquid effluent exposure pathways:
- radioactivity in Ottawa River water;
- radioactivity in fish from the Ottawa River;
- radioactivity in beach sediments on the Ottawa River;
- radioactivity in surface waters at the site; and
- radioactivity in surface waters outside the site.

Sampling locations for this monitoring are shown on maps in Appendix 1. Monitoring results for 1998 are presented in the following sections, 2.3 through 2.12. Dose estimates to members of the critical groups outside the site boundaries, based on the environmental monitoring results are in Section 4.

2.3 Ambient Gamma Radiation in Air

For CRL, ambient gamma radiation in air was monitored using two methods, namely thermoluminescent dosimetry (TLD) measurements with lithium fluoride (see Section 2.3.1) and continuously logging Geiger tube system (Gamma Tracer). The time-based Gamma Tracer measurements were intended, in particular, to distinguish dose contributions from CRL effluents from natural background dose (see section 2.3.2), which cannot be easily done with the accumulated total exposure records provided by the TLDs.

2.3.1 Monitoring with Thermoluminescent Dosimeters

In 1998, AECL maintained a network of 34 thermoluminescent dosimeter (TLD) monitoring stations at and around the CRL site and in neighbouring communities to monitor ambient radiation dose in air (air kerma). Eight of the monitoring stations were within the CRL site, 10 at the site boundary, and 16 in neighbouring communities. Maps 1 and 2 in Appendix 1 show the locations of the monitoring stations.

At the monitoring stations, the lithium fluoride (LiF) TLDs continuously measured the integrated exposure from natural background radiation and, exposure contribution from airborne radioactive material released from CRL facilities, primarily the noble gas argon-41 exposure. Each monitoring station contained two TLD badges, each holding duplicate LiF chips in plaques. One of the TLD badges was collected and analyzed quarterly[5] and the other annually. Each TLD reading was corrected for exposure during storage, handling and transport by subtracting the exposure received by "control" TLDs. During the actual measurement period, the control TLDs remained inside lead shielding in a specifically constructed building at the CRL west boundary where the background radiation, from subsoil, radon and building materials is very low. Consequently, the final TLD results do not include exposure from high energy cosmic radiation that penetrates the lead shielding in which the control TLDs are stored.

[5] Quarterly collection of TLDs is not possible at four locations that are normally inaccessible in winter.

A summary of the monitoring results for 1998 is in Table 5. Figure 1 depicts the total annual dose measured by the TLD method at four key monitoring locations on and off-site, in the dominant wind directions, for 1991 to 1998.

For comparison, external exposure from terrestrial gamma background radiation (due to naturally occurring radionuclides in the earth, air (radon), and building materials) in Canada averages about 330 ± 185 micrograys (μGy) per year [16]. Considerable variations in the levels of natural terrestrial background exposure can occur at different locations and times, due to factors such as types of rock and soil, type and source of material used building construction, building ventilation, depth of snow cover and levels of soil moisture.

Several of the TLD results for the CRL site indicate dose contributions in excess of natural background from CRL operations, primarily due to emissions of the noble gas argon-41 (half-life 1.8 hours) from the NRU/NRX reactor stack [3]. Individual radiation doses to on-site personnel were monitored under AECL's Radiation Protection Program, and results are discussed in [12].

The monitoring results for ambient gamma radiation in air at the CRL site boundary and off-site locations, obtained with TLD measurements, were comparable with the previous six years, after shut down of the NRX reactor in 1992 (see Figure 1) and, in general, within the normal range of variation in levels of natural background radiation in Canada.

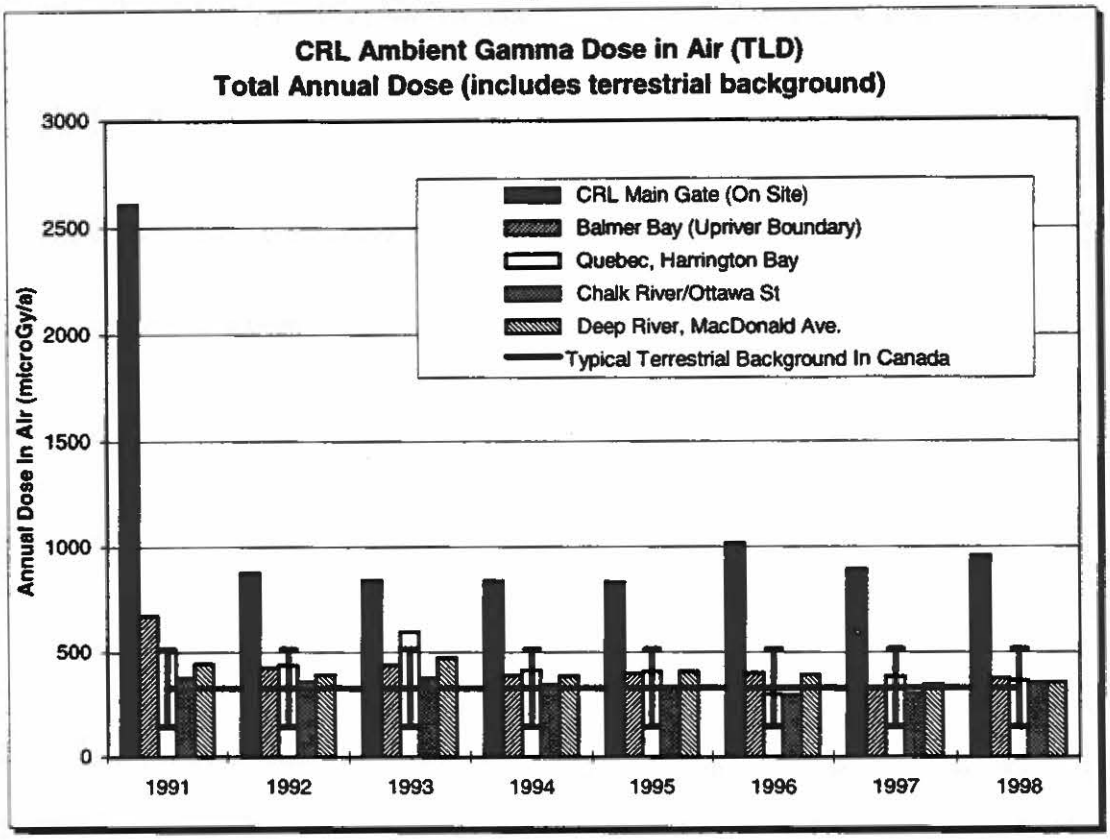
Table 5: CRL Ambient Gamma Radiation Dose In Air Monitoring with TLDs – 1998

TLD Stn. CODE AND LOCATION		Ambient Radiation Dose in Air (Air Kerma) (μGy) (a)						
		Q1	Q2	Q3	Q4	Sum Q1-4	Annual	Average Qtrs & Ann.
	CRL ON-SITE							
T9	*Main Gate*	175	197	222	223	816	828	822
T10	*Bldg. 513, Indoors*	140	140	150	187	617	605	611
T16	*Cafeteria (indoors)*	134	194	167	236	731	808	770
T26	*PIC (indoors)*	205	237	233	269	944	920	932
T27	*PIC (outdoors)*	205	256	253	330	1044	996	1020
T11	*Mattawa Road, Acid Rain Stn.*	94	110	105	114	423	433	428
T33	*Perch Lake Main*	85	75	85	87	332	295	314
T34	*C-2 Fire Trail at Hydro Line*	39	80	58	77	254	244	249
	CRL SITE BOUNDARY							
T1	*Pointe au Baptême*	62	94	109	110	375	384	379
T2	*Perch Lake Satellite*	36	46	55	61	198	201	200
T3	*C-2 Fire Trail*	48	64	67	77	256	237	247
T4	*Ball Diamond b)*	Outlier*	119	88	132	453	399	426
T5	*Chalk River, Ottawa St.*	53	102	88	117	361	346	353
T6	*Mountainview Subdivision*	58	96	67	114	336	295	315
T7	*West Gate at Hydro Line*	56	70	67	81	274	277	276
T8	*Balmer Bay (Sawchuk)*	73	96	91	123	383	375	379
T32	*East Mattawa Road*	62	78	104	96	341	343	342
T43	*Bldg 560*	67	70	70	87	293	265	279
	OFF-SITE							
T12	*Deep River, MacDonald Ave.*	67	99	91	112	370	347	358
T13	*Quebec, Opposite CRL 1)*	N/A	N/A	125	N/A	#N/A	970	#N/A
T15	*Quebec, Harrington Bay*	24	117	84	117	343	388	365
T19	*Quebec, Oiseau Point (Hilborn) 2)*	N/A	N/A	73	N/A	#N/A	286	#N/A
T20	*Petawawa, Gutzman Rd b)*	Outlier*	75	52	88	286	249	267
T21	*Petawawa, Portage Rd*	64	108	95	123	389	345	367
T22	*Pembroke, Lloyd Rd.*	47	78	70	96	292	282	287
T23	*Quebec, Ft. William*	37	69	64	84	254	233	244
T24	*Deep River Hydro Yard b)*	Outlier*	109	71	124	404	410	407
T25	*Quebec, Schyan River 1)*	N/A	N/A	77	N/A	#N/A	733	#N/A
T28	*Quebec, Des Joachims*	60	120	76	126	382	291	336
T29	*Highway 17, NPD Gate b)*	Outlier*	67	38	73	237	249	243
T31	*Point Stewart 1)*	N/A	N/A	100	N/A	#N/A	792	#N/A
T35	*Petawawa Fire Hall*	66	122	116	141	444	478	461
T40	*Demers Centre*	44	92	95	110	340	355	347
T41	*Chichester*	31	80	66	89	265	277	271

(a) Reported results exclude dose from cosmic radiation due to subtraction of exposure to control TLDs.
(b) Reported sum of quarterly TLD results is extrapolation from results for 3 quarters where 1 quarterly result missing.
1) Monitoring period for "Annual" was 1997 July 01 to 1998 June 30.
2) Monitoring period for "Annual" was 1997 October 30 to 1998 June 30.

* Outlier – Exceptionally low value.

Figure 1



2.3.2 Monitoring with GammaTracer System

In addition to ambient gamma radiation measurements with TLDs, three automated continuously logging low level ambient radiation detectors containing dual Geiger tubes ("GammaTracer" units) were used in three key locations, to provide a more accurate measurement of natural background radiation dose and the dose contribution from noble gases (primarily argon-41) from CRL operations. The units were located at Balmer Bay, Harrington Bay, and CRL building 560 (CRL Boundary at Plant Road in Chalk River), near TLD stations 8, 15 and 43, respectively. Balmer Bay and Harrington Bay are the locations of the nearest permanent and seasonal residents in the directions of the two predominant wind directions relative to the CRL site. Consequently, monitoring at these locations provides representative values of doses to the most heavily exposed members of the public. The GammaTracer station at CRL building 560 provides a measure of doses to residents of the town of Chalk River, the closest village but which is located in a relatively low-frequency wind direction. Periods when the plume from CRL operations was passing over the detectors can be readily identified on the records of radiation field versus time. Figure 2 is a sample of the Gamma Tracer results for Balmer Bay, displayed in nanosieverts per hour (nSv/h (H*10)) for 1998. The dose contribution from CRL operations was determined from the GammaTracer results for these three locations, by subtracting the measured baseline background radiation dose from the total dose received during the monitoring period.

Table 6 summarizes the GammaTracer monitoring results for 1998[6]. The results are expressed as ambient dose equivalent (H*10) Sieverts (see [13]). The dose contribution from CRL is also expressed as absorbed dose in air (air kerma, Gy) using conversion factor from the US Department of Energy international intercomparison of

[6] Problems in downloading data in March and July occurred. This led to the loss of some data for Building 560 and Harrington Bay. The problem was traced to a weak battery in the IR transceiver. Consequently, the third quarter ended 98-09-24 and 98-09-25 at Building 560 and Balmer Bay, respectively. Due to another problem with downloading, the third quarter did not end until 98-10-08 at Harrington Bay. The data were aligned the to the first day and last day of each quarter for the rest of the quarters and the end of the year.

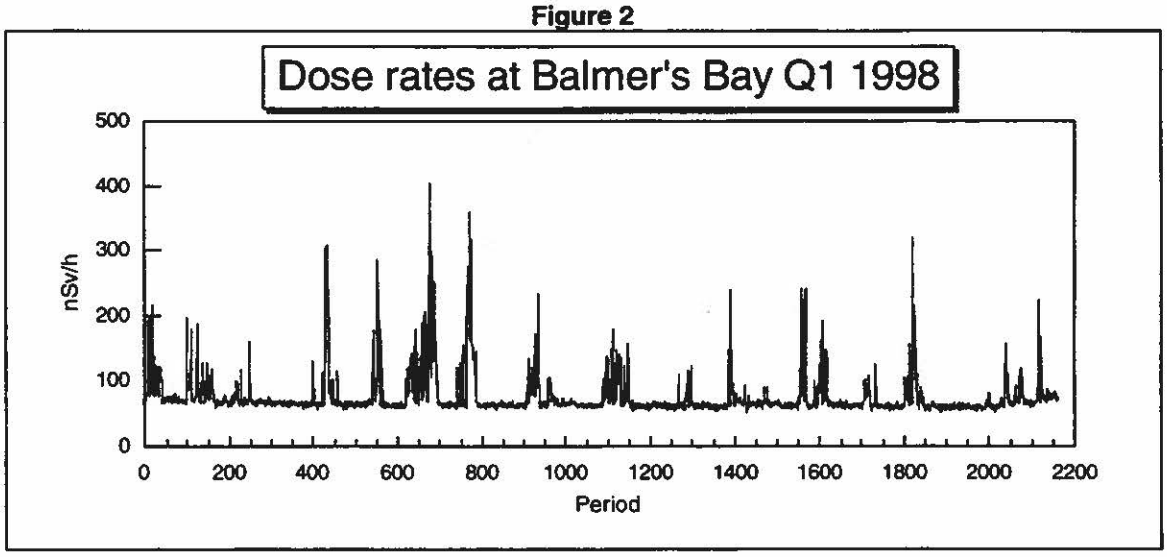
environmental dosimeters [15]. Average annual background dose rates at the three locations (about 74 nSv (H*10)/h or about 540 μGy/a) are consistent with the typical background dose rates in Canada due to terrestrial (330±185 μGy/a) plus cosmic radiation value (240 μGy/a) provided in reference [17].

Table 6: CRL Ambient Radiation Dose in Air – Gamma Tracer Measurements – 1998

Location (Code and Description)/ Period	Total Dose Rate (nSv/h)	Background Dose rate (nSv/h)	Contribution From CRL Noble Gases		
			Dose Rate (nSv/h)	Total Dose for Period	
				(μSv)	(μGy) *(1)*
H9 Bldg. 560 (CRL Boundary at Plant Road)					
1st Quarter	62.8	60.4	2.4	4.9	4.1
2nd Quarter	77.8	75.1	2.6	5.7	4.8
3rd Quarter	79.6	77.7	1.9	3.9	3.2
4th Quarter	75.2	73.5	1.7	3.9	3.3
Average	73.9	71.7	2.2	4.6	3.8
Total				18.4	15.4
H8 Balmer Bay					
1st Quarter	76.5	64.0	12.5	27.1	22.6
2nd Quarter	92.0	83.3	8.7	19.1	15.9
3rd Quarter	97.5	86.8	10.6	22.1	18.4
4th Quarter	95.4	82.2	13.1	30.8	25.6
Average	90.4	79.1	11.2	24.8	20.6
Total				99.0	82.5
H15 Harrington Bay					
1st Quarter	74.1	69.9	4.2	8.4	7.0
2nd Quarter	90.7	87.2	3.5	7.9	6.6
3rd Quarter	96.1	92.4	3.6	8.6	7.2
4th Quarter	92.7	90.7	2.0	4.0	3.3
Average	88.4	85.1	3.3	7.2	6.0
Total				28.9	24.1

1. Background radiation dose includes both terrestrial and cosmic radiation.
2. GammaTracer units were calibrated in "Ambient Dose Equivalent" sieverts (H*10) [13].
3. Converted to absorbed dose in air (air kerma) using conversion factor 1.2 Sv (H*10)/Gy [15].

Figure 2



2.4 Ambient Tritium in Air

Ambient tritium in air concentrations were monitored during 1998 at a total of 11 locations within the CRL site, at the site boundary and off-site. Monitoring was done with passive diffusion samplers designed to sample the ambient air at a rate of 1 litre per day, using sampler fluid that consisted of 50% glycol and 50% water. Sampler fluid was analyzed by liquid scintillation counting. The samplers were collected and analyzed quarterly to coincide with the TLD analysis frequency.

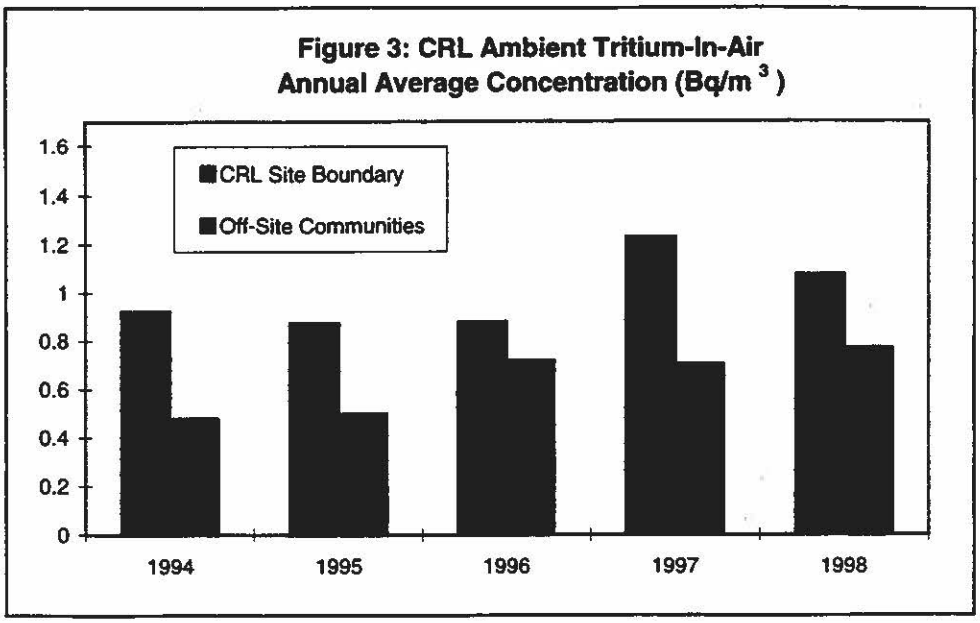
The 1998 results for tritium in air monitoring are in Table 7. Figure 3 shows the annual average concentrations of tritium in air at site boundary stations and in off-site locations for the past five years. Natural background levels of tritium in air in Ontario and Quebec, based on measurements by Health Canada, range from about 0.09 to 0.26 Bq/m^3 [14].

As during earlier years, the tritium in air concentrations at the monitored locations were higher than the natural tritium background. An exception to this, in 1998, were the results for Mountain View Subdivision, close to CRL boundary, where no increase above natural background was observed. The average tritium in air concentrations for the monitored locations close to CRL boundary somewhat decreased compared with 1997, whereas the average values for off-site monitoring locations (Deep River and Petawawa) slightly increased. It must be noted that the values for Petawawa may be affected by the emissions from a local industrial source of tritium, other than AECL, in the area.

Table 7: CRL Ambient Tritium in Air – Average Quarterly and Annual Concentrations in 1998

Stn. Code and #	LOCATION	Q 1 (Bq/m^3)	Q 2 (Bq/m^3)	Q 3 (Bq/m^3)	Q 4 (Bq/m^3)	Mean (Bq/m^3)	Std. Dev. (Bq/m^3)	Mean 1997 (Bq/m^3)
	ON-SITE							
H9	Main Gate, Bldg 449J	14.3 ± 0.1	11.5 ± 0.1	9.7 ± 0.1	5.2 ± 0.1	10.15	3.82	6.8
H568	Sewage Treatment Plant	20.9 ± 0.3	29.1 ± 0.3	23.3 ± 0.3	16.6 ± 0.3	22.47	5.19	27.4
H145I	Bldg 145, Indoors	30.1 ± 0.3	43.6 ± 0.3	32.5 ± 0.3	16.7 ± 0.03	30.75	11.03	37.2
H145O	Bldg 145, Outdoors	38.8 ± 0.5	56.9 ± 0.4	41.5 ± 0.3	27.5 ± 0.3	41.16	12.11	90.1
	CRL SITE BOUNDARY							
H1	CRL Sandspit	2.9 ± 0.1	3.4 ± 0.1	3.1 ± 0.1	1.6 ± 0.04	2.71	0.80	3.02
H4	CRL Ball Diamond	0.4 ± 0.1	0.3 ± 0.1	0.5 ± 0.03	0.4 ± 0.03	0.39	0.08	0.46
H6	Mountain View Subdivision	0.1 ± 0.1	0.4 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.23	0.16	0.40
H8	Balmer Bay, Sawchuck's	1.1 ± 0.1	1.0 ± 0.1	1.1 ± 0.04	0.6 ± 0.04	0.97	0.23	1.04
	OFF-SITE							
H12	MacDonald, Deep River	0.7 ± 0.1	1.3 ± 0.1	1.1 ± 0.1	0.2 ± 0.02	0.82	0.46	0.46
H15	Harrington Bay	1.0 ± 0.1	1.0 ± 0.1	0.6 ± 0.1	0.4 ± 0.1	0.74	0.31	0.73
H35	Petawawa Fire Hall [1)]	1.2 ± 0.1	Sample lost	0.7 ± 0.1	0.4 ± 0.03	0.76	0.41	0.93

1) Monitoring results for Petawawa may be influenced by emissions from local industry in the area, other than AECL.



2.5 Atmospheric Deposition of Radioactive Material

Total wet and dry atmospheric deposition was collected at four locations in open buckets positioned about one metre above the ground. The accumulated deposition was removed from the buckets monthly, and analyzed for gross beta activity and gross alpha activity. Table 8 provides average and range of monthly gross beta activity and gross alpha activity in total atmospheric deposition at the four deposition monitoring stations at CRL site boundary during 1998. The deposition monitoring is primarily intended to serve as a gross trend indicator since it represents an intermediate step in environmental exposure pathways. It also serves as a baseline for emergency preparedness purposes and provides confirmation of the absence of significant quantities of radioactive particulate material in airborne emissions.

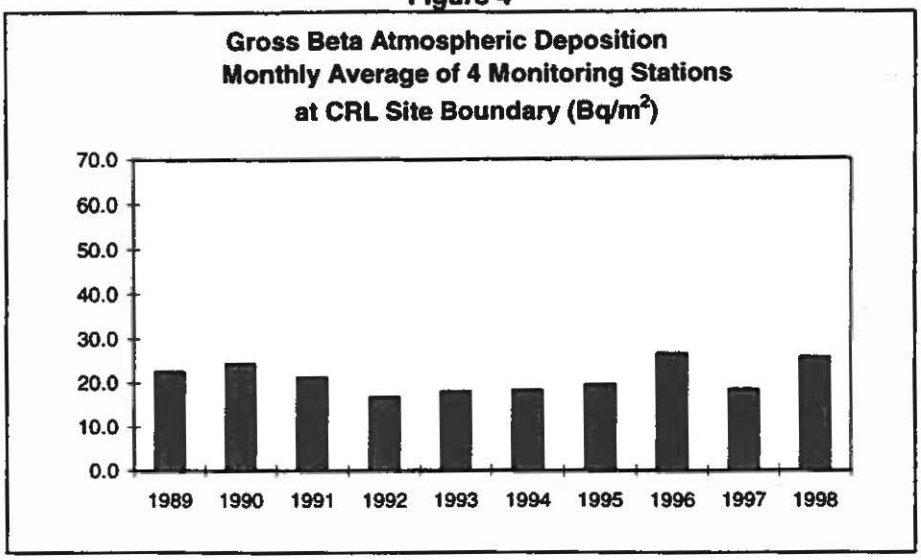
Figure 4 depicts the annual average gross beta activity at the site boundary stations for the past ten years. Locations of these stations correspond approximately with the TLD monitoring stations carrying the same number in the location code (see Appendix 1, Map 2).

Atmospheric deposition of gross beta activity due to fallout of naturally occurring radionuclides (primarily beryllium-7) within Ontario and Quebec typically ranges from about 17 to 30 Bq/m^2 per month [14]. The deposition at CRL and surrounding areas was not distinguishable from the values reported in [14].

Table 8: Atmospheric Deposition of Gross Beta Activity and Gross Alpha Activity at CRL Boundary -- 1998

		Monthly Deposition			
		Gross Beta		Gross Alpha	
Station #	Location	Average (Bq/m^2)	+/- (1 Std. Dev.)	Average (Bq/m^2)	+/- (1 Std. Dev.)
1	Pointe au Baptême	24.4	12.8	14.6	8.1
4	Building 560	24.0	9.8	13.4	8.1
7	West Gate @ Hydroline	24.8	11.1	15.0	10.4
8	Balmer Bay	29.4	15.6	15.2	10.4
	Average	25.6	12.3	14.5	9.3

Figure 4



2.6 Land Gamma Radiation

Radiation levels on road surfaces within the CRL site and Highway 17 East to Pembroke were surveyed using a sensitive dose rate meter (Geiger tube) mounted on a vehicle, and with a newly commissioned solid scintillation detector (plastic-organic scintillator, Eberline FHZ-672) which has an internationally-recognized calibration. The survey is performed annually. The survey routes are predefined and, to the extent possible, remain unchanged form year to year. The surveys are scheduled for periods when interference by airborne radioactive emissions from CRL is negligible. Since land gamma radiation on roads has not been identified as one of the dominant exposure pathways [4], this monitoring serves primarily as a gross trend indicator providing, for example, baseline data for emergency preparedness, and as a check for any accidental contamination.

Land gamma survey results for 1998 are summarized in Table 9. Figure 5 depicts levels of gamma dose rates on roads on CRL site and Highway 17 East for 1994 to 1998. In 1998, the dose rates remained comparable with previous years, at all monitored roads. With one exception (the Petawawa to Pembroke section of Highway 17) the plastic scintillator provided dose rates than those recorded with Geiger tubes, by an average of 18%. The results were otherwise consistent, and it can be concluded that there was no incidental accumulation of radioactive material on the monitored roads.

Table 9: Land Gamma Radiation on Roads
CRL Site Areas and Highway 17 -- 1998

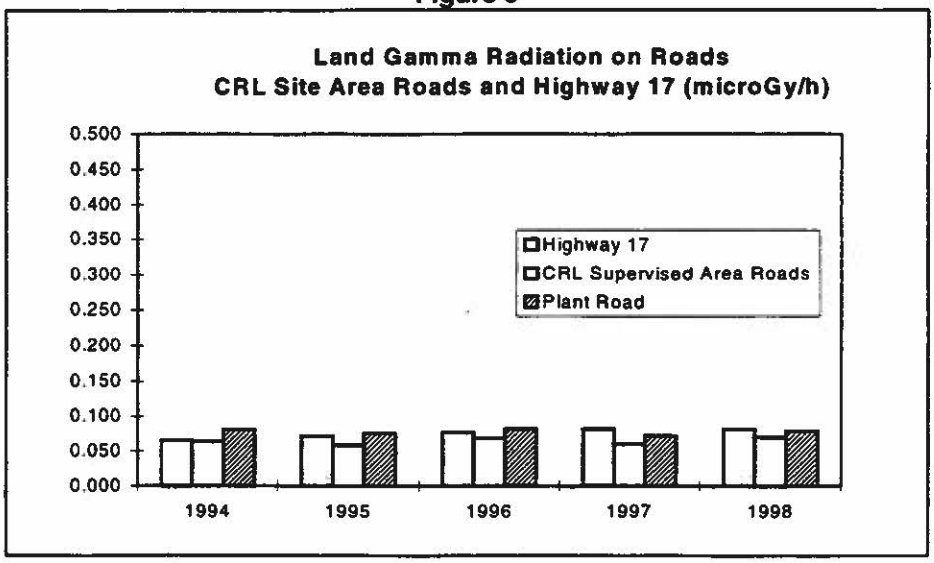
ROAD LOCATION	DOSE RATE (uGy/h)*	
	Old Mon. System	New Mon. System†
PUBLIC AREA		
Chalk River to Pembroke (Highway 17)	0.083	0.090
Chalk River to Deep River (Highway 17)	0.072	**
Petawawa to Pembroke (Highway 17)	0.089	0.077
Average	0.081	0.056
CRL SITE AREA		
Supervised Area (formerly Outer Area)		
Main Stack Road	0.105	0.122
Mattawa Road East	0.061	0.091
Mattawa Road West	0.064	0.079
C-2 Fire Trail	0.051	0.058
Sandspit Road	0.065	0.072
Average	0.069	0.084
Uncontrolled Area		
Plant Road Main Gate to C-2	0.095	0.102
Plant Road C-2 to Highway 17	0.063	0.091
Average	0.079	0.096

* Gamma dose rate in air, excluding cosmic radiation

** Data lost during downloading.

† The 1998 survey was conducted using both the old (Geiger tube) equipment and a new solid scintillation detector (Eberline FHZ-672)

Figure 5



2.7 Radioactivity in Milk

Radioactivity in processed whole milk from the local dairy in Deep River was analyzed using the following methods. Analysis for beta/gamma emitters was done using direct gamma spectrometry of monthly one litre samples of whole liquid milk (particularly for iodine-131) and, gamma spectrometry on quarterly composite samples of ashed[7] milk (particularly for caesium-137 and potassium-40). Tritium analyses were done on water distilled from quarterly composite milk samples, and carbon-14 analyses on combusted solids of quarterly composite milk samples.

Table 10a provides a summary of the 1998 monitoring results as annual average concentrations of radionuclides detected above Lower Limits of Detection (LLD), as well as for iodine-131, a relatively volatile radionuclide with high radiotoxicity potentially present in CRL releases [3]. In the ashed samples, only potassium-40 (a naturally occurring radionuclide) and caesium-137 were detected (see Table 10b for detection limits). The observed caesium-137 concentrations were consistent with the concentrations present in Canadian milk as a result of global fallout from atmospheric testing of nuclear weapons, and the 1986 Chernobyl nuclear accident [14]. Tritium concentrations appear to be slightly elevated above typical background, but may be influenced also by tritium releases from local industry in the area other than AECL. The observed concentrations of carbon-14 were slightly elevated from natural levels (230 Bq per kg of carbon) reported by UNSCEAR [16]. Also low levels of naturally occurring Ra-226, Ra-226P and Th-228 were detected above LLDs in some of the monthly samples by the analysis of liquid milk.

Table 10a: Radioactivity in Milk – Summary 1998

Radionuclide	No. of Samples	Avg. Concentration (Bq/L)	Avg. LLD[a] (Bq/L)
Iodine-131	12	< LLD	0.084 ± 0.014
Potassium-40	4	46.32 ± 0.70	0.146 ± 0.030
Radium-226	12	0.28 ± 0.12	0.31 ± 0.08
Radium-226P	12	0.27 ± 0.12	0.22 ± 0.04
Thorium-228	12	0.46 ± 0.15	0.27 ± 0.05
Caesium-137[c]	4	0.05 ± 0.02	0.016 ± 0.003
Tritium (free water)	1	26 ± 1	2.5
Carbon-14[e]	1	260 ± 6 (Bq/kg of carbon)	200 (Bq/kg of carbon)

a) LLD = lower limit of detection.

[7] The ashing method provides better detection limits for most radionuclides, but is not used to monitor for radioiodines due the potential for to their relative volatility.

Table 10b: Radioactivity in Milk – Gamma Spectrometry Results on Ashed Milk – 1998

Nuclide	ACTIVITY CONCENTRATION (Bq/L)			
	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Be-7	< 2.43E-01	< 3.10E-01	<	< 4.72E-01
Na-24	< 3.70E+24	< 3.70E+24	<	< 3.70E+24
K-40	4.68E+01 ± 6.72E-01	4.46E+01 ± 6.88E-01	4.37E+01 ± 6.60E-01	5.03E+01 ± 7.66E-01
Sc-46	< 2.89E-02	< 3.96E-02	< 3.61E-02	< 5.50E-02
Sc-47	< 3.27E+04	< 2.71E+04	< 2.08E+05	< 2.09E+07
Cr-51	< 5.74E-01	< 5.77E-01	< 5.70E-01	< 1.32E+00
Mn-54	< 1.73E-02	< 2.45E-02	< 2.11E-02	< 2.72E-02
Fe-59	< 1.34E-01	< 1.59E-01	< 1.65E-01	< 2.79E-01
Co-60	< 3.11E-02	< 3.96E-02	< 3.42E-02	< 4.09E-02
Co-60P	< 2.30E-02	< 2.63E-02	< 2.35E-02	< 2.87E-02
Zn-65	< 6.19E-02	< 8.21E-02	< 7.26E-02	< 9.38E-02
As-76	< 1.49E+18	< 8.74E+17	< 3.70E+24	< 3.70E+24
Nb-95	< 5.54E-02	< 7.79E-02	< 7.87E-02	< 1.51E-01
Zr-95	< 6.22E-02	< 9.08E-02	< 8.22E-02	< 1.30E-01
Mo-99	< 6.09E+05	< 5.32E+05	< 6.61E+06	< 1.69E+09
Ru-103	< 4.41E-02	< 5.27E-02	< 5.13E-02	< 9.70E-02
Ru-106	< 1.33E-01	< 1.15E-01	< 1.49E-01	< 2.00E-01
Ag-108m	< 1.30E-02	< 1.91E-02	< 1.43E-02	< 1.99E-02
Ag-110m	< 2.64E-02	< 3.67E-02	< 3.20E-02	< 4.28E-02
Sb-124	< 5.93E-02	< 5.71E-02	< 5.59E-02	< 8.37E-02
Sb-125	< 3.40E-02	< 4.16E-02	< 3.16E-02	< 4.35E-02
I-131	< 5.87E+00	< 5.70E+00	< 1.14E+01	< 9.01E+01
I-132	< 5.79E+04	< 6.41E+04	< 6.16E+05	< 5.97E+07
Cs-134	< 1.74E-02	< 2.42E-02	< 2.06E-02	< 2.63E-02
Cs-137	3.063E-02 ± 6.991E-03	4.950E-02 ± 7.435E-03	7.075E-02 ± 9.750E-03	6.117E-02 ± 1.035E-02
Ba-140	< 2.55E+00	< 3.29E+00	< 4.81E+00	< 1.90E+01
La-140	< 6.54E-01	< 5.90E-01	< 9.24E-01	< 3.36E+00
Ce-141	< 6.73E-02	< 7.90E-02	< 6.50E-02	< 1.56E-01
Ce-143	< 1.19E+14	< 6.08E+13	< 1.62E+16	< 3.70E+24
Ce-144	< 7.46E-02	< 9.51E-02	< 6.16E-02	< 1.07E-01
Eu-152	< 1.29E-01	< 1.71E-01	< 1.43E-01	< 1.80E-01
Eu-154	< 8.16E-02	< 9.56E-02	< 8.42E-02	< 1.01E-01
Hf-175	< 2.24E-02	< 2.38E-02	< 1.93E-02	< 3.29E-02
Hf-181	< 3.71E-02	< 4.72E-02	< 4.36E-02	< 7.87E-02
Ra-226	< 4.84E-02	< 3.30E-02	< 3.61E-02	< 5.25E-02
Ra-226P	< 2.52E-02	< 3.83E-02	< 2.07E-02	< 3.69E-02
Ac-228	< 5.87E-02	< 8.24E-02	< 6.70E-02	< 8.63E-02
Th-228	< 3.54E-02	< 4.64E-02	< 4.56E-02	< 5.33E-02
Pa-233	< 1.72E-01	< 1.69E-01	< 1.66E-01	< 3.90E-01
U-238	< 3.86E-01	< 4.91E-01	< 1.65E-01	< 7.11E-01
Np-239	< 1.08E+08	< 7.13E+07	< 1.66E+09	< 8.84E+11
Am-241	< 3.72E-02	< 1.03E-01	< 2.02E-02	< 1.06E-01

2.8 Radioactivity in Vegetation

Samples of produce from private gardens in Balmer Bay, Deep River, Petawawa and Killaloe were analyzed for tritium, for gross beta activity, and for gamma emitters using gamma spectrometry. Samples from Killaloe, about 55 km south from CRL, in a relatively infrequent wind direction, can be considered not affected by CRL emissions, and thus a suitable location for natural background radioactivity comparison. A summary of the analysis results for 1998 is in Table 11.

Tritium concentrations in all samples, excluding samples from the reference location, Killaloe, appear elevated above expected natural concentrations. Tritium concentrations in vegetables from Balmer Bay appear to be reasonably consistent (a factor of 2 lower) with the expected values based on CRL emissions and measured air concentrations in Balmer Bay (ratio of concentration in Balmer Bay vegetables to 3rd Quarter tritium air concentration (see Table 7) is 26 versus a default transfer parameter value in CSA N288.1 [7] of 50).

Gross beta activity in the leafy vegetable samples (beet tops and lettuce) from Balmer Bay is somewhat higher than in other samples. This appears to reflect the naturally high potassium concentrations in leafy vegetables and, in particular, beet tops [22]. This results in elevated potassium-40 concentrations [23], within the uncertainties of the observed values. Gross alpha concentrations reported for Balmer Bay beet top samples and Petawawa wild cherry samples also seem elevated. The reason is not clear, at this time, because of unavailability of additional sample material for further analyses. Cs-137 was measured marginally above the LLDs in some of the Deep River, Balmer Bay and Petawawa samples. For dose estimations (see Section 4), the values of Cs-137 are conservatively assumed to result from CRL emissions, although some of the Cs-137 activity may be fallout from weapons testing and Chernobyl accident. Also, the somewhat elevated gross alpha activity is conservatively assumed to result from CRL emissions, as americium-241, a radionuclide potentially present in effluents and having the most restrictive DRL value [4].

Table 11: Radioactivity in Vegetation – 1998

Sample Type	Location	1998 Tritium* (Bq/kg fresh wt)	1997 Tritium* (Bq/kg fresh wt)	1998 Gross Beta ** (Bq/kg fresh wt)	1997 Gross Beta ** (Bq/kg fresh wt)	1998 Gross Alpha (Bq/kg fresh wt)	1997 Gross Alpha (Bq/kg fresh wt)	1998 Be-7*** (Bq/kg fresh wt)	1997 Be-7*** (Bq/kg fresh wt)	1998 K-40*** (Bq/kg fresh wt)	1997 K-40*** (Bq/kg fresh wt)	1998 Cs-137*** (Bq/kg fresh wt)	1997 Cs-137*** (Bq/kg fresh wt)
Tomatoes	Deep River	33 ± 2	18 ± 1	69.1 ± 1.2	66.0 ± 1.0	< 0.007	< 0.027	< 0.7	< 1.3	55.5 ± 1.4	76.3 ± 3.7	< 0.1	0.2 ± 0.1
Cucumbers	Deep River	20 ± 2		49.8 ± 0.9		< 0.006		< 0.8		42.1 ± 2.5		0.1 ± 0.1	
Cabbage1)	Deep River	21 ± 2	30 ± 1	84.2 ± 1.6	91.0 ± 2.0	< 0.009	< 0.060	4.0 ± 1.6	< 2.0	82.5 ± 5.3	102.1 ± 5.3	0.4 ± 0.3	< 0.2
Cucumbers	Balmer Bay	35 ± 2		45.9 ± 2.2		< 0.046		< 13.4		65.5 ± 14.3		< 0.7	
Beet Tops	Balmer Bay	26 ± 2		320.7 ± 12.1		5.6 ± 2.6		< 32.9		270.4 ± 45.0		< 2.2	
Leaf Lettuce 2)	Balmer Bay	26 ± 2	80 ± 2	271.4 ± 11.1	173.0 ± 4.0	< 0.194	2.6 ± 2.6	11.8 ± 6.6	51.6 ± 5.5	179.6 ± 19.6	248.0 ± 11.2	1.7 ± 0.7	3.1 ± 0.6
Choke Cherries	Petawawa	18 ± 2		109.6 ± 2.4		2.7 ± 2.0		2.8 ± 0.9		111.7 ± 4.6		0.1 ± 0.1	
Pin Cherries	Petawawa	22 ± 2		67.9 ± 1.6		1.9 ± 1.5		3.8 ± 0.9		85.6 ± 4.3		0.3 ± 0.1	
Tomatoes	Killaloe	4 ± 2		24.3 ± 1.2		< 0.028		< 6.3		42.7 ± 12.5		< 0.9	
Cucumbers	Killaloe	4 ± 2		53.2 ± 2.3		< 0.042		< 5.4		54.3 ± 13.1		< 0.8	
Cabbage	Killaloe	10 ± 2		115.8 ± 4.5		< 0.073		< 15.2		87.0 ± 21.1		< 1.2	
Romaine Lettuce	Killaloe	6 ± 2		144.7 ± 7.0		< 0.147		< 17.6		108.7 ± 36.6		< 2.6	
	Average												
	Deep River	24 ± 2		67.7 ± 1.2		< 0.007		1.8 ± 1.6		60.0 ± 3.1		0.2 ± 0.2	
	Balmer Bay	29 ± 2		212.7 ± 8.5		3.3 ± 2.6		19.4 ± 6.6		171.8 ± 26.3		1.5 ± 0.7	
	Petawawa	20 ± 2		88.8 ± 2.0		2.3 ± 1.8		3.3 ± 0.9		98.6 ± 4.4		0.2 ± 0.1	
	Killaloe	6 ± 2		84.5 ± 3.7		< 0.073		< 11.1		73.2 ± 20.8		< 1.4	

* Free water tritium. Liquid scintillation counting of samples distilled to extract tissue-free water.
** Includes natural beta emitters, such as K-40.
*** Gamma Spectrometry results. Except for some naturally occurring radionuclides and Cs-137, all other radionuclides were below detection limits. (Be-7 and K-40 are naturally occurring radionuclides.). Because of small sample size, LLD for Cs-137 in Killaloe samples and in Balmer Bay beet tops samples, was higher than for other samples.
1) Green beans in 1997
2) Swiss chart in1997

2.9 Radioactivity in Game Animals

As a special project, samples of game animals (roadkills of deer and moose) from CRL site and surrounding areas (within 5 km radius), and from areas not affected by CRL or other nuclear sites and operations[8], were analyzed at CRL for tritium, for gross beta/gamma activity, for gross alpha activity, and for gamma emitters using gamma spectrometry. A strontium analysis was performed on samples that suggested gross beta activity in excess of the detected naturally occurring beta emitters (in particular, potassium-40) and, caesium-137. A summary of the results is in table 12. The results indicate increased tritium, Cs-137 and Sr-90 concentrations in the flesh samples and, increased overall gross beta activity as well as strontium-90 concentrations in bone samples from animals collected from locations reasonably close to the CRL site. It is assumed that these elevated values stem from the consumption of contaminated water and vegetation affected by past and present activities at the CRL Waste Management Areas (see Table 13). Radioactivity concentrations in the reference animals from North Bay (Nipissing University) and Eganville were within natural background values and within fallout levels after Chernobyl accident and nuclear weapons testing. Radioactivity in game animals is being further investigated and, is also included in the routine CRL Environmental Monitoring Program.

[8] In addition to fallouts from the Chernobyl nuclear accident and past nuclear weapons testing.

Table 12: Radioactivity in Game Animals

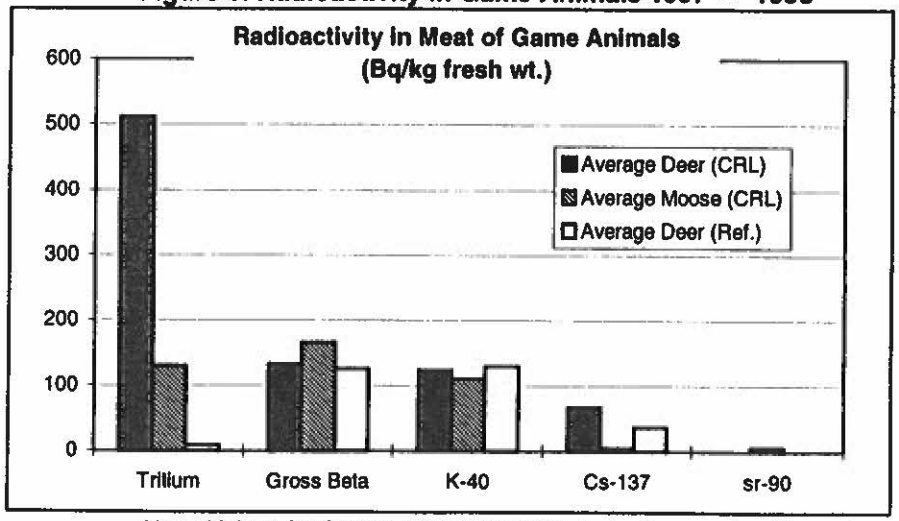
Sample Type	Collection Date	Estim. Age (yeas).	ACTIVITY CONCENTRATION IN FRESH WEIGHT										Location
			Flesh								Bone 1)		
			Tritium (Bq/kg)	Gross Beta (Bq/kg)	Total Alpha (Bq/kg)	K-40 (Bq/kg)	Cs-137 (Bq/kg)	Cs-134 (Bq/kg)	Co-60 (Bq/kg)	Sr-90 (Bq/kg)	Gross Beta (Bq/kg)	Sr-90 (Bq/kg)	
Deer-Doe	4-Nov-97	1.5	1111 ± 7	134 ± 6	< 2.1	137 ± 37	73 ± 7	< 3	< 3	N/A	1196 ± 58	N/A	C-7 Gate, Old Port Hope Road
Deer-Buck	11-Nov-97	1.5	51 ± 3	140 ± 6	< 2.3	118 ± 35	76 ± 7	< 3	< 3	N/A	655 ± 41	N/A	4.5 km from Hwy. 17, South of Disp."B"
Deer-Buck	20-Nov-97	1.5	371 ± 5	125 ± 7	< 3.2	117 ± 32	51 ± 6	< 2	< 2	N/A	220 ± 22	N/A	4 km from Hwy. 17, near Disp."C"
Deer-Buck (Ref.)	Nov-98	3.0	10 ± 1	103 ± 8	< 3.5	135 ± 16	27 ± 2	< 1	< 1	N/A	N/A	N/A	North Bay, Ontario
Deer-Doe (Ref.)	1-Nov-97	2.5	N/A	149 ± 20	< 2.9	124 ± 23	47 ± 4	< 3	< 2	N/A	N/A	N/A	South of Eganville, 70 km from CRL
Moose-Bull	19-Nov-97	1.5	26 ± 2	102 ± 6	< 2.5	119 ± 29	5 ± 2	< 2	< 2	N/A	7356 ± 158	3075 ± 145	2.5 km from Hwy. 17, Maskin. Lk. Hill
Moose-Bull	22-Nov-97	0.5	83 ± 3	289 ± 9	< 2.3	93 ± 32	3 ± 2	< 2	< 2	6 ± 2	N/A	N/A	1 km East of PNFI entrance, Hwy. 17
Moose-Cow	3-Apr-98	4.0	280 ± 5	106 ± 8	< 2.8	119 ± 31	6 ± 2	< 2	< 2	N/A	428 ± 32	N/A	CRL - Plant Road @ PIC entrance
Average Deer (CRL) *			511 ± 5	133 ± 6	< 2.5	124 ± 35	67 ± 6	< 3	< 3	N/A	690 ± 40	N/A	
Average Moose (CRL)			130 ± 3	166 ± 8	< 3.0	110 ± 31	5 ± 2	< 2	< 2	6 ± 2	3892 ± 95	3075 ± 145	
Average Deer (Ref. Loc.)			10 ± 1	126 ± 14	< 3.2	130 ± 20	37 ± 3	< 2	< 1	N/A	N/A	N/A	

* Within 5 km radius from CRL.

1) Samples of bone from animals from reference locations were not submitted to AECL for analysis.

2) Sample matrix comprised of tissue (flesh) from left hind quarter of each animal.

Figure 6: Radioactivity in Game Animals 1997 -- 1998



Note: Values for Sr-90 in deer from CRL and reference location not available at the time of writing.

2.10 Radioactivity in Surface Waters within the CRL Site

Surface waters within the CRL site, that may normally contain some radioactive contaminants as a result of past or present activities at the CRL Waste Management Areas (WMAs), were regularly sampled and analyzed. Sampling and analysis frequency for Chalk (Sturgeon) Lake was semi-annual. Liquid emissions from the CRL site by way of Perch Creek and Maskinonge Lake related to the concentrations in these streams are reported and discussed in the annual effluent monitoring report [Ref. 3, Table B3 of Appendix B]. The results are reported here for completeness and for record purposes.

Table 13 contains a summary of mean concentrations of the most significant radionuclides in the CRL site surface waters related to WMAs during 1998. Radionuclide concentrations in 1998 remained elevated above natural levels and, generally comparable with 1997 results. Since these surface waters are in the supervised areas within the CRL site boundary, they are not normally accessible by members of the public.

Table 13: Mean Concentration of Radionuclides in Surface Waters Associated with CRL Waste Management Areas – 1998

Waste Management Facility/ Sample Loc'n & CODE	Flow (L/day)	Gross Beta (Bq/L)	1σ	90Sr & 90Y (Bq/L)	1σ	Ce-144 (Bq/L)	Ru-106 (Bq/L)	1σ	Cs-137 (Bq/L)	1σ (Bq/L)	Co-60 (Bq/L)	1σ (Bq/L)	Tritium (Bq/L)	1σ (Bq/L)
Liquid Waste Management														
ESW East Swamp Stream	3.54E+05	5.03E+02	± 2.71E+02	1.32E+02	± 2.41E+02	< 6.08E-02	2.66E-01	± 1.24E-01	7.74E-01	2.65E-01	5.61E+00	± 1.55E+00	1.37E+05	± 1.30E+05
Waste Management Area A														
SSW South Swamp Stream	1.43E+03	2.64E+03	± 1.05E+03	*		< 2.73E-01	< 2.90E-01		< 2.88E-02		< 1.22E-01		1.09E+05	± 1.19E+05
MSC Main Stream	2.12E+06	6.19E-01	± 7.55E-01	*		< 6.02E-03	< 1.28E-02		3.62E-03	± 1.03E-03	1.20E-02	± 3.52E-05	8.88E+02	± 2.82E+02
PI2 Perch Lake Inlet # 2	1.67E+06	5.48E+00	± 1.32E+00	*		< 3.51E-02	< 9.47E-02		< 1.13E-02		7.01E-01	± 3.52E-05	1.48E+04	± 9.13E+03
Waste Management Area B														
SBD Spring "B" Disposal	N/A	4.17E+03	± 2.80E+03	2.19E+03	± 3.36E+01	< 6.91E-01	< 7.53E-01		< 9.52E-02		< 8.15E-02		7.85E+03	± 2.83E+03
PL1 Perch Lake Inlet # 1	6.88E+05	5.76E+01	± 2.48E+01	*		< 2.14E-02	< 1.94E-02		< 1.47E-03		< 1.73E-03		1.66E+03	± 4.50E+02
Perch Lake System														
PCW Perch Creek Weir	5.32E+06	7.99E+00	± 4.81E+00	5.23E+00	± 1.80E+00	< 4.58E-02	< 1.10E-01		< 1.17E-02		< 1.20E-02		1.15E+04	± 2.75E+03
Waste Management Area C														
DSW Duke Stream	3.82E+05	3.41E-01	± 9.81E-02	*		< 1.74E-02	< 4.36E-02		7.37E-03	± 4.29E-03	1.01E-02	± 6.07E-03	8.40E+04	± 1.87E+04
MLO Maskinonge Lake Outlet	N/A	3.97E-01	± 2.16E-01	*		< 1.59E-02	< 3.48E-02		< 4.73E-03		< 4.50E-03		1.51E+03	± 2.54E+02
CL Chalk Lake	N/A	4.73E-02	± 7.75E-03	*		< 1.52E-02	< 3.26E-02		< 3.75E-03		3.93E-03		7.58E+01	± 8.40E-01

* Specific analyses for Sr-90 and Y-90 not routinely conducted on these streams.

Various other surface streams within the CRL site that are not expected to contain significant quantities of radioactive contamination were monitored periodically to verify absence of abnormal radionuclide levels or unplanned emission routes. A summary of the results for 1998 is in Table 14. Radionuclide concentrations in these streams appear slightly elevated above natural background levels for tritium due to atmospheric deposition of airborne tritium emissions but, for comparison purposes, remain below Canadian Maximum Acceptable Concentrations (MACs) for drinking water [10].

Table 14: Gross Beta and Tritium in Various On-Site Surface Waters at CRL Mean Annual Concentrations – 1998

Location	*Gross Beta (Bq/L)*	*Tritium (Bq/L)*
Streams in Plant Site Area, Discharging to Ottawa River:		
01 Stream (East end of Controlled Area 1*)	0.08 ± 0.01	196 ± 2
02 Stream (East of Controlled Area 1*)	0.09 ± 0.01	113 ± 4
Streams Discharging to Maskinonge or Chalk Lake:		
Toussaint Lake (NE Chalk Lake)	0.30 ± 0.01	76 ± 1
Black Duck Creek @ Plant Road	0.05 ± 0.01	38 ± 1
For comparison: Maximum acceptable concentration in Canadian drinking water [10]	*5 (assuming Sr-90)*	*7000*

* Formerly "Inner Area"

2.11 Radioactivity in Surface Waters Off the CRL Site

Numerous surface water streams outside the CRL boundary (in addition to monitoring of the Ottawa River -- see Section 2.11) were sampled at least annually and analyzed for gross beta activity and for tritium. Analysis results for 1998 are in Table 15. Figures 7 and 8 depict average annual gross beta and tritium concentrations at the various monitored locations for 1994 to 1998. All values were well below the Canadian MACs for drinking water [10]. Tritium appears slightly elevated above natural background levels, likely due to atmospheric tritium deposition resulting from CRL airborne emissions. Gross beta concentrations in off-site surface waters remained well within the average for the past five years.

Table 15: Annual Tritium and Gross Beta Concentrations in Off-Site Surface Waters – 1998

Location (Code and Description)	Tritium (Bq/L)	Gross Beta (Bq/L)
Streams South and East of CRL discharging to Ottawa River:		
SS1 Spring 1, CRL Petawawa near CRL	Dry	Dry
SS2 Spring 2, CRL Petawawa near CRL	64.2 ± 1.3	0.054 ± 0.013
SS4 Spring 4, CRL Petawawa near CRL	Dry	Dry
SS5 Spring 5, CRL Petawawa near CRL	Dry	Dry
SS6 Spring 6, CRL Petawawa near CRL	25.8 ± 0.5	0.071 ± 0.013
SS7 Spring 7, CRL Petawawa near CRL	30.4 ± 1.1	< 0.036
SSCB Spring, King's Beach	16.4 ± 0.7	< 0.036
SSOB Spring, Oiseau Bay	41.5 ± 1.1	< 0.036
SDBC Downey Bay Creek	22.0 ± 0.7	0.054 ± 0.013
SHL Oiseau Creek	15.1 ± 0.8	< 0.036
Streams South of CRL (Highway 17) discharging to Maskinonge and Chalk Lakes:		
SCRH Chalk River at Highway 17	15.4 ± 0.5	< 0.039
SLTH Little Tucker Creek	12.8 ± 1.2	< 0.039
SBTH Big Tucker Creek	14.6 ± 1.1	0.043 ± 0.013
SBDO Black Duck Creek, Highway 17	22.0 ± 0.7	0.047 ± 0.013
Streams West of CRL discharging to Ottawa River upstream:		
SBHC King's Road Creek at Highway 17	26.4 ± 2.0	0.072 ± 0.014
SWRC Kennedy Creek at Wylie Road	19.1 ± 2.8	< 0.039
SKHC Kennedy Creek at Highway 17	14.5 ± 0.5	< 0.039
SKMC Kennedy Creek, Welsh's Bay	16.0 ± 0.4	0.050 ± 0.013
SBMC Balmer Bay Creek	29.6 ± 0.8	0.070 ± 0.014
SSHC Spring Creek at Highway 17	18.5 ± 2.6	< 0.039
Average –Off-Site Streams	23.8 ± 1.1	0.047 ± 0.013

Figure 7

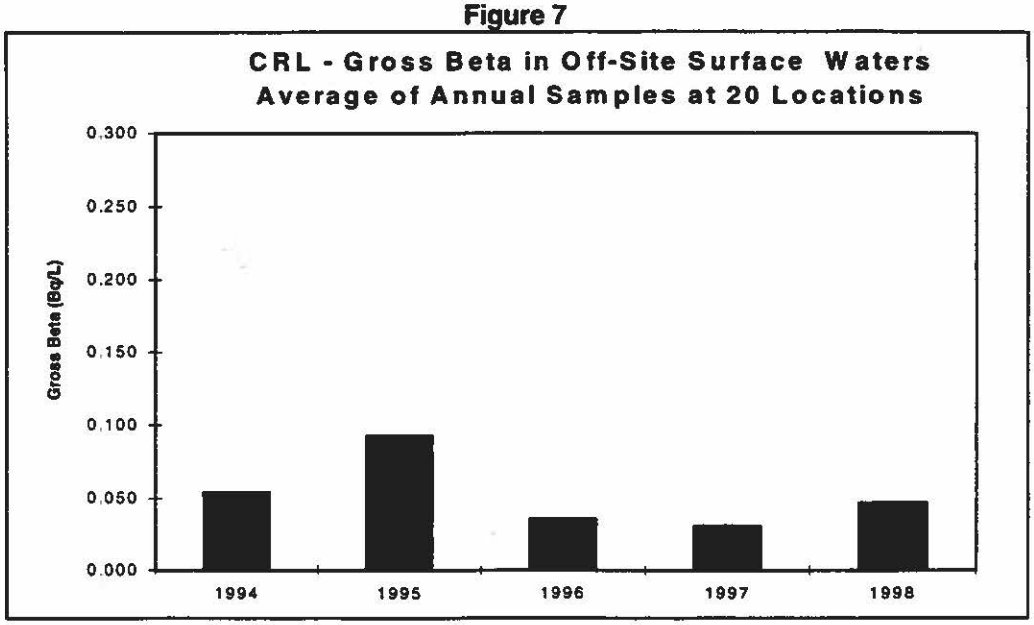
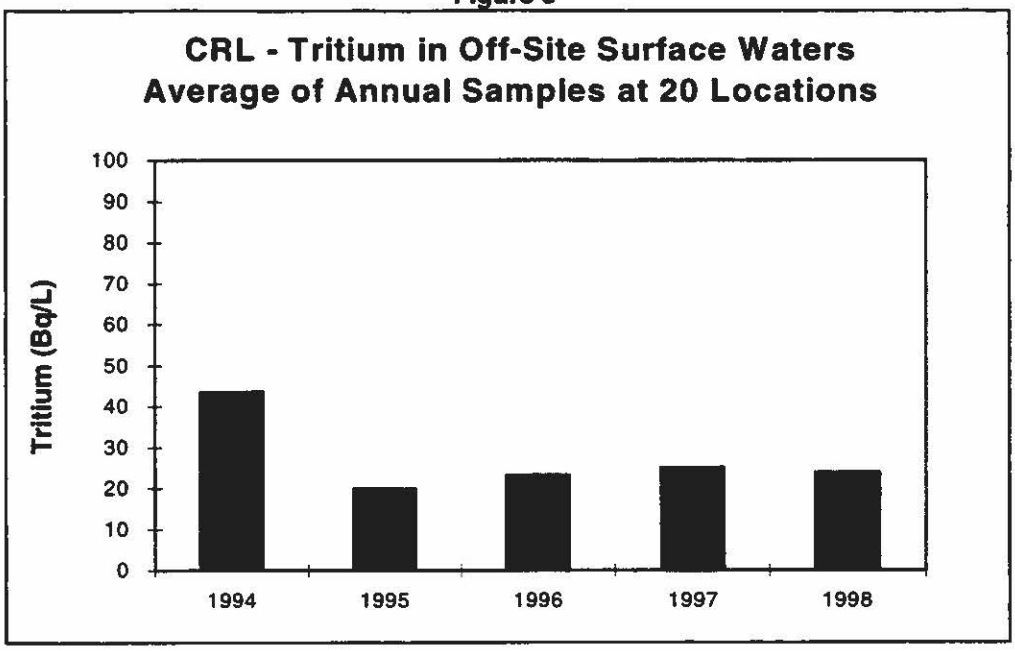


Figure 8



2.12 Radioactivity in Ottawa River

2.12.1 Water

Ottawa River water was sampled daily at pumping stations upstream of the CRL site at Rolphton (upstream of the decommissioned NPD nuclear generating station), at Deep River, and downstream of the CRL site at Pembroke. Monthly composite samples were analyzed for tritium, for gross beta activity, for strontium-90 and for gamma emitters. Weekly samples were collected at Point au Baptеme near the downstream boundary of the CRL site and, monthly composites of these were analysed for tritium and gross beta activities.

Table 16a provides annual mean and maximum monthly concentrations of radionuclides in the Ottawa River water at the above mentioned monitoring locations in 1998, as well as results of an annual verification sample 8 km

downstream from CRL. Average concentrations for 1997, and values of the Canadian Maximum Acceptable Concentrations (MACs) of radionuclides in drinking water [10] are provided, for comparison. Table 16b provides detailed monthly monitoring results. Figures 9, 10 and 11 depict the annual average concentrations of tritium, strontium-90 and caesium-137 upstream and downstream of CRL for the past 10 years. Downstream concentrations were slightly higher than upstream values due to emissions from CRL, but all were well below 1% of the MACs [10]. Results in 1998 were generally comparable with results for the past five years.

Table 16a: Radioactivity in Ottawa River Water – Summary
Annual Mean Concentration – 1998

Sample Location	Nuclide	Average (Bq/L)	+/- (Bq/L)	Max (Bq/L)	Max Month	1997 Average (Bq/L)
Rolphton--Monthly composites of daily samples						
(28 km upstream)	Tritium	3.9	0.6	7.8	July	3.2
	Caesium-137	0.003	0.001	0.006	Jan.	0.002
	Strontium-90	0.005	0.001	0.008	March	0.009
	Gross Beta	0.044	0.004	0.069	Nov.	0.040
Deep River--Monthly composites of daily samples						
(9 km upstream)	Tritium	3.7	0.8	5.4	Nov.	3.9
	Caesium-137	0.001	0.0005	0.004	Jan.	0.001
	Strontium-90	0.004	0.001	0.009	March	0.007
	Gross Beta	0.045	0.004	0.069	June	0.034
Pte. au Bapteme--Monthly composites of weekly samples						
(CRL downstream	Tritium	389.0	39.1	961.0	Sep.	504
boundary)	Gross Beta	0.229	0.031	0.624	Jan.	0.459
Highview--Annual Sample						
(8 km downstream)	Tritium	9.7	0.6	N/A	July	10.4
	Gross Beta	0.063	0.013	N/A	July	0.011
Pembroke--Monthly composites of daily samples						
(28 km donwstream)	Tritium	11.0	0.9	20.8	Dec.	9.8
	Caesium-137	0.003	0.0005	0.005	Oct & Nov.	0.004
	Strontium-90	0.013	0.002	0.026	Feb.	0.012
	Gross Beta	0.047	0.004	0.061	Nov.	0.039

NOTE: For comparison, the current Canadian Maximum Acceptable Concentrations (MACs) for radionuclides in drinking water [10], based on 10% of the ICRP recommended annual dose limit for members of the public, 1 mSv [13] are:

Tritium:	7000 Bq/ L
Caesium-137:	10 Bq/ L
Strontium-90:	5 Bq/ L
Gross Beta (assuming Sr-90):	5 Bq/ L

Figure 9

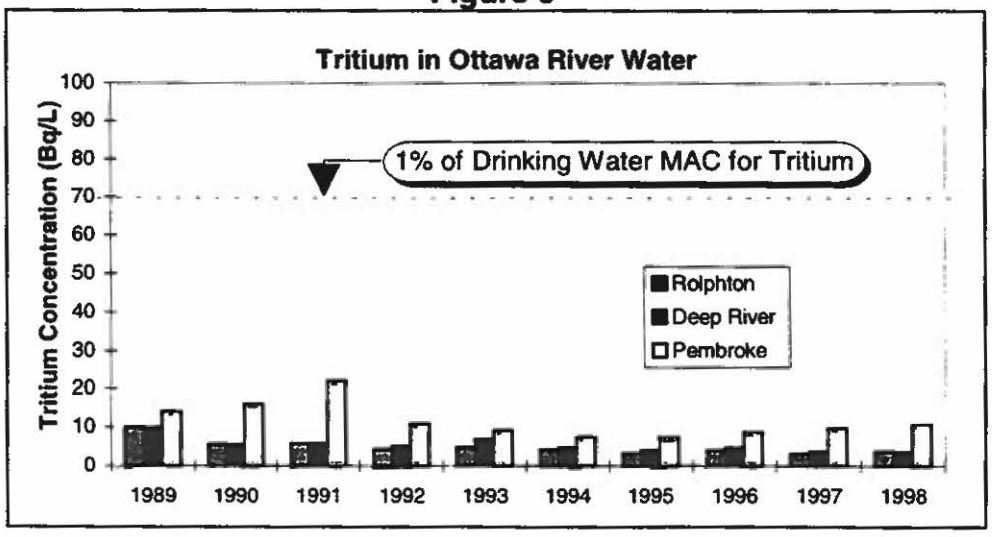


Figure 10

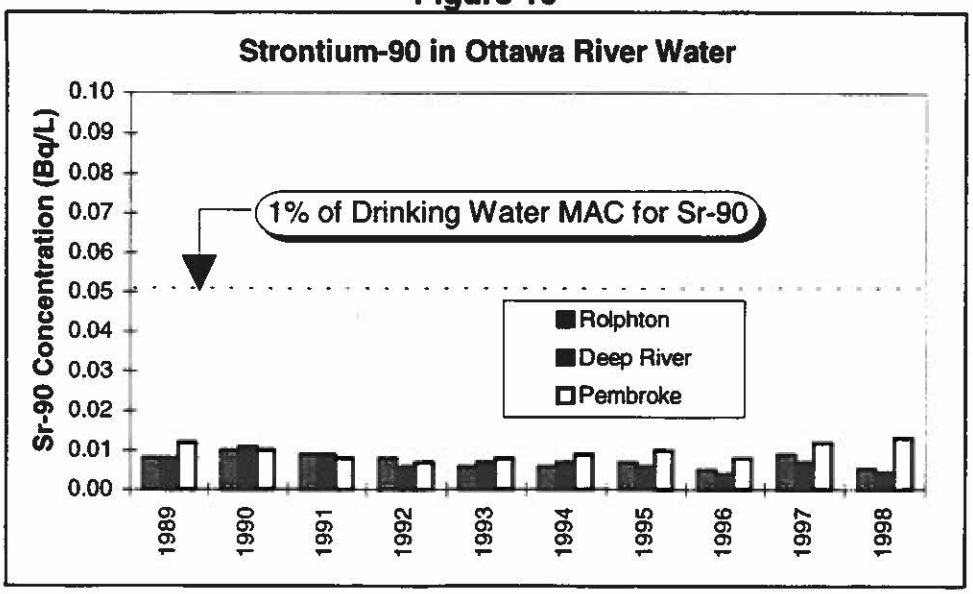


Figure 11

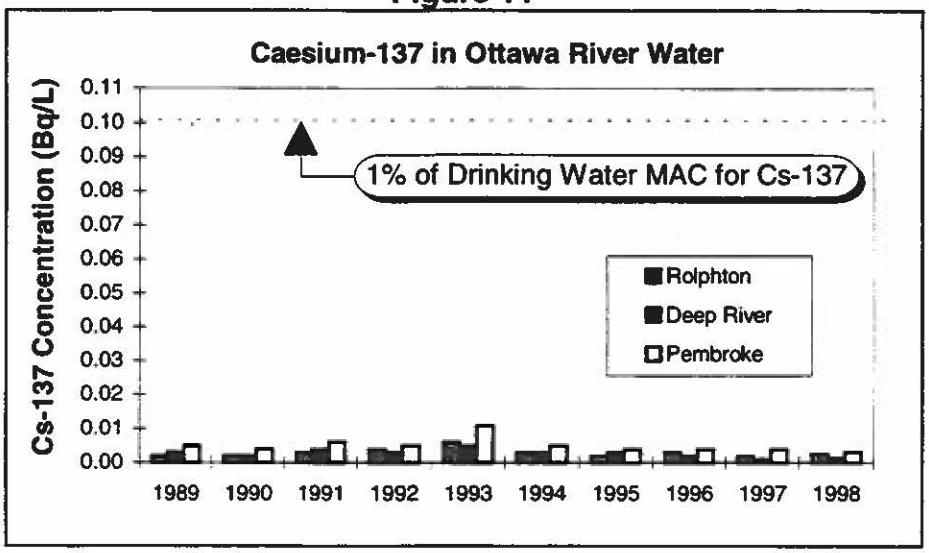


Table 16b: Radioactivity in Ottawa River Water
Monthly Monitoring Results – 1998

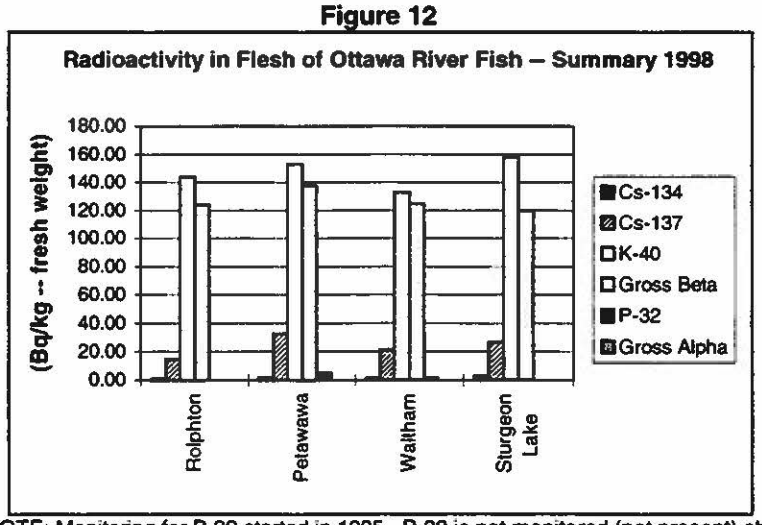
Month	Total Beta Bq/m^3						^{137}Cs Bq/m^3						^{90}Sr Bq/m^3								
	Rolphton	±	Deep River	±	Pembroke	±	Rolphton	±	Deep River	±	Pembroke	±	Rolphton	±	Deep River	±	Pembroke	±	Rolphton	±	Deep River
Jan	43.0	3.4	43.1	3.7	48.1	4.0	< 0.9		3.8	0.7	< 1.7		7.2	0.8	5.4	0.7	17.5	2.7	1.92E+03	9.60E+02	2.76E+03
Feb	42.4	3.7	44.4	3.5	53.8	4.6	< 1.0		2.4	0.6	< 1.3		8.2	0.9	8.2	0.8	25.6	3.6	3.72E+03	3.60E+02	3.48E+03
Mar	42.5	3.1	39.1	3.0	36.4	3.0	3.0	0.5	2.5	0.4	2.2	0.5	< 8.3	0.9	8.6	0.8	19.3	3.1	2.64E+03	4.80E+02	3.72E+03
Apr	38.9	3.1	49.0	4.3	44.7	4.0	2.6	0.6	< 0.8		< 1.1		5.1	0.7	5.9	0.7	21.9	3.6	4.44E+03	6.00E+02	4.20E+03
May	42.3	3.7	40.9	3.5	49.8	4.3	< 1.0	0.5	< 0.6		2.5	0.6	7.5	0.9	6.9	0.7	18.0	3.2	3.48E+03	4.80E+02	2.28E+03
Jun	43.9	4.7	69.2	6.0	42.3	4.4	1.8	0.5	< 0.7		2.7	0.4	< 3.8	0.8	5.2	0.9	12.7	2.8	2.76E+03	4.80E+02	3.00E+03
Jul	44.6	4.3	40.2	2.7	41.8	2.9	5.2	1.5	< 0.5		3.2	0.3	6.5	0.9	0.9	0.1	3.8	1.1	7.80E+03	6.00E+02	4.44E+03
Aug	35.6	3.2	37.8	2.6	40.2	2.9	3.7	0.7	1.3	0.3	4.8	0.4	3.1	0.1	3.2	0.1	19.8	3.8	3.72E+03	6.00E+02	3.24E+03
Sep	45.7	2.0	42.2	1.4	51.3	1.8	5.9	0.7	< 1.0		4.9	0.5	3.2	0.4	2.1	0.3	5.2	1.2	4.32E+03	3.60E+02	3.96E+03
Oct	43.8	3.3	41.6	3.3	43.7	3.1	< 1.6		< 1.3		5.2	0.7	1.4	0.2	3.9	0.4	4.8	1.3	3.48E+03	6.00E+02	3.24E+03
Nov	53.6	2.6	40.6	1.9	61.4	2.6	2.7	0.8	< 0.9		5.2	0.3	4.3	1.1	2.2	0.7	1.4	0.4	4.92E+03	9.60E+02	5.40E+03
Dec	49.9	11.0	54.3	10.1	55.0	9.5	< 1.8		< 0.9		2.7	0.5	4.8	1.2	1.1	0.3	7.1	1.8	3.60E+03	6.00E+02	4.08E+03
MEAN	43.8	4.0	45.2	3.8	47.4	3.9	2.6	0.7	1.4	0.5	3.1	0.5	5.3	0.7	4.5	0.5	13.1	2.4	3.90E+03	5.90E+02	3.65E+03
Mean Bq/L	0.044	0.004	0.045	0.004	0.047	0.004	0.003	0.001	0.001	0.0005	0.003	0.0005	0.005	0.001	0.004	0.001	0.013	0.002	3.9	0.6	3.7
MAX	53.6	11.0	69.2	10.1	61.4	9.5	5.9	1.5	3.8	0.7	5.2	0.7	8.3	1.2	8.6	0.9	25.6	3.8	7.80E+03	9.60E+02	5.40E+03
Max Month	Nov.	Dec.	June	Dec.	Nov.	Dec.	Sep.	July	Jan.	Jan.	Oct & Nov	Oct.	March	Dec.	March	June	Feb.	August	July	Jan. & Nov.	Nov.
Max Bq/L	0.054	0.011	0.069	0.010	0.061	0.010	0.006	0.001	0.004	0.001	0.005	0.001	0.008	0.001	0.009	0.001	0.026	0.004	7.8	1.0	5.4

2.12.2 Fish

Fish samples (Walleye, Pike, Bass) were collected from the Ottawa River at locations upstream (above the Rolphton dam, Mackey) and downstream from CRL, as well as from the Sturgeon (Chalk) Lake (section located within the CRL site). The fish muscle tissue was dried and ground for gamma spectrometry and for phosphorus-32 analysis. An aliquot was ashed for gross beta activity and alpha activity analyses. After chemical separation of phosphorus, the samples were counted for radiophosphorus using a liquid scintillation method. All results were corrected for the decay time between sample collection and analysis.

A summary of the monitoring results is in Table 17 along with average values from three previous years. Figure 12 depicts 1998 results for all monitored locations. Figures 13 through 15 depict monitoring results for each of the monitored lotions for 1994 to 1998 (excluding Sturgeon Lake, where fish monitoring was started in 1998 and whose results are included in Figure 12). Results for 1998 were comparable with previous years. Naturally occurring potassium-40 (not attributable to CRL operations) was present at similar concentrations in the upstream and downstream samples as well as samples from Sturgeon (Chalk) Lake, and represented the majority of radioactivity in fish flesh. Note that also majority of the measured total gross beta activity consists of natural potassium-40. Phosphorus-32 (from NRU reactor operations) was detected in downstream samples, showing somewhat increased concentrations compared with 1997. No increase in P-32 releases was observed by CRL effluent verification monitoring [3]. Cs-137 was detectable in upstream and downstream samples and remained at earlier years' levels. Cs-137 concentrations in downstream samples were somewhat elevated over the upstream samples, above levels currently expected to be present as a result of fallouts from the Chernobyl accident in 1986 and from nuclear weapons testing, in areas not affected by radioactive releases [17, 18, 19][9]. Cs-134 was detectable, near the detection limits, in samples from Petawawa area and from Sturgeon (Chalk) Lake, and in some samples from Westmeath (42 km downstream from CRL). Cs-134 is attributable to CRL operations. Also, naturally occurring Th-228 was detected marginally above Lower Limits of Detection (LLDs). Gross alpha values were below detection limits in all samples.

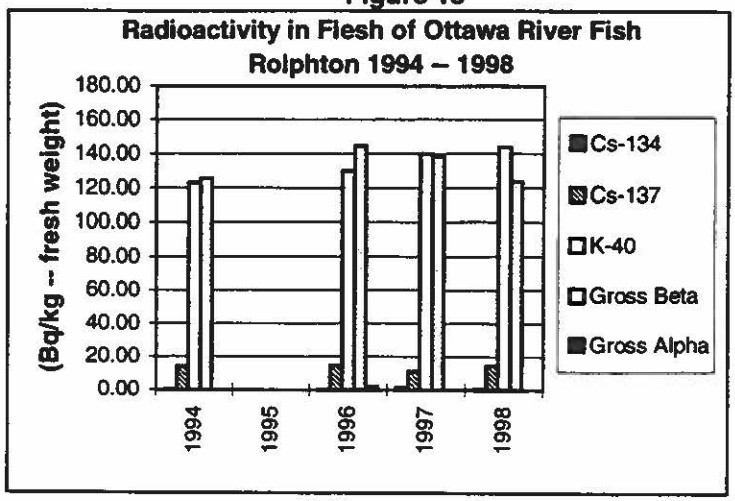
Figure 12



NOTE: Monitoring for P-32 started in 1995. P-32 is not monitored (not present) above Rolphton dam, upstream from CRL.

[9] Suspected relatively low potassium concentration in Ottawa River water may have increased the caesium concentrations in fish flesh, via increased bioaccumulation of caesium.

Figure 13



Results for 1995 not available.

Figure 14

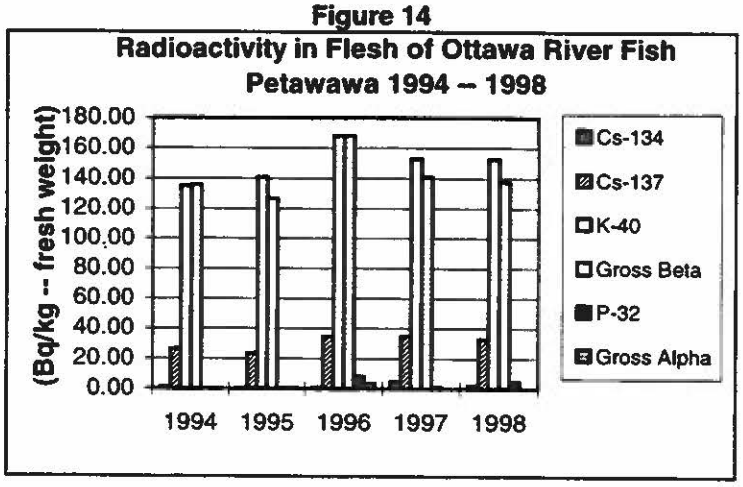


Figure 15

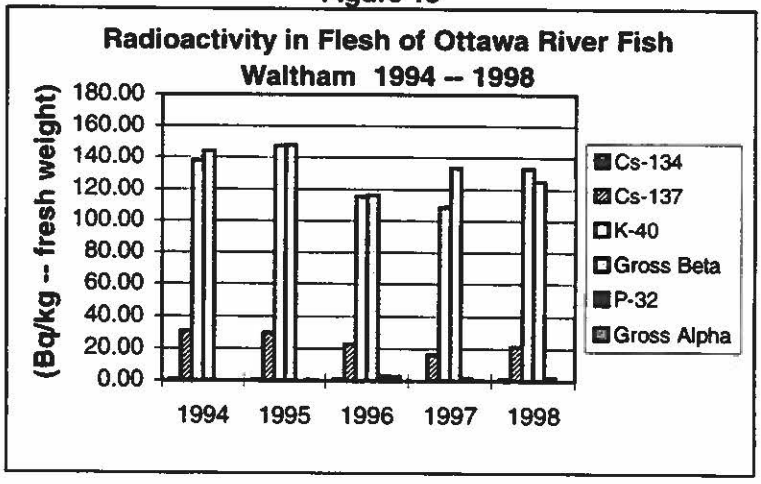


Table 17: Radioactivity in Ottawa River Fish – 1998

	Length (cm)	Cs-134 (Bq/kg wet wt)	Cs-137 (Bq/kg wet wt)	K-40 (Bq/kg wet wt)	Gross Beta (Bq/kg wet wt)	P-32 (Bq/kg wet wt)	Gross Alpha (Bq/kg wet wt)
Above Rolphton (Mackey)							
Walleye, Pike 7 samples	33	< 0.65	14.8 ± 0.59	144 ± 7.65	124 ± 7.30		<0.014
Range	24 - 51	<0.39 - <0.93	11.3 - 22.3	128 - 147	73 - 177		< 0.7 - 0.03
1997		< 1.46	11.3 ± 0.4	140 ± 6	139 ± 5		0.1 ± 0.13
1996		< 0.35	14.6 0.4	131 ± 4.6	145 ± 10		< 2.5
1994		< 0.53	14.0 ± 2.8	124 ± 15	126 ± 35		
Petawawa Area (Highview), 9 km downstream							
Walleye, Pike 5 samples	56	2.30 ± 0.23	32.7 ± 0.7	153 ± 6.15	138 ± 6.66	4.91 ± 0.89	<0.01
Range	45 - 71	1.75 - 3.45	19.0 - 44.8	146 - 164	82 - 257	1.60 - 8.97	< 0.004 - < 0.02
1997		4.61 ± 0.23	34.7 ± 0.7	153 ± 6	141 ± 4	1.25 ± 0.10	0.09 ± 0.18
1996		1.00 ± 0.40	34.5 ± 0.8	168 ± 7	168 ± 11	8.20 ± 0.20	< 3.6
1995		< 0.23	23.7 ± 3.7	141 ± 4	127 ± 15	0.80 ± 0.13	< 0.64
1994		1.10 ± 0.37	26.3 ± 2.0	135 ± 16	136 ± 16		< 0.2
Westmeath Area (Waltham), 42 km downstream							
Bass 5 Samples	37	< 1.40	21.5 ± 0.59	133 ± 5.2	125 ± 5.23	1.82 ± 0.43	<0.014
Range	34 - 43	<1.20 - 1.55	16.99 - 23.99	125 - 146	106 - 140	1.42 - 2.00	<0.013 - <0.014
1997	32	< 1.52 <	16.1 ± 0.48	109 ± 4.79	134 ± 3.95	1.71 ± 0.11	< 0.4
1996		< 0.84	22.9 ± 0.6	115 ± 5.1	116 ± 7.0	3.13 ± 0.30	< 2.8
1995		< 0.40	29.4 ± 3.0	148 ± 14.7	148 ± 32.4		< 0.45
1994		< 1.00	30.4 ± 5.4	138 ± 5.7	144 ± 11.3		< 0.2
Sturgeon Lake (on CRL Site)							
Walleye, Pike 5 samples	50	2.93 ± 0.24	27.0 ± 0.6	158 ± 5.5	120 ± 5.6		<0.013
Range	33 - 72	<1.14 - 6.63	13.02 - 49.11	145 - 173	91 - 184		

2.12.3 Beach Sediment

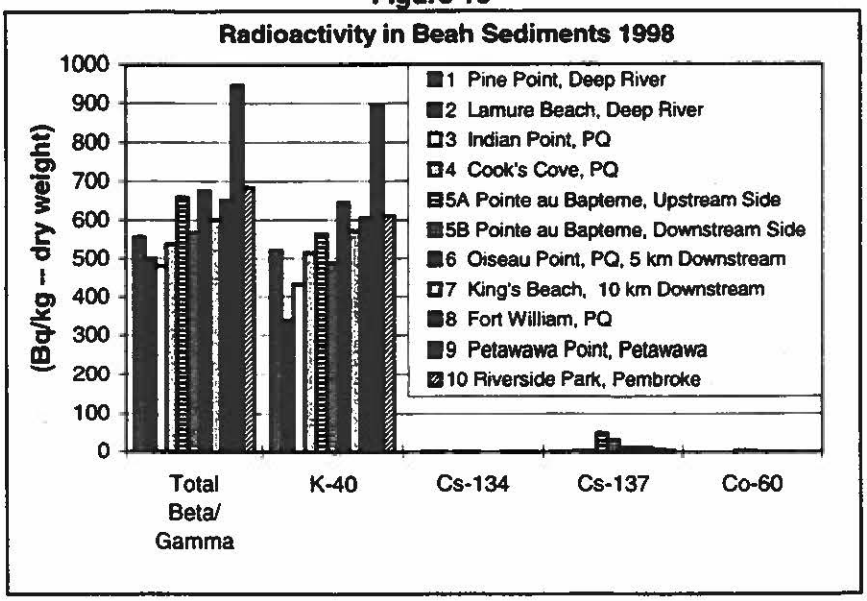
Sediment samples from various public beaches on the Ottawa River were analyzed for gamma emitting radionuclides using gamma spectrometry. At each monitoring location, a composite sample of surface sand (0 to 3 cm deep) was collected in the region representative of typical occupancy, between low and high water level. The results of the analyses are in Table 18.

Naturally occurring potassium-40 was by far the dominant radionuclide, with downstream concentrations comparable to those upstream, as expected. Concentrations of caesium-137, caesium-134 and cobalt-60 were slightly elevated close to CRL and, decreased further downstream. 1998 results for these nuclides at beaches close to the CRL boundary were somewhat lower than during the five past years. The other results were generally comparable with earlier years. Also naturally occurring Ac-228, Th-228, Tl-208, Pb-212, Bi-214, Pb-214, and Ra-226 were detected, at quantities slightly above the detection limits, in upstream and downstream samples.

Table 18: Radionuclide Concentrations in Ottawa River Beach Sediments, 1994 – 1998

Beach Code and Location	Total Beta/Gamma Activity (Bq/dry sed.)	Cs-134 (Bq/kg) (dry sediment)	Cs-137 (Bq/kg) (dry sediment)	C0-60 (Bq/kg) (dry sediment)	K-40 (Bq/kg) (dry sediment)
Upstream of CRL					
1 Pine Point, Deep River	558	0.4 ± 0.1	1.8 ± 0.1	< 0.2	522 ± 7.3
2 Lamure Beach, Deep River	501	1.3 ± 0.1	1.5 ± 0.1	< 0.2	339 ± 4.9
3 Indian Point, PQ	482	0.4 ± 0.1	4.3 ± 0.1	< 0.2	433 ± 6.2
4 Cook's Cove, PQ	538	< 0.1	4.0 ± 0.1	< 0.2	515 ± 7.1
Upstream Average -- 1998	520	0.7	2.9	< 0.2	452
1997	470	0.6	3.5	< 0.3	435
1996	636	0.4	5.2	< 0.3	604
1995	563	< 0.2	4.2	< 0.3	515
1994	582	< 0.3	4.7	< 0.3	538
CRL Downstream Boundary					
5A Pointe au Bapteme, Upstream	660	1.1 ± 0.1	48.3 ± 0.6	5.4 ± 0.1	564 ± 7.8
5B Pointe au Bapteme, Downstream	568	0.7 ± 0.1	31.6 ± 0.4	2.6 ± 0.1	487 ± 6.9
Pointe au Bapteme Average -- 1998	614	0.9	39.9	4.0	525
1997	764	1.1	47.8	3.2	677
1996	697	0.8	44.9	2.5	614
1995	828	0.8	55.4	6.0	702
1994	678	1.0	44.4	5.0	597
Downstream of CRL					
6 Oiseau Point, PQ, 5 km	676	< 0.2	12.4 ± 0.2	1.0 ± 0.1	646 ± 8.9
7 King's Beach, 10 km Downstream	601	< 0.2	11.7 ± 0.2	0.3 ± 0.1	574 ± 8.0
8 Fort William, PQ	652	0.5 ± 0.1	12.2 ± 0.2	0.7 ± 0.1	606 ± 8.3
9 Petawawa Point, Petawawa	947	0.5 ± 0.1	6.8 ± 0.2	< 0.3	898 ± 12.1
10 Riverside Park, Pembroke	685	0.6 ± 0.1	5.1 ± 0.1	< 0.2	611 ± 8.4
Downstream Average -- 1998	712	0.4	9.6	0.5	667
1997	719	0.3	10.8	0.6	681
1996	725	0.4	10.6	0.4	680
1995	762	0.3	11.8	< 0.4	699
1994	724	0.4	11.0	0.4	679

Figure 16



2.13 Meteorological Conditions

Meteorological conditions at the CRL site and surrounding areas were continuously monitored using instrumentation mounted on a meteorological tower at Perch Lake and on top of building 456 within the CRL Controlled Area 1 (formerly Inner Area). Monitoring at Perch Lake was done at 30 m and 60 m height.

Tables 19, 20 and 21 summarize the results for monitoring of meteorological conditions for 1998. Appendix 3 shows the 1998 annual windrose diagrams (wind direction and speed) for the monitored locations. The data at the Perch Lake Tower are representative of conditions at the NRU reactor stack, which is on a ridge about one km from the Ottawa River. The data at the top of building 456 are representative of conditions at the stack and roof vents within the CRL Controlled Area 1 (formerly Inner Area) and Controlled Area 2 (formerly Active Area) closer to the river. The diagrams follow the meteorological convention indicating the direction from where the wind is blowing. The Ottawa River valley strongly channels the winds at both monitoring locations.

Table 19: CRL Wind Direction -- Frequency Distribution in 1998

Windrose Sector (Wind from)			Perch Lake	Perch Lake	Building 456
#		Degrees	60 m	30 m	Roof
1	N	0	0.023	0.017	0.016
2	NNE	22.5	0.023	0.021	0.023
3	NE	45	0.040	0.035	0.027
4	ENE	67.5	0.043	0.040	0.031
5	E	90	0.041	0.041	0.031
6	ESE	112.5	0.106	0.097	0.044
7	SE	135	0.123	0.114	0.116
8	SSE	157.5	0.044	0.042	0.060
9	S	180	0.022	0.016	0.023
10	SSW	202.5	0.020	0.013	0.009
11	SW	225	0.024	0.017	0.012
12	WSW	247.5	0.039	0.037	0.019
13	W	270	0.075	0.074	0.059
14	WNW	292.5	0.159	0.177	0.096
15	NW	315	0.133	0.117	0.165
16	NNW	337.5	0.050	0.022	0.056
Calm	-	-			0.215

Table 20: CRL Wind Speed Class -- Frequency of Occurrence in 1998

Speed Class #	1	2	3	4	5	6	7	Total
Speed (km/h)	0-1.50	1.5-6	6.1-12	12.1-20	20.1-30	30.1-39	>39.0	
Perch Lake 60 m	0.035	0.181	0.349	0.335	0.092	0.008	0.001	1.000
Perch Lake 30 m	0.120	0.288	0.379	0.183	0.029	0.002	0.000	1.000
Bldg. 456	0.215	0.187	0.265	0.232	0.092	0.010	0.001	1.000

Table 21: CRL Stability Class -- Frequency And Mean Wind Speed in 1998

	STABILITY CLASS						Total
	A	B	C	D	E	F	
Perch Lake 60 m							
Frequency	0.154	0.045	0.098	0.274	0.284	0.144	1.000
Mean Wind Speed	10.8	9.6	11.1	13.6	12.1	8.1	
Perch Lake 30 m							
Frequency	0.258	0.075	0.148	0.241	0.173	0.105	1.000
Mean Wind Speed	8.6	8.9	9.2	9.5	7.5	1.7	
Building 456							
Frequency	0.199	0.070	0.158	0.275	0.152	0.147	1.000
Mean Wind Speed	10.3	11.1	11.5	12.7	7.1	1.1	

2.13.1 CRL Atmospheric Dispersion Coefficients

The atmospheric dispersion coefficient (or dilution factor), which relates the concentration of a radionuclide in air at a location downwind of an effluent source to the rate of release of that radionuclide to the atmosphere from that source, is a key parameter in the calculation of Derived Release Limits (DRLs) for all airborne effluent exposure pathways. To verify values for atmospheric dispersion coefficients assumed in DRL calculations for CRL [4], two separate and diverse sets of 1998 environmental monitoring data were compared with CRL site emissions during 1998 to assess the actual atmospheric dispersion at three key locations:

a) Balmer Bay -- the location of the nearest permanent resident outside the CRL boundary in the direction of the dominant upriver windrose direction, and location of the off-site "critical groups" for the most significant CRL: airborne emissions (i.e., argon-41 and other noble gases) in the current DRL report for the CRL [4]. The value of the annual average dispersion coefficient for this location assumed in [4] is 1.93E-07 s/m^3.
b) Harrington Bay -- south-east of the CRL site, on the opposite shore of the Ottawa River, at location of the nearest seasonal residents in the dominant downriver wind direction. The DRL report currently in effect [4], assumes that a dispersion coefficient of 5.5E-08 s/m^3 is applicable at this location.
c) Building 560 (CRL "Low Background Building") -- located at the CRL site westerly boundary, at the Plant Road, near the Village of Chalk River. The atmospheric dispersion coefficient for this location is assumed to be 4.6 E-08 s/m^3 [4].

GammaTracer data on ambient radiation dose in air contribution from noble gas emissions from the CRL site were used in conjunction with data on argon-41 emissions from CRL during 1998 as one means of determining the atmospheric dispersion coefficients. The atmospheric dispersion coefficient was calculated using the CSA N288.1 [7] model expression for external exposure to a semi-infinite cloud of radioactive material (Appendix E3 of [7]), modified by adding a finite cloud correction factor (from Figure E3 of [7]) to provide a conservative result.

$$D_s \text{ (Gy/s)} = 6.195E\text{-}14 * E\gamma * \chi * FCCF$$

Where: $E\gamma$ = gamma energy per disintegration (MeV) (= 1.28 for argon-41)

χ = air concentration of radionuclide at receptor (Bq/m^3)

$= R * \exp(-\lambda T) * P_{01} / 6.05E+05$

FCCF = finite cloud correction factor (= ~ 0.8 for argon-41 at >/= ~ 6 km)

R = Release rate of radioactive material (argon-41) from source (Bq/week)

λ = Radioactive decay constant for argon-41 = 0.38 (h^{-1})

T = Transport time from source to receptor (h) = distance / mean wind speed

(mean wind speed ~ 12 km/h)
P_{01} = Atmospheric dispersion coefficient (s/m^3)
6.05E+05 = time units conversion factor (seconds/week)

To convert Gamma Tracer data from units of ambient dose equivalent (H*10) to absorbed dose in air (air kerma (Gy), a conversion factor of 1.2 Sv (H*10)/Gy has been used [15]. Thus:

D_s (Gy/s) = D_{GT} (Sv(H*10)/h) / {1.2 (Sv(H*10) / Gy) * 3600 (s/h)}

Table 22: CRL Atmospheric Dispersion Coefficients Based on Ambient Gamma Dose-In-Air Data -- 1998

Period- 1998	Ar-41 Average Emissions (Bq/week)	Gamma Dose In Air -- CRL Contribution (nSv*/h) (GammaTracer Measurements)			Calculated Atmospheric Dispersion Coefficient P_{01} (s/m3)		
		Balmer Bay	Harrington Bay	Bldg 560 (Chalk River)	Balmer Bay	Harrington Bay	Bldg 560 (Chalk River)
		Distance From Stack (km)			*6*	*11*	*6*
		Compass Bearing (deg.)			*308*	*128*	*234*
1st Quarter	3.7E+14	12.5	4.2	2.4	9.0E-08	3.5E-08	1.7E-08
2nd Quarter	2.9E+14	8.7	3.5	2.6	8.1E-08	3.8E-08	2.4E-08
3rd Quarter	3.5E+14	10.6	3.6	1.9	8.1E-08	3.2E-08	1.5E-08
4th Quarter	3.5E+14	13.1	2.0	1.7	9.9E-08	1.8E-08	1.3E-08
1998 Average	3.4E+14	11.2	3.3	2.2	8.8E-08	3.1E-08	1.7E-08

* GammaTracer Results are expressed as Ambient Dose Equivalent (H*10) [13]

The second method used for assessing atmospheric dispersion was to compare the ambient tritium in air concentrations measured at these locations in 1998 using passive tritium samplers, with the total monitored airborne tritium emissions from the site in 1998. The average dispersion coefficient over a monitoring period is taken to be:

$$P_{01}\ (s/m^3) = (C - C_0) * 6.05E+05 / R$$

Where: C = Average ambient tritium in air concentration at location (Bq/m^3)
C_0 = Normal background tritium concentration (~ 0.2 Bq/m^3 assumed)
R = Average tritium release rate during period (Bq/week)
6.05E+05 = time units conversion (seconds/week).

Table 23: CRL Atmospheric Dispersion Coefficients Based on Ambient Tritium-In-Air Data -- 1998

	Period	Q1	Q2	Q3	Q4	Average
CRL Avg. Airborne Tritium Release (Bq/week)		5.12E+12	4.98E+12	4.59E+12	4.36E+12	4.76E+12
Ambient Average Tritium In Air Concentration (Bq/m^3)						
MONITORING LOCATION	CODE					
Ball Diamond	H4	0.40	0.30	0.50	0.40	0.40
Balmer Bay (Sawchuk)	H8	1.10	1.00	1.10	0.60	0.95
Harrington Bay, PQ	H15	1.00	1.00	0.60	0.40	0.75
Calculated Atmospheric Dispersion Coefficient (s/m^3)						
Ball Diamond	H4	2.4E-08	1.2E-08	3.5E-08	2.4E-08	2.4E-08
Balmer Bay (Sawchuk)	H8	1.1E-07	9.5E-08	1.1E-07	4.7E-08	8.9E-08
Harrington Bay, PQ	H15	9.5E-08	9.5E-08	4.7E-08	2.4E-08	6.5E-08

Both of the above described methods of estimating the atmospheric dispersion coefficient at these locations gave similar results. Values for all monitoring sites are generally consistent with the dispersion values in the current DRL report [4]. The results confirmed, consistent with CRL windrose frequencies, that the largest value is at Balmer Bay, with progressively lesser values at Harrington Bay and Chalk River.

3. WL ENVIRONMENTAL MONITORING PROGRAM AND RESULTS FOR 1998

3.1 WL Site Location

The WL site is located in southeastern Manitoba on the east bank of the Winnipeg River, about 100 km northeast of Winnipeg. Map 3 in Appendix 2 is a regional map showing the location of the WL site, major geographical features including the Winnipeg River, the local roads network, and the nearby communities that include Lac du Bonnet, Seven Sisters and Pinawa. Many of the sampling locations discussed in this report are also shown in Map 3 in Appendix 2.

3.2 WL Environmental Monitoring Program and Results

An Environmental Monitoring Program is implemented at the Whiteshell Laboratories (WL) site in order to meet the objectives described in Section 1.2.

In a continuing environmental monitoring program, radioactivity is monitored in a number of media at various points in the environment in the vicinity of the WL site. Some of the results of this monitoring are also used to estimate the incremental dose to members of the public who could potentially be exposed to effluents originating at the WL site. This report contains monitoring results for 1998 for:

- ambient gamma radiation in air;
- land gamma radiation;
- atmospheric deposition of radioactive material;
- radioactivity in native vegetation near the site boundary;
- radioactivity in surface waters at the WL site;
- radioactivity in waters of the Winnipeg River;
- radioactivity in flesh of fish from the Winnipeg River;
- radioactivity in river-bottom sediments of the Winnipeg river;
- radioactivity in cultivated (garden) vegetables;
- radioactivity in wildlife; and
- wind directions.

In most cases, results of environmental monitoring for the years 1994 to 1997 have been presented along with 1998 data in order to identify any trends. The wind direction data for 1998 (Appendix 4) is only for the period January 1 to August 31, because the operation of the meteorological tower was discontinued at the end of August. Consequently, no meteorological data will be included in future reports of this series.

For ambient gamma radiation in air, radioactivity is expressed in units of grays (Gy) per time units. Gross beta activity and gross alpha activity are measured in almost all other cases. The gross activity measurements provide a good indication of the total radioactivity, and in most cases, are supplemented with spectral measurements for individual radionuclides that may be responsible for the gross activity. The gamma spectrum is scanned for artificially produced radionuclides, as well as for naturally occurring radionuclides such as K-40 and Be-7. In many instances, it is apparent that the gross activity is mainly due to the natural radionuclides. For conservative estimates of dose caused by the activity, it is also usually assumed that the gross activity is entirely caused by the most radiologically toxic radionuclide (one with the most restrictive Derived Release Limit [6]) that could be responsible for the given gross activity.

Incremental doses, that could be caused by effluents from WL, have been estimated for adults and infants in the critical group at the WL boundary, who it is assumed ingest Winnipeg River water, Winnipeg River fish, vegetables irrigated with Winnipeg River water and who are subject to beach exposure from beach sands representative of river-bottom sediments.

For a complete description of sampling procedures, field operating procedures, equipment performance checks, quality verification procedures and laboratory administrative procedures, refer to the Whiteshell Laboratories Environmental Monitoring Quality Assurance Manual [29]. As a result of quality verification checks and for improved accuracy, the efficiency factor for gross alpha counting for 1998 data has been calculated differently than in previous years. If the method of calculation used for 1998 data had been used in the previous years, the gross alpha readings for the previous years would have been higher than have been previously reported, by as much as a factor of three in some cases. Consequently, higher gross alpha values for 1998, apparent in a few of the tables and trend diagrams in this report may not be actual, but simply a result of the revised calculation procedure for the efficiency factor.

Sampling locations for this monitoring are shown on maps in Appendix 2. Results of the monitoring during 1998 are presented in the following sections, 3.3 through 3.8. Dose estimates to members of the critical group off-site, based on the environmental monitoring results are in Section 4.

3.3 Ambient Gamma Radiation in Air

In 1998, ambient gamma radiation in air was monitored by means of thermoluminescent lithium fluoride dosimeters (TLDs) at 12 locations in the three following general areas:

- at 5 locations near the perimeter of the WL site;
- at the Pinawa hospital, Pinawa Resort (Kelsey House), Pinawa town yard; and
- at 4 locations on the Controlled Area fence.

Refer to Map 3 in Appendix 2 for the locations of the Ambient Radiation Monitoring Stations (ARMS). The TLDs were placed one metre above the ground surface and continuously record gamma radiation for the entire calendar year.

The annual TLD readings for years 1994 to 1998 for each of the 12 TLD monitoring locations are shown in Table 24 in units of milligray per year (mGy/a). Figure 17 shows the mean of the readings from the TLDs at the site perimeter, Pinawa and WL site Controlled Area fence areas, respectively, for the years 1994 to 1998. The reported readings include the gamma background exposure caused by terrestrial and cosmic radiations. Land ambient gamma radiation background was measured as part of the pre-operational environmental surveys for WL, and in 1964 was found to range from 2.1 to 3.6 nC/kg.h [30] which in air converts to 0.7 to 1.2 mGy/a which is about the same as the ambient gamma readings recorded in 1998. This is as expected since WL has at present no operating reactors and therefore no emissions of noble gases. Since the background and the readings are about the same, the background has not been subtracted from the readings.

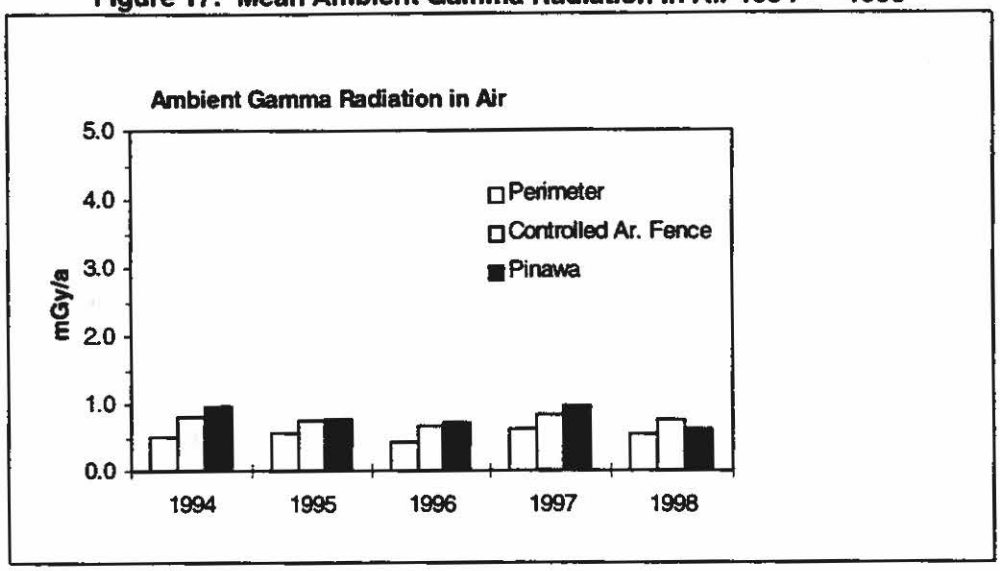
Data in Table 24 and Figure 17 show that ambient gamma radiation at all locations has remained stable over the period 1994 to 1998 at levels well below 1 mGy/a. The 1998 levels are marginally lower than the 1997 levels, but such small variations in extremely low levels are of no particular significance.

Table 24: Ambient Gamma Radiation in Air

LOCATION	TOTAL GAMMA DOSE (mGy/a)				
	1994	1995	1996	1997	1998
Perimeter					
1 North	0.530	0.603	0.503	0.719	0.668
2 East-southeast	0.390	0.482	0.381	-	0.511
3 South-southeast	0.523	0.617	0.497	0.636	0.526
4 West	0.588	0.605	0.410	0.628	0.466
5 Northwest	0.520	0.570	0.403	0.540	0.559
Mean (perimeter)	0.510	0.575	0.439	0.631	0.546
Pinawa					
Town Yard	1.134	0.699	0.527	0.831	0.609
Resort (Kelsey House)	0.956	1.044	1.116	1.173	N/A
Hospital	0.852	* 0.601	0.532	0.877	N/A
Mean (Pinawa)	0.981	0.782	0.725	0.960	0.609
Controlled Area Fence					
South Fence	0.712	0.727	0.662	0.634	0.735
East Fence	0.732	0.849	0.699	0.771	0.673
North Fence	0.683	0.732	0.694	0.874	0.931
West Fence	1.066	0.734	0.664	1.079	0.661
Mean (Fence)	0.798	0.761	0.680	0.839	0.750

N/A Data not available because of vandalism of TLDs.
Sum of 3rd and 4th quarter readings multiplied by two.
Natural background, caused by cosmic and terrestrial sources, has not been subtracted.

Figure 17: Mean Ambient Gamma Radiation in Air 1994 -- 1998



3.4 Land Gamma Radiation

The dose rate due to ambient gamma radiation was measured once during 1998 at control points on road routes along a 16 km radius surrounding the WL site. The survey was done from a slow moving vehicle, using a hand-held AEP 2153A low-range gamma monitor. Results for 13 points in the off-site public area and 10 points within the WL site are shown in Table 25 for the years 1994 to 1998. Most of the locations listed in Table 25 are identified in Map 3 in Appendix 2. The results for 1998 are similar to those for previous years.

Table 25: Land Gamma Radiation at WL and Vicinity

	Mean Gamma Dose Rate (μGy/h)				
	1994	1995	1996	1997	1998
Public Area (16 km Route)					
Plant Road & HWY. 211	0.06	0.10	0.12	0.11	0.1
HWY. 211 & Rifle Range	0.07	0.11	0.11	0.12	0.09
Pinawa Stage 1	0.07	0.14	0.13	0.11	0.11
Pinawa Stage 2	0.07	0.13	0.14	0.12	0.12
Junction HWY. 11 & HWY. 307	0.05	0.09	0.15	0.11	0.11
Bridge to Seven Sisters	0.06	0.11	0.12	0.13	0.12
Town Circuit at Dam	0.05	0.11	0.13	0.12	0.1
Junction HWY. 214 & HWY. 11	0.08	0.06	0.08	0.1	0.09
Lac du Bonnet Circuit	0.09	0.08	0.09	0.09	0.09
West Side of LDB Bridge	0.11	0.09	0.08	0.11	0.08
Hwy. 520 at Old Pinawa	0.14	0.11	0.13	0.14	0.11
Riverland School	0.12	0.11	0.12	0.12	0.12
Road at ARMS #1	0.14	0.13	0.15	0.12	0.11
WL Site					
Bldg. 401 into Active Area	0.08	0.09	0.11	0.12	0.13
Road South side of 300	0.12	0.09	0.13	0.19	0.1
Road West side of 300	0.12	0.07	0.15	0.13	0.16
South side of 200 & 411	0.23	0.13	0.4	0.19	0.2
East of 100	0.19	0.07		0.14	0.16
East gate	0.13	0.09	0.1	0.11	0.14
North Road at Lagoon Road	0.12	0.06	0.12	0.09	0.09
Rd. East of Canister Area	0.19	0.1	0.16	0.17	0.17
East Rd. at WMA Gate	0.11	0.12	0.2	0.18	0.15
East Rd. at Landfill site	0.12	0.06	0.1	0.09	0.11

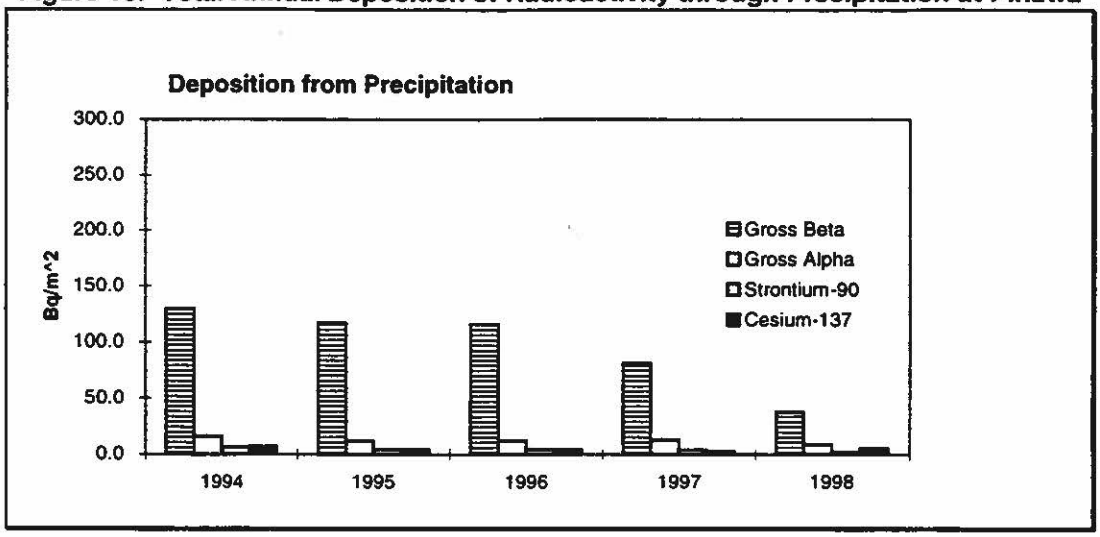
3.5 Atmospheric Deposition of Radioactive Material

Atmospheric deposition of radioactive material due to precipitation was measured at the Pinawa town yard, located about 9 km east of WL and 2 km west of Pinawa (Figure 18). Rainfall was collected in a lined container mounted one metre above ground. Snowfall was collected on aluminum sheets at ground level or in lined rainfall containers. Samples were analyzed monthly for gross beta, gross alpha, strontium-90, caesium-137 and starting in 1998, also for potassium-40. The total annual deposition, in units of becquerel per square metre (Bq/m^2), is shown in Table 26 for the years 1994 to 1998. For the 1998 readings, two standard deviations based on counting statistics are also shown. The same data are also shown in the bar chart in Figure 18. The 1998 levels are marginally lower than those for the previous year. The overall trend is of a decline in the radioactivity in the precipitation which may be due to lower precipitation, e.g., 1998 was a relatively dry year.

Table 26: Mean Atmospheric Deposition of Radioactivity through Precipitation at Pinawa 1994 -- 1998

	Total Annual Deposition (Bq/m^2)					
	1994	1995	1996	1997	1998	'98 2SD
Gross Beta	130.0	117.0	115.9	81.4	38	24
Gross Alpha	16.4	12.2	12.4	13.0	9	5
Strontium-90	6.7	4.5	4.4	4.0	2	3
Caesium-137	7.4	4.7	4.5	2.69	5	6
Potassium-40	NA	NA	NA	NA	60	31

Figure 18: Total Annual Deposition of Radioactivity through Precipitation at Pinawa



3.6 Radioactivity in Surface Waters Within the WL Site

Radioactivity was monitored in surface waters of two ditches draining land near the Waste Management Area (WMA). One of these ditches, flowing west to the Winnipeg River, was sampled at the point labelled 9 in Map 4 of Appendix 2, and the other ditch, flowing north, was sampled at the location labelled 8. Water from the recharge area east of the WMA is diverted around the WMA to the west-flowing ditch and into the Winnipeg River. The other ditch, running north to the WL boundary, drains the land north of WMA up to the site boundary.

Table 27: Annual Mean Gross Beta and Gross Alpha Radioactivity in Ditches Near WMA -- 1998

LOCATION	Activity (Bq/L)				
	1994	1995	1996	1997	1998
9 - Ditch From Waste Management Area					
west to Winnipeg River					
Gross Beta	0.27	0.2	0.16	0.25	0.33
Gross Alpha	0.03	0.03	0.02	0.04	0.03
8 - Ditch From Waste Management Area					
north to WL boundary					
Gross Beta	0.62	0.55	0.33	0.43	0.83
Gross Alpha	0.07	0.1	0.01	0.04	0.03

The ditches were sampled monthly whenever there was sufficient runoff to enable sampling. The results for both ditches, for years 1994 to 1998, are shown in Table 27 and Figures 19 and 20. Data show a slight increase in the gross beta activity in the north ditch, otherwise, the activity is stable over the five-year period. Refer to Map 4 in Appendix 2 for sampling locations.

Figure 19: Gross Beta Activity in Surface Waters from Streams Flowing from the WL Waste Management Area, 1994 -- 1998

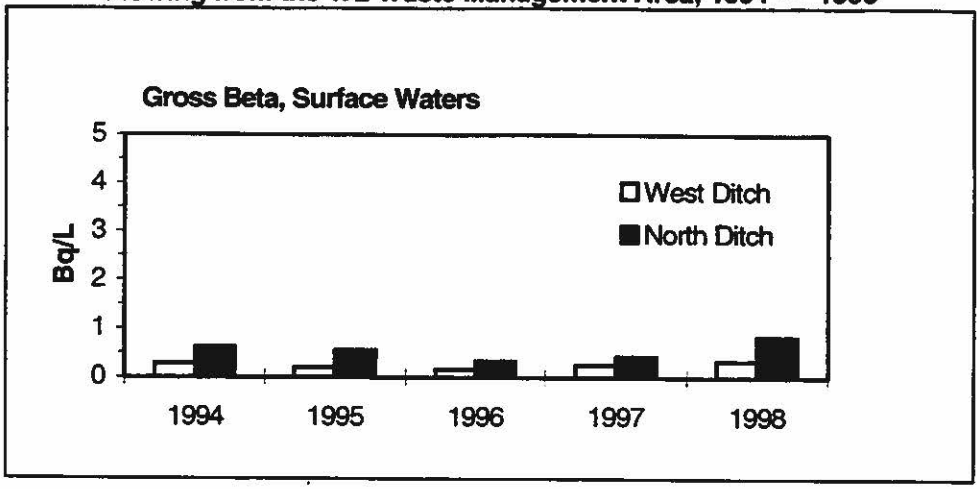
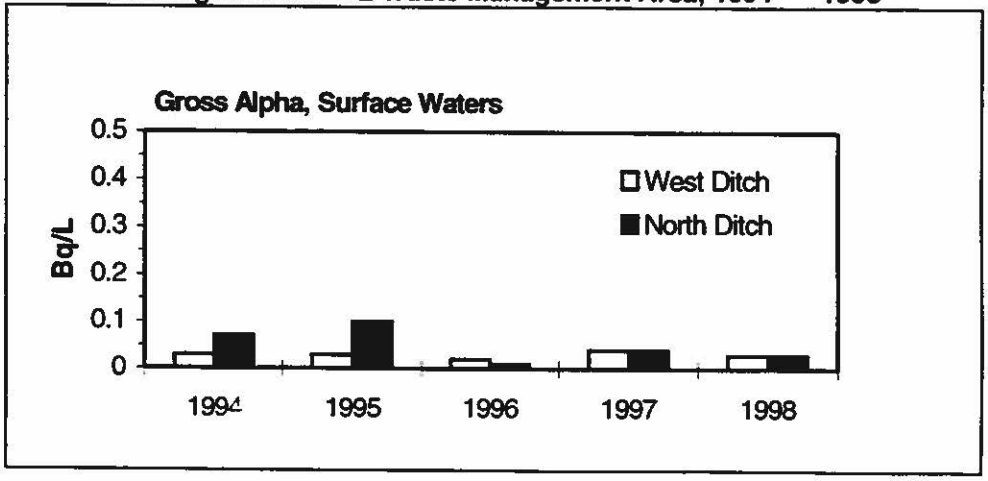


Figure 20: Gross Alpha Activity in Surface Waters from Streams Flowing from the WL Waste Management Area, 1994 -- 1998



3.7 Radioactivity in Winnipeg River

3.7.1 Water

Monthly composite samples of Winnipeg River water were collected from four locations: about 17 km upstream of the process outfall (at Pinawa), 2 km downstream at the WL boundary, 10 km downstream at the Lac du Bonnet water intake and 28 km downstream at the Great Falls generating station. In 1998, the samples were analyzed for strontium-90, gross beta activity, gross alpha activity and, scanned by gamma spectroscopy which provided values for Cs-137. Data for 1994 to 1998 for each of the four monitoring locations are shown in Table 28 and in Figures 21 through 23. Concentrations in 1998 were comparable to those in previous years. As can be noted from Figures 21 through 23, the measured concentrations were very small fractions of the Maximum Acceptable Concentrations (MACs) for radioactivity in drinking water in Canada, specified by Health Canada [10]. The 1998 concentrations at the sampling points downstream of WL were not much different from the concentrations at the upstream sampling point.

Table 29 shows the mean, maximum and minimum daily flow rates for 1998 of the Winnipeg River recorded at the Seven Sisters generating station, upstream of WL. The mean daily flow rate at 575 $m^3.s^{-1}$ is considerably lower than in previous years.

Table 28: Radioactivity in Winnipeg River Water

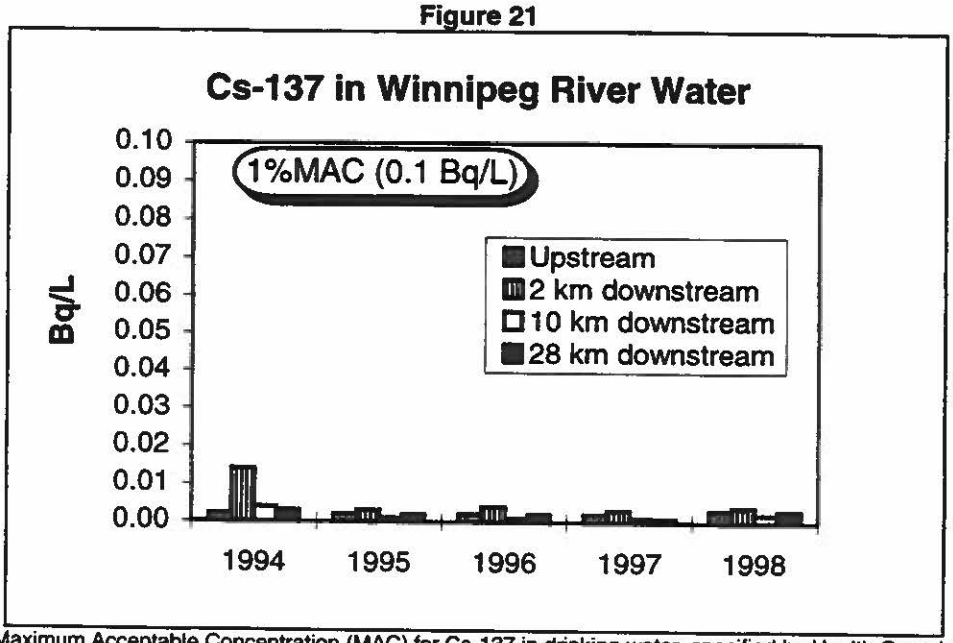
LOCATION	Mean Concentration (Bq/L)					
	1994	1995	1996	1997	1998	+/-
Pinawa (upstream from WL)						
Cesium-137	0.002	0.002	0.002	0.002	0.003	0.001
Potassium-40	NA	NA	NA	NA	0.046	0.015
Strontium-90	0.015	0.016	0.016	0.011	0.014	0.006
Gross Beta	0.064	0.063	0.059	0.057	0.059	0.006
Gross Alpha			0.013	0.017	0.035	0.014
Location K11 (2km downstream)						
Cesium-137	0.014	0.003	0.004	0.003	0.004	0.002
Potassium-40	NA	NA	NA	NA	0.068	0.021
Strontium-90	0.022	* 0.021	0.018	0.011	0.015	0.009
Gross Beta	0.095	0.08	0.078	0.074	0.072	0.03
Gross Alpha			0.016	0.014	0.035	0.02
Lac du Bonnet (10km downstream)						
Cesium-137	0.004	0.001	0.001	0.001	0.002	0.001
Potassium-40	NA	NA	NA	NA	0.045	0.017
Strontium-90	0.017	0.017	0.015	0.011	0.012	0.003
Gross Beta	0.077	* 0.061	0.069	0.059	0.057	0.006
Gross Alpha			0.011	0.01	0.03	0.012
Great Falls (28 km downstream)						
Cesium-137	0.003	0.002	0.002	0.001	0.003	0.003
Potassium-40	NA	NA	NA	NA	0.039	0.011
Strontium-90	0.017	0.017	0.015	0.014	0.013	0.005
Gross Beta	0.077	0.077	0.072	0.067	0.075	0.024
Gross Alpha			0.011	0.012	0.035	0.013

** Mean excluding two results considered to be outliers.*
+/- values shown for 1998 are 2 standard deviations of the average activity per month.
Monitoring for gross alpha commenced in 1996.

Table 29: Winnipeg River Mean Flow Rate At Seven Sisters Generating Station

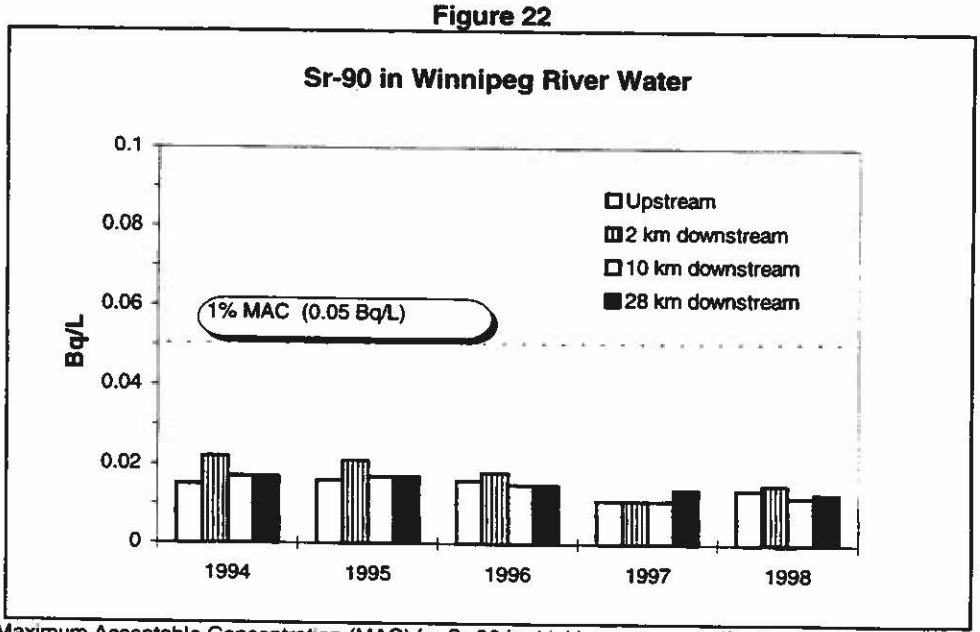
MEAN DAILY FLOW RATE (m^3/s)					
	1994	1995	1996	1997	1998
HIGH	1228	1334	2011	2395	1043
Date	Dec-27	Jan-14	Jun-07	May-10	May-19
LOW	503	426	723	413	178
Date	Jun-25	Oct-09	Sep-28	Sep-30	Oct-04
MEAN	884	903	1196	1109	575

Figure 21



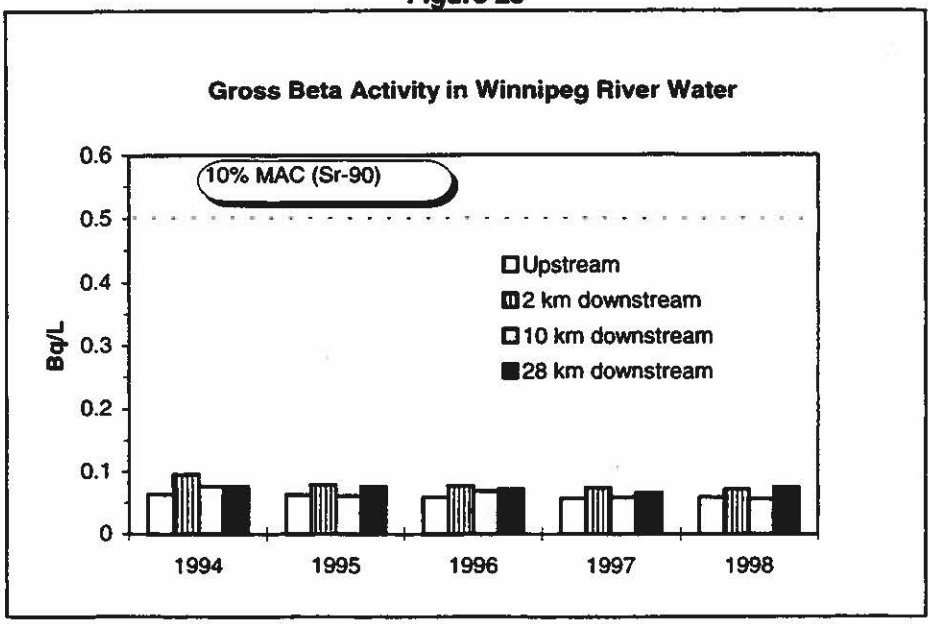
The Maximum Acceptable Concentration (MAC) for Cs-137 in drinking water, specified by Health Canada, is 10 Bq/L [10].

Figure 22



The Maximum Acceptable Concentration (MAC) for Sr-90 in drinking water, specified by Health Canada, is 5 Bq/L [10].

Figure 23



3.7.2 Fish

Four species of fish (whitefish, common sucker, pickerel and northern pike) were caught in the Winnipeg River in 1998 October from three locations upstream of WL and two locations downstream. The flesh was analyzed for gross beta activity and scanned by gamma spectroscopy which provided values for caesium-137 and potassium-40. The detailed results including length, weight and activity in becquerels per kilogram fresh weight for eviscerated flesh are given in Table 30. A summary of caesium-137, potassium-40 and gross beta activity in fish flesh is in Table 31 for the years 1992 to 1998. Figures 24 to 26 show caesium-137 concentrations in pickerel, common sucker and pike for one upstream location and two downstream locations for the years 1992 to 1998. (Data for 1997 for 5 km downstream are not available). It is evident from these figures that generally, fish in the downstream locations have higher concentrations of caesium-137. All three species show an elevated concentration in 1996 at 0.5 km downstream of the outfall. Otherwise, concentrations are uniform over the seven years except for a slight decline in 1997 and 1998.

Table 30: Radioactivity in Flesh of Winnipeg River Fish – 1998 (Bq/kg Fresh Weight)

Date/1998	Location	Species	Length (cm)	Weight (kg)	Activity (Bq/kg)					
					Cs-137	Cs-137 +/-	K-40	K-40 +/-	Gross Beta	Beta +/-
21-Oct-98	Upstream of WL	Whitefish	42	4.200	0.16	0.09	120.9	3.3	103.3	7.1
	Crater Lake	Whitefish	38	0.950	0.20	0.12	124.3	3.8	116.3	8.0
		Whitefish	36	0.850	0.18	0.06	201.9	4.0	110.2	7.5
		Average			**0.18**	**0.09**	**149.0**	**3.7**	**109.9**	**7.5**
		Stdev				**0.02**		**45.9**		**6.5**
		Common Sucker	44	1.150	0.35	0.06	210.5	3.6	110.3	7.5
		Common Sucker	38	1.000	0.33	0.06	217.5	3.7	111.0	7.5
		Common Sucker	36	0.950	0.24	0.06	180.3	3.7	99.0	6.7
		Average			**0.31**	**0.06**	**202.8**	**3.7**	**106.8**	**7.2**
		Stdev				**0.06**		**19.7**		**6.7**
		Pickerel	32	1.600	1.01	0.15	123.8	3.9	104.7	7.1
		Pickerel	30	0.600	2.30	0.50	130.6	11.0	92.0	6.3
		Pickerel	28	0.500	1.98	0.47	106.8	10.5	87.6	6.0
		Average			**1.76**	**0.37**	**120.4**	**8.5**	**94.8**	**6.5**
		Stdev				**0.67**		**12.3**		**8.9**
		Pike	58	1.500	0.73	0.18	130.4	6.0	94.7	6.4
		Pike	41	0.400	0.55	0.06	179.4	3.3	98.0	6.6
		Pike	38	0.350	0.52	0.08	185.0	4.0	91.8	6.3
		Average			**0.60**	**0.11**	**165.0**	**4.4**	**94.8**	**6.4**
		Stdev				**0.12**		**30.0**		**3.1**
21-Oct-98	Upstream of WL	Whitefish	48	1.800	0.29	0.15	136.0	5.7	92.9	6.3
	Sylvia Lake	Whitefish	44	1.400	0.34	0.07	182.0	3.6	85.5	5.8
		Whitefish	38	0.850	0.24	0.08	188.0	4.0	90.9	6.2
		Average			**0.29**	**0.10**	**169.0**	**4.5**	**89.8**	**6.1**
		Stdev				**0.05**		**28.3**		**3.8**
		Common Sucker	42	1.400	0.25	0.07	185.0	3.8	99.4	6.8
		Common Sucker	41	1.200	0.37	0.08	188.0	4.0	86.0	5.9
		Common Sucker	38	1.125	0.27		103.0	4.7	85.0	6.0
		Average			**0.31**	**0.30**	**159.0**	**4.2**	**90.1**	**6.2**
		Stdev				**0.09**		**48.0**		**8.1**
		Pickerel	47	1.550	1.15	0.27	120.0	8.0	91.3	6.2
		Pickerel	33	0.500	0.86	0.39	111.0	9.9	72.2	4.9
		Pickerel	28	0.350	1.33	0.47	118.0	10.8	83.4	5.7
		Average			**1.12**	**0.38**	**116.0**	**9.6**	**82.3**	**5.6**
		Stdev				**0.24**		**4.7**		**9.6**
		Pike	50	1.400	0.92	0.18	114.0	5.3	83.1	5.8
		Pike	49	1.000	0.78	0.23	109.0	6.4	85.0	5.8
		Pike	42	0.800	0.74	0.13	176.0	5.8	86.6	6.1
		Average			**0.81**	**0.18**	**133.0**	**5.8**	**84.9**	**5.9**
		Stdev				**0.10**		**37.4**		**1.8**
10-Oct-98	Upstream of WL	Common Sucker	45	1.750	1.04	0.15	124.2	5.2	96.8	6.6
	Crowduck Lake	Common Sucker	40	1.300	1.15	0.25	127.7	6.2	90.5	6.2
		Average			**1.10**	**0.20**	**125.9**	**5.7**	**93.6**	**6.4**
		Stdev				**0.08**		**2.5**		**4.4**
		Pike	68	2.350	4.13	0.23	97.7	4.1	80.0	5.5
		Pike	65	2.500	3.49	0.22	100.2	4.0	91.6	6.2
		Average			**3.81**	**0.23**	**99.0**	**4.1**	**85.8**	**5.9**
		Stdev				**0.45**		**1.7**		**8.2**

Table 30 (continued): Radioactivity in Flesh of Winnipeg River Fish – 1998

Date/1998	Location	Species	Length	Weight	Activity (Bq/kg)					
			(cm)	(kg)	Cs-137	Cs-137 +/-	K-40	K-40 +/-	Gross Beta	Beta +/-
		Bass	23	0.350	1.95	0.63	164.1	14.3	96.3	6.6
		Average			**1.95**	**0.63**	**164.1**	**14.3**	**96.3**	**6.6**
14-Oct-98	0.5 km d'stream	Whitefish	37	0.850	0.51	0.21	144.3	6.1	119.0	7.7
		Whitefish	40	1.200	0.49	0.15	135.1	4.5	122.1	7.9
		Whitefish	51	2.000	0.36	0.19	140.6	6.7	103.7	6.7
		Average			**0.45**	**0.18**	**140.0**	**5.7**	**114.9**	**7.5**
		Stdev				**0.08**		**4.6**		**9.8**
		Common Sucker	26	0.300	0.63	0.18	90.6	6.2	81.8	5.4
		Common Sucker	35	0.600	0.93	0.23	114.8	6.0	89.8	5.8
		Common Sucker	42	1.300	1.54	0.30	121.0	7.1	89.1	5.2
		Average			**1.03**	**0.24**	**108.8**	**6.4**	**86.9**	**5.5**
		Stdev				**0.47**		**16.1**		**4.5**
		Pickerel	38	0.700	0.89	0.22	84.4	5.4	68.2	4.6
		Pickerel	39	0.850	1.96	0.46	205.3	13.1	147.6	10.0
		Pickerel	54	2.100	3.04	0.68	159.4	16.7	108.3	7.3
		Average			**1.96**	**0.45**	**149.7**	**11.8**	**108.0**	**7.3**
		Stdev				**1.07**		**61.0**		**39.7**
		Pike	43	0.700	4.56	0.18	116.1	3.4	97.9	6.7
		Pike	50	1.150	0.85	0.13	122.2	3.6	95.0	6.5
		Pike	66	2.050	0.41	0.23	115.7	5.1	99.9	6.8
		Average			**1.94**	**0.18**	**118.0**	**4.0**	**97.6**	**6.7**
		Stdev				**2.28**		**3.6**		**2.5**
14-Oct-98	5 km downstream	Whitefish	48	1.675	0.38	0.16	110.0	5.1	86.5	5.6
		Whitefish	42	1.175	0.36	0.16	133.3	5.8	96.0	6.3
		Whitefish	41	1.050	0.32	0.10	104.4	3.1	89.5	5.8
		Average			**0.35**	**0.14**	**115.9**	**4.7**	**90.7**	**5.9**
		Stdev				**0.03**		**15.3**		**4.9**
		Common Sucker	41	1.600	1.97	0.39	204.4	13.9	165.3	11.3
		Common Sucker	37	0.800	1.41	0.32	138.6	9.1	89.8	5.8
		Common Sucker	34	0.650	0.70	0.14	118.9	4.3	96.0	6.2
		Average			**1.36**	**0.28**	**154.0**	**9.1**	**117.1**	**7.8**
		Stdev				**0.63**		**44.7**		**41.9**
		Pickerel	48	1.400	1.45	0.20	133.8	5.9	100.7	6.5
		Pickerel	33	0.500	1.82	0.21	128.3	5.7	111.4	7.2
		Pickerel	29	0.300	1.92	0.14	130.0	3.9	104.9	6.8
		Average			**1.73**	**0.18**	**130.7**	**5.1**	**105.7**	**6.9**
		Stdev				**0.25**		**2.8**		**5.4**
		Pike	60	1.600	0.78	0.28	128.7	8.4	87.7	5.7
		Pike	51	1.400	1.19	0.14	114.0	3.9	92.9	6.0
		Pike	46	1.000	1.32	0.09	105.8	2.7	82.5	5.4
		Average			**1.10**	**0.17**	**116.1**	**5.0**	**87.7**	**5.7**
		Stdev				**0.28**		**11.6**		**5.2**

Table 31: Average Radioactivity in Flesh of Winnipeg River Fish, 1992 -- 1998

	Sucker (Bq/kg)			Pickerel (Bq/kg)			Pike (Bq/kg)			Whitefish (Bq/kg)		
	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta
Upstream of WL (Pinawa)												
1992	0.56	125	92	1.11	105	87	2.26	122	98	1.29	118	99
1993	0.42	116	91	1.22	121	96	0.16	115	90	-	-	-
1994	0.45	110	97	1.22	113	94	0.69	114	98	0.17	118	95
1995	0.33	99	92	0.75	112	94	0.63	98	91	0.28	108	105
1996	0.40	124	98	0.98	132	97	0.66	116	90	0.58	134	105
1997	0.37	126	100	1.03	141	102	0.76	135	98	0.26	135	105
1998	0.57	162	97	1.44	119	89	1.74	132	89	0.24	159	100
Average	**0.44**	**123**	**95**	**1.11**	**120**	**94**	**0.99**	**119**	**93**	**0.47**	**129**	**101**
0.5Km Downstream of WL												
1992	1.65	115	87	3.66	110	90	2.54	115	90	4.28	127	87
1993	1.84	122	96	2.04	117	90	2.53	118	94	0.53	112	96
1994	1.81	112	104	2.35	116	101	2.62	103	100	0.55	111	102
1995	2.18	99	93	2.21	112	99	1.72	99	99	1.96	95	97
1996	2.87	120	92	3.26	136	103	4.63	114	99	1.56	121	90
1997	1.31	130	96	1.88	133	98	1.42	125	103	0.38	122	96
1998	1.03	109	87	1.96	150	108	1.94	118	98	0.45	140	115
Average	**1.81**	**115**	**93**	**2.48**	**125**	**98**	**2.49**	**113**	**98**	**1.39**	**118**	**98**
5Km Downstream of WL												
1992	1.22	117	88	2.69	118	92	2.07	112	86	0.79	120	90
1993	1.56	120	96	2.46	122	100	1.32	62	91	0.66	120	100
1994	0.93	108	90	1.80	114	96	2.08	99	86	0.60	111	105
1995	1.41	102	93	1.90	109	97	1.53	99	95	0.51	91	91
1996	1.56	121	90	1.30	130	104	1.62	118	101	0.72	120	92
1997	-	-	-	-	-	-	-	-	-	-	-	-
1998	1.36	154	117	1.73	131	106	1.10	116	88	0.35	116	91
Average	**1.34**	**120**	**96**	**1.98**	**121**	**99**	**1.62**	**101**	**91**	**0.61**	**113**	**95**

**Note : results reported are for fish flesh only.
Trace amounts of ^{232}Th, ^{235}U, ^{226}Ra were detected in a few of the fish flesh samples.

Figure 24: Cs-137 in Pickerel Flesh

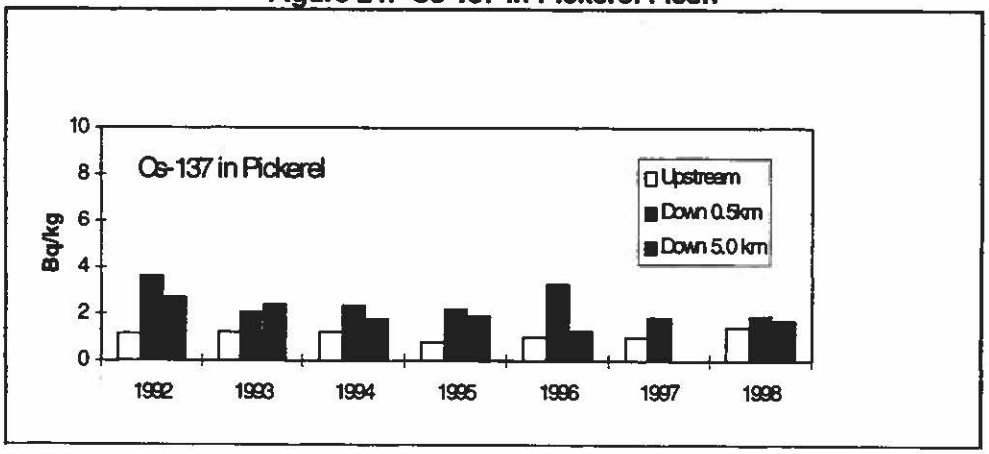


Table 31: Average Radioactivity in Flesh of Winnipeg River Fish, 1992 -- 1998

	Sucker (Bq/kg)			Pickerel (Bq/kg)			Pike (Bq/kg)			Whitefish (Bq/kg)		
	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta	Cs-137	K-40	Gross Beta
Upstream of WL (Pinawa)												
1992	0.56	125	92	1.11	105	87	2.26	122	98	1.29	118	99
1993	0.42	116	91	1.22	121	96	0.16	115	90	-	-	-
1994	0.45	110	97	1.22	113	94	0.69	114	98	0.17	118	95
1995	0.33	99	92	0.75	112	94	0.63	98	91	0.28	108	105
1996	0.40	124	98	0.98	132	97	0.66	116	90	0.58	134	105
1997	0.37	126	100	1.03	141	102	0.76	135	98	0.26	135	105
1998	0.57	162	97	1.44	119	89	1.74	132	89	0.24	159	100
Average	**0.44**	**123**	**95**	**1.11**	**120**	**94**	**0.99**	**119**	**93**	**0.47**	**129**	**101**
0.5Km Downstream of WL												
1992	1.65	115	87	3.66	110	90	2.54	115	90	4.28	127	87
1993	1.84	122	96	2.04	117	90	2.53	118	94	0.53	112	96
1994	1.81	112	104	2.35	116	101	2.62	103	100	0.55	111	102
1995	2.18	99	93	2.21	112	99	1.72	99	99	1.96	95	97
1996	2.87	120	92	3.26	136	103	4.63	114	99	1.56	121	90
1997	1.31	130	96	1.88	133	98	1.42	125	103	0.38	122	96
1998	1.03	109	87	1.96	150	108	1.94	118	98	0.45	140	115
Average	**1.81**	**115**	**93**	**2.48**	**125**	**98**	**2.49**	**113**	**98**	**1.39**	**118**	**98**
5Km Downstream of WL												
1992	1.22	117	88	2.69	118	92	2.07	112	86	0.79	120	90
1993	1.56	120	96	2.46	122	100	1.32	62	91	0.66	120	100
1994	0.93	108	90	1.80	114	96	2.08	99	86	0.60	111	105
1995	1.41	102	93	1.90	109	97	1.53	99	95	0.51	91	91
1996	1.56	121	90	1.30	130	104	1.62	118	101	0.72	120	92
1997	-	-	-	-	-	-	-	-	-	-	-	-
1998	1.36	154	117	1.73	131	106	1.10	116	88	0.35	116	91
Average	**1.34**	**120**	**96**	**1.98**	**121**	**99**	**1.62**	**101**	**91**	**0.61**	**113**	**95**

**Note : results reported are for fish flesh only.
Trace amounts of ^{232}Th, ^{235}U, ^{226}Ra were detected in a few of the fish flesh samples.

Figure 24: Cs-137 in Pickerel Flesh

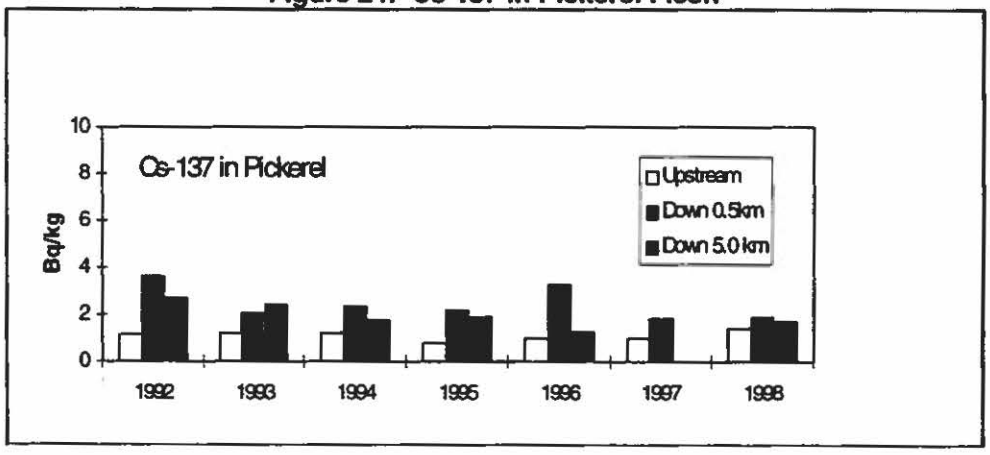


Figure 25: Cs-137 in Sucker Flesh

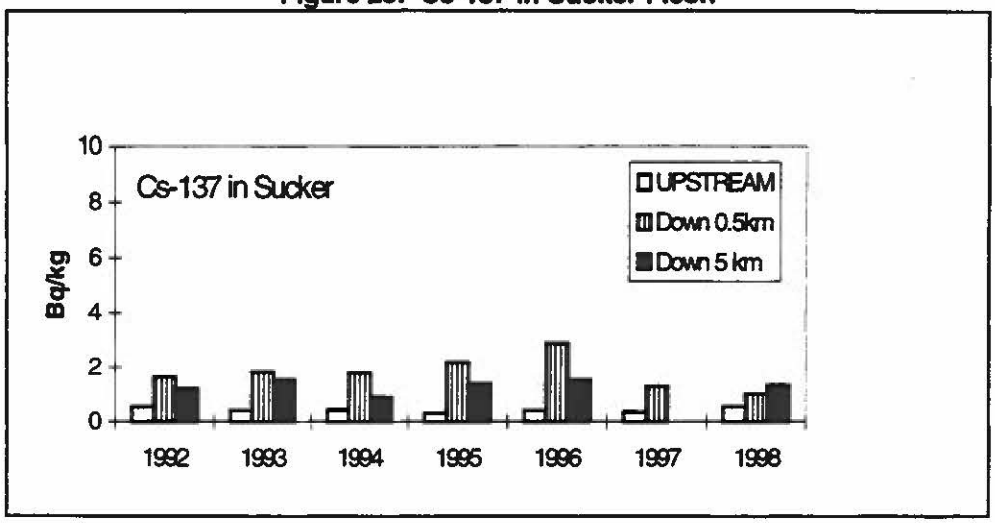
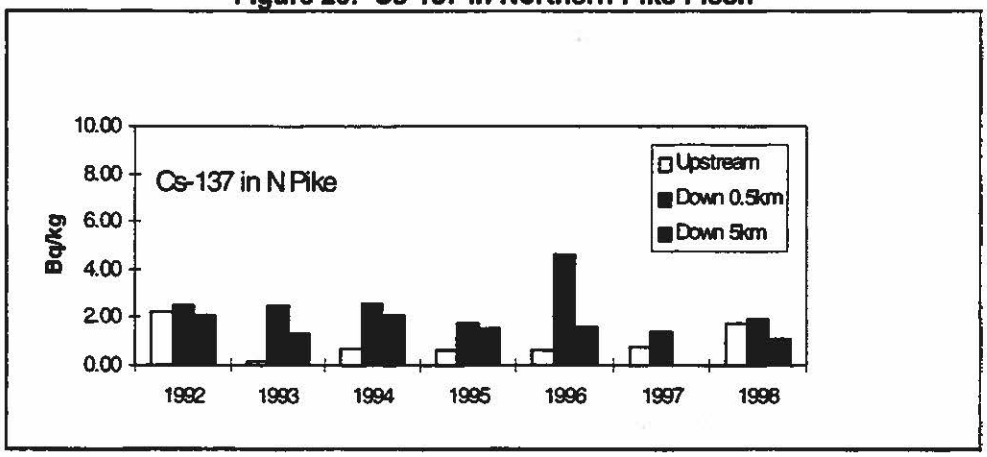


Figure 26: Cs-137 in Northern Pike Flesh



3.7.3 River Sediment

River-bottom sediments were collected from 12 locations along the Winnipeg River, ranging from 0.8 km upstream to 13.1 km downstream of the process outfall. Three samples, each consisting of the top centimetre of the sediment were collected in a corer at each location, and the average and the standard deviation of the three readings for each station have been reported. The core diameters were 2.8 cm, that is, surface area of the cores was 6.2 cm^2 .

Table 32 shows the gross beta, gross alpha and caesium-137 activities (in Bq/kg dry weight) of the river-bottom sediments from the 12 locations along the Winnipeg River for the years 1994 to 1998. Data for 1998 are also shown in the alternate units of kBq/m^2 (Table 33) in order to facilitate dose estimate calculations. Table 34 shows the distance from shore and depth of water at each sampling site and the weights of each of the three samples collected at every site.

The results of core sediment analysis are plotted in Figures 27 to 29. For each of the years 1994 to 1998, twelve bars are shown, one for each sampling location. The bars are arranged upstream (left) to downstream (right), with the third bar from the left being the process outfall. The apparent increase in 1998 gross alpha values could be due to the change in the method of calculation of the calibration factor, noted earlier. It should be noted that the standard deviations are very high, particularly for caesium-137 (see Table 32), and therefore many of the differences apparent in Figures 27 to 29 lie within the levels of uncertainty. Caesium-137 concentrations in sediments at the process outfall are also shown separately in Figure 30 at a scale suitable to accommodate the high values. The measured caesium-137 concentrations are highly variable over the years with high values reported in 1994 and 1997. This is most likely caused by small isolated pockets of sediments containing elevated concentrations of caesium-137.

Table 32: Radioactivity in River-Bottom Sediments, 1995 -- 1998

	ACTIVITY (Bq/kg Dry Weight)																			
	1994			1995			1996			1997			1998							
LOCATION	Gross Beta	Gross Alpha	Cs-137	Gross Beta	Gross Alpha	Cs-137	Gross Beta	Gross Alpha	Cs-137	Gross Beta	Gross Alpha	Cs-137	Gross Beta	+/-	Gross Alpha	+/-	Cs-137	+/-	K-40	+/-
J04 -0.76	662	11.2	10.1	334	33	7	377	150	3	659	135	13	506	159	< 1065		16	10	542	41
J02 -0.37 (upstream)	519	1.05	4.37	500	41	8	410	169	3	609	112	8	503	146	< 603		8	13	447	53
OFL 0 (outfall)	5740	27.9	75500	1168	105	868	1628	230	2285	20751	717	20604	663	333	< 608		499	848	456	37
K01 0.15 (down stream)	694	18.9	206	659	152	94	712	155	59	684	164	114	736	337	< 930		41	37	568	253
K03 0.52	1210	11.2	440	1518	157	508	637	216	111	667	204	139	721	214	< 1025		157	46	535	102
K05 0.79	549	13.1	49.2	551	186	25	542	197	73	678	192	142	699	556	495	373	79	114	539	80
K14 2.56	838	12.0	93.6	675	209	95	480	181	96	498	185	82	550	146	583	415	76	81	348	26
K19 3.48	754	11.2	116	291	200	44	381	124	42	386	242	36	393	171	< 609		38	14	320	25
K22 4.63													694	109	< 610		152	133	467	23
K23 4.78	881	19.9	123	874	211	124	790	188	123	860	198	230	802	366	538	393	63	51	579	67
K24 4.93													510	139	503	378	7	7	521	154
K30 13.06	778	21.2	110	772	183	79	832	219	26	673	161	54	686	349	< 1040		28	84	536	80

Notes: Three sediment samples were collected at each location. The average and2 standard deviation of those 3 readings are reported above
Large errors result from variations in sample activity, particularly for Cs-137.

Table 33: Radioactivity in River-Bottom Sediments -- 1998 (kBq/m^2),

	J04	J02	OFL	K01	K03	K05	K14	K19	K22	K23	K24	K30
Gross Beta kBq/m^2	10.8	11.0	11.8	14.3	8.3	9.9	8.4	7.3	16.2	9.9	18.5	20.4
Gross Alpha kBq/m^2	<10	<13	<11	<8	<5	2.7	6.9	<11	,14	6.6	9.5	<14
Cs-137 kBq/m^2	0.31	0.19	8	0.78	1.79	6.9	1.09	0.71	3.88	0.81	0.25	0.76

Table 34: Weights of River-Bottom Sediment Samples and Characteristics of Sampling Locations

					Core depth (cm)	Dried Gamma Weight (g)	Sample Date	Water Depth (m)	Distance from shore (m)
WH	J04	S	9808	001	1	4.94835	10-Aug-98	2.6	30.0
				002	1	7.23424	10-Aug-98		
				003	1	3.45685	10-Aug-98		
	J02			001	1	12.26866	10-Aug-98	2.5	10.0
				002	1	13.19992	10-Aug-98		
				003	1	14.59010	10-Aug-98		
	OFL			001	1	9.51768	11-Aug-98	3.2	20.0
				002	1	6.96552	11-Aug-98		
				003	1	10.72863	11-Aug-98		
	K01			001	1	11.74797	11-Aug-98	2.0	20.0
				002	1	9.79985	11-Aug-98		
				003	1	8.70497	11-Aug-98		
	K03			001	1	6.62569	11-Aug-98	3.5	25.0
				002	1	6.27737	11-Aug-98		
				003	1	7.50800	11-Aug-98		
	K05			001	1	4.00437	11-Aug-98	5.0	20.0
				002	1	4.22288	11-Aug-98		
				003	1	3.45727	11-Aug-98		
	K14			001	1	9.14313	11-Aug-98	5.0	20.0
				002	1	7.03960	11-Aug-98		
				003	1	7.73250	11-Aug-98		
	K19			001	1	10.65740	11-Aug-98	3.5	15.0
				002	1	11.90238	11-Aug-98		
				003	1	9.92273	11-Aug-98		
	K22			001	1	10.76877	10-Aug-98	4.5	20.0
				002	1	19.91056	10-Aug-98		
				003	1	11.16288	10-Aug-98		
	K23			001	1	9.71690	10-Aug-98	5.0	30.0
				002	1	6.74033	10-Aug-98		
				003	1	4.61504	10-Aug-98		
	K24			001	1	15.66566	10-Aug-98	3.8	15.0
				002	1	13.14967	10-Aug-98		
				003	1	8.79442	10-Aug-98		
	K30			001	1	8.67162	10-Aug-98	3.2	30.0
				002	1	15.64707	10-Aug-98		
				003	1	16.32910	10-Aug-98		

Core diameter = 2.8 cm, core area 6.2 cm^2

The following Figures 27 to 29 depict radioactivity in Winnipeg River sediments in becquerels per kilogram dry weight. Bars are arranged from upstream (left) to downstream (right).

Figure 27

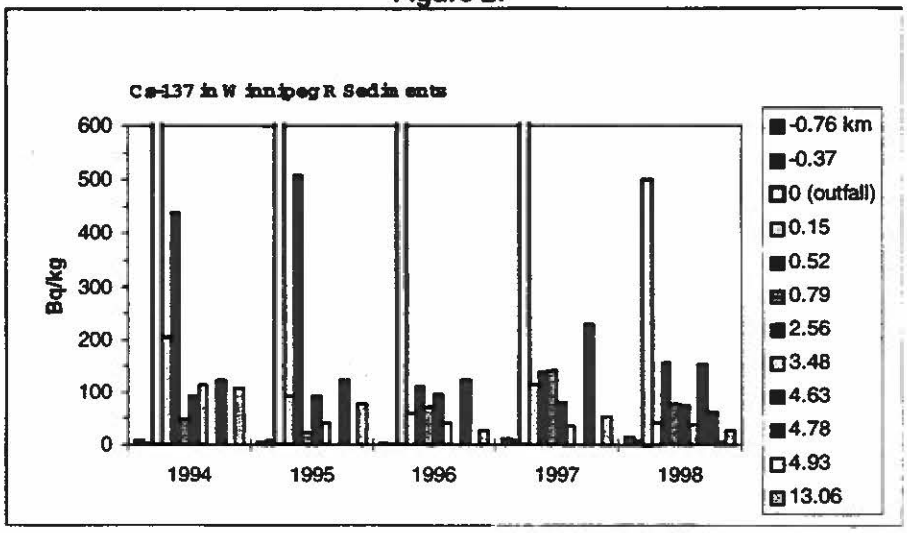


Figure 28

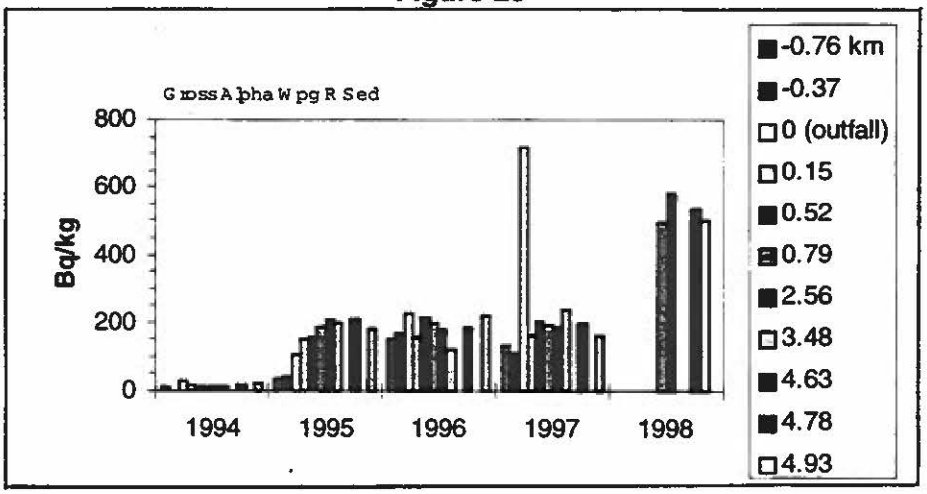


Figure 29

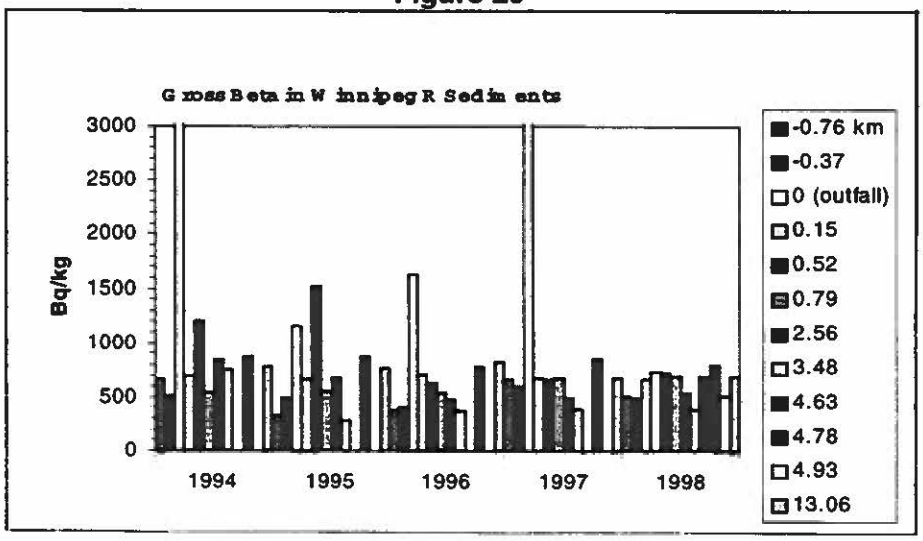
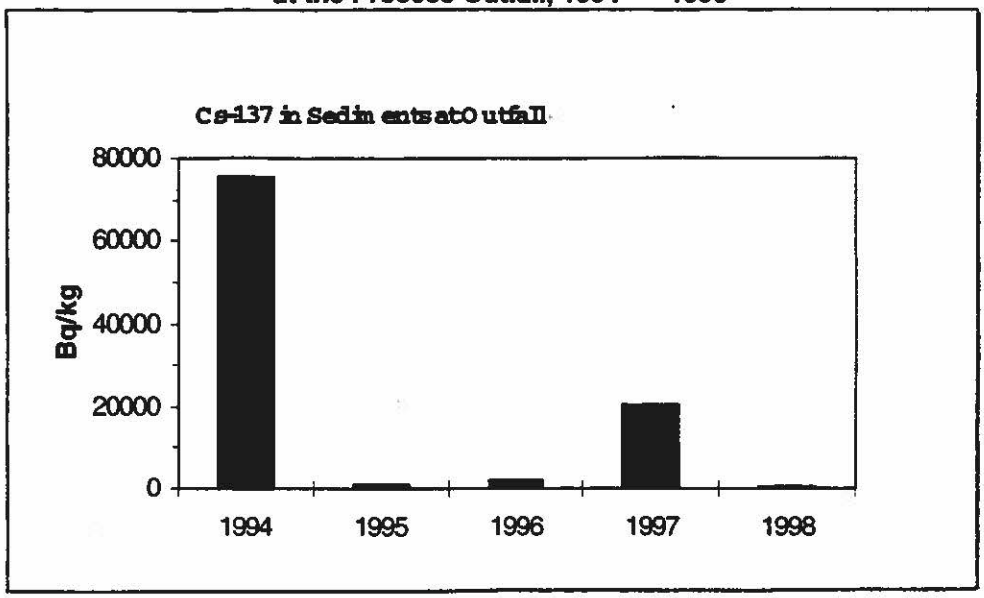


Figure 30: Caesium-137 in River-Bottom Sediment at the Process Outfall, 1994 – 1998



3.8 Radioactivity in Vegetation

3.8.1 Native Vegetation

Radioactivity in native vegetation, in units of Bq/kg fresh weight, is reported from 6 locations in WL in Table 35. Refer to Maps 3 and 4 in Appendix 2 for the sample locations.

Table 35: Radioactivity in Native Vegetation at WL – 1998 (Bq/kg Fresh Weight)

	Gross Beta		Gross Alpha		K-40		Sr-90		Cs-137	
	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-
ARMS 1, North	87.1	6.11	11.1	7.74	111	5.29	<19		<0.23	
ARMS 3, South-southeast	209	14.2	<12		220	9.46	<30		<0.43	
ARMS 4 West	150	10.2	9.00	8.72	182	7.59	<24		<0.29	
ARMS 5, Northwest	152	10.4	<12		157	7.04	<22		0.314	0.2
West of WMA	450	32	<55		480	30	NA		<1.1	
North of Canisters	234	21	125	52	138	20	15	2	<1.9	

< indicates values less than limit of detection.
+/- indicates 2 standard deviations based on counting statistics.

3.8.2 Radioactivity in Cultivated Vegetables

Radioactivity was measured in lettuce, zucchini and carrots from gardens irrigated with Winnipeg River water about 17 km upstream (Pinawa) and about 5 km downstream of the process outfall. Analyses were done for gross alpha activity, gross beta activity, Sr-90, K-40, Cs-137, Ra-226, Be-7 and Th-232. The results are presented in Table 36. Data on the naturally occurring radionuclides, K-40, Ra-226, Be-7 and Th-232, are useful for interpreting gross beta and gross alpha activity.

Table 36: Radioactivity in Cultivated Vegetables (Bq/kg Fresh Weight)

	Gross Alpha		Gross Beta		Sr-90		K-40		Cs-137		Ra-226		Be-7		Th-232	
	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-	(Bq/kg)	+/-
Upstream																
Lettuce	<11		126	9	0.7	0.1	161	7	0.18	0.16	< 0.5		10.3	2.2	0.4	0.3
Zucchini	<4		56	4	<0.1		72	2	< 0.1		< 0.1		< 2		< 0.2	
Carrots	<11		80	6	9.2	0.5	95	5	< 0.3		0.3	0.2	< 3		< 0.4	
Downstream																
Lettuce	<30		303	21	1.2	0.3	403	17	0.04	0.02	1.2	1.0	12.8	5.3	< 2	
Zucchini	<4		45	3	< 0.1		58	2	0.10	0.06	< 0.1		< 1		< 0.2	
Tomato	<10		88	6	15	1	112	8	< 0.3		< 0.5		< 3		< 1	
Potato	<10		82	5	4.9	0.3	184	6	< 0.2		< 0.3		< 2		< 0.3	
Carrots	6	3	62	4	0.2	0.1	86	6	0.3	0.1	< 0.3		< 3		< 0.5	

Notes: Results are decay corrected to sample reference date.
Errors reported are 2 standard deviations based on counting statistics for a single determination.

3.9 Radioactivity in Flesh of Wildlife

Roadkills from the vicinity of WL were collected and analyzed for radioactivity. Analyses for flesh for gross beta, gross alpha, Cs-137 and K-40 are shown in Table 37 for samples of the species bear, grouse, red fox, and deer.

Table 37: Radioactivity in Flesh of Wildlife (mBq/g fresh weight)

	GROSS BETA		Cs-137		K-40	
	(mBq/g)	+/-	(mBq/g)	+/-	(mBq/g)	+/-
Bear	57.5	3.9	4.6	0.2	68.7	2.7
Grouse	67.2	4.6	2.6	0.3	89.0	6.8
Red Fox	114.7	7.7	27.6	0.7	120.6	7.8
Grouse	90.9	6.2	0.9	0.3	134.7	9.9
Red Fox	143.7	9.5	82.4	1.0	125.2	6.0
Deer	100.8	6.8	11.1	0.3	119.5	3.6

3.10 Meteorological Conditions

Rose diagrams for wind directions at WL at 6, 10, 25 and 61 m elevations are shown in Appendix 4.

4. ASSESSMENT OF DOSES TO THE PUBLIC

4.1 General

The following sections, 4.2 to 4.4, examine and assess the radiation doses, due to emissions from the CRL and WL sites, during 1998, to the most heavily exposed off-site members of the public in the critical groups as identified in the Derived Release Limit (DRL) reports for these sites [4, 6]. The dose assessments are based on the results of environmental monitoring of the dominant environmental pathways leading to critical group dose, where the monitoring indicates an actual or potential contribution above normal background from AECL. Dose conversion factors for calculating effective dose from inhalation, ingestion, or exposure to surfaces contaminated by radionuclides are from reference [7].

For comparison with the dose estimates below, the current regulatory dose limit in Canada specified by Atomic Energy Control Regulations, to members of the public as a result of human activities involving ionizing radiation (excluding medical diagnostic or treatment procedures) is 5 mSv in a year whole body (effective) dose. The draft revised Canadian regulations propose to reduce this public dose limit to 1 mSv in a year, consistently with the 1990 recommendations of the International Commission on Radiological Protection (ICRP) [13].

Also for comparison with the estimated doses in this report, typical annual average background radiation doses to adults from major natural sources of radiation and from medical diagnostic procedures, reported by the NCRP [17] and the UNSCEAR [16] are in Table 38. Actual background doses can vary considerably (one or more order of magnitude) depending on various factors such as elevation above sea level, local geology and housing construction, and medical requirements.

Table 38: Typical Annual Average Background Radiation Dose in Canada

Source of Exposure	Annual Average Effective Dose (mSv)
Natural Sources:	
-Cosmic radiation (Canada) [16]	0.27
-Terrestrial gamma radiation (Canada) [16]	0.23
-Radionuclides in the body (except radon) - (worldwide) [15]	0.23
-Radon and its decay products (worldwide) [15]	1.3
Consumer products and services (worldwide) [17]	0.025 – 0.095
Medical diagnostic procedures (industrialized countries) [15]	1.1
Total Dose (Natural Sources + Medical Procedures + Consumer Products and Services)	3.2

4.2 CRL Air Effluent Exposure Pathways

As noted in Section 1.3 of this report, the critical groups for airborne emissions from CRL identified in the DRL report for CRL [4] are either adults or infants at Balmer Bay, or infants at Sheenboro. The dominant pathways are air immersion of noble gases, milk ingestion (tritium, C-14, radioiodines), exposure to contaminated ground (gross beta particulates) and inhalation of alpha particulates. Other environmental pathways may cause lesser doses.

Environmental monitoring of air effluent exposure pathways during 1998 indicated detectable or potential contributions from CRL at Balmer Bay /Sheenboro in ambient gamma radiation dose in air due to emissions of noble gases (primarily Argon-41), ambient tritium in air, vegetables and milk. Milk was obtained from a local diary at Deep River. Consequently, the measured radioactivity concentrations in milk were generally applicable also to the critical group at Sheenboro.

Noble Gases- External Exposure in Plume

External gamma exposure due to noble gas emissions is estimated using the results of the GammaTracer ambient gamma radiation dose contribution from CRL noble gases measured at Balmer Bay after subtracting the natural background exposure. As noted in Section 1.3, emissions for noble gases, and argon-41 in particular, represent the largest CRL emissions as a percentage of the DRLs for the site. Because the noble gases are chemically inert and decay with a fairly short radioactive half life, virtually all radiation dose from these emissions is due to external exposure to the atmospheric plume.

Table 39: CRL 1998 Critical Group Dose at Balmer Bay From Noble Gas Emissions

GammaTracer Ambient Dose Rate Contribution From CRL Noble Gas Emissions [Table 1]		Dose Conversion Factors Air kerma to effective dose (Sv/Gy)		Annual Effective Dose (mSv/a)	
Ambient Dose Equivalent -H*10 (nSv/h)	Air kerma (nGy/h) [see note 1]	Adult [4]	Infant [4]	Adult	Infant
11.2	9.3	0.76	0.91	0.061	0.074
Assumptions: Fraction of time exposed		1	1		

Note 1: The GammaTracer devices are calibrated to provide output in units of Ambient Dose Equivalent (H*10) [13]. A factor of 1.2 Sv (H*10)/Gy is used here to convert to units of absorbed dose in air (air kerma) [15].

Milk Ingestion

The critical group dose from milk ingestion was calculated using measured concentrations in milk supplied by a local dairy, and obtained from dairy herds within Renfrew County. The calculations assume measured annual average values of tritium, ignoring natural background concentrations and possible contributions from other sources of tritium emissions within the area, measured values of caesium-137 (without background reduction) and measured values of iodine-131 (assumed to be equal to detection limit even though all results were less than detection limit), and carbon-14 values with background reduction [16].

Table 40: CRL – 1998 Dose To Critical Group at Sheenboro From Milk Ingestion

Radionuclide	Concentration In Milk (Bq/L)	Dose Conversion Factor For Ingestion (Sv/Bq)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Tritium	26	2.00E-11	5.80E-11	6.2E-05	3.3E-04
I-131	0.084 LLD	1.10E-08	8.70E-08	1.1E-04	1.6E-03
Cs-137	0.053	1.40E-08	1.40E-08	8.9E-05	1.6E-04
C-14*	1.05	5.20E-10	1.60E-09	6.6E-05	3.7E-04
			Total Dose	2.6E-04	2.1E-03
Assumptions: Milk Consumption Rate (L/a) [7]		120	220		
Fraction from local sources		1	1		

*Assuming 35 g of carbon in one L of milk. Specific Activity for C-14 is 230 Bq / kg carbon [16], and CRL contribution about 30 Bq of C-14 in one kg of carbon.

Tritium - Inhalation/Immersion

Critical group dose due to inhalation of atmospheric tritium was estimated from the annual average measured ambient tritium in air at Balmer Bay for 1998. To be conservative, normal background concentrations of tritium in air in Ontario (typically about 0.2 Bq/m^3) was ignored. The dose was estimated using the following expression, which includes a factor of two increase in calculated inhalation dose to account for possible tritium uptake through skin absorption (as recommended in [7]):

$$\text{Dose} = C \times I_a \times DCF_i \times OF_i \times A_s$$

Table 41: CRL–1998 Dose to Critical Group at Balmer Bay /Sheenboro From Inhalation of Tritium

Radionuclide	Concentration in Air (Bq/m^3)	Dose Conversion Factor For Inhalation (Sv/Bq)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Tritium (HTO)	0.97	2.00E-11	5.80E-11	3.3E-04	1.6E-04
Assumptions:					
I_a = Breathing Rate (m^3/a) [7]		8400	1400		
OF_i = Fraction of time exposed		1	1		
A_s = Skin absorption intake factor [7]		2	2		

Vegetable Ingestion

Critical group dose from consumption of vegetables grown at Balmer Bay was estimated using the measured concentrations in vegetables from Balmer Bay, of radionuclides with concentrations potentially in excess of background (tritium, caesium-137, gross beta particulates assuming Sr-90 and gross alpha particulates, assuming all Am-241). The dose to the critical group was estimated using the following expression. Natural background concentrations of these radionuclides were ignored in the calculation. It was assumed that 10% of vegetables consumed during the year were grown locally [7] in Balmer Bay (equation 5.15 in [7]):

Dose (nuclide n) = $C_n \times I_f \times G_f \times DCF_f$, where

Gf = fraction of food from contaminated source (0.1)
If = consumption rate
DCFf = dose conversion factor for ingestion

Table 42: CRL -- 1998 Dose To Critical Group at Balmer Bay From Vegetable Ingestion

Radionuclide	Concentration in Vegetables (Bq/kg fresh wt)	Dose Conversion Factor For Ingestion (Sv/Bq)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Tritium	23	2.0E-11	5.8E-11	9.2E-06	1.1E-05
Cs-137	1.5	1.4E-08	1.4E-08	4.2E-04	1.8E-04
Gross Beta (as Sr-90)*	39.4	3.4E-08	2.4E-07	2.7E-02	7.9E-02
Gross Alpha (as Am-241)	3.227	2.3E-08	3.4E-08	1.5E-03	9.2E-04
			Total Dose	2.9E-02	8.1E-02
Assumptions:					
Vegetable Consumption (kg/a) [7]		200	84		
Fraction from local sources		0.1			

*Gross beta minus K-40 and Cs-137.

Table 43: 1998 Total Estimated Dose to Critical Group At Balmer Bay From Air Effluent Exposure Pathways

Pathway	Adult	Infant
External Exposure to Noble Gases	7.4E-02	9.0E-02
Tritium Inhalation/Immersion	3.3E-04	1.6E-04
Vegetable Ingestion	2.9E-02	8.1E-02
Milk Ingestion	2.6E-04	2.1E-03
Total Effective Dose (mSv/a)	1.0E-01	1.7E-01
Total Dose (as % of public dose limit)	2.1	3.5
Total Dose as % of typical background dose (Table 38)	3.2	5.4

The total estimated doses in 1998 to members of the critical group at Balmer Bay from the above pathways, as summarized in Table 39, represent 2.1 % and 3.5 % of the annual public dose limit of 5mSv (whole body) effective dose to adults and infants respectively. In comparison, air emissions from the CRL site in 1998 (Table 1) represented, in total, 2.76 % of the DRLs [4] based on this dose limit.

4.3 CRL Liquid Effluent Exposure Pathways

As noted in Section 1.3, the critical group for liquid emissions from CRL identified in the DRL report [4] are adults downstream of CRL on the Ottawa River in Ft. William. The dominant exposure pathways are identified as fish ingestion, water ingestion, exposure to ground, and exposure to beach although other pathways may also contribute lesser doses.

Environmental monitoring of liquid effluent exposure pathways during 1998 indicated concentrations of radionuclides above Lower Limits of Detection (LLDs) and in excess of background attributable to CRL operations in Ottawa River water, fish and beach sediments.

Drinking Water

The dose to members of the downstream critical group due to drinking water from the Ottawa River was estimated from the annual average measured downstream concentrations (Pembroke) minus the average upstream concentrations at Rolphton. It was assumed there was no filtration or other pretreatment of the water prior to consumption that might remove any of the radionuclides. Dose was calculated using the following expression:

$$\text{Dose (nuclide n)} = C_n \times I_f \times G_f \times DCF_f$$

Table 44: CRL - 1998 Dose To Critical Group At Ft. William/Petawawa from Drinking Water

Radionuclide	Concentration In Drinking Water from CRL (Bq/L) (Table 16)	Dose Conversion Factor For Ingestion (Sv/Bq)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Tritium	6.9	2.0E-11	5.8E-11	9.7E-05	3.6E-05
Caesium-137*	0.003	1.4E-08	1.4E-08	2.9E-05	3.8E-06
Strontium-90	0.008	3.4E-08	2.4E-07	1.9E-04	1.7E-04
			Total Dose	3.2E-04	2.1E-04
Assumptions:					
Water consumption rate (L/a) [7]		700	90		
Fraction of water from Ottawa River		1	1		

* Because of an exceptionally high Cs-137 value in upstream samples [see Table 16], downstream concentration is conservatively assumed to be entirely due to CRL releases.

Fish Ingestion

The dose to members of the critical group was estimated from the average measured concentrations in fish from the Ottawa River in the Highview area (between CRL and Petawawa) minus the average upstream concentrations in fish from upstream (Mackay above the Rolphton dam). The dose calculation used the following expression adapted from the National Standard of Canada CAN/CSA N288.1 [7].

$$\text{Dose (nuclide n)} = C_n \times I_f \times G_f \times DCF_f$$

The fish consumption rates for adults (18 kg/a) and for infants (1 kg/a) were taken from the current CRL DRL report [4].

Table 45: CRL - 1998 Dose to Critical Group At Ft. William/Petawawa from Fish Ingestion

Radionuclide	Concentration In Fish - Contrib. from CRL (Bq/kg) (Table 17)	Dose Conversion Factor For Ingestion (Sv/Bq)		Effective (mSv/a)	
		Adult	Infant	Adult	Infant
Caesium-137	17.9	1.40E-08	1.40E-08	4.5E-03	2.5E-04
Caesium-134	1.1	2.0E-08	1.7E-08	4.0E-04	1.9E-05
Phosphorus-32	4.9	2.3E-09	1.3E-08	2.0E-04	6.4E-05
Gross Alpha (as Am-241)	0.006	6.00E-07	5.40E-06	6.5E-05	3.2E-05
Gross Alpha (as Am-241,	0.006	1.10E-05	8.90E-05	1.2E-03	5.3E-04
				5.2E-03	3.7E-04
Assumptions:					
Fish Consumption Rate (kg/a) [7]		18	1		
Fraction from local sources		1	1		

Table 46: CRL - 1998 Dose to Critical Group at Deep River/Ft. William/Petawawa from Game Animal Ingestion

Radionuclide	Concentration In Game Animal Meat - Contrib. from CRL (Bq/kg) (Table 12)	Dose Conversion Factor For Ingestion (Sv/Bq)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Tritium	501	2.00E-11	5.80E-11	7.1E-04	7.0E-04
Caesium-137	30.0	1.40E-08	1.40E-08	3.0E-02	1.0E-02
Caesium-134	1.0	2.0E-08	1.7E-08	1.4E-03	4.1E-04
Sr-90	6.0	3.4E-08	2.4E-07	1.4E-02	3.5E-02
Co-60	1	1.70E-08	3.60E-08	1.2E-03	8.6E-04
			Total Dose	4.7E-02	4.6E-02
Assumptions:					
Sr-90 in deer flesh assumed equal to moose flesh					
Flesh consumption rate (kg/a) [7] (as beef)		71	24		
Fraction from local sources		1	1		

Beach Exposure

Dose to members of the downstream critical group due to assumed exposure to contaminated beach sediments was estimated from the average measured radionuclide concentrations at the beach at Pointe au Baptême, minus the average of measured concentrations at beaches upstream of CRL. Members of the critical group were assumed to spend about 100 hours per year on this beach, located near the downstream boundary of the CRL property. Dose was calculated using the following expression adapted, along with default parameters, from [7]:

$$\text{Dose (nuclide n)} = C_n \times OF_s \times W \times d_s \times DCF_g$$

Table 47: CRL – 1998 Dose To Critical Group at Ft. William From Exposure to Beaches

Radionuclide	Concentration In Beach Sand - Contrib. from CRL (Bq/kg) (Table 18)	Dose Conversion Factor - Ground Exposure - DCF_g ($Sv.a^{-1}.Bq^{-1}.m^2$)		Effective Dose (mSv/a)	
		Adult	Infant	Adult	Infant
Caesium-137	37.0	1.65E-08	2.5E-08	4.9E-05	7.4E-05
Cobalt-60	4.0	6.2E-08	9.2E-08	2.0E-05	2.9E-05
Beta /Gamma (as Sr-90)	21	3.4E-07	5.1E-07	5.7E-04	8.6E-04
			Total Dose	6.4E-04	9.6E-04
Assumptions:					
Beta/Gamma =total - K-40					
Avg Conc. at Pt. Au Bapteme (upstream)					
OF_s =Occupancy Factor [7]		0.01	0.01		
W = shore width factor for river [7]		0.2	0.2		
d_s = effective sediment density(kg/m_2) [7]		40	40		

*Assuming the total Gross beta minus K-40 consists all of Sr-90.

Table 48: 1998 Total Estimated Dose to Critical Group At Ft. William/Petawawa From Liquid Effluent Exposure Pathways

Pathway	Adult	Infant
Drinking Water	2.0E-04	1.3E-04
Fish Consumption	9.0E-03	5.5E-04
Contaminated Beach Exposure	6.4E-04	9.6E-04
Game Animal Meat Ingestion	4.7E-02	4.6E-02
Total Effective Dose (mSv/a)	5.7E-02	4.8E-02
Total Dose (as % of public dose limit)	1.14	0.95
Total Dose as % of typical background dose (Table 38)	1.77	1.49

The total estimated doses in 1998 to members of the critical group at Ft. William / Petawawa area from the above pathways, as summarized in Table 50 above, represent 1.14 % and 0.95 % of the annual public dose limit of 5mSv (whole body) effective dose to adults and infants respectively. In comparison, liquid emissions from CRL in 1998 represented, in total, 0.22 % of the DRL based on this dose limit.

4.4 WL Air and Liquid Effluent Exposure Pathways

Field data presented in this report have been used to estimate incremental dose to members of critical groups that could be caused by operations at WL. Such estimates have been done for: water ingestion, fish ingestion, vegetable ingestion and beach exposure. Dose estimates due to immersion in air and ingestion of wildlife (game) were not calculated because of the extremely low radioactivity levels associated with these two sources.

The general equation used for calculating dose due to nuclide n is

(1) Dose (nuclide n) = Cn . DCF . I . G

where

C(n) = incremental concentration of nuclide n,
DCF = Dose Conversion Factor,
I = Consumption rate,
G = Fraction from local sources.

Units vary according to the case being considered. Refer to Table 51 for a detailed analysis of the four cases considered and the units used. DCFs and consumption rates are the same as used for the calculation of Derived Release Limits currently in use for WL [6].

Water Ingestion

Doses due to Cs-137 and gross beta activity in drinking water have been calculated, with Sr-90 Dose Conversion Factors applied to gross beta. Unit of DCF is Sv/Bq. Doses were calculated on the basis of concentration differences between downstream (2 km) and upstream (Pinawa, 17 km) locations (Table 28). It was conservatively assumed that all water consumed by the individuals in the critical group was obtained from the Winnipeg River. Consumption rates were 700 L/a for adults and 90 L/a for infants [6]. Total incremental doses of 3.19E-04 mSv/a for adults and 2.82E-04 mSv/a for infants due to drinking water were estimated.

Fish Ingestion

Doses due to Cs-137 in pickerel were estimated which is the species showing the largest concentration difference between downstream and upstream locations (Table 30). Unit of DCF is Sv/Bq. Concentration data were used from samples from Pinawa and the location 0.5 km downstream of the process outfall. Assumed consumption rates were 20 kg/a for adults [6] and a nominal 1 kg/a for infants. Incremental doses due to fish ingestion for adults and infants in the critical group were 1.46E-04 and 7.28E-06 mSv/a respectively.

Vegetable Ingestion

Doses arising from Sr-90 due to ingestion of lettuce were calculated. The differences between downstream and upstream concentrations were obtained from Table 36. Unit of DCF is Sv/Bq. Assumed consumption rates were 14 kg/a for adults and 10 kg/a for infants. The incremental doses for adults and infants were calculated to be 5.95E-05 mSv/a and 3.00E-04 mSv/a respectively.

Beach Exposure

Doses due to beach exposure have been calculated, but it should be noted that the beach exposure scenario is totally hypothetical. It is assumed in the calculations that a member of the critical group would spend time on a beach whose radioactivity equals that of river-bottom sediments. However, no such beaches exist in the area. Only one beach in the area, at Lac du Bonnet, is used for public recreation and the sand of that beach has been trucked in from elsewhere. Doses due to gross alpha (assumed to be entirely Am-241) and Cs-137 have been calculated. Unit of DCF is $Sv.a^{-1}.Bq^{-1}.m^2$. The downstream location selected for the concentration differential was 2.56 km downstream of the Outfall, and the upstream location was 0.76 km upstream. Equation (1) has been used for calculating the beach exposure, where "consumption" was the fraction of time spent by the individual at the beach

(0.01) and the "local fraction" was the shore width factor (0.2). Incremental doses due to beach exposure for adults and infants are 3.69E-05 mSv/a and 5.57E-05 mSv/a respectively.

It can be noted from Table 49 that the total incremental doses due to water ingestion, fish ingestion, vegetable ingestion and beach exposure, for adults and infants, are 5.61E-04 mSv/a and 6.45E-04 mSv/a respectively, which can also be expressed as 0.011% and 0.013% respectively of the (current at the time of writing this report) annual regulatory limit of 5 mSv/a. Figure 31 depicts the doses estimated above.

Figure 31: Estimates of Incremental Dose Due to Effluents from WL

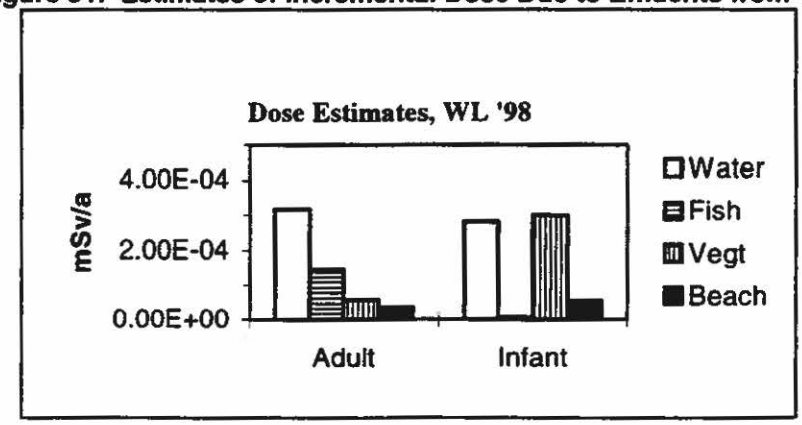


Table 49: Calculations for Incremental Dose Due to Effluents From WL

	Local Fract	CONCENTRATION				ADULT				INFANT			
		Down stream	Up-stream	Difference	Unit	DCF Sv/Bq	Consumption	Unit	Dose mSv/a	DCF Sv/Bq	Consumption	Unit	Dose mSv/a
Water Ingestion													
Cs-137	1	0.004	0.003	0.001	Bq/L	1.4E-8	700	L/a	9.8E-6	1.4E-8	90	L/a	1.26E-6
Gr Beta (Sr-90)	1	0.072	0.059	0.013	Bq/L	3.4E-8	700	L/a	3.09E-4	2.4E-7	90	L/a	2.81E-4
Total Water									**3.19E-4**				**2.82E-4**
Fish Ingestion (Pickerel) Cs-137	1	1.96	1.44	0.52	Bq/kg	1.4E-8	20	kg/a	**1.46E-4**	1.4E-8	1	kg/a	**7.28E-6**
Vegetable Ingestion (lettuce) Sr-90	0.25	1.2	0.7	0.5	Bq/kg	3.4E-8	14	kg/a	**5.95E-5**	2.4E-7	10	kg/a	**3.00E-4**
Beach Exposure													
GrAlpha (Am-241)	0.2	6900	0	6900	Bq/m^2	8.08E-10	0.01		1.12E-5	1.2E-9	0.01		1.67E-5
Cs-137	0.2	1090	310	780	Bq/m^2	1.65E-8	0.01		2.57E-5	2.5E-8	0.01		3.9E-5
Total Beach									**3.69E-5**				**5.57E-5**
Grand Total (mSv/a)									**5.61E-4**				**6.45E-4**
Grand Total (%Limit)									**0.011**				**0.013**

Notes: For beach exposure, units of DCF are $Sv.a^{-1}.Bq^{-1}.m^2$; occupancy factor (fraction time) is shown in "consumption" column; shore width factor is shown in "local fraction" column.

5. QUALITY ASSURANCE

General quality assurance objectives for AECL's Environmental Monitoring Program are set out in RC-2000-21, AECL Environmental Protection Program Manual [8]. In detail, the CRL and WL Environmental Monitoring Programs are conducted in accordance with laboratory specific environmental monitoring quality assurance manuals. The manuals include detailed working procedures for field operations, laboratory operations, laboratory administration, equipment performance and quality verification of analytical results.

Quality verification activities within the Environmental Monitoring Programs include periodic calibrations of counting instruments against traceable standards, process control measurements and data recording (for bias, precision, and background), historical reviews of measurements against previous results, and participation in intercomparison programs involving laboratories within and outside AECL.

Process control measurements include the routine calibration of instruments using traceable standards and the routine measurement of instrument backgrounds. Both of these types of data are incorporated into control charts to track instrument performance. Instruments and methods are tested using check sources and spike additions of known quantities of radionuclides, and regular analysis of duplicate or replicate samples.

5.1 CRL Environmental Laboratories

5.1.1 Instrument Performance

In 1998, the following quality verification tests were performed on the radiochemical counting equipment used for environmental and liquid effluent monitoring at CRL Environmental Laboratory:

Gross Alpha and Gross Beta Analyses - Re-calibration for discrimination of alpha and beta activities and determination of efficiencies was performed every two months. Control blanks and reference standards were checked weekly. An alpha background non-compliance was detected in February. Performance returned to normal after the counter was cleaned and re-calibrated. Gross beta performance remained in compliance.

Alpha Spectroscopy - Efficiency and energy calibrations and backgrounds were measured with every sample set. The system remained in compliance.

Gamma Spectroscopy - Efficiency and energy calibrations of standard geometries were determined annually and re-checked weekly. Environmental backgrounds were determined five times per year. The system remained within compliance.

Tritium - Instrument performance was tested weekly and remained in compliance. Background and reference control samples were included with each sample set. All excursions beyond control limits were within statistical probabilities for such excursions.

5.1.2 Analytical Reproducibility

Most analytical reproducibility measurements are made on samples collected in the effluent monitoring component of ERB services. Results of duplicate measurements are discussed in the 1998 Effluent Monitoring Report. A number of the environmental monitoring measurements employ the same preparation and counting procedures, and where this is the case the reproducibility performance discussed in the effluent monitoring report also has application here.

5.1.3 Inter-Laboratory Comparisons

In 1998, CRL Environmental Laboratory did not participate in laboratory inter-comparisons directly relevant[10] to the current CRL Environmental Monitoring Program since the programs run by the COG or by the US Environmental Protection Agency (EPA), in which CRL has previously participated, did not operate.

---

[10] The CRL tritium laboratory participated, with good results, in an international intercomparison on analysis of organically bound tritium, a parameter that is currently not monitored under the CRL Environmental Monitoring Program.

5.1.4 Program Improvements

In 1998, a project to bring the radiological liquid effluent and environmental monitoring QA program [28] to compliance with the National Standard of Canada, CAN/CSA-Z753-95, "Requirements for the Competence of Environmental Laboratories" was initiated. A review performed in 1998 indicated that many technical aspects of QA required by the CAN/CSA-Z753-95 [25] are in place. Improvement efforts were focused on control documentation for recently commissioned counting instruments.

5.2 CRL Dosimetry Laboratory

Quality control and assurance procedures and requirements for preparing, analysing, and reporting thermoluminescent dosimeter information are provided in [26]. The CRL Radiation Biology and Health Physics (RBHP) dosimetry laboratory, which prepares and analyses environmental TLDs at CRL, participates in environmental TLD intercomparisons sponsored by the US Department of Energy (USDOE). These are generally held at 2-year intervals, and no intercomparison was held in 1998.

5.3 WL Environmental Laboratories

Results of two Quality Assurance (QA) tests for WL procedures are reported here.

Table 52 summarizes the results of internal quality verification tests conducted by the Environmental monitoring section at WL. Results are for 11 different methods with an overall pass rate of 95.1%.

Table 50: Results of Internal Quality Verification Tests

Method	No. of Tests	No. Fail	% Pass
Total Alpha	**1510**	**90**	**94.0**
Instrumentation	1403	75	94.7
Animal. Fish &	1	1	0.0
Sediment & Soil	1	1	0.0
Water Samples	105	13	87.6
Total Beta	**1519**	**115**	**92.4**
Instrumentation	1404	104	92.6
Animal. Fish &	2	0	100.0
Sediment & Soil	8	3	62.5
Water Samples	105	8	92.4
Gamma	**910**	**20**	**97.8**
Instrumentation	800	8	99.0
Animal. Fish &	11	1	90.9
Sediment & Soil	36	4	88.9
Water Samples	63	7	88.9
Sr-90	**43**	**3**	**93.0**
Animal. Fish &	5	1	80.0
Water Samples	38	2	94.7
Plutonium	**13**	**2**	**84.6**
Polonium	**163**	**2**	**98.8**
Radium	**98**	**1**	**99.0**
Tritium	**110**	**1**	**99.1**
Uranium	**352**	**14**	**96.0**
Conductivity	**228**	**0**	**100.0**
pH	**114**	**1**	**99.1**
1998 Total	**5060**	**249**	**95.1**

Note: For total alpha, total beta, gamma and Sr-90, shaded lines show method totals with details in unshaded lines

Table 51 shows the results of intercomparison tests on WL data carried out by the US Environmental Protection Agency (EPA). A pass rate of 85% was attained.

Table 51: Quality Assurance Program - EPA Intercomparison Results

Water Analysis	Sample Date	EPA Value Bq/L	+/-	WL EM Bq/L	+/-	Test Summary	Number of tests	% pass
GROSS	30-Jan-98	1.13	0.28	0.76	0.10	warning		
ALPHA	21-Apr-98	2.02	0.50	1.54	0.09	pass		
	24-Jul-98	0.27	0.19	0.19	0.03	pass		
	20-Oct-98	1.11	0.28	1.03	0.30	pass		
	13-Nov-98	1.74	0.44	0.65	0.17	fail		
							5	80
GROSS	30-Jan-98	0.14	0.19	0.30	0.03	pass		
BETA	21-Apr-98	3.50	0.37	3.92	0.02	pass		
	24-Jul-98	0.47	0.19	0.26	0.00	pass		
	20-Oct-98	3.48	0.37	2.46	0.24	fail		
	13-Nov-98	0.13	0.19	0.20	0.03	pass		
							5	80
GAMMA								
Cobalt-60	21-Apr-98	1.85	0.19	2.06	0.08	pass		
	05-Jun-98	0.44	0.19	0.56	0.04	pass		
	20-Oct-98	0.78	0.19	0.88	0.06	pass		
	06-Nov-98	1.41	0.19	1.43	0.06	pass		
							4	100
Zinc-65	05-Jun-98	3.85	0.37	3.17	0.96	warning		
	06-Nov-98	4.85	0.48	5.27	0.15	pass		
							2	100
Cesium-134	21-Apr-98	0.81	0.19	0.62	0.02	pass		
	05-Jun-98	1.15	0.19	0.94	0.06	pass		
	20-Oct-98	0.22	0.19	0.16	0.02	pass		
	06-Nov-98	3.89	0.19	2.74	0.11	fail		
							4	75
Cesium-137	21-Apr-98	0.37	0.19	0.38	0.06	pass		
	05-Jun-98	1.30	0.19	1.48	0.10	pass		
	20-Oct-98	1.85	0.19	1.60	0.06	warning		
	06-Nov-98	4.11	0.22	3.74	0.15	warning		
							4	100
Barium-133	05-Jun-98	1.48	0.19	1.76	0.06	warning		
	06-Nov-98	2.07	0.22	2.06	0.12	pass		
							2	100
RADIOCHEMICAL								
Strontium-89	16-Jan-98	0.30	0.19	0.39	0.09	pass		
	21-Apr-98	0.22	0.19	0.06	0.02	pass		
	17-Jul-98	0.78	0.19	0.11	0.04	fail		
	20-Oct-98	0.70	0.19	0.38	0.02	warning		
							4	75
Strontium-90	16-Jan-98	1.18	0.19	0.75	0.12	fail		
	21-Apr-98	0.67	0.19	0.49	0.04	pass		
	17-Jul-98	0.26	0.19	0.52	0.00	warning		
	20-Oct-98	0.30	0.19	0.26	0.00	pass		
							4	75
						Total	**34**	**85**

with 7 results in the warning range

6. ACKNOWLEDGMENTS

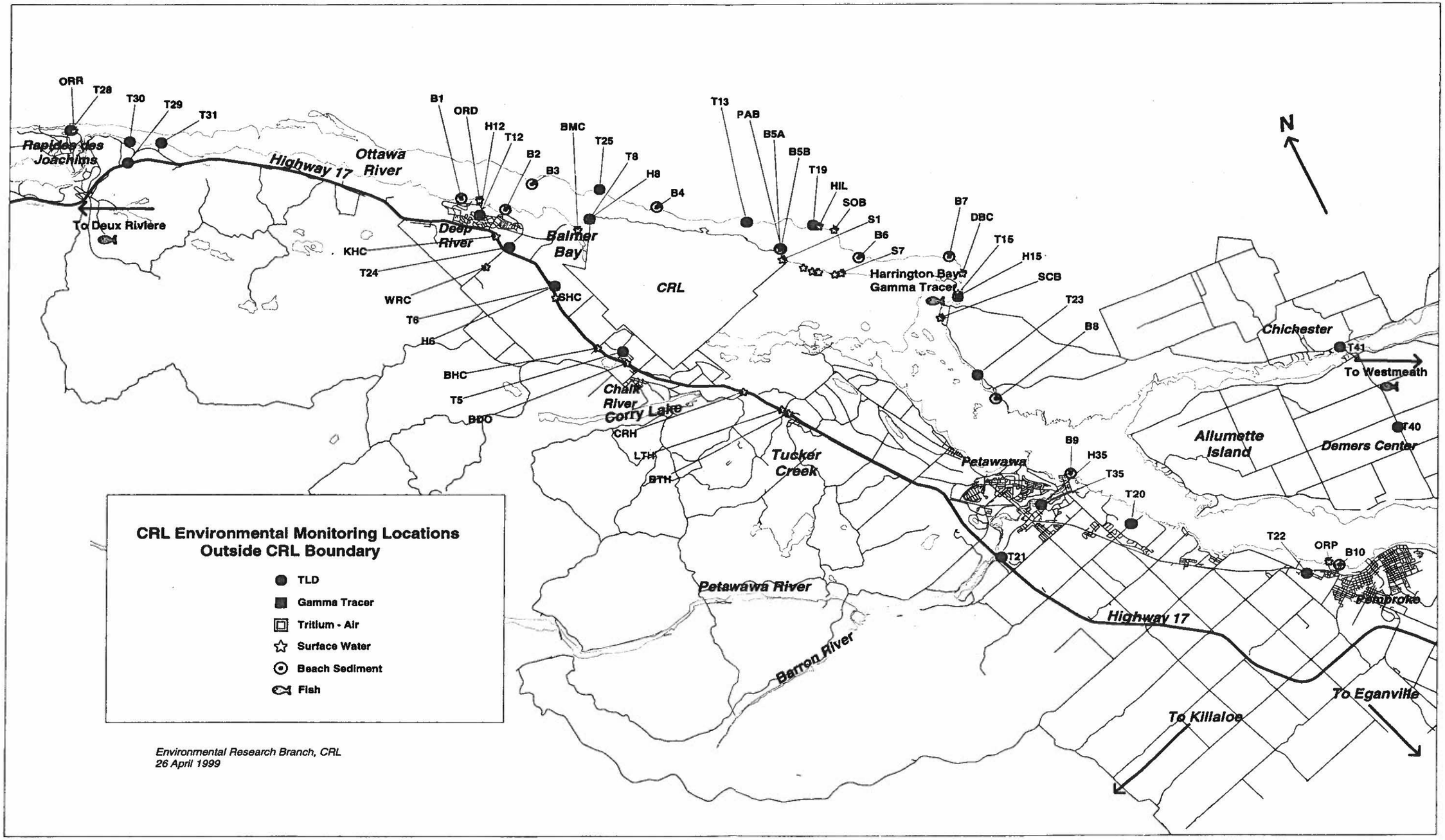
The authors wish to thank the staff of the Environmental Research Branch (ERB) at CRL and the Environmental Science Branch (ESB) at WL for providing the data for this report, and for their assistance in compiling the report. In particular, we wish to thank T. Eve, T. Chaput, B. O' Donnell, D. Killey, W. Workman, T. Kotzer and J. Cheung of the ERB at CRL, and K. Ross of the ESB at WL who also provided several in-depth reviews and constructive suggestions for the WL report, as well as T. Lair of Safety and Radiological Protection (SRP) and L. Yamazaki (ERB), for their help in producing the report.

7. REFERENCES

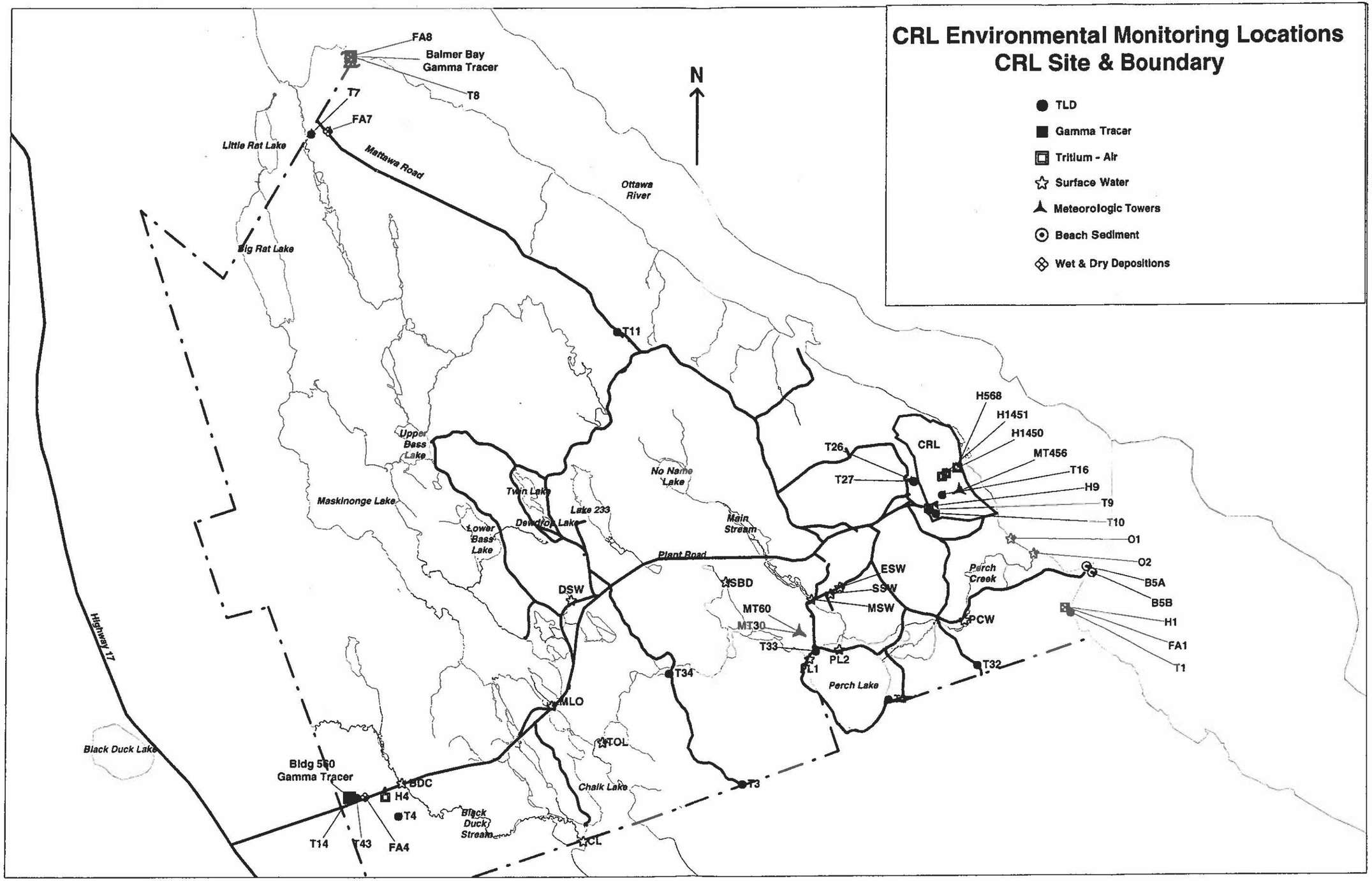
1. Atomic Energy Control Board, *"Chalk River Laboratories, Licence No. NRTE 1/98"*, 1998 October.
2. Atomic Energy Control Board, *"Whiteshell Laboratories, Licence No. NRTE 2/98"*, 1998 October.
3. Niemi, T.A., Soonawala, N. M., *"1998 Annual Report of Radiological Monitoring Results For the Chalk River And Whiteshell Laboratories Sites Volume 2 -- Effluent Monitoring"*, AECL-MISC-362-98, Vol.2, 1999 March*.
4. Audet, M.C., Baker, J.C., *"Derived Release Limits for Airborne and Liquid Effluents from Chalk River Laboratories During Normal Operations"*, RC-1731, Rev. 2, 1998 July.
5. Palmer, J.F., "*Derived Release Limits (DRLs) for Airborne and Liquid Effluents from the Chalk River Nuclear Laboratories During Normal Operations*," Atomic Energy of Canada Limited, AECL-7243, 1981.
6. Lemire, A.E., *"Derived Release Limits for Radionuclides in Airborne and Liquid Effluents for the Whiteshell Nuclear Research Establishment*," Atomic Energy of Canada Limited, AECL-10028, 1989*, and Addendum 1, 1992.
7. Canadian Standards Association, "*Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities*", Canadian Standard, CAN/CSA-N288.1-M87, 1987 August.
8. Atomic Energy of Canada, "*AECL Environmental Protection Program Manual*", RC-200-021.*
9. Canadian Standards Association, "*Guidelines for Radiological Monitoring of the Environment*", Canadian Standard, CAN/CSA-N288.4-M90, 1990 November.
10. Health Canada, *"Guidelines For Canadian Drinking Water Quality"*, Sixth Edition, Supply and Services Canada, Hull, 96-EHD-96, 1996.
11. Graham, R.D., Soonawala, N.M., Niemi, T.A., *"1997 Annual report of Radiological Monitoring Results for the Chalk River Laboratories and Whiteshell Laboratories Sites, Volume 3 – Environmental Monitoring"*, AECL-MISC-362-97 (Vol. 3), 1998 April.*
12. Heinmiller, B.E, *"1997 Annual report of Radiological Monitoring Results for the Chalk River Laboratories and Whiteshell Laboratories Sites, Volume 1, Personnel Dosimetry"*, AECL-MISC-362-97, (Vol. 1), 1998 March*.
13. International Commission on Radiological Protection (ICRP), *"The 1990 Recommendations of the International Commission on Radiological Protection"* ICRP Publication 60, (Annals of the ICRP Vol. 21, No. 1-3), 1991.
14. Cooper, E.L., *"Available Data For Establishing Background Levels in the Vicinity of Canadian CANDU Stations"*, RC-1185, COG-94-75, 1994 March.*
15. Department of Energy (DOE), *"11th International Intercomparison of Environmental Dosimeters"*, 1997.
16. United Nations Committee on the Effects of Atomic Radiation, "*Sources and Effects of Ionizing Radiation*", UNSCEAR 1993 Report to the General Assembly, with Scientific Annexes, United Nations, 1993.
17. National Council on Radiation Protection and Measurement, *"Exposure of the Population in the United States and Canada from Natural Background Radiation"*, Recommendations of the National Council on Radiation Protection and Measurement, NCRP Report No. 94, 1987.
18. Health Canada, Environmental Radioactivity in Canada – "*1986, Radiological Monitoring Annual Report*", 87-EDH-136
19. Olafsdottir, E.D., Palsson, S.E., Magnuson, S.M., "*Caesium-137 in the Icelandic Marine Environment, 1989 -- 1995"*
20. Rissanen, K., Rahola, T., "*Radioactivity Levels in Foodstuff in Finnish Lappland,"* Finnish Centre for Radiation and Nuclear Safety, Nordisk Sellskap for Stralevern, 11 Ordinarie Mote 1995.
21. Petrousi et al, "*Organ Doses for Foetuses, Babies, Children and Adults From Environmental Gamma Rays*", Radiation Protection Dosimetry, Vol. 37, No.1, 1991.
22. Lide, D.R., CRC Handbook of Chemistry and Physics, 71st Edition, CRC Press, 1990 – 1991.
23. Weast, R.C., Astle, M.J., Beyer, W.H., CRC Handbook of Chemistry and Physics, 69th Edition, CRC Press, 1988 -- 1989.
24. Nutrition Canada, "*Food Consumption Patterns Report*", Department of National Health and Welfare Canada, 1977.
25. Canadian Standards Association, "*Requirements for the Competence of Environmental Laboratories*", CAN/CSA-Z753-95, 1995 January.
26. Heinmiller, B.E., "*Technical Basis Document For External Dosimetry At CRL*", Atomic Energy of Canada Limited, Report RC-1525, 1995*.
27. International Commission on Radiological Protection (ICRP), *"Data for Use in Protection against External Radiation"*, ICRP Publication 51, (Annals of the ICRP Vol. 17, No. 2/3).

28. Jirovec, J.O., "Environmental Research Branch Quality Assurance manual for Environmental Monitoring", ERB-ERM-5, Rev. 1.0, Atomic Energy of Canada, 1997 February.*
29. Whiteshell Laboratories Environmental Monitoring QA manual, Volumes 1 to 3. Version 1.0, 1996 March.
30. Guthrie, J.E. and Scott, G.A.J., *"Preoperational Environmental Survey Report of the Whiteshell Nuclear Research Establishment Area"*, WNRE-756, Atomic Energy of Canada Limited, 1988.

* Unpublished report; sole source of copies is Scientific Document Distribution Office (SDDO), AECL, Chalk River, Ontario, K0J 1P0.

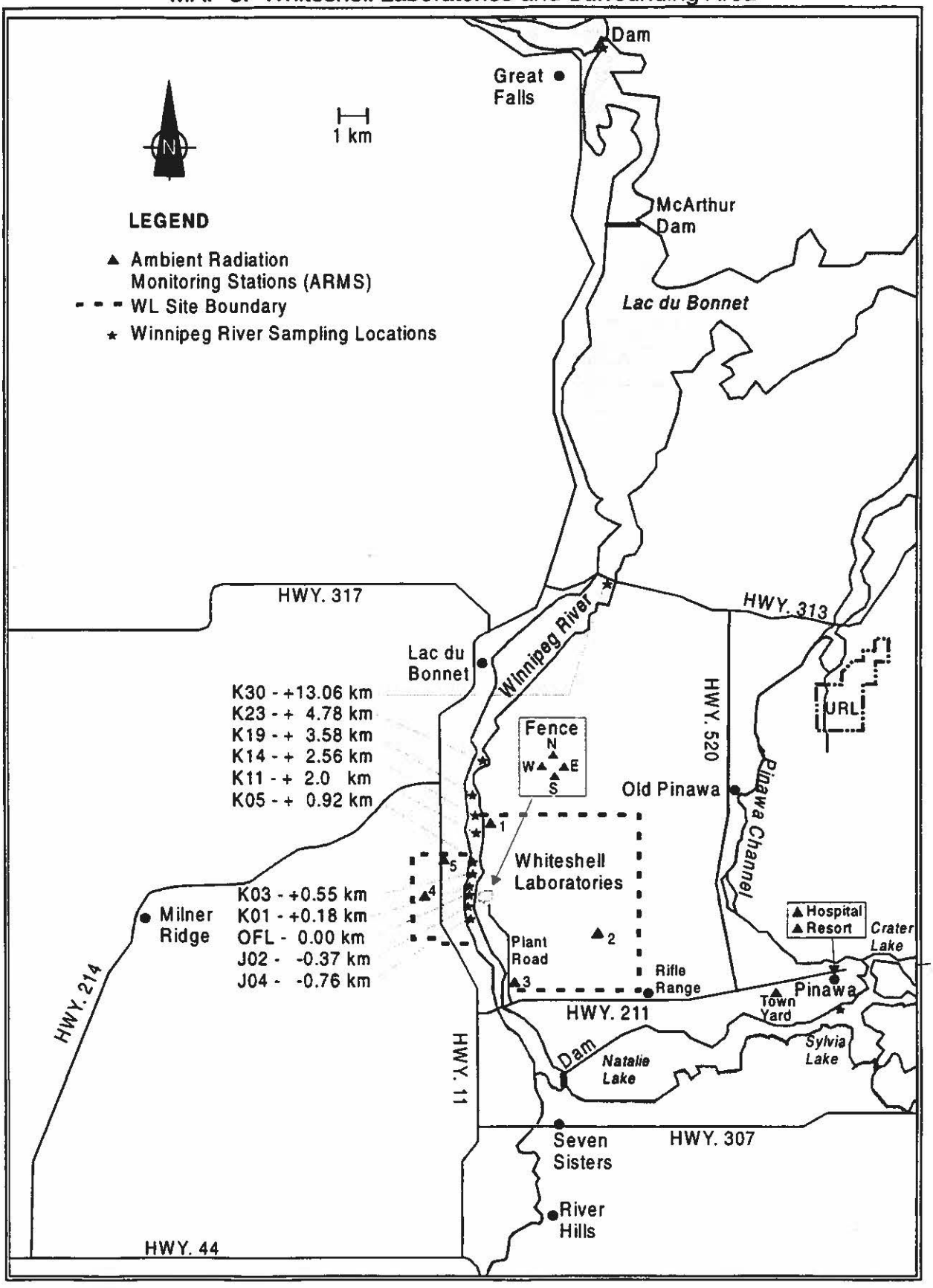


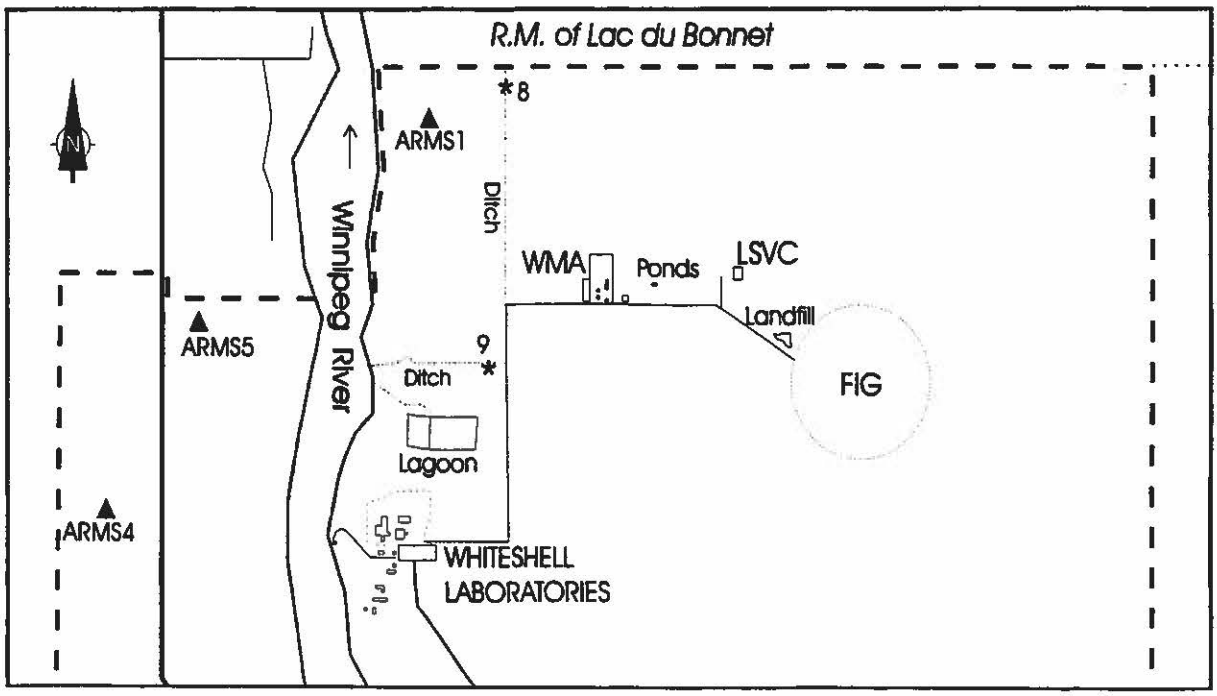
MAP 1: CRL Environmental Monitoring Locations
(Outside CRL Boundary)



MAP 2: CRL Environmental Monitoring Locations
CRL Site & Boundary

MAP 3: Whiteshell Laboratories and Surrounding Area





MAP 4: Whiteshell Laboratories Site

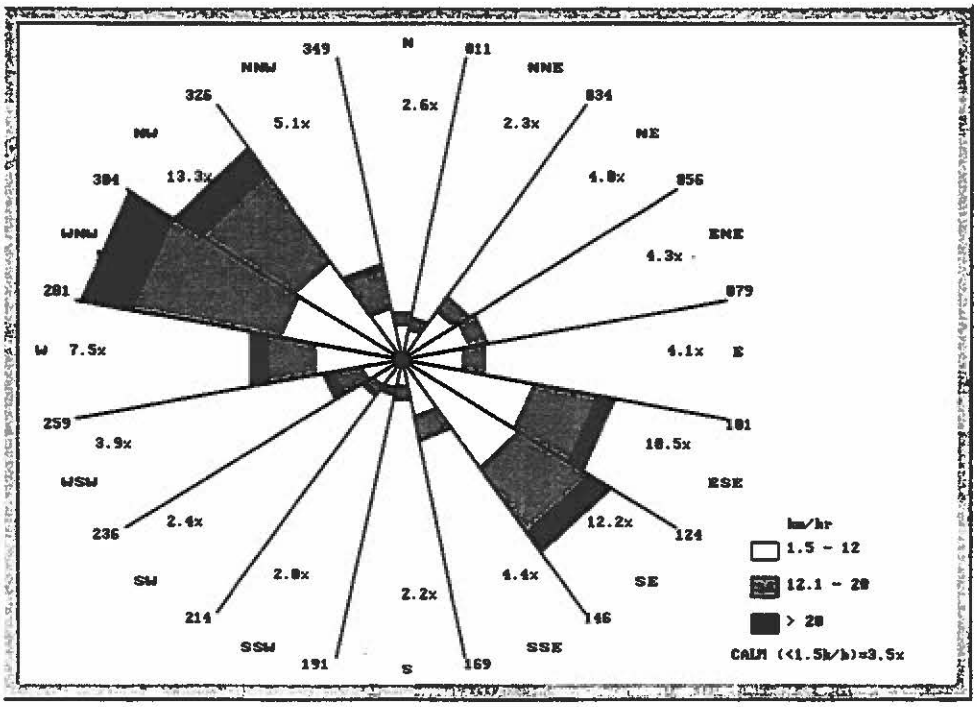


Diagram 1: CRL Windrose Perch Lake 60 m, 1998

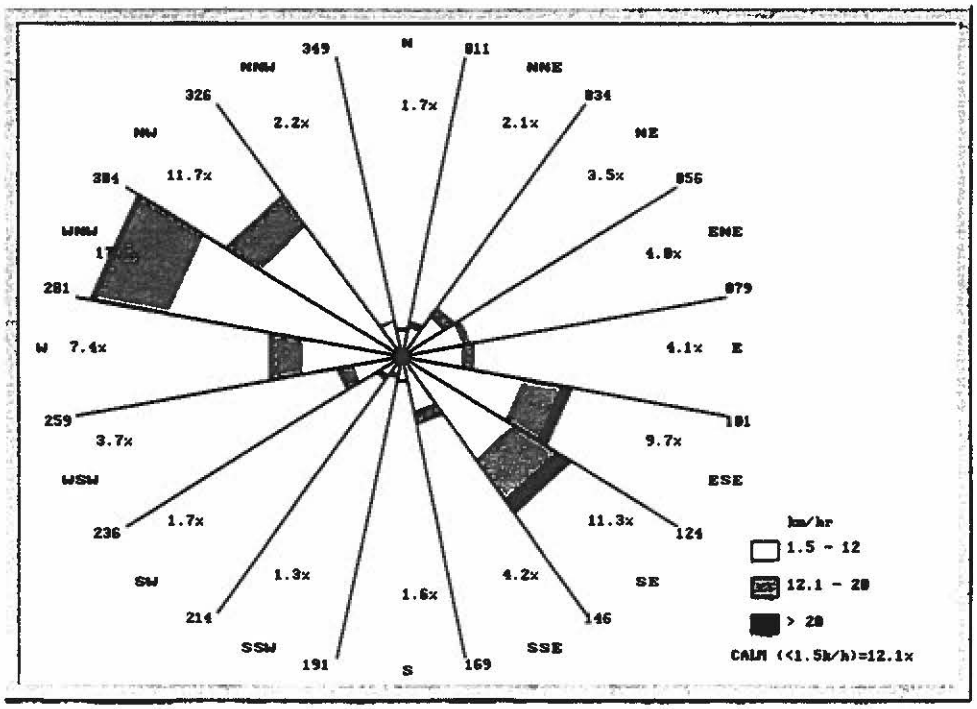


Diagram 2: CRL Windrose - Perch Lake 30 m, 1998

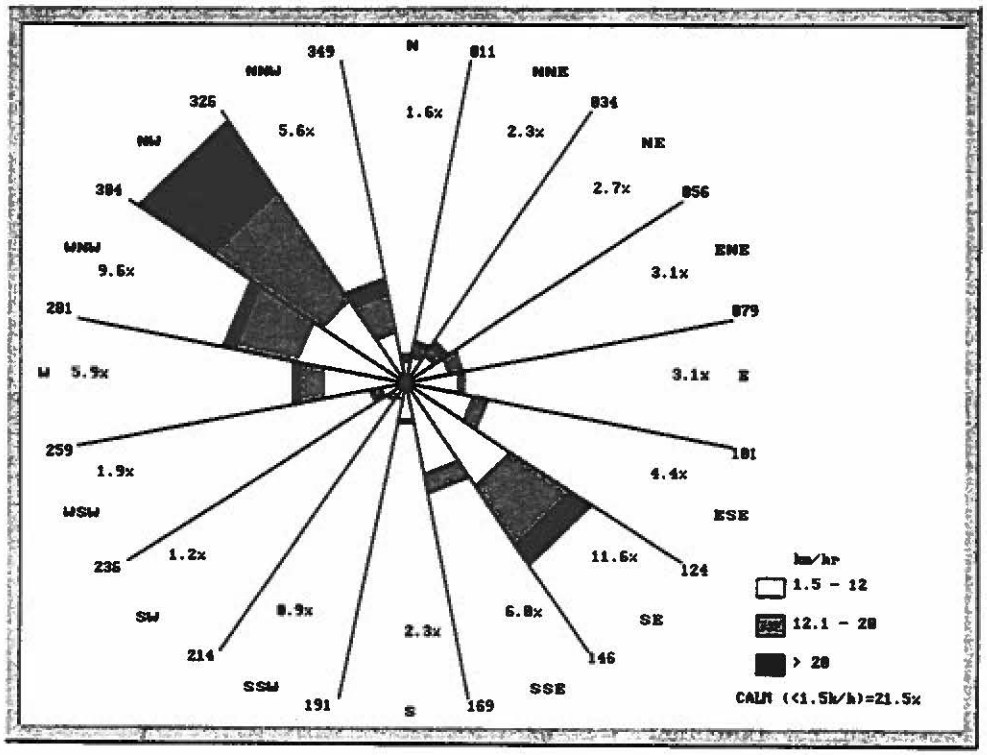


Diagram 3: CRL Windrose - Building 456, 1998

1998 WL 61 m Windrose

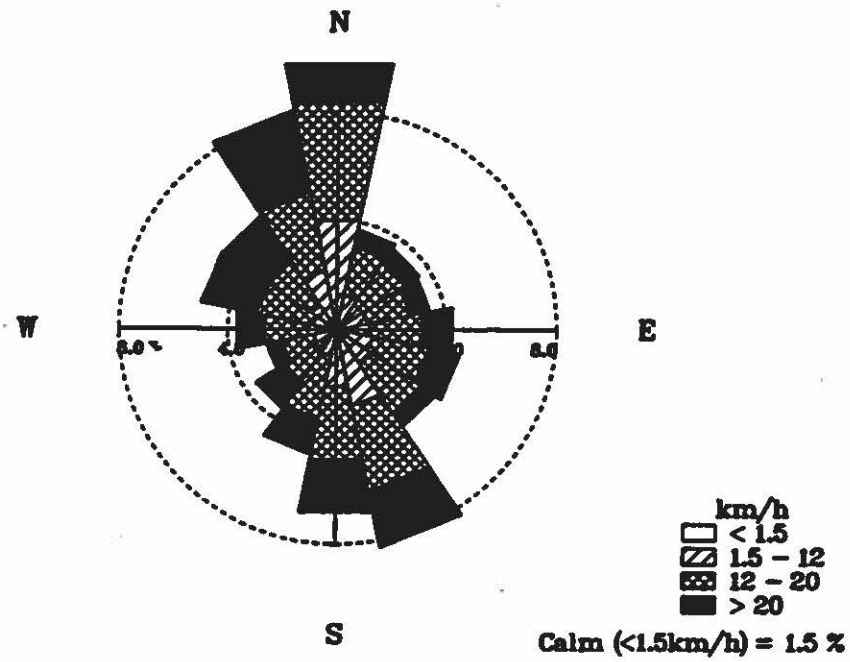


Diagram 1

1998 WL 25 m Windrose

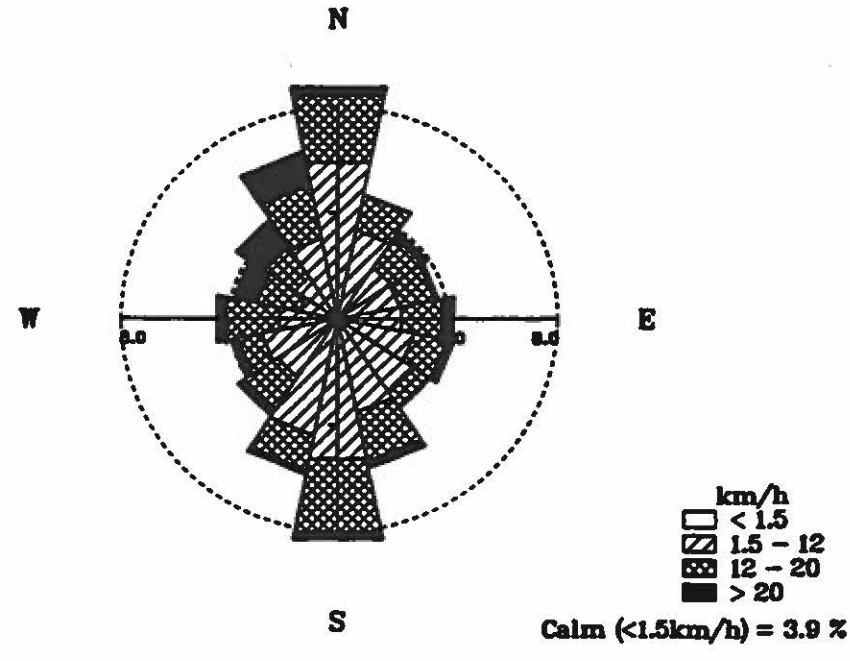


Diagram 2

1998 WL 6 m Windrose

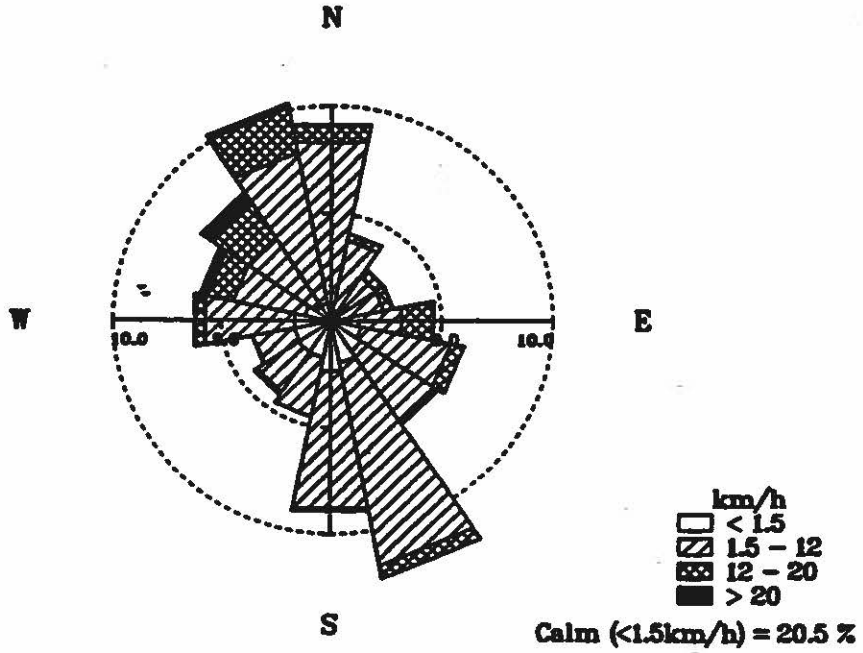


Diagram 3

1998 AES WL 10 m Windrose

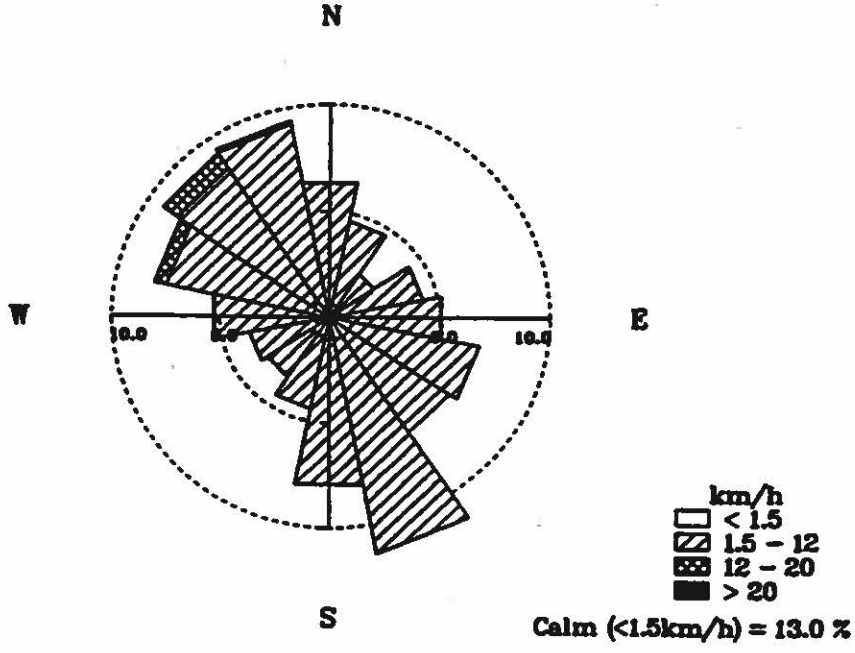


Diagram 4

Notice:

This document is restricted. Keep it in a locked container or locked office when it is not being used; never leave it on open display. Do not photocopy, loan, or destroy the document. When you no longer need it, return it to:

Information Centre
AECL
Chalk River, Ontario
Canada KOJ IJO

Fax: (613) 584-8144 Tel.: (613) 584-3311
ext. 4623

or

Reports Section (Station 71)
AECL
Pinawa, Manitoba
Canada ROE 1L0

Fax: (204) 753-8490 Tel: (204) 753-2311
ext. 2908

Copyright © Atomic Energy of Canada Limited, 1999