Radiological Environmental Survey outside the Chalk River Laboratories Site

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Laboratoire de
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ACKNOWLEDGMENT

Many citizens on each side of the Ottawa River, from Deep River to Pembroke, were helpful in the selection and acquisition of environmental samples.

For their contribution to this report they deserve our gratitude.

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1 – INTRODUCTION

In September 2005, Atomic Energy of Canada Limited (AECL) gave a mandate to Laval University to execute a radiological environmental survey outside the Chalk River Laboratories (CRL) site. The survey had to be of similar extent and nature as the surveys done in 1999 and 2000, but should also include samples from Allumette Island.

This report contains details on sampling, treatment of samples and radiological analysis. For each type of sample, activity results of man-made radionuclides are presented and compared with results from previous surveys.

The results presented in this report are very similar to those presented in previous reports. The nature, level and distribution of detected radionuclides are not different from those found in 1999 and 2000.

Environmental samples were of two types. Samples integrating the surrounding radioactivity during a lengthy period of time, such as fish, milk, vegetation and river sediment, were taken upstream and downstream from CRL. Instantaneous water samples and 24 h air samples were also taken upstream and downstream from CRL.

The results are compared with those of 1999 and 2000. Other survey data are presented, from environmental reports that are accessible on the Internet. When possible, the same sources as in 2000 were consulted.

2 - GENERAL INFORMATION

2.1 - Sampling

Environmental media were chosen that have the capacity to contain and transport radionuclides, such as air and water. Other media were sampled that can incorporate radionuclides transported by air and water. They are milk, fish, vegetation and river sediments.

All samples were obtained during the second week of September 2005.

Sampling locations were chosen as close as possible to those of 1999 and 2000. Two new locations are centered on Allumette Island. For each type of sample, the number of samples is greater in 2005 than in 2000 or 1999.

Global Positioning System, marine and road maps were used to position the sampling locations. All positions of sampling are presented in Figure 1.

2.2 - Treatment of Samples

The sampled material was identified in the field, isolated and kept at controlled temperature from the time of sampling to that of treatment in the laboratory.

All operations on the samples were done in an environment of low-level radioactivity with material and chemicals containing the lowest possible amounts of natural radionuclides.

2.3 Radioactivity Measurements

Gamma emitters were analysed with a HPGe detector (High Purity Germanium). The samples were positioned on the detector, in the amount and under the geometry appropriate for the type of sample and for the instrument calibration. Reference standards in matrices similar to those of the samples were used for calibration. Identification of peaks in the gamma spectra was done by referring to a computer file library of more than 100 radionuclides. No peak was left unidentified. Counting time was chosen to provide very low minimum detectable activity values for most radionuclides. The minimum counting time was 24 hours.

Beta emitters were analysed using a low-level scintillation counter. Samples were mixed with a scintillator cocktail in plastic vials. Calibration was done with reference standards in matrices identical or similar to that of the samples. Counting time varied from 1 to 4 hours, but was long enough to assure a 5% (2 σ) precision on most of the results.

The limits of detection are the same as in 1999 and 2000. They are adequate to enable the identification and quantification of any radioactivity originating from human activities.

2.4 Quality Assurance

Field sampling procedures, chain of custody of the samples, calibration and standardisation programs, and a data processing program make up the Quality Assurance.

Quality Control was maintained through frequent instrument calibration and counting efficiency determination for different detector geometries. Blanks and background concentration analyses, together with analytical results from reference standards and spiked samples, provided the basis for calculating the radioactivity of the environmental samples. Duplicate analysis on fractions of samples and analysis on duplicate samples were also performed. Table 1 shows results from the inter-comparative study QAP-60, under the direction of the United States Department of Energy (Laval University has the identification number 0403ZZCU). For some radionuclides, reference standards have been used as control samples.

Table 1. CONTROL SAMPLES

GAMMA ANALYSIS RESULTS
QAP 60

Radionuclide	Energy keV	Expected Activity	Measured Activity	Radionuclide	Energy keV	Expected Activity	Measured Activity
		AIR				WATER	
		(Bq/filter)	(Bq/filter)			(Bq/L)	(Bq/L)
Cs-134	604.7	18.2 ± 0.4	16.5 ± 0.3	Co-60	1173.2	163.2 ± 5.9	154 ± 3
Co-60	1173.2	35.4 ± 0.9	34.6 ± 0.3	Cs-137	661.6	51.9 ± 2.7	51 ± 2
Cs-137	661.6	26.4 ± 0.9	25.7 ± 0.3				
		VEGETATION				SOIL	
		(Bq/kg) dry	(Bq/kg) dry			(Bq/kg) dry	(Bq/kg) dry
K-40	1460.8	720 ± 38	773 ± 50	K-40	1460.8	539 ± 29	492 ± 30
Co-60	1173.2	14.5 ± 0.6	16 ± 2	Cs-137	661.6	1323 ± 66	1245 ± 50
Cs-137	661.6	585 ± 29	658 ± 25	Bi-212	727.2	50.4 ± 4.6	48 ± 4
				Pb-212	238.6	47.7 ± 2.5	47 ± 4
				Bi-214	1120.8	58.4 ± 2.2	46 ± 3
				Pb-214	352.0	61 ± 2.4	50 ± 3
				Ac-228	911.1	49 ± 2.0	43 ± 5

BETA ANALYSIS RESULTS

Radionuclide	Energy keV	Sample	Expected Activity (Bq/L)	Measured Activity (Bq/L)
Tritium	1-12.5	**QAP-60**	186.6 ± 3.3	215 ± 6
Tritium	1-12.5	NES-003 (Dow)	100 ± 5	102 ± 8
Sr-90	12-500	NIST 4919	0.30	0.31 ± 0.02
P-32	50-1700	BLU002250UCPE	1.00	0.95 ± 0.07

3 – RESULTS

For each type of environmental medium, details on sampling and counting are given, followed by a comparison with values from the preceding surveys. The results for the 2005 survey are presented in tables containing ranges of results for the 1999 and 2000 surveys.

3.1 - Radioactivity in Air

Gamma radioactivity and tritium results are given in Table 2. Gamma radioactivity in air was analysed by adsorbing air particulates on glass fibre filters, using a high-volume air sampler at three stations, east (A1), south (A2) and west (A3) from CRL limits, during the period between September 11 and September 13. The sampler was positioned in open space at a level of 1 m, and was operated under a 100 m^3/h flow rate during 12 to 24 hours. After sampling, the filters were kept in envelopes until counting time. They were folded in a predefined geometry and counted during 55 hours. As in 1999 in 2000, the only measurable gamma emitting radionuclide found on the filters is natural beryllium-7. In 2005, the level of activity of Be-7 is close to 7 mBq/m^3.

Referenced reports give Be-7 activities in the range of 1 to 3 mBq/m^3 (ref. 1 and 2), in Europe, and up to 18 mBq/m^3 in Australia (ref. 3).

For tritium radioactivity in air moisture, samples were obtained at four locations: on the east (T1) and west (T2) sides of CRL limits, and at two of the three stations used for sampling of air particulates (T3 and T4). The samples of tritiated water present as water vapour in the air were obtained by forcing about 1 m^3 of air through a molecular sieve during 60 minutes. The highest activity of tritium is 10 Bq/m^3, measured at Meehan Bay (T2) under wind blowing from the direction of CRL buildings. Activities less than 0.5 Bq/m^3 were measured at locations T3 and T4, whereas T1 showed a tritium activity close to 3 Bq/m^3. The 2005 results do not differ markedly from those of 1999 or 2000.

In the vicinity of Swiss industries using tritium (ref. 2), tritium activity is continuously measured at levels ranging from 2 to 20 Bq/m^3.

Table 2. AIR SAMPLES

PARTICULATE AIR SAMPLES: GAMMA ANALYSIS RESULTS

Name	Energy keV	2005 Deep River A1 Activity (mBq/m^3)	2005 Petawawa A2 Activity (mBq/m^3)	2005 Allumette Island A3 Activity (mBq/m^3)	2005 Error† (mBq/m^3)	2005 LLD* (mBq/m^3)	1999-2000 4 samples Min. to Max. Activity (mBq/m^3)
Natural radionuclides							
Ac-228	911.1	ND**	ND	ND	0.09	0.15	ND
Pb-212	238.6	ND	ND	ND	0.03	0.04	ND
Tl-208	583.1	ND	ND	ND	0.07	0.12	ND
Bi-214	609.3	ND	ND	ND	0.05	0.08	ND
Bi-214	1120.3	ND	ND	ND	0.01	0.03	ND
Pb-214	352.0	ND	ND	ND	0.05	0.07	ND
Ra-226	186.0	ND	ND	ND	0.17	0.28	ND
Be-7	477.6	6.10	6.60	7.40	0.30	0.37	**ND to 4.10**
K-40	1460.8	ND	ND	ND	0.48	0.41	ND
U-235	185.7	ND	ND	ND	0.03	0.05	ND
Fission Products							
Ba-140	537.4	ND	ND	ND	0.15	0.26	ND
Ce-141	145.5	ND	ND	ND	0.03	0.04	ND
Ce-144	133.5	ND	ND	ND	0.11	0.19	ND
Cs-137	661.6	ND	ND	ND	0.03	0.05	ND
I-131	364.5	ND	ND	ND	0.03	0.07	ND
Nb-95	765.8	ND	ND	ND	0.03	0.05	ND
Ru-103	497.1	ND	ND	ND	0.03	0.05	ND
Ru-106	621.9	ND	ND	ND	0.15	0.37	ND
Zr-95	724.2	ND	ND	ND	0.05	0.09	ND
Zr-95	756.7	ND	ND	ND	0.05	0.09	ND
Activation products							
Sb-124	1691.0	ND	ND	ND	0.02	0.04	ND
Sb-125	636.2	ND	ND	ND	0.20	0.32	ND
Co-60	1173.2	ND	ND	ND	0.02	0.04	ND
Co-60	1332.5	ND	ND	ND	0.02	0.04	ND
Fe-59	1099.2	ND	ND	ND	0.05	0.09	ND
Mn-54	834.8	ND	ND	ND	0.02	0.04	ND
Nb-94	702.6	ND	ND	ND	0.02	0.04	ND
Sc-46	889.3	ND	ND	ND	0.03	0.05	ND
Zn-65	1115.5	ND	ND	ND	0.06	0.10	ND

TRITIUM AIR SAMPLES: BETA ANALYSIS RESULTS

Name	2005 Chalk River T1 Activity (Bq/m^3)	2005 Meehan Bay T2 Activity (Bq/m^3)	2005 Petawawa T3 Activity (Bq/m^3)	2005 Allumette Island T4 Activity (Bq/m^3)	2005 Error (Bq/m^3)	2005 LLD* (Bq/m^3)	1999-2000 8 samples Min. to Max. Activity (Bq/m^3)
Tritium	3.20	10.60	0.48	0.24	0.06	0.10	**ND to 19.48**

† : Error: Expanded uncertainty (~ 95 % level of confidence)

* : LLD = Lower Limit of Detection

** : ND = Not detected; 95 percent probability that value is below LLD

3.2 - Radioactivity in Water

Discrete water samples were taken on September 12 in the Ottawa River, upstream from CRL (W1 and W2), near CRL (W3) and downstream from CRL (W4 to W7). The samples were collected in duplicates by partially submerging bottles directly into the water and allowing them to fill with at least 3 L of water. The bottles were kept closed until analysis. Gamma radioactivity and tritium results are presented in Table 3.

Gamma emitters were analysed on raw 1 L samples by counting during 28 hours. No radionuclide was detected above the minimum detectable activity.

Strontium-90 was extracted from samples by filtering 3 L water through an Empore^{TM} Strontium Rad Disk and placing the disk with a scintillator cocktail into a vial. Analysis was done by scintillation counting during 2 hours. No sample contains detectable Sr-90.

Tritium was analysed on raw samples by liquid scintillation during 4 hours. Tritium activity varies from less than 5 Bq/L upstream from CRL to a high value of 15 Bq/L near CRL. Downstream from CRL, activities range from less than 5 Bq/L to 12 Bq/L. The level of tritium activity is comparable to that of 2000.

Tritium activity was measured up to 19 Bq/L in river water downstream from Swiss nuclear installations (ref. 2).

Table 3. WATER SAMPLES

		2005									1999-2000
		UPSTREAM		CRL	DOWNSTREAM						4 samples
		W1	W2	W3	W4	W5	W6	W7			Min. to Max.
Radionuclide	Energy keV	Activity (Bq/L)	Activity (Bq/L)	Activity (Bq/L)	Activity (Bq/L)	Activity (Bq/L)	Activity (Bq/L)	Activity (Bq/L)	Error† (Bq/L)	LLD* (Bq/L)	(activity) (Bq/L)
GAMMA ANALYSIS RESULTS											
Natural radionuclides											
Ac-228	911.1	ND**	ND	ND	ND**	ND	ND	ND	0.35	0.58	ND
Pb-212	238.6	ND	ND	ND	ND	ND	ND	ND	1.6	2.7	ND
Tl-208	583.1	ND	ND	ND	ND	ND	ND	ND	4	7	ND
Bi-214	609.3	ND	ND	ND	ND	ND	ND	ND	0.2	0.32	ND
Bi-214	1120.3	ND	ND	ND	ND	ND	ND	ND	0.68	1.09	ND
Pb-214	352	ND	ND	ND	ND	ND	ND	ND	0.19	0.32	ND
Ra-226	186	ND	ND	ND	ND	ND	ND	ND	0.71	1.12	ND
Be-7	477.6	ND	ND	ND	ND	ND	ND	ND	0.5	1.69	ND
K-40	1460.8	ND	ND	ND	ND	ND	ND	ND	4	2	ND
U-235	185.7	ND	ND	ND	ND	ND	ND	ND	0.03	0.05	ND
Fission Products											
Ba-140	537.4	ND	ND	ND	ND	ND	ND	ND	0.9	1.92	ND
Ce-141	145.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.16	ND
Ce-144	133.5	ND	ND	ND	ND	ND	ND	ND	0.28	0.47	ND
Cs-137	661.6	ND	ND	ND	ND	ND	ND	ND	0.07	0.18	ND
I-131	364.5	ND	ND	ND	ND	ND	ND	ND	0.35	0.7	ND
Nb-95	765.8	ND	ND	ND	ND	ND	ND	ND	0.1	0.23	ND
Ru-103	497.1	ND	ND	ND	ND	ND	ND	ND	0.1	0.23	ND
Ru-106	621.9	ND	ND	ND	ND	ND	ND	ND	0.7	1.58	ND
Zr-95	724.2	ND	ND	ND	ND	ND	ND	ND	0.22	0.44	ND
Zr-95	756.7	ND	ND	ND	ND	ND	ND	ND	0.18	0.37	ND
Activation products											
Sb-124	1691	ND	ND	ND	ND	ND	ND	ND	0.11	0.18	ND
Sb-125	636.2	ND	ND	ND	ND	ND	ND	ND	0.7	1.42	ND
Co-60	1173.2	ND	ND	ND	ND	ND	ND	ND	0.1	0.17	ND
Co-60	1332.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.17	ND
Fe-59	1099.2	ND	ND	ND	ND	ND	ND	ND	0.25	0.4	ND
Mn-54	834.8	ND	ND	ND	ND	ND	ND	ND	0.1	0.17	ND
Nb-94	702.6	ND	ND	ND	ND	ND	ND	ND	0.07	0.16	ND
Sc-46	889.3	ND	ND	ND	ND	ND	ND	ND	0.12	0.2	ND
Zn-65	1115.5	ND	ND	ND	ND	ND	ND	ND	0.21	0.34	ND
BETA ANALYSIS RESULTS											
Tritium	1-12.5	ND	ND	14.5	ND	7	13	7	2.5	5	**ND to 10.9**
Sr-90	12-500	ND	ND	ND	ND	ND	ND	0.05	0.006	0.018	ND

† : Error: Expanded uncertainty (~ 95 % level of confidence)

* : LLD = Lower Limit of Detection

** : ND = Not detected; 95 percent probability that value is below LLD

3.3 - Radioactivity in Milk

Three 4 L samples of whole milk were obtained from two farms (M1 and M2) and a dairy (M3), all in the neighbourhood of Pembroke. Search for other milk sampling sites remained unsuccessful. The samples were stabilised by adding formaldehyde. Analyses for gamma emitters and tritium were done during the following week. Results are given in Table 4.

Gamma spectrometry was performed on 1 L sub-samples during 28 hours. Natural potassium-40 is the only detected gamma emitter, present as in 1999 and 2000 at a level of about 40 Bq/L..

Tritium was analysed in water distilled from 1 L sub-samples. The tritium activity varies from 80 to 130 Bq/L, higher than in 1999 or 2000.

Tritium, up to 40 Bq/L, has been found in milk from dairies located as far as 30 km to a nuclear site in the U.S (ref. 4) and from farms in the neighbourhood of a Swiss industry using tritium (ref. 2).

Table 4. MILK SAMPLES

Radionuclide	Energy keV	2005 Farm M1 Activity (Bq/L)	2005 Farm M2 Activity (Bq/L)	2005 Dairy M3 Activity (Bq/L)	Error† (Bq/L)	LLD* (Bq/L)	1999-2000 2 samples Min. to Max. Activity (Bq/L)
GAMMA ANALYSIS RESULTS							
Natural radionuclides							
Ac-228	911.1	ND**	ND	ND	0.35	0.58	ND
Pb-212	238.6	ND	ND	ND	1.60	2.70	ND
Tl-208	583.1	ND	ND	ND	4.00	7.00	ND
Bi-214	609.3	ND	ND	ND	0.20	0.32	ND
Bi-214	1120.3	ND	ND	ND	0.68	1.09	ND
Pb-214	352.0	ND	ND	ND	0.19	0.32	ND
Ra-226	186.0	ND	ND	ND	0.71	1.12	ND
Be-7	477.6	ND	ND	ND	0.50	1.69	ND
K-40	1460.8	36	42	34	4.00	2.00	**45-47**
U-235	185.7	ND	ND	ND	0.03	0.05	ND
Fission Products							
Ba-140	537.4	ND	ND	ND	0.90	1.92	ND
Ce-141	145.5	ND	ND	ND	0.10	0.16	ND
Ce-144	133.5	ND	ND	ND	0.28	0.47	ND
Cs-137	661.6	ND	ND	ND	0.07	0.18	ND
I-131	364.5	ND	ND	ND	0.35	0.70	ND
Nb-95	765.8	ND	ND	ND	0.10	0.23	ND
Ru-103	497.1	ND	ND	ND	0.10	0.23	ND
Ru-106	621.9	ND	ND	ND	0.70	1.58	ND
Zr-95	724.2	ND	ND	ND	0.22	0.44	ND
Zr-95	756.7	ND	ND	ND	0.18	0.37	ND
Activation products							
Sb-124	1691.0	ND	ND	ND	0.11	0.18	ND
Sb-125	636.2	ND	ND	ND	0.70	1.42	ND
Co-60	1173.2	ND	ND	ND	0.10	0.17	ND
Co-60	1332.5	ND	ND	ND	0.10	0.17	ND
Fe-59	1099.2	ND	ND	ND	0.25	0.40	ND
Mn-54	834.8	ND	ND	ND	0.10	0.17	ND
Nb-94	702.6	ND	ND	ND	0.07	0.16	ND
Sc-46	889.3	ND	ND	ND	0.12	0.20	ND
Zn-65	1115.5	ND	ND	ND	0.21	0.34	ND
BETA ANALYSIS RESULTS							
Tritium	1-12.5	131.0	94.0	84.5	2.5	5.0	**50.2-50.6**

† : Error: Expanded uncertainty (~ 95 % level of confidence)

* : LLD = Lower Limit of Detection

** : ND = Not detected; 95 percent probability that value is below LLD

3.4 - Radioactivity in Fish

Fish samples were graciously given by fishermen. Pickerel and catfish species were captured on September 12 and identified as sample F1 and sample F2. Frozen fillets from fishes, caught in the vicinity of Meehan Bay on September 10, were identified as sample F3. All samples were transported in iceboxes and were analysed inside a few days after arrival in Quebec City.

About 500 g of tissue from each sample were gamma counted under appropriate geometry during 28 hours. After gamma spectrometry, about 100 g of tissue were dried, calcined and digested in nitric acid. The acidified solution was passed through an Empore^{TM} Strontium Rad Disk. The disk was counted during 1 hour for strontium-90 activity by placing it in a vial containing the scintillator cocktail. The disk-filtered solution was counted during 1 hour for phosphorus-32 beta activity by mixing an aliquot of the solution with the scintillator cocktail in a vial. The results of the radiological analyses are shown in Table 5.

As in 2000, the only radionuclides found under gamma spectrometry are the natural isotope K-40, at the level of 140 Bq/kg, and the man-made radionuclide Cs-137, at 8 Bq/kg (F1 and F2) and 14 Bq/kg (F3).

As in 1999 and 2000, Sr-90 was undetected in all samples. Duplicate P-32 counting revealed no detectable activity in all samples, whereas in 2000 one fish sample showed a signal close to the detection limit.

In Germany, fish samples show cesium-137 activities ranging from 0.3 to 195 Bq/kg (ref. 5 and 6).

Table 5. OTTAWA RIVER FISH SAMPLES

Radionuclide	Energy keV	2005 UPSTREAM F1 Activity (Bq/kg) fresh	2005 DOWNSTREAM F2 Activity (Bq/kg) fresh	2005 DOWNSTREAM F3 Activity (Bq/kg) fresh	2005 Error† (Bq/kg) fresh	2005 LLD* (Bq/kg) fresh	1999-2000 3 samples Min. to Max. Activity (Bq/kg) fresh
GAMMA ANALYSIS RESULTS							
Natural radionuclides							
Ac-228	911.1	ND**	ND	ND	0.4	1.0	ND
Pb-212	238.6	ND	ND	ND	0.2	0.3	ND
Tl-208	583.1	ND	ND	ND	0.4	0.7	ND
Bi-214	609.3	ND	ND	ND	0.3	0.5	ND
Bi-214	1120.3	ND	ND	ND	1.0	2.4	ND
Pb-214	352.0	ND	ND	ND	0.2	0.4	ND
Ra-226	186.0	ND	ND	ND	0.9	1.6	ND
Be-7	477.6	ND	ND	ND	1.2	2.9	ND
K-40	1460.8	160	140	120	10.0	3.0	**130 to 140**
U-235	185.7	ND	ND	ND	0.1	0.2	ND
Fission Products							
Ba-140	537.4	ND	ND	ND	1.7	8.0	ND
Ce-141	145.5	ND	ND	ND	0.1	0.4	ND
Ce-144	133.5	ND	ND	ND	0.2	0.7	ND
Cs-137	661.6	8.7	7.1	14.3	0.1	0.3	**19.1 to 28.2**
I-131	364.5	ND	ND	ND	0.3	0.6	ND
Nb-95	765.8	ND	ND	ND	0.2	0.5	ND
Ru-103	497.1	ND	ND	ND	0.1	0.4	ND
Ru-106	621.9	ND	ND	ND	0.7	2.2	ND
Zr-95	724.2	ND	ND	ND	0.2	0.8	ND
Zr-95	756.7	ND	ND	ND	0.2	0.7	ND
Activation products							
Sb-124	1691.0	ND	ND	ND	0.2	0.3	ND
Sb-125	636.2	ND	ND	ND	0.3	2.0	ND
Co-60	1173.2	ND	ND	ND	0.1	0.4	ND
Co-60	1332.5	ND	ND	ND	0.1	0.3	ND
Fe-59	1099.2	ND	ND	ND	0.5	1.1	ND
Mn-54	834.8	ND	ND	ND	0.1	0.3	ND
Nb-94	702.6	ND	ND	ND	0.1	0.2	ND
Sc-46	889.3	ND	ND	ND	0.2	0.4	ND
Zn-65	1115.5	ND	ND	ND	0.4	0.8	ND
BETA ANALYSIS RESULTS							6 samples
Sr-90	12-500	ND	ND	ND	0.2	0.6	ND
P-32	5-1700	ND	ND	ND	1.5	5.0	**ND to 6.8**

† : Error: Expanded uncertainty (~ 95 % level of confidence)

* : LLD = Lower Limit of Detection

** : ND = Not detected; 95 percent probability that value is below LLD

3.5 - Radioactivity in Vegetables

Fresh vegetables were obtained on September 12 and September 13, from home gardens at Deep River (V1 to V3), Chalk River (V4 to V7), Allumette Island (V8 to V10), and from a vegetable grower at Pembroke (V11 to V14). Samples were placed in closed bags until treatment and analysis. Radiological results are presented in Table 6 and Table 6a.

For gamma spectrometry, about 3 kg of each sample were washed, dried at 105^{o}C, and ground. The samples were counted in Marinelli beakers during 28 hours. No man-made radionuclide was found in any of the samples.

Tritium was measured in free water of the samples. The samples were dried under vacuum and the water vapour collected and analysed by liquid scintillation. As in 1999 and 2000, the samples from Pembroke show a higher level of tritium than the other samples, with activities ranging from 200 to 400 Bq/kg. At other locations, the tritium activity varies from a low level of 20 Bq/kg at Deep River and Allumette Island to a medium value of 50 Bq/kg at Chalk River. The distribution of tritium activities is similar to the one observed in 1999 and 2000.

In Switzerland, vegetables grown in the vicinity of an industry using tritium, show tritium activity up to 790 Bq/kg (ref. 2).

Table 6. VEGETATION SAMPLES (Deep River and Chalk River)

		2005									1999-2000
		Deep River			Chalk River						
Radionuclide	Energy keV	V1 Beet Activity (Bq/kg) fresh	V2 Bean Activity (Bq/kg) fresh	V3 Squash Activity (Bq/kg) fresh	V4 Potatoe Activity (Bq/kg) fresh	V5 Tomatoe Activity (Bq/kg) fresh	V6 Cucumber Activity (Bq/kg) fresh	V7 Zucchini Activity (Bq/kg) fresh	Error† (Bq/kg)	LLD* (Bq/kg)	7 samples Min. to Max. Activity (Bq/kg) fresh
GAMMA ANALYSIS RESULTS											
Natural radionuclides											
Ac-228	911.1	ND**	ND	ND	ND	ND	ND	ND	0.4	1.0	ND
Pb-212	238.6	ND	ND	ND	ND	ND	ND	ND	0.2	0.3	ND
Tl-208	583.1	ND	ND	ND	ND	ND	ND	ND	0.4	0.7	ND
Bi-214	609.3	ND	ND	ND	ND	ND	ND	ND	0.3	0.5	ND
Bi-214	1120.3	ND	ND	ND	ND	ND	ND	ND	1.0	2.4	ND
Pb-214	352.0	ND	ND	ND	ND	ND	ND	ND	0.2	0.4	ND
Ra-226	186.0	ND	ND	ND	ND	ND	ND	ND	0.9	1.6	ND
Be-7	477.6	ND	ND	ND	ND	ND	ND	ND	1.2	2.9	ND
K-40	1460.8	117	57	83	63	198	127	84	10.0	3.0	**63 to 213**
U-235	185.7	ND	ND	ND	ND	ND	ND	ND	0.1	0.2	ND
Fission Products											
Ba-140	537.4	ND	ND	ND	ND	ND	ND	ND	1.7	8.0	ND
Ce-141	145.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Ce-144	133.5	ND	ND	ND	ND	ND	ND	ND	0.2	0.7	ND
Cs-137	661.6	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
I-131	364.5	ND	ND	ND	ND	ND	ND	ND	0.3	0.6	ND
Nb-95	765.8	ND	ND	ND	ND	ND	ND	ND	0.2	0.5	ND
Ru-103	497.1	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Ru-106	621.9	ND	ND	ND	ND	ND	ND	ND	0.7	2.2	ND
Zr-95	724.2	ND	ND	ND	ND	ND	ND	ND	0.2	0.8	ND
Zr-95	756.7	ND	ND	ND	ND	ND	ND	ND	0.2	0.7	ND
Activation products											
Sb-124	1691.0	ND	ND	ND	ND	ND	ND	ND	0.2	0.3	ND
Sb-125	636.2	ND	ND	ND	ND	ND	ND	ND	0.3	2.0	ND
Co-60	1173.2	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Co-60	1332.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
Fe-59	1099.2	ND	ND	ND	ND	ND	ND	ND	0.5	1.1	ND
Mn-54	834.8	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
Nb-94	702.6	ND	ND	ND	ND	ND	ND	ND	0.1	0.2	ND
Sc-46	889.3	ND	ND	ND	ND	ND	ND	ND	0.2	0.4	ND
Zn-65	1115.5	ND	ND	ND	ND	ND	ND	ND	0.4	0.8	ND
BETA ANALYSIS RESULTS											6 samples
Tritium	1-12.5	23.5	38.0	28.5	21.0	27.0	30.0	55.5	2.5	5.0	**12,9 to 88.8**

† : Error: Expanded uncertainty (~ 95 % level of confidence)
* : LLD = Lower Limit of Detection
** : ND = Not detected; 95 percent probability that value is below LLD

Table 6a. VEGETATION SAMPLES (Allumette Island and Pembroke)

		2006									1999-2000
		Allumette Island			Pembroke						
Radionuclide	Energy keV	V8 Tomatoe Activity (Bq/kg) fresh	V9 Carrot Activity (Bq/kg) fresh	V10 Pumpkin Activity (Bq/kg) fresh	V11 Carrot Activity (Bq/kg) fresh	V12 Cabbage Activity (Bq/kg) fresh	V13 Beet Activity (Bq/kg) fresh	V14 Tomato Activity (Bq/kg) fresh	Error † (Bq/kg)	LLD* (Bq/kg)	6 samples Min. to Max. Activity (Bq/kg) fresh
GAMMA ANALYSIS RESULTS											
Natural radionuclides											
Ac-228	911.1	ND**	ND	ND	ND	ND	ND	ND	0.4	1.0	ND
Pb-212	238.6	ND	ND	ND	ND	ND	ND	ND	0.2	0.3	ND
Tl-208	583.1	ND	ND	ND	ND	ND	ND	ND	0.4	0.7	ND
Bi-214	609.3	ND	ND	ND	ND	ND	ND	ND	0.3	0.5	ND
Bi-214	1120.3	ND	ND	ND	ND	ND	ND	ND	1.0	2.4	ND
Pb-214	352.0	ND	ND	ND	ND	ND	ND	ND	0.2	0.4	ND
Ra-226	186.0	ND	ND	ND	ND	ND	ND	ND	0.9	1.6	ND
Be-7	477.6	ND	ND	ND	ND	ND	ND	ND	1.2	2.9	ND
K-40	1460.8	156	127	136	92	101	87	132	10.0	3.0	**71 to 146**
U-235	185.7	ND	ND	ND	ND	ND	ND	ND	0.1	0.2	ND
Fission Products											
Ba-140	537.4	ND	ND	ND	ND	ND	ND	ND	1.7	8.0	ND
Ce-141	145.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Ce-144	133.5	ND	ND	ND	ND	ND	ND	ND	0.2	0.7	ND
Cs-137	661.6	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
I-131	364.5	ND	ND	ND	ND	ND	ND	ND	0.3	0.6	ND
Nb-95	765.8	ND	ND	ND	ND	ND	ND	ND	0.2	0.5	ND
Ru-103	497.1	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Ru-106	621.9	ND	ND	ND	ND	ND	ND	ND	0.7	2.2	ND
Zr-95	724.2	ND	ND	ND	ND	ND	ND	ND	0.2	0.8	ND
Zr-95	756.7	ND	ND	ND	ND	ND	ND	ND	0.2	0.7	ND
Activation products											
Sb-124	1691.0	ND	ND	ND	ND	ND	ND	ND	0.2	0.3	ND
Sb-125	636.2	ND	ND	ND	ND	ND	ND	ND	0.3	2.0	ND
Co-60	1173.2	ND	ND	ND	ND	ND	ND	ND	0.1	0.4	ND
Co-60	1332.5	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
Fe-59	1099.2	ND	ND	ND	ND	ND	ND	ND	0.5	1.1	ND
Mn-54	834.8	ND	ND	ND	ND	ND	ND	ND	0.1	0.3	ND
Nb-94	702.6	ND	ND	ND	ND	ND	ND	ND	0.1	0.2	ND
Sc-46	889.3	ND	ND	ND	ND	ND	ND	ND	0.2	0.4	ND
Zn-65	1115.5	ND	ND	ND	ND	ND	ND	ND	0.4	0.8	ND
BETA ANALYSIS RESULTS											6 samples
Tritium	1-12.5	40.0	32.5	33.0	207.5	281.0	263.0	396.5	2.5	5.0	**211.7 to 298.5**

† : Error: Expanded uncertainty (~ 95 % level of confidence)
* : LLD = Lower Limit of Detection
** : ND = Not detected; 95 percent probability that value is below LLD

3.6 - Radioactivity in River Sediments

Gamma radioactivity in river bottom sediments was measured on samples taken in the Ottawa River on September 12. Locations of samples are close to those of 1999 and 2000. As in 1999 and 2000, only coarse-grained sediments were found along the shores of the river. The seven grab samples consist of material taken as deep as 80 cm in order to include any suspended material that would have deposited in the preceding months. Two samples were taken upstream from CRL (S1, S2), one close to CRL (S3) and four downstream from CRL (S4 to S7). Table 7 contains all results.

About 500 g of each sample were dried at 105^{o}C, ground and submitted to counting in a Marinelli beaker during 28 hours. The pattern in radionuclide distribution and activities is the same as the one observed in 1999 or 2000. The absence of detectable Be-7 indicates that no sample contained freshly deposited suspended matter. Other natural radionuclides are at the same level as in 1999 and 2000. Cesium-137 is the only anthropogenic radionuclide measured at all locations. Cobalt-60 is, as in 1999 and 2000, undetected in upstream samples. The maximum level of activity is found close to CRL (S3), with 52 Bq/kg for Cs-137 and 20 Bq/kg for Co-60. Downstream from CRL, Cobalt-60 shows activities between 1 and 5 Bq/kg, values similar to those found in 1999 and 2000.

River sediments downstream from Swiss nuclear installations contain radionuclides such as Co-60, up to 60 Bq/kg, and Cs-137 up to 20 Bq/kg (ref. 2).

Table 7. OTTAWA RIVER SEDIMENT SAMPLES

		2005									1999-2000
		UPSTREAM		CRL	DOWNSTREAM						14 samples
		S1	S2	S3	S4	S5	S6	S7			Min. to Max.
Radionuclide	Energy keV	Activity (Bq/kg)	Activity (Bq/kg)	Activity (Bq/kg)	Activity (Bq/kg)	Activity (Bq/kg)	Activity (Bq/kg)	Activity (Bq/kg)	Error† (Bq/kg)	LLD* (Bq/kg)	Activity (Bq/kg)
Natural radionuclides											
Ac-228	911.1	13	13	8	22	17	14	12	2.0	2.5	**5 to 21**
Pb-212	238.6	12	11	7	18	16	13	12	1.0	1.9	**7 to 25**
Tl-208	583.1	4	4	3	7	6	4	5	1.0	1.9	**3 to 20**
Bi-214	609.3	14	13	11	22	14	13	11	1.0	1.2	**8 to 22**
Bi-214	1120.3	20	18	11	27	13	19	16	4.0	6.1	**7 to 25**
Pb-214	352.0	17	14	13	25	14	15	13	1.0	1.3	**7 to 25**
Ra-226	186.0	14	10	7	18	20	13	13	4.0	6.1	**6 to 31**
Be-7	477.6	ND*	ND	ND	ND	ND	ND	ND	2.0	6.2	**ND to 11**
K-40	1460.8	768	755	685	664	868	795	814	16.0	7.7	**458 to 619**
U-235	185.7	0.7	0.5	0.3	0.9	0.9	0.6	0.6	0.2	0.3	**0.3 to 1.5**
Fission Products											
Ba-140	537.4	ND	ND	ND	ND	ND	ND	ND	2.2	6.0	ND
Ce-141	145.5	ND	ND	ND	ND	ND	ND	ND	0.3	0.9	ND
Ce-144	133.5	ND	ND	ND	ND	ND	ND	ND	0.7	2.9	ND
Cs-137	661.6	6.2	9.2	52.3	12.1	13.8	15.9	60.9	0.6	0.7	**1.1 to 22.4**
I-131	364.5	ND	ND	ND	ND	ND	ND	ND	1.1	2.2	ND
Nb-95	765.8	ND	ND	ND	ND	ND	ND	ND	0.5	0.9	ND
Ru-103	497.1	ND	ND	ND	ND	ND	ND	ND	0.3	0.8	ND
Ru-106	621.9	ND	ND	ND	ND	ND	ND	ND	2.6	5.9	ND
Zr-95	724.2	ND	ND	ND	ND	ND	ND	ND	1.0	1.6	ND
Zr-95	756.7	ND	ND	ND	ND	ND	ND	ND	0.5	1.3	ND
Activation products											
Sb-124	1691.0	ND	ND	ND	ND	ND	ND	ND	0.2	0.9	ND
Sb-125	636.2	ND	ND	ND	ND	ND	ND	ND	1.1	5.2	ND
Co-60	1173.2	ND	ND	18.7	1.9	4.8	1.3	ND	0.5	0.9	**1.0 to 7.1**
Co-60	1332.5	ND	ND	19.5	2.3	4.9	1.1	ND	0.3	0.7	**0.7 to 6.8**
Fe-59	1099.2	ND	ND	ND	ND	ND	ND	ND	0.8	2.0	ND
Mn-54	834.8	ND	ND	ND	ND	ND	ND	ND	0.4	0.7	ND
Nb-94	702.6	ND	ND	ND	ND	ND	ND	ND	0.3	0.6	ND
Sc-46	889.3	ND	ND	ND	ND	ND	ND	ND	0.3	0.8	ND
Zn-65	1115.5	ND	ND	ND	ND	ND	ND	ND	1.2	1.9	ND

† : Error: Expanded uncertainty (~ 95 % level of confidence)

* : LLD = Lower Limit of Detection

** : ND = Not detected; 95 percent probability that value is below LLD

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FIGURE 1- SAMPLING LOCATIONS