Environmental Monitoring Report for the Point Lepreau, N.B. Nuclear Generating Station - 1991 to 1994

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ABSTRACT:

R.W.P. Nelson, K.M. Ellis, and J.N. Smith. 1999. Environmental monitoring report for the Point Lepreau, N.B., Nuclear Generating Station – 1991 to 1994.

The Point Lepreau Environmental Monitoring Program (PLEMP) was established within the Department of Fisheries and Oceans in 1978 to assess the environmental impact of radioactive, thermal and chemical releases from the Point Lepreau Nuclear Generating Station (NGS) located on the Bay of Fundy. This report contains results from the 9th to the 12th year's (1991 – 1994) of the operational phase of the program. Samples were collected for radionuclide analysis from the marine, atmospheric, terrestrial and freshwater environments in the vicinity of the Point Lepreau NGS. Radionuclide levels measured in these samples were compared to pre-operational levels to assess the environmental implications of the operation of nuclear reactors in coastal regions and to determine the critical parameters governing the long-term transport of radionuclides through the environment. Tritium remains the only radionuclide released from the Point Lepreau NGS which can be detected in vegetation, water, and air, although levels are significantly below those considered harmful to organisms. Time series plots were constructed covering the lifetime of the monitoring program to document the changes that have been observed in radionuclide concentrations in the study area.

RÉSUMÉ

R.W.P. Nelson, K.M. Ellis, and J.N. Smith. 1999. Environmental monitoring report for the Point Lepreau, N.B., Nuclear Generating Station – 1991 to 1994.

Le Programme de surveillance de l'environnement de Point Lepreau (PSEPL) a été mis sur pied au ministère des Pêches et des Océans en 1978 dans le but d'évaluer l'impact sur l'environnement des émissions radioactives, thermiques et chimiques de la Centrale nucléaire de Point Lepreau située sur la baie de Fundy. Le présent rapport contient les résultats de la 9^{e} à la 12^{e} année (1991 – 1994) de la phase opérationnelle du programme. Des échantillons ont été prélevés aux fins de l'analyse des radionucléides contenus dans les milieux marin, atmosphérique, terrestre et des eaux douces à proximité de la Centrale nucléaire de Point Lepreau. Les concentrations de radionucléides mesurées dans ces échantillons ont été comparées aux concentrations avant la phase opérationnelle afin d'évaluer les répercussions sur l'environnement de l'exploitation de réacteurs nucléaires dans des régions côtières et de déterminer les paramètres critiques qui régissent le transport à long terme des radionucléides dans l'environnement. Le tritium demeure le seul radionucléide émis par la Centrale nucléaire de Point Lepreau qui peut être détecté dans la végétation, l'eau et l'air, bien que les concentrations mesurées soient significativement inférieures à celles considérées comme étant nuisibles aux organismes. Des graphiques de séries temporelles couvrant la durée du programme de surveillance ont été tracés dans le but de documenter les changements qui ont été observés dans les concentrations de radionucléides dans la région étudiée.

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1.0 Introduction

The Point Lepreau Environmental Monitoring Program (PLEMP) was established in 1978 to assess the impact of the operation of the CANDU 600 MW nuclear reactor which was built at Point Lepreau on the shores of the Bay of Fundy (Figure 1). PLEMP, under the advisement of a working group made up of scientists from various departments (Appendix 1), was designed to provide a broad understanding of the processes which govern the distribution of radioactivity released from the Point Lepreau Nuclear Generating Station (NGS) into the environment. The sampling program was designed to include the major environmental reservoirs - atmospheric, marine, terrestrial and freshwater and the measurement of key oceanographic parameters in order to identify critical transport pathways and to determine fluxes of radionuclides along specific pathways. The responsibility for the maintenance of PLEMP lies with the Atlantic Environmental Radiation Unit (AERU) within the Marine Chemistry Section, Marine Environmental Sciences Division, Maritime Region, Fisheries and Oceans Canada, located at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

The initial pre-operational program extended from 1978 to 1982 and the results are reported in Bishop *et al* (1980), Smith *et al* (1981,1982) and Ellis *et al* (1984). The operational phase of PLEMP has continued from 1983 when the reactor became fully operational to the present and results for the second phase of the program are found in Nelson *et al* (1985, 1986, and 1988) and Ellis *et al* (1990). The present report covers the four year period from 1991 to 1994. All previously published reports related to the

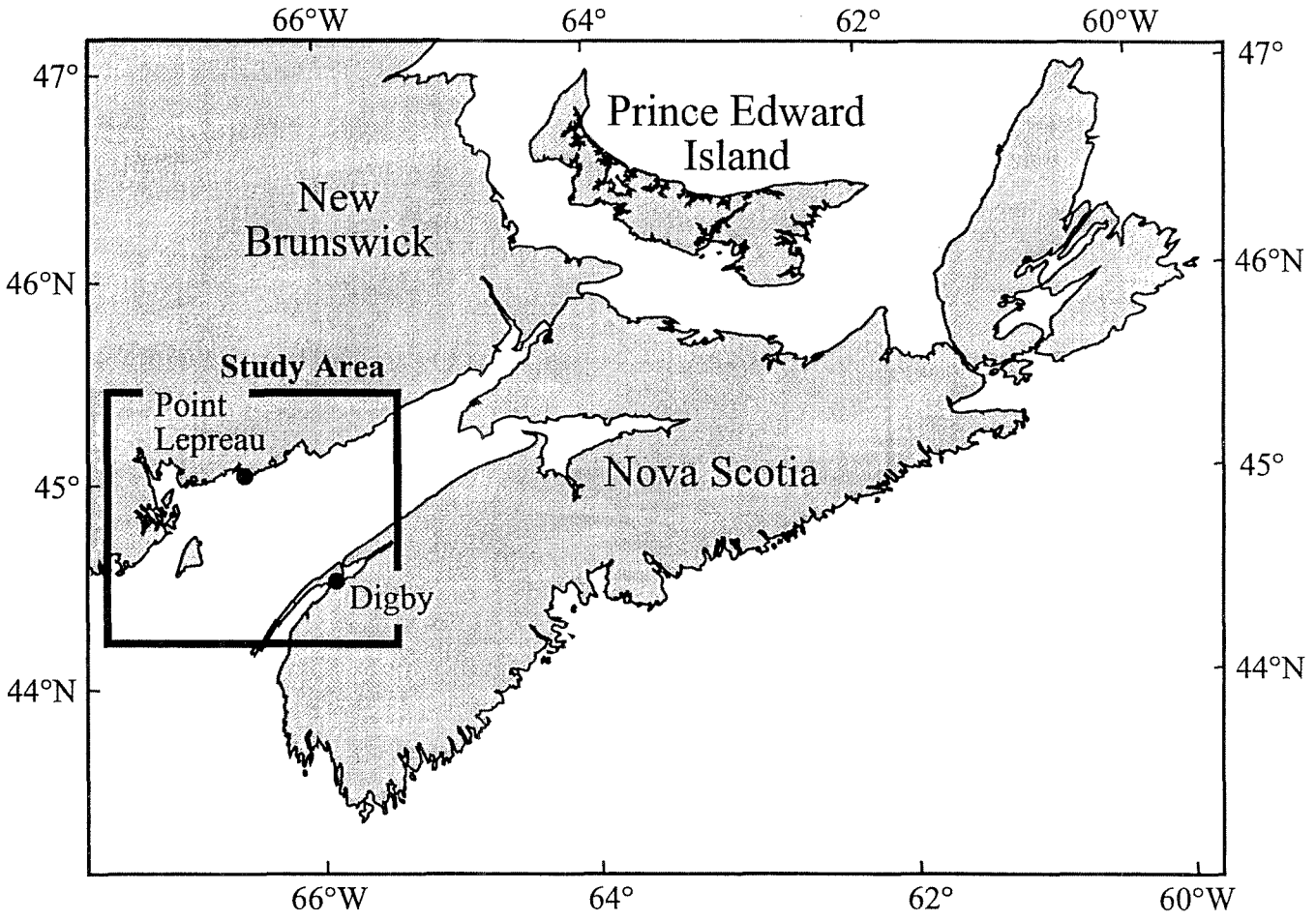

Figure 1: Location of the Point Lepreau study area in the Bay of Fundy.

PLEMP monitoring program are listed in Appendix 2. A summary of radionuclide levels in the Bay of Fundy has been compiled by K. M. Ellis. (Percy *et al* 1998).

The detailed data base compiled in previous years has permitted a reduction in the number of indicator species and sampling locations from the original program without significantly reducing the overall effectiveness of the program. For this report, the number of terrestrial sampling sites was reduced to seven. The temporal study of radionuclides in lichen and of tritium in conifer needles was continued through 1994. A major oceanographic cruise in the Bay of Fundy was conducted in the fall of 1993.

In addition to monitoring releases from the Point Lepreau NGS, PLEMP has proven useful in studying atmospheric nuclear fallout. In particular, inputs from the Chinese nuclear test in 1980 (Smith *et al*, 1982, Ellis and Smith, 1987) and the Chernobyl nuclear power station accident in 1986 (Nelson *et al*, 1988, Smith and Ellis, 1990) have been observed in New Brunswick and Nova Scotia as part of this program. A review of the monitoring program is given in Nelson *et al.* (1998).

2.0 POINT LEPREAU NUCLEAR GENERATING STATION EFFLUENT RELEASES

Radioactive materials are produced as a result of various processes involved in the production of nuclear power (e.g. activation products created by neutron activation of reactor support and encasement materials) and are released to the environment from the Point Lepreau NGS. These environmental emissions are monitored at the source under the mandate of the Liquid Effluent Monitoring Program (LEM) and the Gaseous Effluent Monitoring Program (GEM) conducted by the New Brunswick Electric Power Commission (NBEPC). The reactor has generally operated at full power from 1991 to 1994 with the exception of annual maintenance shutdowns for two to three weeks in April-May of each year and a steam generator tube leak in 1992. The gross capacity factors for power generation were 97% for 1991, 87% for 1992, 96% for 1993, and 94% for 1994.

The yearly liquid effluent summaries are presented in Table 1 for 1991 to 1994 (NBEPC, 1994). Monthly summaries for previous years have been included in earlier reports. The summaries for 1991 to 1994 show slight increases in the activities released from 1991 to 1993 for most isotopes, followed by decreases in 1994.

Tritium was routinely measured by NBEPC in gaseous effluent and the monthly releases are illustrated in Figure 2. (NBEPC, 1991, 1992, 1993, 1994). All releases were well below the DEL (Derived Emission Limits) set by the Atomic Energy Control Board (AECB).

Table 1: Quantities of radionuclides released in liquid effluent for 1991 to 1994, (NBEPC, 1991, 1992, 1993, 1994).

Radionuclide	Annual DEL* (Bq)	Total Yearly Release (Bq)			
		1991	1992	1993	1994
H-3	5E+19	1.1E+14	3.2E+14	4.7E+14	2.6E+14
C-14	1E+15	-	-	-	-
Cr-51	2E+16	4.6E+8	2.5E+7	1.1E+9	1.2E+8
Mn-54	2E+14	2.1E+6	3.0E+6	2.7E+7	1.3E+7
Co-58	8E+14	-	-	-	2.8E+5
Fe-59	1E+14	2.4E+6	3.5E+6	1.4E+8	3.7E+7
Co-60	4E+14	4.6E+7	9.7E+7	8.9E+8	3.1E+8
Zn-65	1E+14	3.3E+7	-	4.0E+6	1.5E+6
Sr-90	2E+15	7.5E+5	5.8E+5	-	4.6E+4
Zr-95	7E+14	1.4E+8	4.2E+8	3.5E+8	2.1E+8
Nb-95	7E+14	2.1E+8	8.9E+8	6.6E+8	4.0E+8
Ru-103	1E+15	1.0E+6	1.2E+7	8.3E+6	2.8E+7
Ru-106	2E+14	-	7.5E+6	3.9E+6	2.5E+8
Ag-110	1E+14	3.0E+5	1.2E+7	3.9E+6	1.4E+7
Sb-124	1E+13	1.4E+8	6.2E+7	1.6E+8	2.2E+8
I-131	1E+14	2.9E+9	4.5E+8	1.8E+9	5.7E+9
Cs-134	5E+14	9.0E+6	6.7E+5	1.4E+7	7.3E+7
Cs-137	8E+14	3.4E+7	2.1E+7	6.9E+7	1.8E+8
La-140	2E+15	-	-	-	-
Ba-140	2E+15	-	-	-	-
Ce-141	2E+15	-	7.5E+5	5.4E+6	5.1E+6
Ce-144	2E+14	-	6.0E+5	1.5E+6	4.9E+6

* DEL = Derived Emission Limits

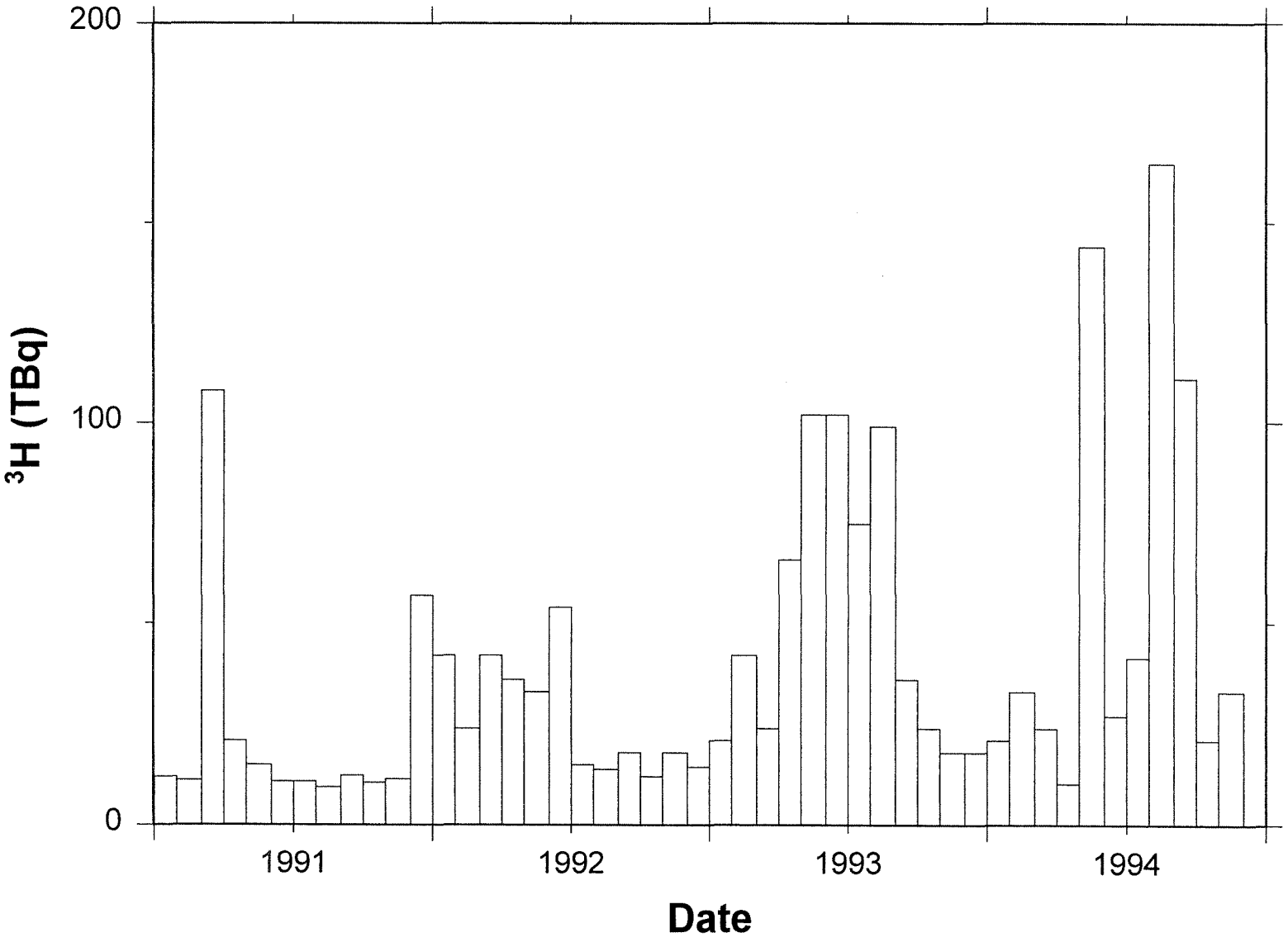

Figure 2: Monthly tritium emissions from 1991 to 1994. (NBEPC,1991 to 1995)

3.0 MARINE ENVIRONMENT

Emissions of concern from the Point Lepreau NGS into the Bay of Fundy include the release of radioactive fission and activation products in liquid and gaseous effluent, the discharge of cooling water at temperatures of up to 20 °C higher than ambient temperature and the introduction of biocides when these organic substances are required to reduce fouling in the cooling system. A series of missions and field surveys have been carried out since 1979 in order to measure levels of artificial radioactivity and to study the marine environment around Point Lepreau. An oceanographic mission (# 93-033) was conducted in the Bay of Fundy on board the CSS Parizeau from October 16 to 25, 1993 in order to; 1) collect samples of water, sediment and suspended particles for measurements of radioactivity levels; 2) study the circulation of the lower Bay of Fundy under fall conditions using salinity, temperature, nutrient and current meter measurements and 3) characterize the dispersion of effluents in the vicinity of the outfall under various tidal conditions. The station locations for cruise 93-033 are illustrated in Figure 3.

3.1 Water Circulation

The largest tides of the world occur in the Bay of Fundy and influence the currents around Point Lepreau on a predominantly semi-diurnal basis. The extremely high tidal range, (up to 16 m at the head of the Bay and 7 m at Point Lepreau), leads to a large volume of water entering and leaving the Bay resulting in a fast flushing time, estimated at about 75 days for the Bay of Fundy (Ketchum and Keen, 1953).

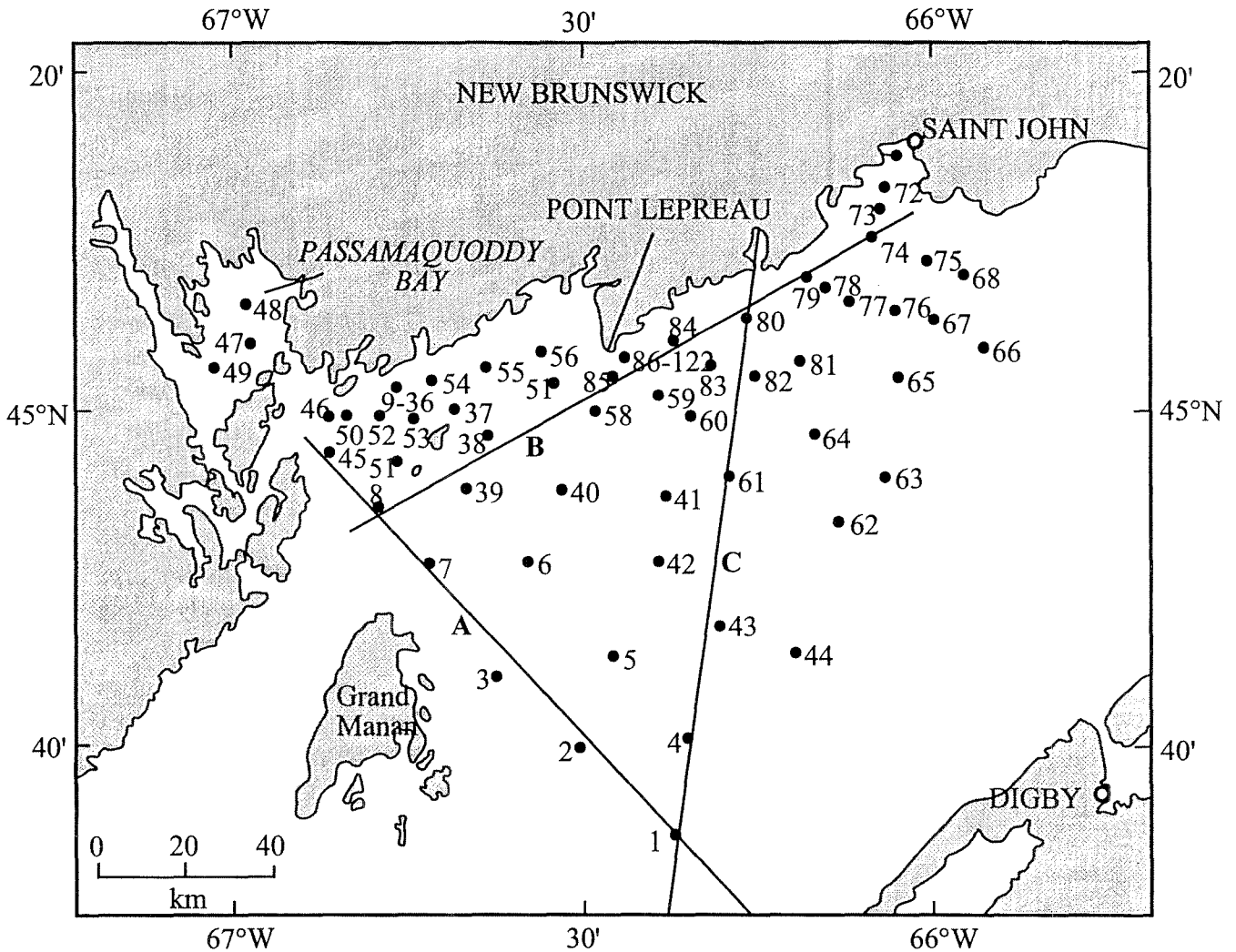

Figure 3: Station locations for Cruise 93-033 from October 16-25, 1993.

Residual water circulation patterns in the Bay of Fundy are dominated by a cyclonic, anticlockwise gyre with inflow along the coast of Nova Scotia and outflow along the New Brunswick coast passing to the east of Grand Manan Island (Bumpus and Lauzier, 1965). Low salinity water created largely by inputs from the Saint John River (which accounts for up to 60% of the freshwater inputs) flows out at the surface, while denser shelf and slope waters mix across the shelf break and enter the Bay of Fundy at depths predominately below 100 meters. Water circulation patterns are seasonal and are largely controlled by the amount of freshwater input. Maximum river runoff occurs in the spring, resulting in maximum stratification and reduced vertical mixing. During the other seasons when freshwater runoff is diminished, there is less stratification allowing more vertical mixing.

More efficient mixing and dispersion of radionuclides is expected in the fall season at the time of the oceanographic sampling expedition. Currents are predominantly from the southwest, parallel to the shore line bathymetry and have an average magnitude of approximately 0.5 m/s. Salinity-depth profiles (Figure 4) from Transects A, B and C marked in Figure 3 illustrate the dominant circulation features during the October 1993 mission. The freshwater plume from the Saint John River, although evident in Transect B where surface salinities as low as 31.4 are observed, is smaller compared to the spring season (Nelson *et al*,1985), resulting in less stratification. As evident in the results from Transect A (Figure 4), the core of the freshwater plume is located at

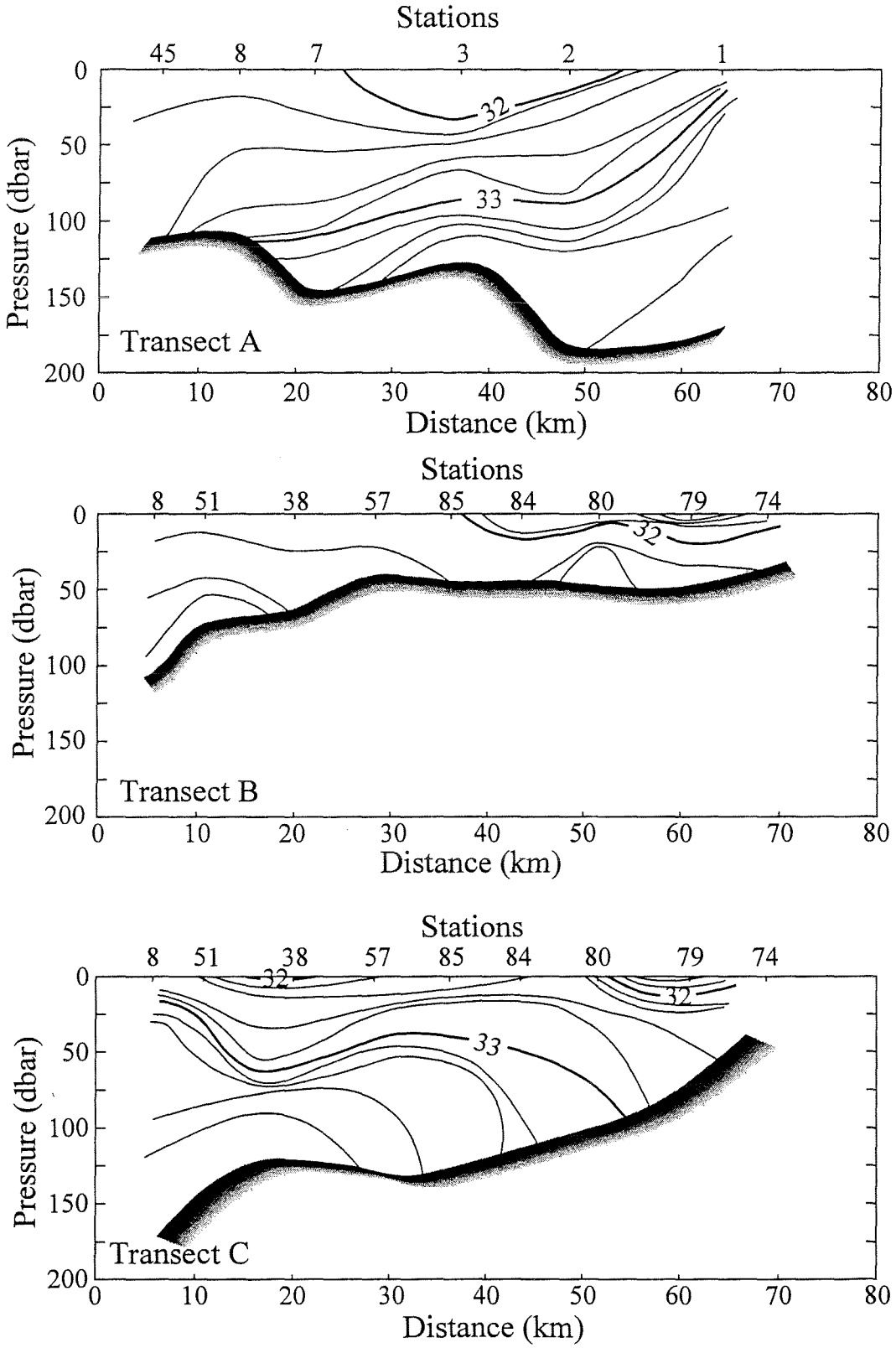

Figure 4: Salinity contours for transects A, B and C on figure 3 for cruise 93-033.

Station 3, east of Grand Manan Island where water flows southerly out of the Bay of Fundy. The intrusion of high salinity shelf and slope water at depths of 100 m is also observed in Transects A and C.

3.2 Chemical Oceanography

3.2.1 Sampling

During mission 93-033, water samples were collected for salinity, nutrients and tritium at surface (2 m) and bottom (5-10 m off the bottom) depths using 12 l Niskin bottles mounted on a Rossette-CTD sampler. Large volume water samples were collected for radionuclide analysis by combining several Niskin samples from the same depth or by using a shipboard pumping system. Suspended particulate matter (SPM) samples were collected for radionuclide analysis from large volume samples on Whatman paper filter cartridges. SPM gravimetric concentrations were determined from 1 litre samples filtered through 0.4 μm pore size Nuclepore filters. Temperature and salinity profiles were measured at each station using the Guildline CTD unit. A tidal study was undertaken by sampling water from a small boat through various stages of the tide and by sampling from the CSS Parizeau while the ship was anchored near the outfall. Sediment samples were collected at 14 locations using a box corer and 5 locations using a Lehigh gravity corer. In addition, during annual field surveys seawater samples were collected from the shore at Duck Cove, east of Point Lepreau in the vicinity of the reactor effluent release point. Large volume water samples (48 l) were processed as illustrated in Figure 5. Water samples were passed through (1) a Whatman in-line cartridge filter to remove

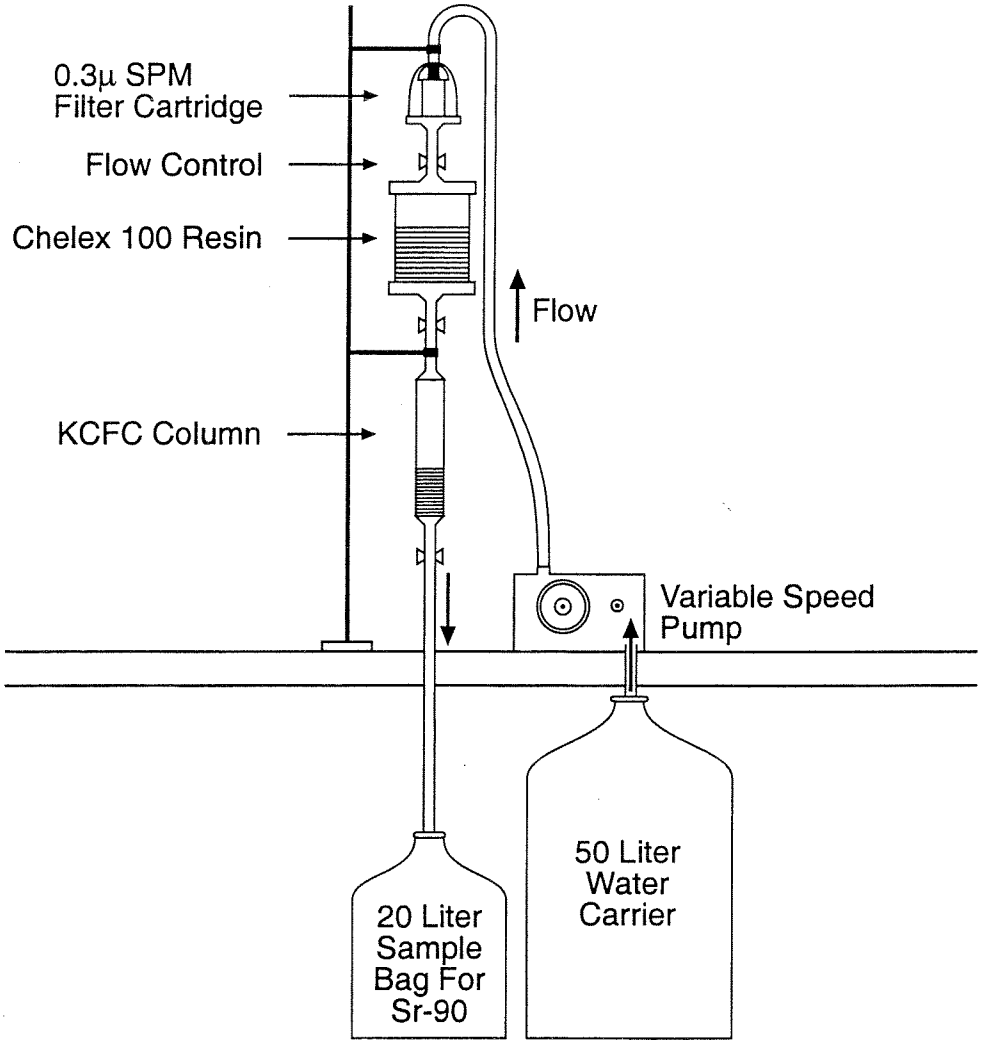

Figure 5: Schematic diagram of columns used to concentrate radionuclides from seawater.

particles approximately 0.3 μm or larger; (2) Chelex-100 cation exchange resin to remove activation products and (3) a KCFC (potassium cobalt ferrocyanide) column to remove ^{137}Cs (Ellis *et al*, 1984). This water was retained for ^{90}Sr analysis. Filters, Chelex-100 and KCFC were analyzed directly for gamma-emitting radionuclides using 25 to 50 % efficient hyper-pure Ge detectors. Polonium-210 and ^{210}Pb were concentrated from 20 l filtered and unfiltered samples by coprecipitation with CoAPDC (Fleer and Bacon, 1984). The remaining separation, plating and counting of the precipitates and filters were completed in the BIO laboratory. The nuclear instrumentation used in all analyses is outlined in Table 2.

3.2.2 Water Column Results

3.2.3 Dissolved ^{137}Cs

Cesium-137 is a relatively long-lived ($t_{½}$ = 30.2 y) fission product which originates from nuclear weapons tests and nuclear power production and was released during the Chernobyl accident. It is present in seawater in dissolved ionic form (Kupferman *et al*, 1979) and fallout ^{137}Cs is measurable in surface seawater. Results for dissolved ^{137}Cs (i.e. < 0.03 μm) for the 1993 October cruise are given in Table 3. Results for seawater samples collected during field trips from 1991 to 1994 are found in Table 4. Table 5 summarizes all values of ^{137}Cs, ^{90}Sr and tritium measured during the pre-operational and operational phases of the monitoring program.

Table 2: Summary of Nuclear Instrumentation used in the AERU Laboratory.

Nuclide	Environmental Phase	Counting Matrix	Detection System
^{137}Cs	Seawater	KCFC	Ge Detector
^{137}Cs	SPM	Filter Cartridge (0.3μm)	Ge Detector
^{137}Cs	Sediment	Dried Sediment	Ge Detector
^{90}Sr	Seawater	^{90}Y on Filter Paper	Beta Counter
Gamma-emitters	Seawater	Chelex 100 Eluant	Ge Detector
Gamma-emitters	SPM	Filter Cartridge (0.3μm)	Ge Detector
^{3}H	Seawater	Gel (Water/cocktail)	Liquid Scintillation Counter
$^{210}Pb/^{210}Po$	Seawater, SPM and Sediment	Nickel Disks	Alpha Spectrometer
^{239,240} Pu, ^{238}Pu	Sediment	Steel Disks	Alpha Spectrometer
^{226}Ra	Sediment	^{222}Rn gas	Gas Phase Scintillation Counter
^{226}Ra	Sediment	^{214}Bi in Dried Sediment	Ge Detector

Table 3: Results from Bay of Fundy mission 93-033.

Sample #	Sta #	Depth (m)	SAL	SiO_3 (μm/l)	PO_4 (μm/l)	NO_3 (μm/l)	SPM (mg/l)	^{137}Cs (mBq/l)	^{3}H (Bq/l)
128510	3	104	33.238	8.41	1.102	11.99	0.186	1.9 ± 0.5	3.1 ± 1.5
128511	3	55	32.685	7.45	1.062	9.96	0.476	2.6 ± 0.5	< 4
128512	3	1	31.907	5.08	0.889	6.30	0.294	2.3 ± 0.4	5.7 ± 1.5
128536	37	50	32.356	8.49	1.010	8.56	1.568	2.2 ± 0.4	2.3 ± 1.5
128537	37	1	32.262	6.56	0.883	6.42	0.768	2.1 ± 0.5	< 4
128544	40	65	32.912	9.04	1.169	10.56	10.65	2.0 ± 0.4	< 4
128545	40	1	32.095	5.18	0.832	6.01	0.604	2.5 ± 0.4	< 4
128561	45	85	32.365	6.86	0.980	7.78	2.047	2.5 ± 0.5	2.1 ± 1.5
128562	45	44	32.230	7.39	0.998	8.02	1.700	2.6 ± 0.6	< 4
128563	45	1	32.170	8.11	1.076	8.57	1.580	2.6 ± 0.6	< 4
128590	56	20	32.148	6.30	0.942	7.50	3.675	2.7 ± 0.3	1.3 ± 1.5
128591	56	1	32.150	6.66	0.930	7.41	2.746	2.9 ± 0.4	< 4
128634	76	75	32.672	6.56	1.010	8.98	2.013	2.5 ± 0.5	-
128635	76	1	31.682	5.59	0.909	6.96	1.038	2.8 ± 0.4	< 4
128638	78	52	32.530	5.83	0.896	7.28	8.677	2.9 ± 0.6	< 4
128639	78	1	31.313	6.18	0.914	6.89	2.56	2.8 ± 0.6	< 4
128648	82	75	32.810	6.88	1.005	9.46	4.66	3.4 ± 0.5	-
128649	82	1	31.939	5.66	0.924	7.67	0.744	3.0 ± 0.6	-
128654	84	36	32.149	5.85	0.942	7.64	3.88	2.5 ± 0.4	-
128655	84	1	31.524	6.40	0.922	7.43	1.319	2.3 ± 0.4	-
128660	86	35	32.078	6.22	0.942	7.50	2.01	2.6 ± 0.3	-
128661	86	1	32.071	6.20	0.914	7.42	1.56	2.5 ± 0.5	-
128666	88	40	32.068	6.10	0.976	7.56	4.60	2.9 ± 0.5	-
128667	88	1	32.022	5.76	0.978	7.46	1.33	3.0 ± 0.6	-
128672	90	35	32.166	6.46	1.022	8.04	3.56	2.5 ± 0.5	-

Table 3: Results from Bay of Fundy mission 93-033 (Cont'd)

Sample #	STN	Depth m	SAL	SiO_3 (µm/l)	PO_4 (µm/l)	NO_3 (µm/l)	SPM (mg/l)	^{137}Cs (mBq/l)	^{3}H (Bq/l)
128673	90	1	32.091	5.58	0.944	7.09	2.61	2.2 ± 0.6	-
128678	92	35	32.129	6.30	1.034	7.96	2.24	2.4 ± 0.2	-
128679	92	1	32.011	5.72	0.968	7.07	1.34	2.3 ± 0.4	-
128684	94	1	31.983	6.10	0.952	6.92	2.05	2.7 ± 0.3	-
128685	94	34	32.041	5.83	0.997	7.36	2.75	2.6 ± 0.6	-
128690	96	1	32.113	6.05	0.990	7.41	1.93	2.7 ± 0.6	-
128691	96	33	32.109	6.41	1.026	7.76	2.12	2.2 ± 0.4	-
128696	98	48	32.077	6.72	1.020	7.68	2.10	2.6 ± 0.7	-
128697	98	1	31.881	6.28	0.985	7.23	2.07	2.3 ± 0.3	-
129702	100	39	31.974	6.27	0.945	7.48	2.55	2.7 ± 0.6	-
129703	100	1	31.757	5.49	0.881	6.70	1.34	2.2 ± 0.3	-
129704	102	25	32.164	6.71	1.000	7.92	3.79	2.2 ± 0.4	-
129705	102	1	32.012	6.40	0.958	7.44	2.04	2.8 ± 0.4	17 ± 2
129708	104	1	31.402	5.90	0.932	6.52	0.71	2.4 ± 0.4	< 4
129709	104	37	32.272	7.00	1.052	7.99	5.60	2.4 ± 0.5	< 4
129713	106	1	31.397	5.98	0.890	6.52	0.60	2.8 ± 0.9	< 4
129714	106	33	31.873	5.69	0.941	6.83	3.44	2.9 ± 0.5	6 ± 2
129717	108	1	30.577	6.59	0.888	6.61	0.59	2.4 ± 0.7	< 4
129718	108	31	31.824	5.93	0.924	6.69	1.45	2.0 ± 0.4	3 ± 2
129721	110	1	31.956	6.01	0.956	7.18	2.20	2.4 ± 0.4	6 ± 2
129722	110	33	31.144	6.18	0.902	7.02	1.00	2.1 ± 0.4	1 ± 2
129725	112	37	31.831	6.23	0.979	7.39	1.77	2.4 ± 0.3	1 ± 2
129726	112	1	30.781	6.58	0.914	6.96	0.60	2.6 ± 0.6	1 ± 2
129731	114	39	31.835	5.91	0.956	7.08	2.61	2.3 ± 0.6	-
129732	114	1	31.411	6.44	0.962	7.26	0.75	2.9 ± 0.4	-
129737	116	1	32.099	6.82	0.936	8.29	1.07	2.4 ± 0.4	-

Table 3: Results from Bay of Fundy mission 93-033 (Cont'd)

Sample #	STN	Depth m	SAL	SiO_3 (μm/l)	PO_4 (μm/l)	NO_3 (μm/l)	SPM mg/l	^{137}Cs (mBq/l)	^{3}H (Bq/l)
129738	116	37	31.523	6.56	1.000	7.66	2.03	3.4 ± 0.8	-
129743	118	1	31.228	5.86	0.846	6.64	1.41	2.6 ± 0.3	-
129744	118	34	32.101	6.58	0.996	8.35	2.53	2.7 ± 0.6	-
129749	120	1	31.194	6.50	0.939	7.02	1.07	2.2 ± 0.5	-
129750	120	30	31.612	6.44	1.002	7.72	1.63	1.7 ± 0.4	-
129756	122	1	31.246	6.43	0.914	7.44	1.36	2.4 ± 0.6	-
129757	122	30	31.456	6.16	0.932	7.22	0.89	2.9 ± 0.6	-
129782	132	1	33.970	11.07	1.270	13.54	-	3.3 ± 0.5	-

Table 4: ^{137}Cs levels in seawater collected near the reactor outfall during field trips, (1991 to 1994).

Sample date	^{137}Cs (mBq/l)	
	Particulate	Soluble
June 1991	< 0.5	-
September 1992	< 2	2.9 ± 0.1
July 1993	< 1	1.6 ± 0.2
November 1994	0.4 ± 0.3	2.4 ± 0.3

Table 5: Average radionuclide values measured in seawater in the Bay of Fundy (1979 to 1993).

Cruise No.	Sample Date	^{137}Cs (mBq/l)		^{90}Sr (mBq/l)	^{3}H (mBq/l)
		Part.	Soluble***	Soluble	Total
Pre-operational					
79-007	May 1979	-	3.8 ± 0.7 (n=28)	3.0 ± 1.0 (n=21)	2700 ± 3000
79-027	Oct 1979	< 0.8	2.6 ± 0.8 (n=43)	-	1700 ± 2700
80-018	Jun 1980	< 0.8	4.2 ± 0.3 (n=43)	-	< 2300
81-500	Feb 1981	< 1.5	4.4 ± 0.5 (n=20)	-	2840 ± 120
81-050	Apr 1981	< 1.2	3.5 ± 0.3 (n=33)	-	2210 ± 580
Operational					
83-033	Apr 1983	-	3.3 ± 0.6 (n=30)	-	2525 ± 910
84-025	July 1984	< 0.4	3.0 ± 0.5 (n=28)	-	2933 ± 611
85-041	Dec 1985	< 0.5	3.2 ± 0.4 (n=18)	-	3885 ± 1343
87-015	May 1987	< 0.5	3.5 ± 0.3 (n=46)	3.6 ± 0.3 (n=3)	< 3900
-	June 1988	< 0.5**	3.1 ± 1.8**	-	-
-	July 1989	< 2**	3 ± 1**	-	-
-	June 1990	< 2**	5 ± 1**	-	-
93-033	Oct 1993	< 1	2.5 ± 0.4 (n=18)	-	-

* Reported error is the standard deviation from the mean value.
** Single measurement, reported error is the counting error.
*** Mean radionuclide activities are calculated using a single value for the 24 hour anchor station.

Activities of dissolved ^{137}Cs during the 1993 October cruise ranged from 1.9 to 3.4 mBq/l with an average level of 2.55 (σ = 0.35) mBq/l, lower than previous measurements made during the pre-operational or operational phase of the monitoring program (Table 5). This average value is comparable to values (2.4 mBq/l, Table 3, Station 132) measured at the same time in the surface water on the Scotian Shelf off Nova Scotia and of 2.4 to 2.6 mBq/l in Atlantic Ocean surface water at 45° latitude (Bourlat *et al*, 1996). The measured decrease in ^{137}Cs activity since 1979 is greater than that expected for radioactive decay since the time of maximum weapons testing in the late 1950s and early 1960s (Figure 6). The decrease corresponds to a half-life of 20 years, shorter than the 30 year ^{137}Cs radioactive half-life and is a result of gradual dilution by deep Atlantic water and fresh water containing lower ^{137}Cs activities. A 20-year half-life compares well with the residence time determined for ^{137}Cs in the Pacific and N Atlantic (Bourlat *et al*, 1996) of approximately 15 years. The ^{137}Cs activities for samples collected in October of 1993 were relatively constant and did not vary significantly with salinity (Figure 7a) over the salinity range encountered.

3.2.4 Suspended Particulate Matter (SPM)

The Whatman paper filter cartridges used to collect SPM for radionuclide measurements, (referred to as Relative SPM), consistently collected more material (44 % higher) than the Nucleopore filters although a good correlation (r^2 = 0.77) was obtained between the two filter types (Figure 8). The Whatman paper filter values are higher

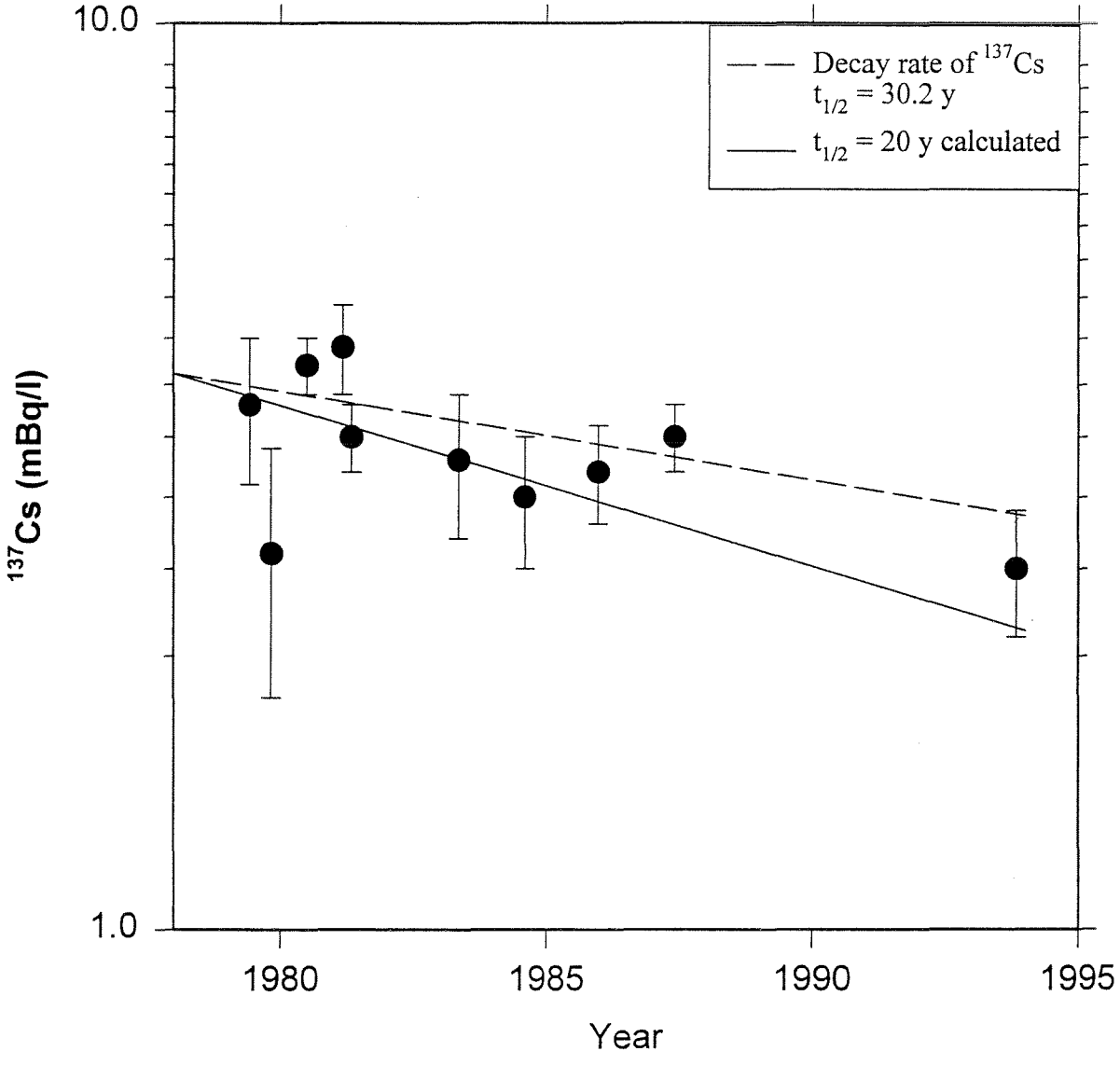

Figure 6: Average ^{137}Cs values in the Bay of Fundy since 1979.

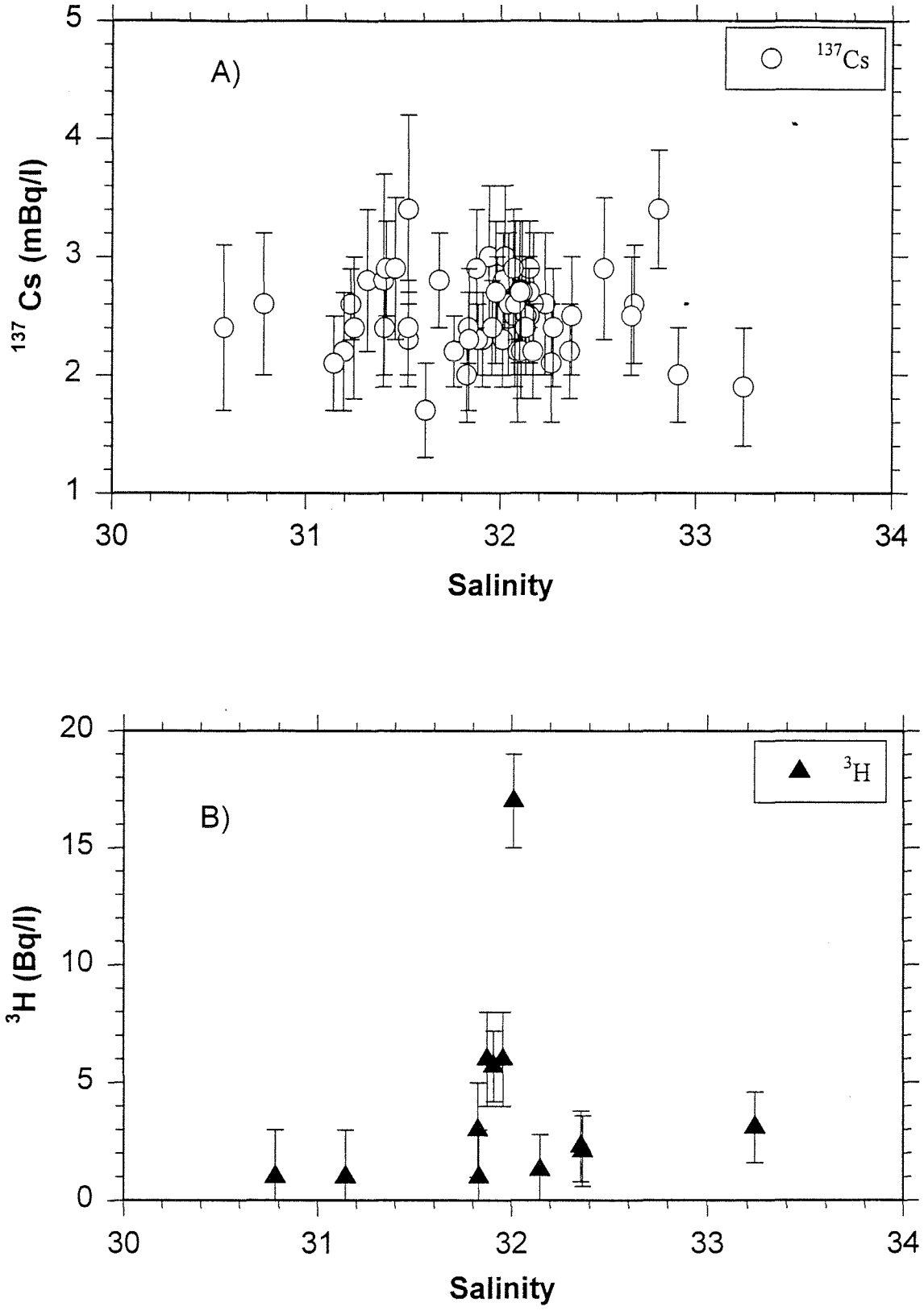

Figure 7: ^{137}Cs and ^{3}H vs salinity for Cruise 93-033.

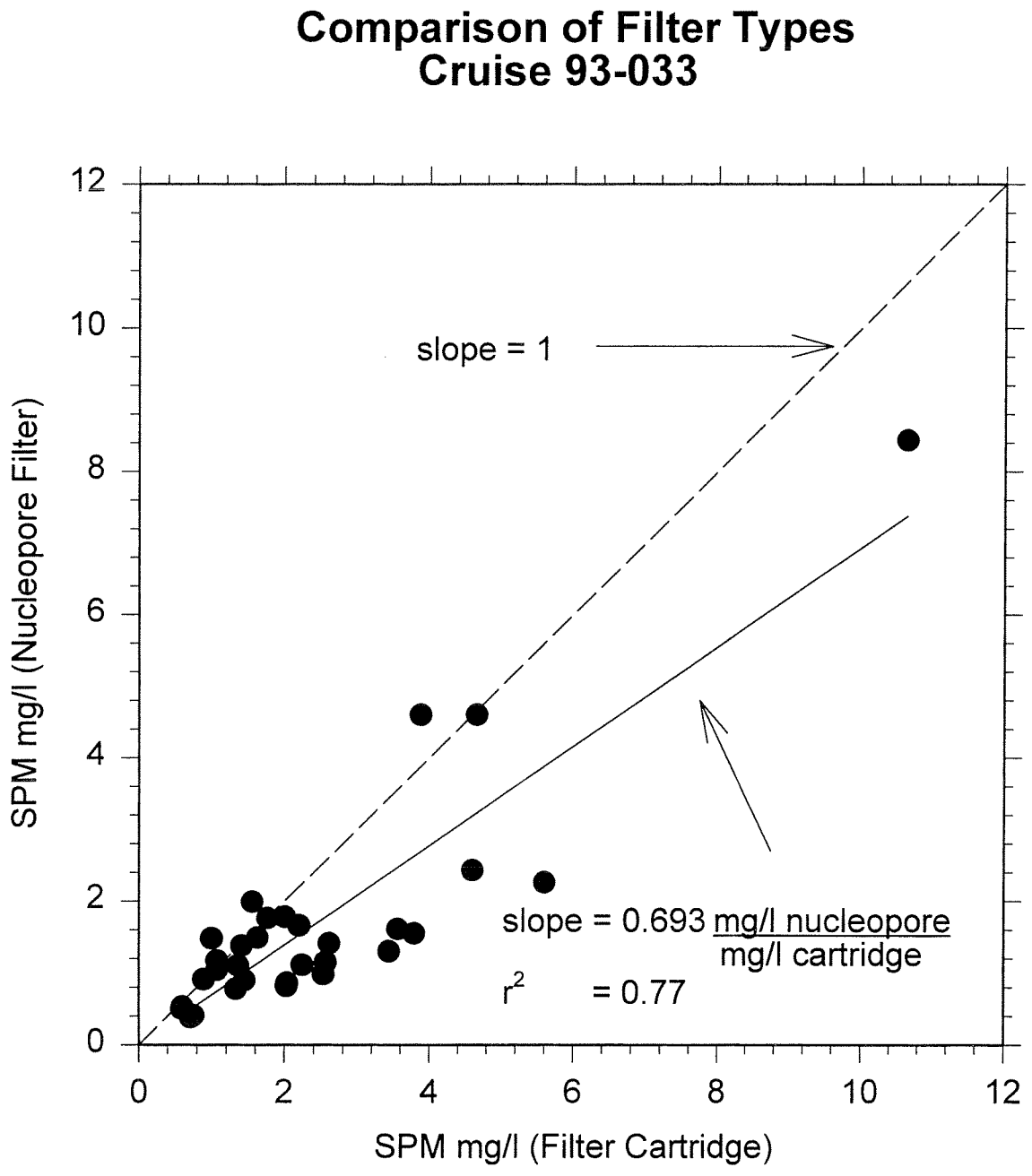

Figure 8: Comparison of SPM collected on nucleopore filters and RSPM collected on Whatman filter paper cartridges.

because; (1) the smaller pore size collects more material, (2) the effective pore size decreases as the filter becomes loaded and (3) washing the salt off the paper filter is more difficult. The paper filters are useful for collecting bulk samples but results shown in Figure 8 verify that quantitative measurement of SPM requires the use of Nucleopore filters as was done during cruise 93-033.

3.2.5 Dissolved and Particulate Radionuclides

Levels of ^{137}Cs and other gamma-emitting isotopes measured in SPM and Chelex-100 samples were below detection limits as was observed in previous years. Detection limits for typical counting conditions (water volume of 48 l, counting time of 1500 minutes, one month after sample collection) are given in Table 6.

3.2.6 ^{226}Ra, ^{210}Pb and ^{210}Po in The Water Column

Radium-226, which is present mainly in dissolved form in the ocean, decays to granddaughters ^{210}Pb and ^{210}Po, which are particle-reactive and are rapidly adsorbed onto particles. Measurements of the disequilibria between the ^{238}U series isotopes ^{226}Ra, ^{210}Pb and ^{210}Po provide one of the best methods for determining removal rates of particle-reactive substances from the water column and for studying the processes of scavenging (Fleer and Bacon, 1984). ^{210}Pb and ^{210}Po results are shown in Figure 9 for (Station 120) at the anchor station at falling tide. Levels of total ^{210}Po and ^{210}Pb are less than the range

Table 6: Detection limits for SPM in seawater for typical sampling and counting conditions (48 l sample, 1500 min count time and 1 month between sampling and counting times).

Nuclide	Chelex	SPM	
	(mBq/l)	(Bq/g)	(mBq/l)
^{56}Co	4.0	1.0	1.5
^{57}Co	0.02	0.3	0.4
^{58}Co	7.0	1.1	1.6
^{60}Co	0.02	0.6	0.9
^{51}Cr	1.2E7	16	24
^{59}Fe	1000	3.1	4.6
^{54}Mn	0.02	0.7	1.1
^{65}Zn	0.06	1.7	2.6
^{134}Cs	-	0.6	0.9
^{137}Cs	-	0.4	0.6

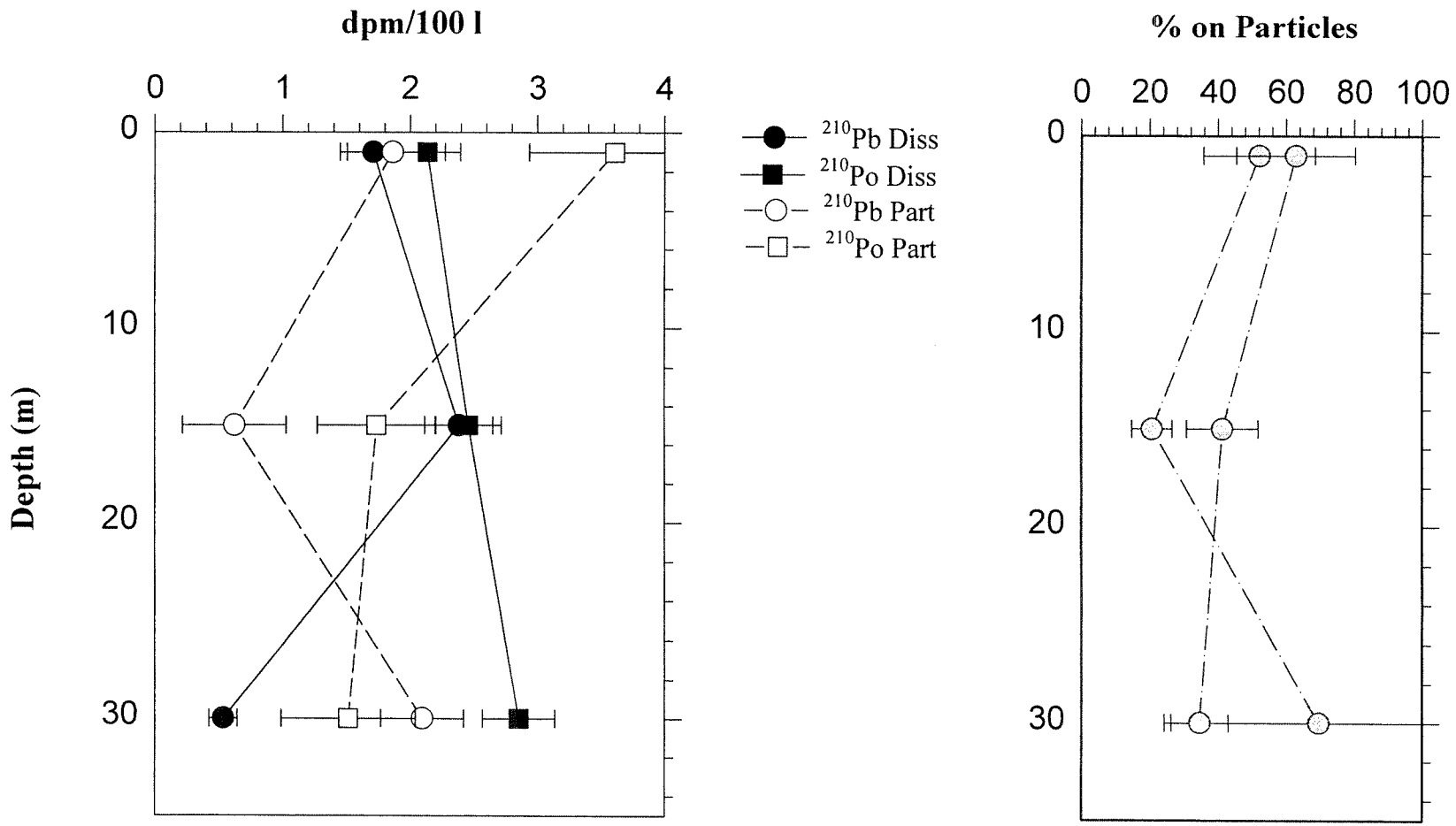

Figure 9: ^{210}Pb, ^{210}Po activities versus water depth at the anchor station in the Bay of Fundy for cruise 93-033.

of 8.2 to 8.6 dpm/100 l measured for parent ^{226}Ra in 1984 in the Bay of Fundy (Ellis et al, 1990), consistent with removal of ^{210}Po and ^{210}Pb by particles. Both ^{210}Po and ^{210}Pb are strongly associated with particles, with greater than 30 - 80% measured in the particulate phase in all but one sample.

3.2.7 Tritium

Environmental releases of tritium from CANDU nuclear reactors are substantially greater than those for any other radionuclide due to the use of heavy water, D_2O, as a moderator and coolant. Tritium is measured in seawater samples by mixing samples with a scintillation cocktail and counting directly for 500 to 1000 minutes using a liquid scintillation counter (LSC). The development of scintillation cocktails, which can be used with high salt solutions, has allowed direct counting of seawater samples with minimal amount of increase in scatter and counting background from that obtained with distilled samples. Tritium levels measured in seawater in the Bay of Fundy (Table 3) were generally at or below the detection limit (approximately 4.0 Bq/l) as was found during previous cruises (Table 5). Some elevated levels were observed close to the outfall at the anchor station and during the launch surveys at times of effluent release (see sections 3.3 Anchor Station and 3.4 Thermal Plume Study). Tritium activities did not tend to vary with salinity (Figure 7b).

3.3 ANCHOR STATION

The CSS Parizeau was anchored near the Point Lepreau NGS cooling water outfall (Figure 3, Station 86) during Mission 93-033 for 36 hours to characterize the dispersion of effluents in the vicinity of the outfall under various tidal conditions. During this period a current meter, which logged temperature, salinity, current speed and direction every 30 seconds, was suspended from a crane, on the afterdeck of the vessel, at a water depth of 2 meters. In addition, hourly, vertical temperature and salinity profiles were logged and discrete water samples were collected at the surface and bottom. Values obtained for ^{3}H, ^{137}Cs, nutrients, RSPM and discrete salinity are included in Table 3. The ^{3}H values, ^{137}Cs activity, RSPM, salinities and predicted tidal height at Saint John N.B. are plotted against time in Figure 10. The current meter observations are shown in Figure 11.

The currents near the cooling water outfall (Figure 11) are complicated by eddies which are set up at various stages of the tide (Nelson *et al,* 1986). Briefly, following low water at the start of the flood tide, currents near the anchored ship tend toward the north as expected (Figure 11). As the current speed increases, the flow separates near the tip of Point Lepreau and a relatively large counter-clockwise eddy is set up on the eastern side of the point. This results in a southerly flow, opposite to that expected on a flooding tide, along the eastern side of the point which carries water from the vicinity of the outfall past the anchored ship. This is indicated by the elevated temperatures shown at this stage of the tide in Figure 11. Following high water, the southerly currents of the eddy are enhanced by the southwesterly flow of the ebbing tide. The anchored ship remains in the

Anchor Station Time Series

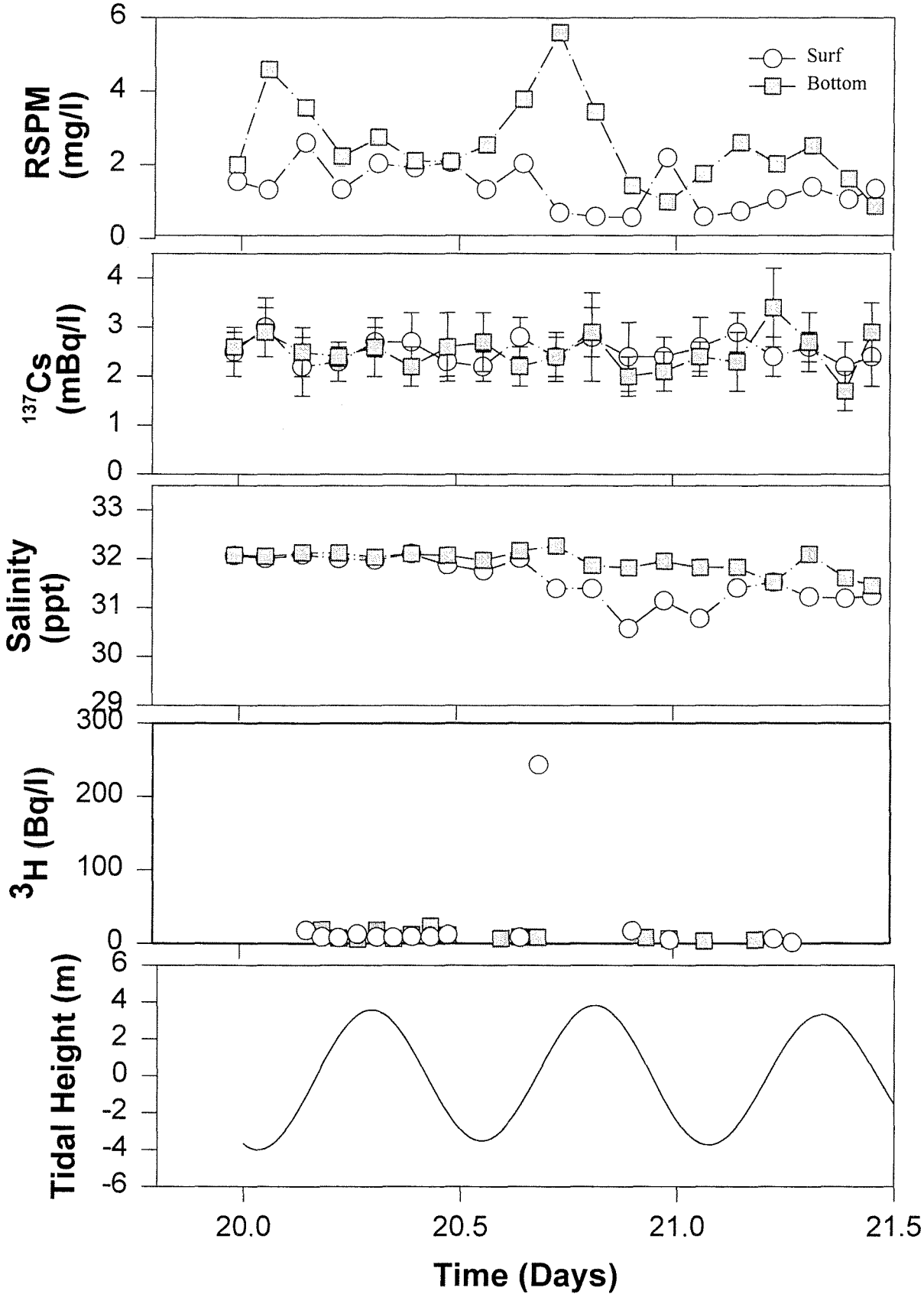

Figure 10: Anchor station time series.

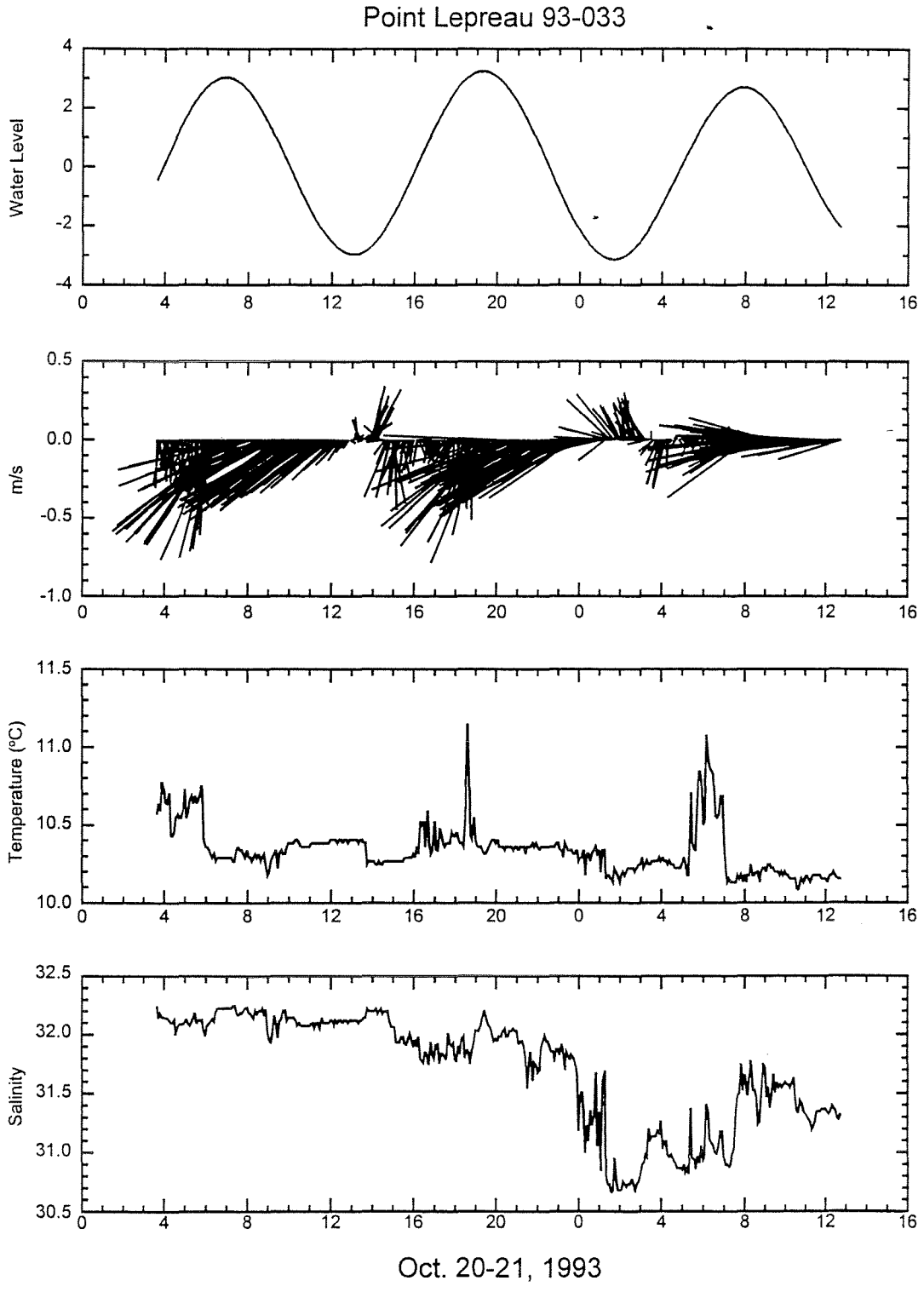

Figure 11. Predicted water level at St. John N.B. and current meter data obtained from CSS Parizeau while moored at the position shown in Figure 12.

strong southwesterly flow. However, flow separation occurs near the outfall and results in a smaller clockwise eddy in the cove to the north. This eddy carries the discharge in northerly direction, opposite of that expected on an ebbing tide (see Nelson *et al* 1986). As the ebbing tide dies away near low water, the eddy expands and decays with the northward flow on its shoreward side blending with the flow from the next flood tide as the cycle repeats.

At the anchor station, RSPM values for the bottom water ranged from 0.9 mg/l to 5.6 mg/l and tended to increase with increasing current speed. This suggests stronger currents were resuspending bottom sediments. Surface RSPM values ranged from 0.7 mg/l to 2.6 mg/l and were relatively independent of current speed.

The average surface ^{137}Cs activity (2.53 ± 0.25 mBq/l) and the average bottom activity (2.53 ± 0.39 mBq/l) are identical, indicating the uniform distribution of ^{137}Cs with depth. During the second day of the anchor station fresher surface water was advected into the area (Figures 10, 11), probably from the discharge plume of the Saint John River. The surface ^{137}Cs activity did not appear to be correlated with salinity.

The surface and bottom ^{3}H values are close to background levels except for the one elevated surface sample, which occurred in conjunction with elevated surface temperatures at the ship and is related to a controlled liquid waste pumpout from the NGS as discussed in the following section.

3.4 Thermal Plume Study

Two detailed surveys were carried out near the cooling water outfall using a Boston Whaler deployed from the ship, while the CSS Parizeau was at the anchor station. During each survey, stations were occupied on a 500-meter grid in the vicinity of the NGS subsurface cooling water outfall. At each station, vertical profiles of temperature and salinity were obtained using a Seabird 25 CTD system and surface water samples were collected for ^{3}H analysis. The first survey was conducted from approximately 12:00Z to 14:40Z (93.10.20) and spanned low water. The second survey extended from approximately 16:15Z (Zulu or Greenwich Mean Time) to 16:45Z (93.10.20) and was representative of a flooding tide. During the later part of the first survey, the NGS undertook a controlled liquid waste pumpout to provide a source of ^{3}H for tracking the effluent plume.

Figure 12 shows the surface temperature values observed during the two thermal plume surveys. During survey # 1, shown in the top diagram of Figure 12, the thermal plume, characterized by higher surface temperatures, extends in a northeasterly direction from the outfall into the cove to the north as expected near low water (Nelson et al, 1986). The receiving waters, which were vertically unstratified during the thermal plume surveys, had a temperature of about 10.2 °C. The maximum observed surface temperature rise was about 1 °C and occurred near the outfall (Figure 12). During survey # 2, shown in the bottom diagram of Figure 12, the thermal plume extends in a southerly

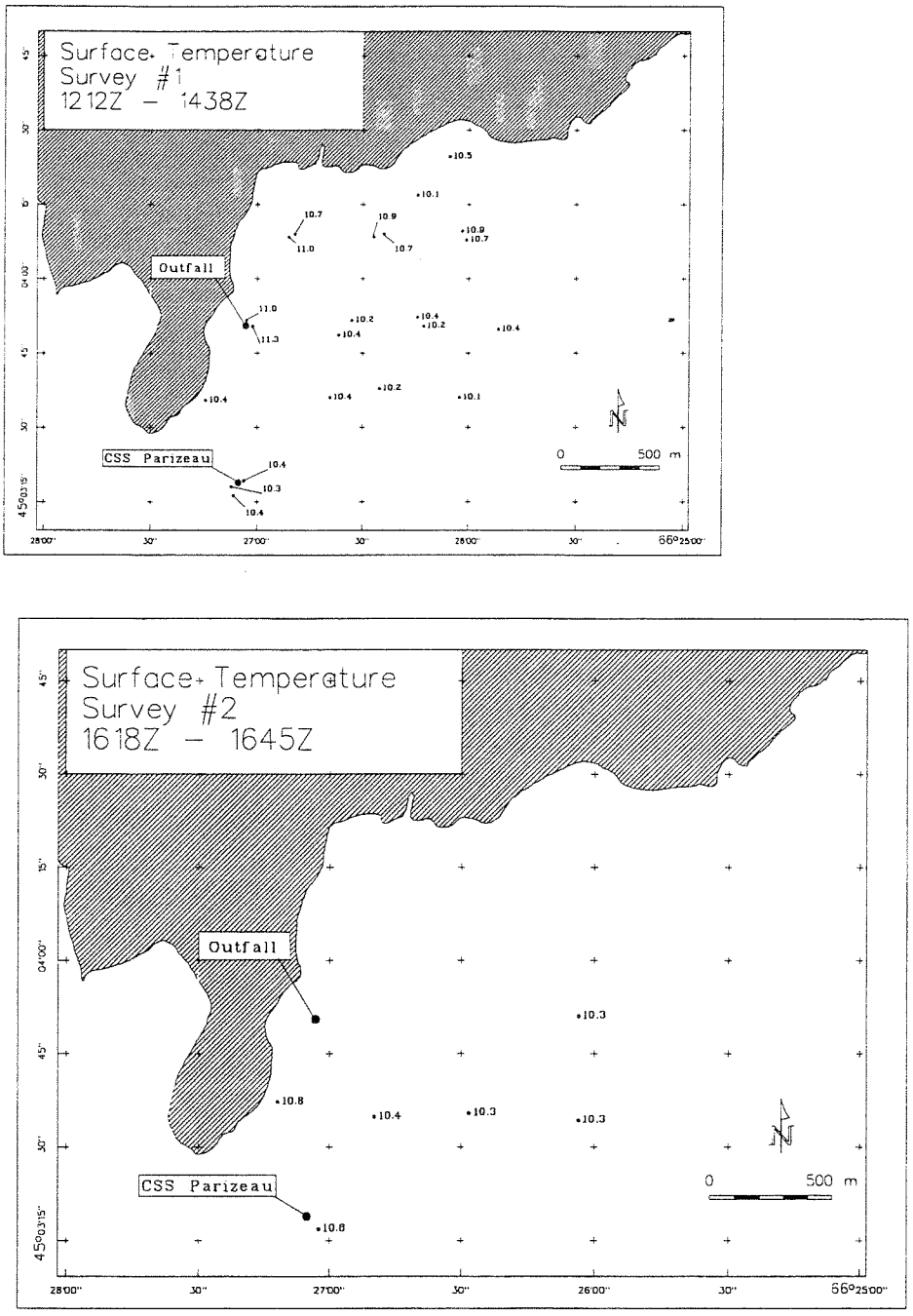

Figure 12. Surface temperature values in °C from the thermal plume surveys October 20 1993. Also shown are the surface temperatures observed during the hourly CTD casts from CSS Parizeau. The ship swinging on its anchor is responsible for the different positions of the Parizeau observations.

direction as expected on a rising tide. The elevated temperatures seen in both Figures 11 and 12 at this time are consistent with the known tidal currents.

The controlled liquid waste pumpout lasted from 12:56 Z to about 13:46 Z. During the pumpout, the undiluted outfall ^{3}H activity and temperature were estimated to be 1.23 x 10^{5} Bq/l and 23.2 °C. These values are calculated from nominal cooling water flow values and are approximate only. Figure 13 shows the surface tritium values observed during the two thermal plume surveys. Only those observations made after the direction as expected on a rising tide. The elevated temperatures, seen in both Figures 11 and 12 at this time, are consistent with this pattern.

The controlled liquid waste pumpout lasted from 12:56 Z to about 13:46 Z. During the pumpout, the undiluted outfall ^{3}H activity and temperature were estimated to be 1.23 x 10^{5} Bq/l and 23.2 °C. These values are calculated from nominal cooling water flow values and are approximate only. Figure 13 shows the surface tritium values observed during the two thermal plume surveys. Only those observations made after the start of the pumpout are shown. The surface tritium values obtained from the first survey are consistent with the effluent plume distribution derived from the surface temperatures. The tritium distribution observed during the second survey showed that elevated values were still present in the plume three hours after the end of the waste pumpout. This suggests that effluent may be trapped in the clockwise eddy formed on the previous falling tide and may remain in the area for several hours before dissipating.

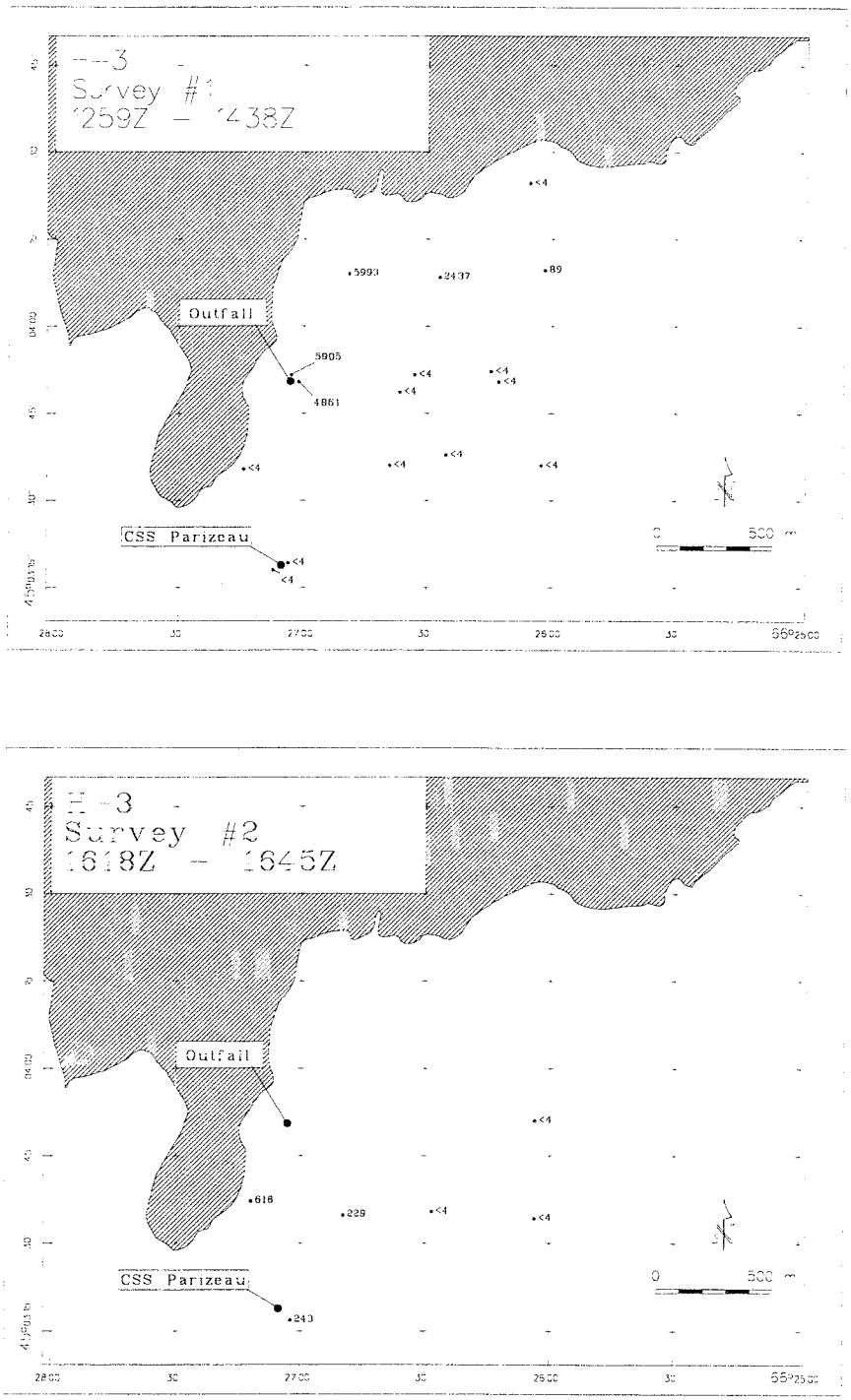

Figure 13. Surface tritium values in Bq/l from thermal plume surveys October 20 1993. Values below the detection limit are shown as <4.

Figure 14 shows the temperature/tritium-mixing diagram for surface samples taken during the thermal plume surveys. As the waste pumpout lasts for less than an hour, there is no opportunity for any sort of consistency to be reached between the temperature and tritium distributions. The distribution of points on Figure 14 is consistent with mixing between the assumed end point members (10.2 °C and 0 Bq/l for the receiving waters and 23.2 °C, 1.23 x 10^5 Bq/l for the discharge) and some remixing with warmer waters discharged either before or after the liquid waste pumpout.

3.5 Sediment Results

Box and Lehigh gravity cores have been collected from a wide range of locations in the Bay of Fundy since 1978 as part of PLEMP. These sediment cores have been analyzed for the natural radionuclides ^{210}Pb and ^{226}Ra in order to determine sedimentation and mixing or bioturbation rates (Smith and Walton, 1980; Smith *et al.*, 1987; Smith *et al.*, 1995). ^{210}Pb is an excellent tracer of fine-grained clays and organic matter. Inventories of ^{210}Pb measured during the 1993 mission of the CSS Parizeau have been

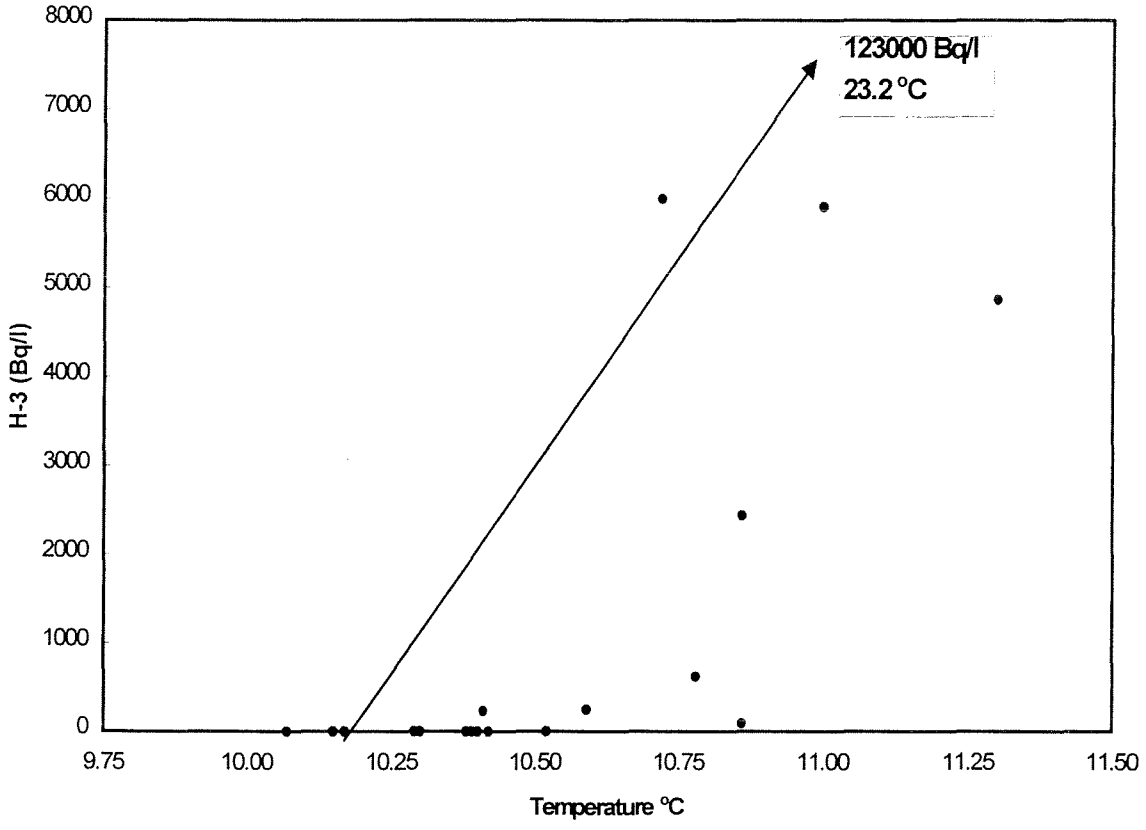

Figure 14. Temperature-tritium mixing diagram for surface samples collected during the thermal plume surveys. The assumed end point members are 10.2 °C and 0 Bq/l for the receiving waters and 23.2 °C, 123000 Bq/l for the effluent discharge.

combined with previously reported data (Ellis *et al.*, 1990) to update their distribution in the Bay of Fundy (Figure 15). The largest inventories, significantly in excess of the steady-state cumulative fallout inventory of 32 dpm/cm^2 predicted for the Bay of Fundy, are measured in the Quoddy region, at the northerly approaches to Passamaquoddy Bay. This is a region of fine-grained muds (Figure 16) having relatively high sedimentation rates, (0-2 cm/y), and represents a net depositional regime for particle-reactive elements such as ^{210}Pb. In contrast, the sediments in the immediate vicinity of Point Lepreau are sandier and are distinguished by much lower levels of ^{210}Pb. Particle-reactive radioisotopes released from the Point Lepreau Nuclear Generating Station should be carried into the Quoddy region and deposited in these rapidly accumulating sediments.

Cesium-137 has been introduced into the environment during atmospheric weapons tests in the 1950s and 1960s. Like ^{210}Pb, it is scavenged by fine particles in freshwater and to a lesser extent in marine systems and accumulates in fine-grained depositional regimes. Cesium-137 has been used extensively to validate sediment geochronology's determined using the ^{210}Pb dating method in Bay of Fundy sediments. The distribution of ^{137}Cs inventories in sediments in the Bay of Fundy (Figure 17) also reflects the distribution of fine-grained muds throughout this region. Only a relatively large release of ^{137}Cs from the Point Lepreau NGS would be distinguishable from the ^{137}Cs fallout background in Bay of Fundy sediments.

Sediment cores collected in the Bay of Fundy during the 1993 CSS Parizeau cruise were analyzed for a suite of trace metals. Levels of Zn, Cu and Pb measured in sediments from the Quoddy region and the harbours of Digby and Saint John are

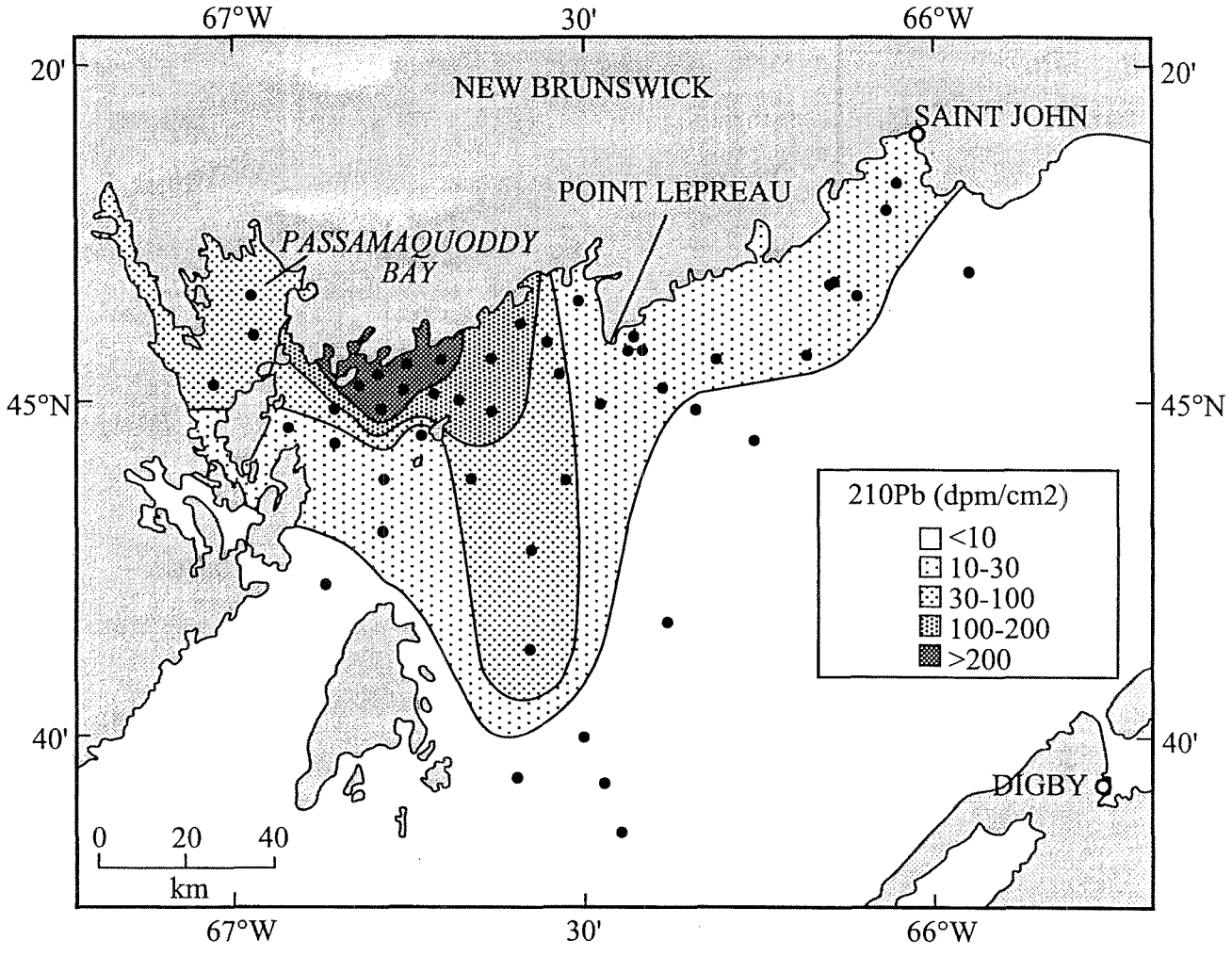

Figure 15: ^{210}Pb inventories measures in sediment cores collected between 1997 and 1984 in the Bay of Fundy, show the highest levels of ^{210}Pb in the fine grained depositional regime in the Quoddy region.

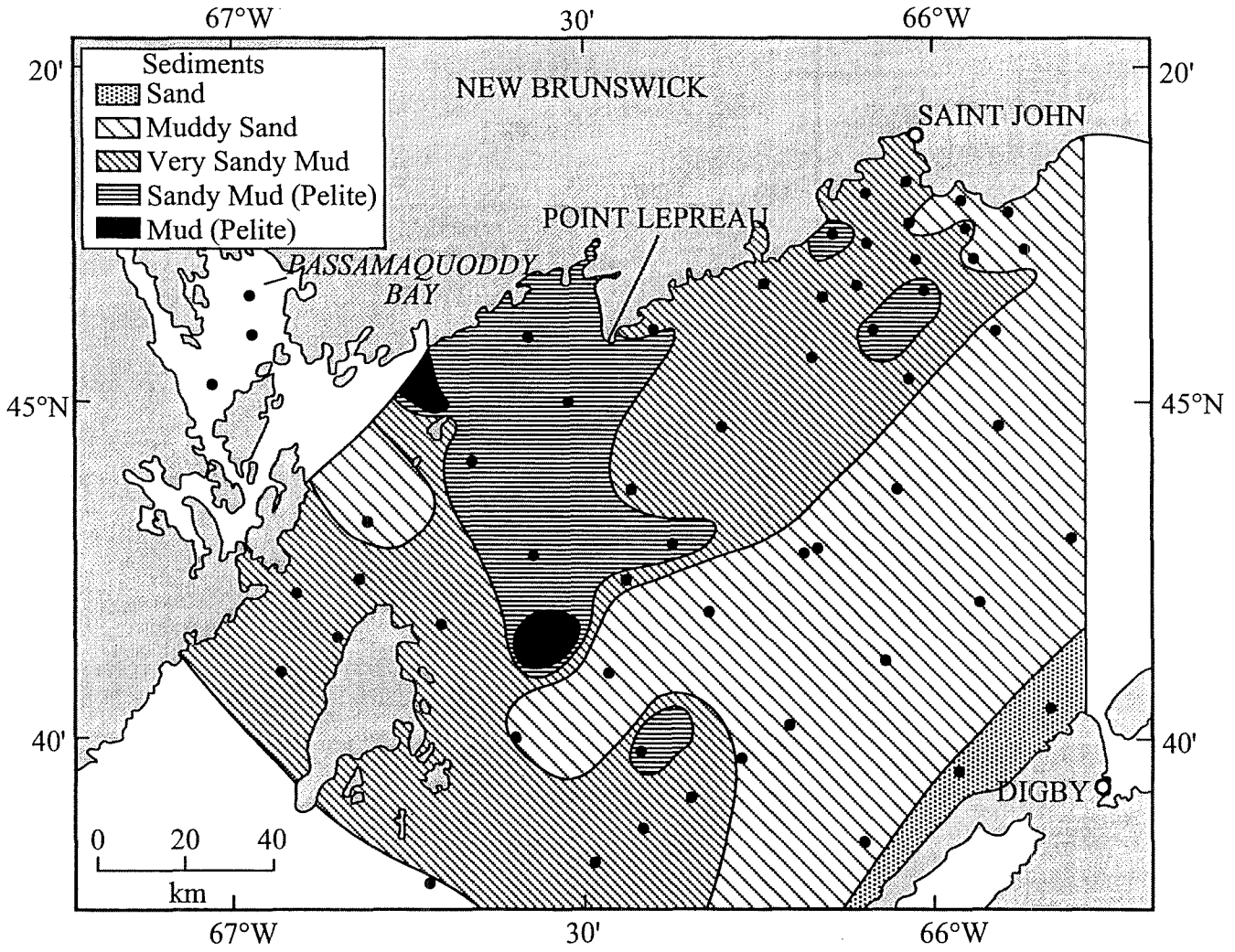

Figure 16: Particle size distributions in sediment from the Bay of Fundy, (Loring, 1979)

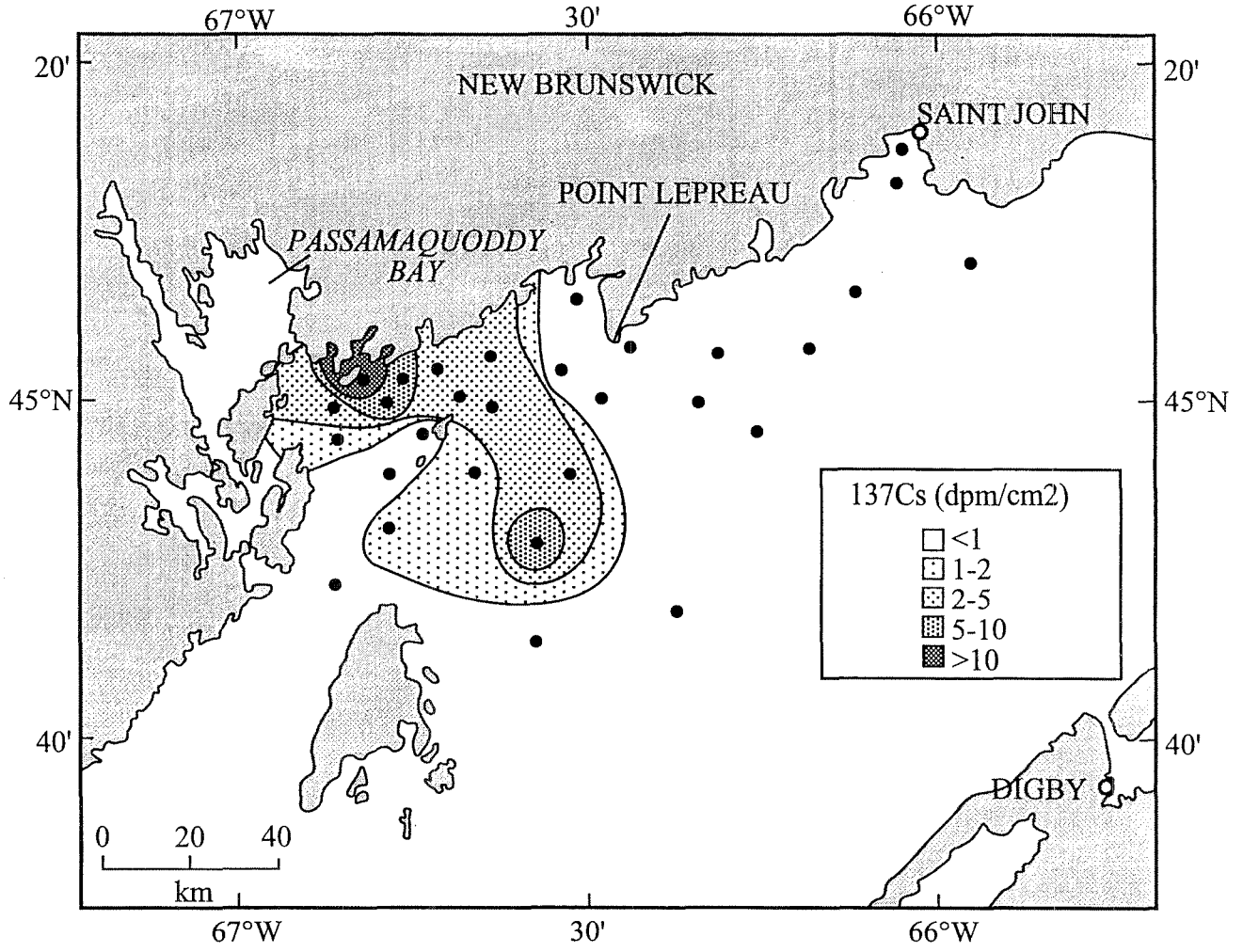

Figure 17: ^{137}Cs inventories in sediment cores in the Bay of Fundy during missions from 1979 to 1993.

relatively low and uniform as a function of core depth compared to metal concentrations in a core from the Northwest Arm of Halifax Harbour (Gearing et al., 1991; Figure 18). The elevated metal levels in the upper 15 cm of the Halifax Harbour core represent contamination associated with industrial and municipal waste discharges during the past 100 years. There is little evidence for significant anthropogenic metal contamination in the Bay of Fundy cores. However, the metal levels in the core from Saint John Harbour are probably low because the core was collected in a partially scoured depositional regime where rates of fine particle sedimentation were also low.

3.5.1 Intertidal Sediments

Radionuclide results for intertidal sediments collected in Duck Cove near the reactor outfall (Figure 12) from 1991 to 1994 are given in Table 7. The low levels found for ^{137}Cs (< 1.1 Bq/kg) are similar to pre-operational levels in the Duck Cove area (Smith *et al*, 1982). The sediments to the east of Point Lepreau at Duck Cove are characterized as 'very sandy mud' (Loring, 1979) made up of larger size particles and smaller overall surface area, which typically have lower radionuclide concentrations.

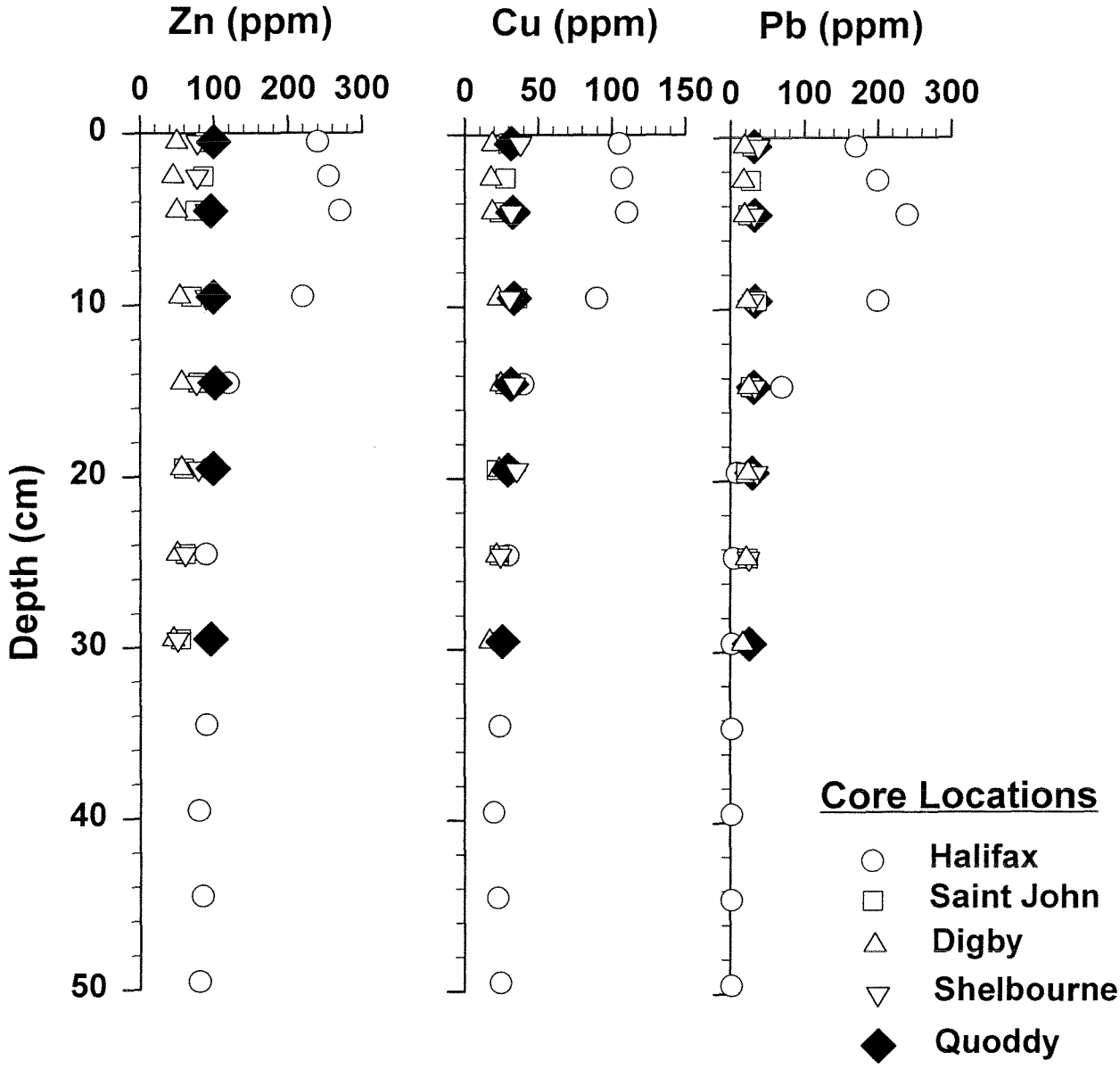

Figure 18: Metal concentrations in sediment cores from the Bay of Fundy compared to harbours and embayments in Nova Scotia and New Brunswick.

Table 7: Radionuclide results for intertidal sediments collected from 1991 to 1994.

Collection Date	Sample Number	Site Number	^{137}Cs (Bq/kg)
17/06/91	98740	I17	1.1 ± 0.5
23/09/92	107658	I17	0.84 ± 0.45
14/07/93	107749	I17	0.82 ± 0.51
29/11/94	129520	I17	0.5 ± 0.4

4.0 ATMOSPHERIC MONITORING

Radionuclides released from the NGS in the form of gaseous and atmospheric particulate emissions enter the marine, aquatic and terrestrial environment through direct deposition, precipitation that has incorporated atmospheric radionuclides and through exchange with surface water. The atmospheric monitoring program at the Point Lepreau NGS consists of; (1) the ongoing compilation of a meteorological data base for the Point Lepreau region which can be applied to modeling the transport of airborne pollutants and (2) the collection of atmospheric samples (water vapor, gaseous iodine and particulates) for radionuclide analysis.

4.1 Meteorological Data Collection

The meteorological data collection station is located at the Department of Transport depot in Musquash, New Brunswick (Figure 19). The station consists of a Fisher and Porter precipitation gauge and a Campbell Scientific temperature and relative humidity probe. Wind speed and direction data (at an elevation of 10 m) collected from an on-site tower at the Point Lepreau NGS were provided by NBEPC. The Atmospheric Environment Service extracts the wind, temperature, rainfall and relative humidity data for use in the monitoring program.

The monthly rainfall amounts, average monthly temperatures and average monthly windspeeds at Musquash are presented in Table 8. The rainfall amounts for 1992 of 942 mm and for 1993 of 1016 mm were lower than the 10-year average from

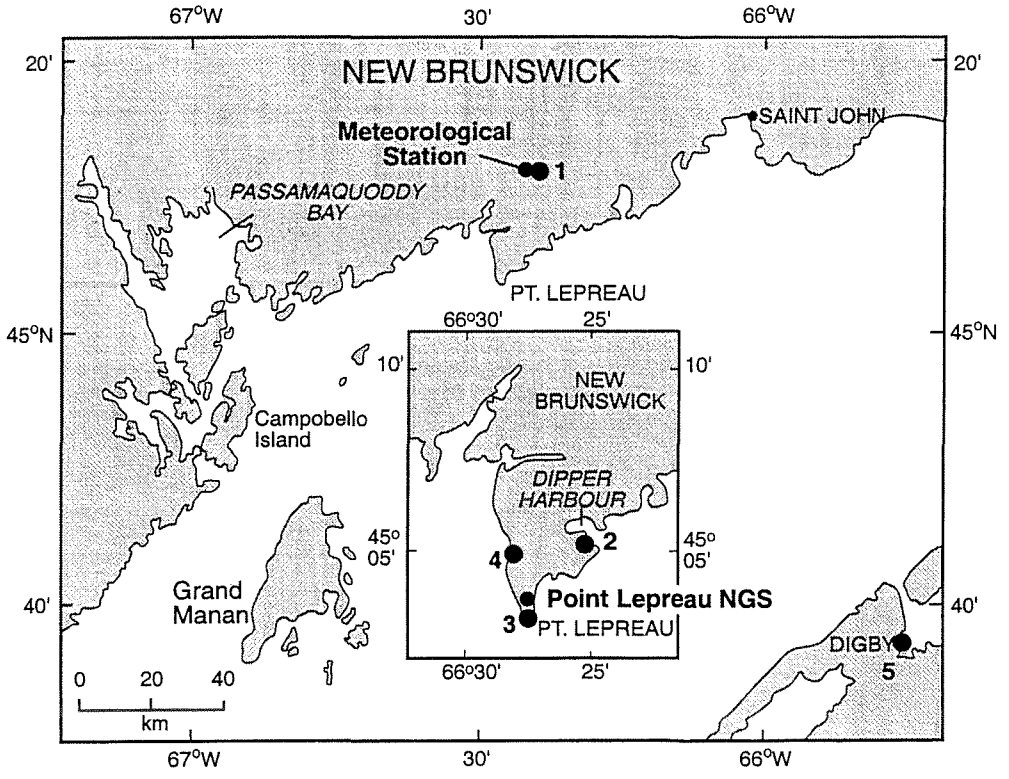

Figure 19: Locations of the air monitoring stations.

Table 8: Meteorological data for Point Lepreau for the years 1991 to 1994. Precipitation data from 1991 is from the Musquash meteorological station; data from 1992 to 1994 is from the Point Lepreau meteorological station.

Year -Month		Precipitation (mm)	Average Temp (°C)	Average Windspeed (km/h)
1991	Jan	112.6	-8.8	16.1
	Feb	38.5	-5.2	19.7
	Mar	140.0	-0.8	16.8
	Apr	117.9	4.0	11.2
	May	96.5	10.5	12.0
	Jun	24.0	14.6	10.3
	Jul	113.0	17.9	8.7
	Aug	203.4	15.8	10.1
	Sep	152.4	12.7	11.4
	Oct	85.1	9.8	14.8
	Nov	93.4	4.8	15.0
	Dec	74.5	-3.9	15.6
Annual		1144		
1992	Jan	65.6	-6.0	16.9
	Feb	92.3	-5.3	15.5
	Mar	76.2	-2.4	14.1
	Apr	52.3	2.2	10.8
	May	41.3	7.0	8.3
	Jun	83.3	11.6	8.2
	Jul	124.6	13.4	7.9
	Aug	79.9	14.6	8.7
	Sep	45.8	12.3	9.8
	Oct	99.1	7.8	12.4
	Nov	110.6	2.3	12.0
	Dec	71.2	-1.9	16.4
Annual		942.2		

Table 8: Meteorological data for Point Lepreau for the years 1991 to 1994. Precipitation data from 1991 is from the Musquash meteorological station; data from 1992 to 1994 is from the Point Lepreau meteorological station. (cont'd).

Year -Month		Precipitation (mm)	Average Temp (°C)	Average Windspeed (km/h)
1993	Jan	69.4	-6.1	15.3
	Feb	56.4	-8.9	15.2
	Mar	79.8	-2.0	13.4
	Apr	99.0	3.4	12.2
	May	29.5	8.1	10.2
	Jun	100.0	11.1	9.1
	Jul	42.3	14.8	8.1
	Aug	0.8	15.1	7.2
	Sep	102.7	12.8	10.6
	Oct	138.8	7.6	15.8
	Nov	93.8	3.8	16.3
	Dec	203.7	-1.3	17.6
Annual		1016.2		
1994	Jan	84.6	-10.0	17.6
	Feb	15.9	-6.9	14.0
	Mar	181.6	-0.3	13.0
	Apr	149.8	4.0	12.3
	May	160.2	7.8	12.2
	Jun	82.3	12.9	9.7
	Jul	53.0	17.5	8.2
	Aug	50.7	16.1	8.5
	Sep	40.0	13.6	10.7
	Oct	59.0	9.4	11.3
	Nov	111.7	5.4	16.2
	Dec	102.8	-1.2	16.0
Annual		1091.6		

1981 to 1990 of 1282 (σ = 186 mm). The quantities of rain recorded for 1991 of 1144 mm and for 1994 of 1092 mm were typical for the area. The region is characterized by relatively high winds throughout the year, with yearly average wind speeds of 13.5 km/h in 1991, 11.8 km/h in 1992, 12.6 km/h in 1993 and 12.5 km/h in 1994 which are similar to the 14 km/h average windspeed measured during previous years (Ellis *et al*, 1990, 1992). Monthly wind distributions are shown in Figure 20. Wind speeds are greatest in the winter when wind direction is characterized by strong northerly winds and tend to diminish and become dominated by southwest winds in the summer.

4.2 Air Monitoring Results

AERU operates a network of air monitoring stations (AMS) with locations shown in Figure 19. At present, there are four stations in service, AMS 1,2,3 and 5; Figure 19, with three in the Point Lepreau area and one located in Digby, Nova Scotia. The design for the air monitoring stations is shown in Figure 21 and the components have been described in previous reports. (Bishop *et al*, 1980, Ellis *et al*, 1990).

The approximate detection limits for the three major components of the air monitoring program are $4x10^{-5}$ mBq/m^3 for particulate ^{137}Cs, $3x10^{-2}$ mBq/m^3 for gaseous ^{131}I on the charcoal cartridge and $1x10^{-2}$ Bq/m^3 for ^{3}H in water vapor. These detection limits assume a 10 day delay between sampling and analysis. Technical problems resulted in some counting delays for filters and cartridges of up to several months.

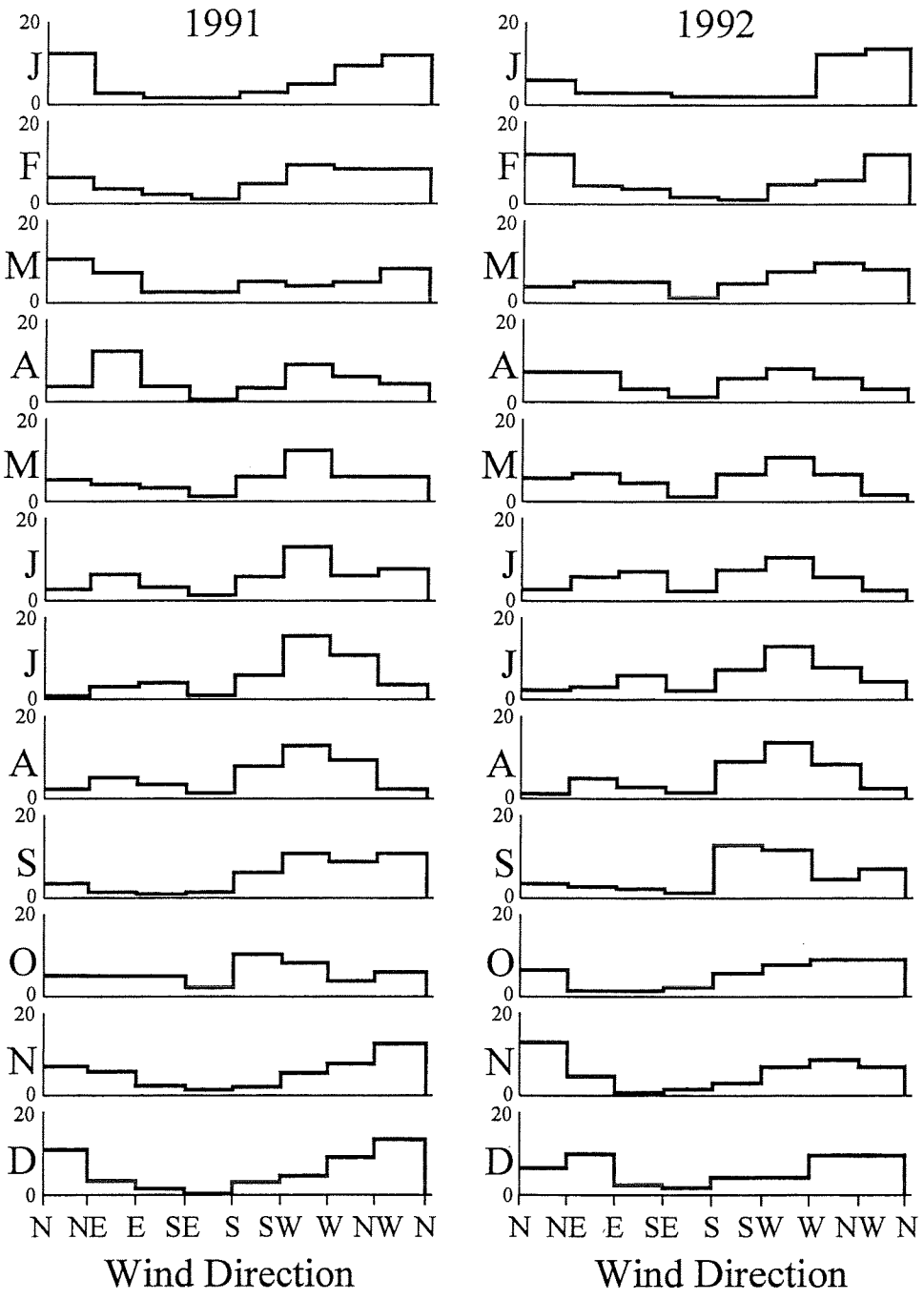

Figure 20A: Monthly wind direction distribution at Point Lepreau NGS from 1991 to 1994, showing the percentage of time (y-axis) for each of the 8 wind directions for each month.

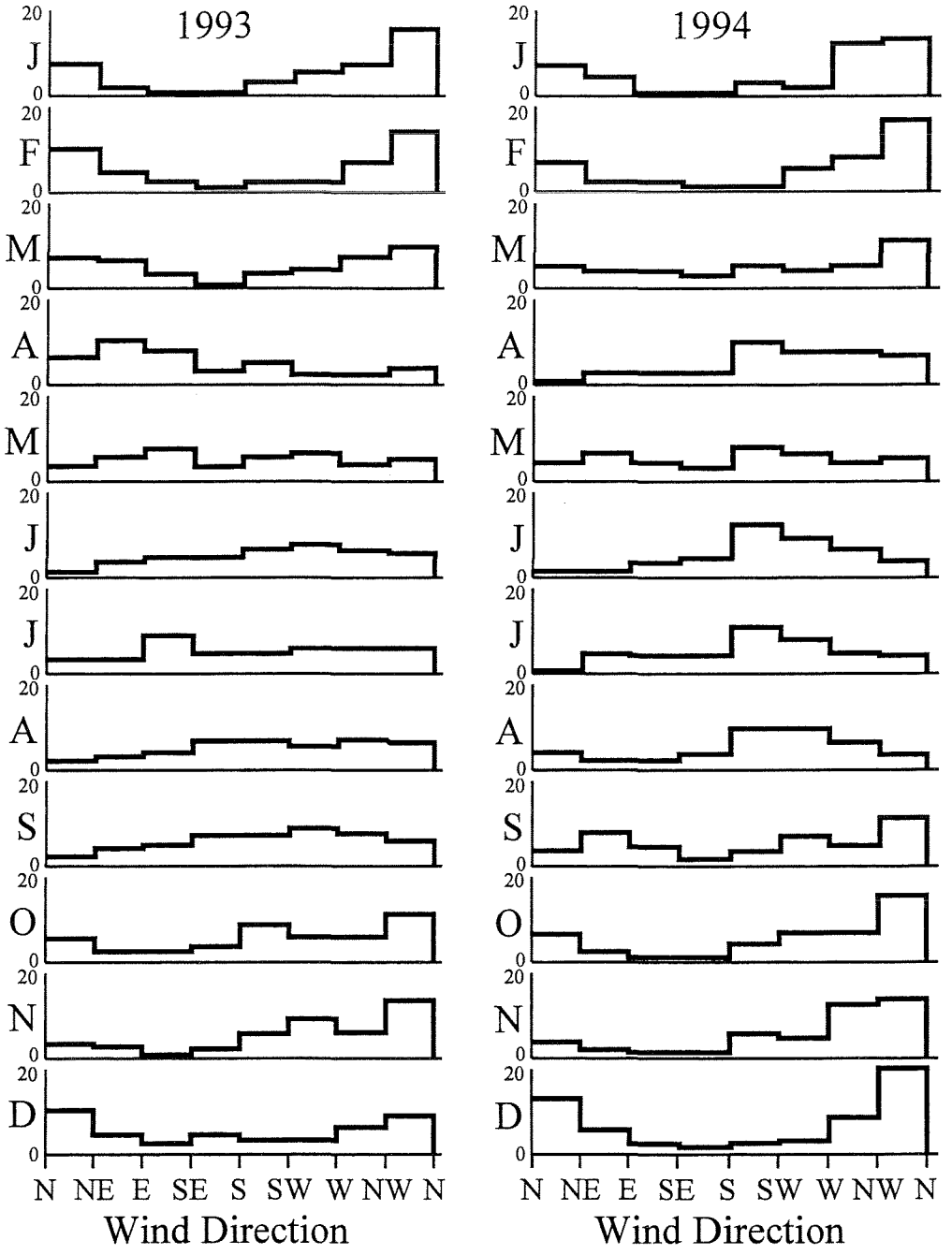

Figure 20B: Monthly wind direction distribution at Point Lepreau NGS from 1991 to 1994, showing the percentage of time (y-axis) for each of the 8 wind directions for each month.

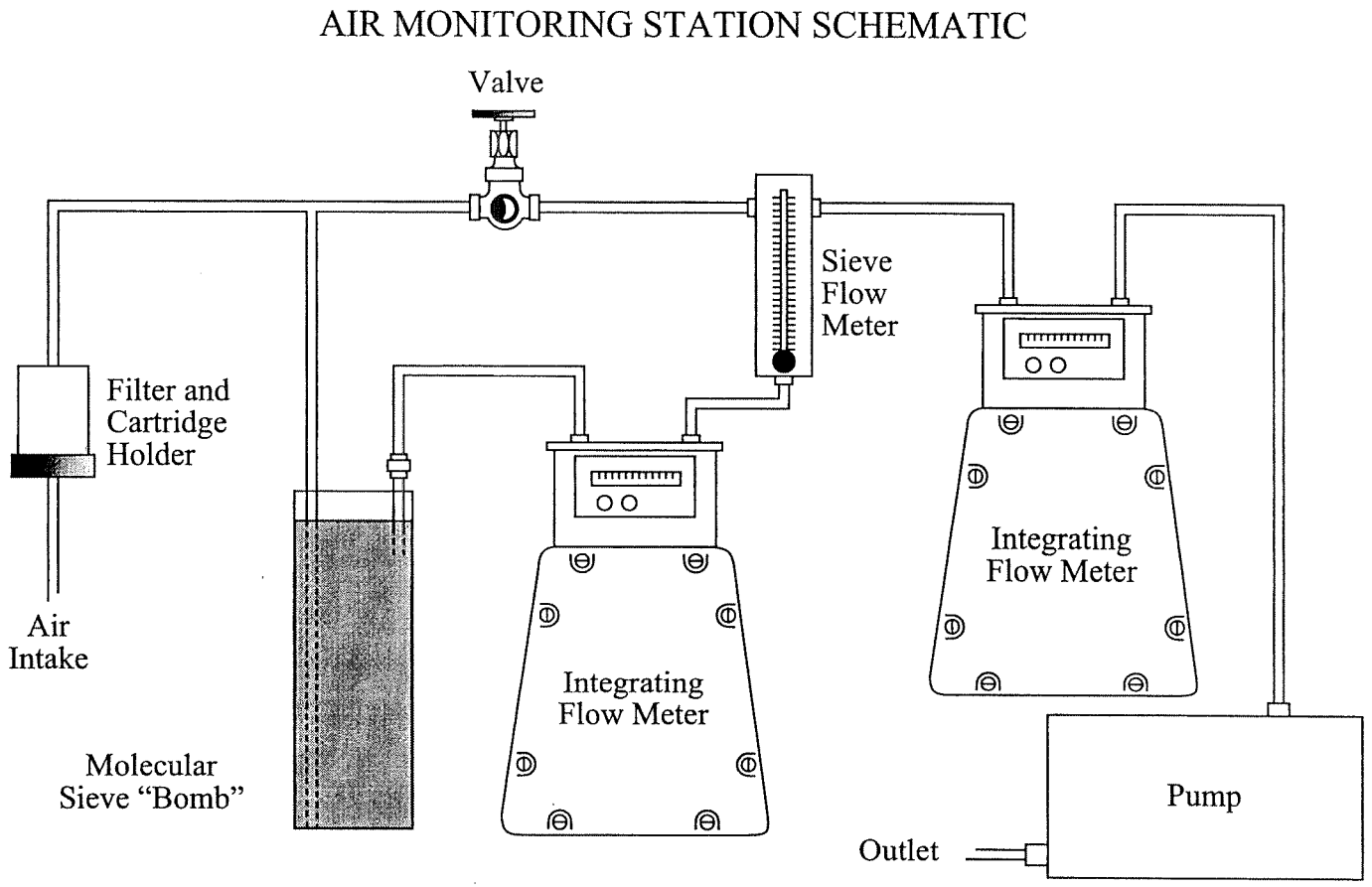

Figure 21: Schematic of an air monitoring station.

4.2.1 Tritium in Atmospheric Water Vapor

Tritium distributions in atmospheric water vapor (Bq/l) for AMS 1 at Musquash, AMS 2 at Dipper Harbor, AMS 3 at Point Lepreau and AMS 5 at Digby, N. S. from 1991 to 1994 are illustrated in Figure 22.

Tritium activities have increased from the pre-operational average level of 5.9 Bq/l (range of < 2 to 16 Bq/l) to an average value of 41 Bq/l (range of < 4 to 309 Bq/l) in 1989 to 74 Bq/l (range of < 4 to 413 Bq/l) by 1994. The increase in the ^{3}H signal reflects the increase in the quantity of ^{3}H released from the NGS as gaseous emissions (Figure 2). As expected, the highest tritium activities have been measured at AMS 3, located at the tip of Point Lepreau less than 1 km from the NGS. The yearly average has increased from 100 Bq/l in 1989 and 203 Bq/l in 1991 to values of 360 Bq/l in 1992 and 1993. Maximum values at AMS 3 are generally measured in the winter and spring when the wind patterns are dominated by north-northwest winds and AMS 3 is immediately downwind of the NGS atmospheric outfall.

Tritium activities have also shown an increase at AMS 5 during this time period. The average tritium activity has increased from 5 Bq/l (range 2 to 17 Bq/l) during the pre-operational program to 14 Bq/l (σ = 11) in 1991, 53 (σ = 57) in 1992, 61 (σ = 92) in 1993 and then decreased in measurements made during 1994 to 8 Bq/l (single measurement). Figure 22 illustrates the distribution in tritium activities from 1991 to 1994 and shows that elevated tritium levels were observed at AMS 5 during the late spring and early summer in both 1992 and 1993. These elevated tritium activities tend to coincide with periods of increased tritium emissions from the NGS (Figure 2) during

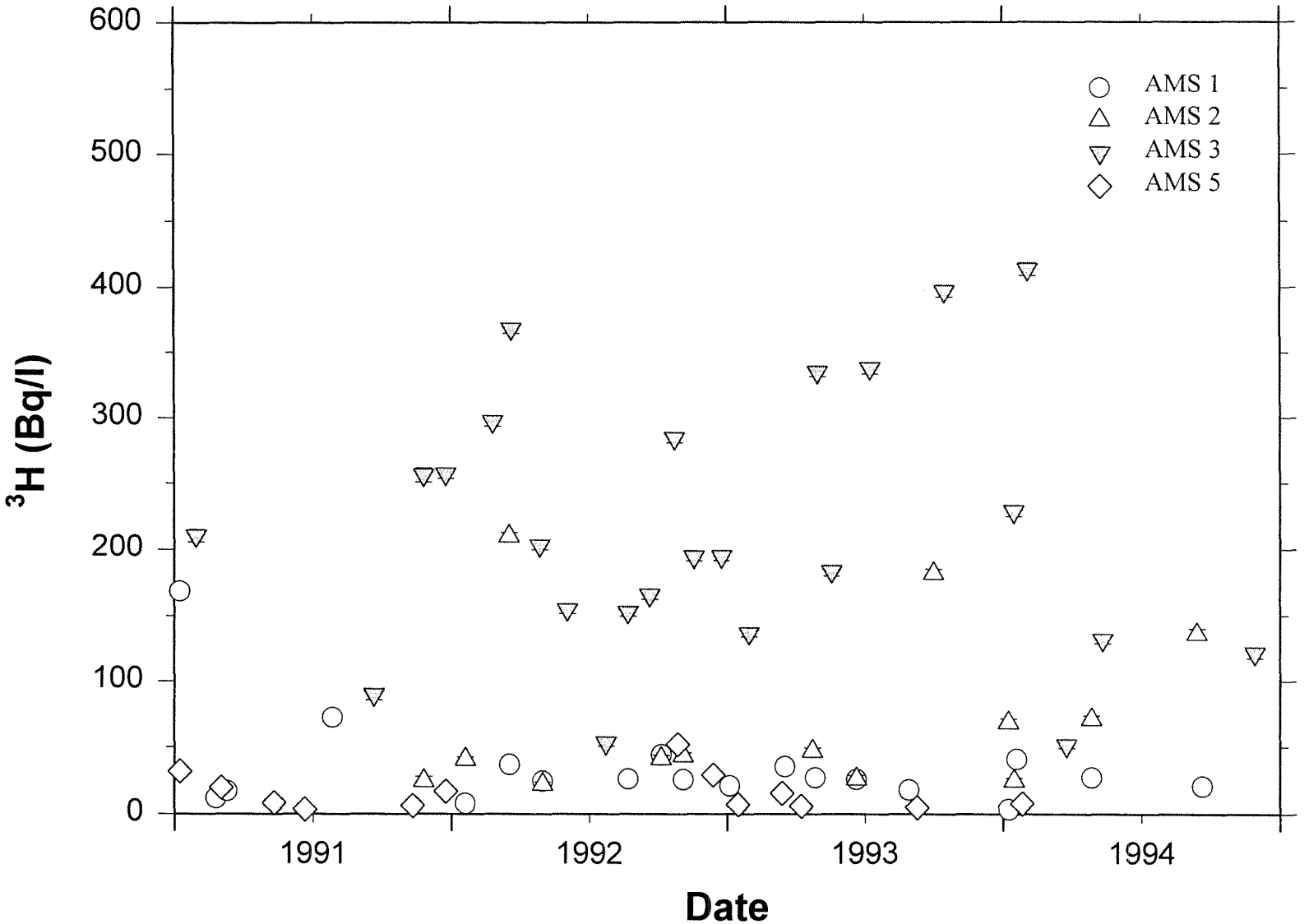

Figure 22: Tritium activities measured in atmospheric moisture (Bq/l) from 1991 to 1994 for stations 1, 2, 3 and 5, with the symbols for AMS 3, the station closest to the reactor darkened.

which the prevailing wind direction (NNW) would transport releases towards Digby N.S. The measurement of tritium activities above pre-operational levels at the Digby locations effectively eliminates these sites from use as background sampling locations and indicates that occasional atmospheric transport of emissions occurs from the Point Lepreau NGS across the Bay of Fundy to Nova Scotia.

4.2.2 Tritium in Air

Tritium activities in atmospheric moisture (Bq/l) are converted to activities per unit volume of air (Bq/m^3) using flow meter volumes for the molecular sieve or using relative humidity and temperature data from the meteorological station at Musquash. The conversion of these data to Bq/m^3 removes the biases that result from increases in relative humidity during the summer. (Smith *et al,* 1981). The results for tritium in air (Bq/m^3) are presented in Table 9 and Figure 23.

The results from the four AMS reflect the trend in increasing tritium activities near the NGS. The activities at AMS 3 show an increase from the average value of 0.38 Bq/m^3 (range of 0.1 to 0.76) in 1989, to a maximum average value of 0.7 Bq/m^3 (range of 0.2 to 1.02) in 1993, compared to the pre-operational activity of 0.07 Bq/m^3 for all stations. The four year average activities from AMS 1, and AMS 5 indicate enhanced ^3H levels at AMS 1 of 0.15 Bq/m^3, with results from AMS 5 of 0.072 Bq/m^3, being near pre-operational activities. The tritium data for AMS 2 have not been reported on an air volume basis because volume calibration problems were encountered with this station. Tritium activities at AMS 1 and 5 show occasional elevated ^3H levels when wind speeds

Table 9: Radionuclide levels in air from 1991 to 1994.

Station #	Sample #	Collection Date	Vol. (m^3)	^3H (Bq/ m^3)	^7Be (mBq/ m^3)
1	35665	8.1.91	4968	0.13 ± 0.01	2.8 ± 0.1
1	35670	22.2.91	1215	0.016 ± 0.004	1.22 ± 0.05
1	35676	11.3.91	2851	0.02 ± 0.01	1.44 ± 0.06
1	98712	26.7.91	371	1.58 ± 0.09	1.36 ± 0.06
1	35693	20.1.92	896	0.010 ± 0.002	2.3 ± 0.1
1	107901	16.3.92	871	0.130 ± 0.006	2.22 ± 0.07
1	107908	28.4.92	845	0.050 ±0.003	3.1 ± 0.2
1	107915	20.8.92	2998	0.084 ± 0.008	1.15 ± 0.08
1	107918	5.10.92	1284	0.084 ± 0.005	1.05 ± 0.08
1	107921	2.11.92	1349	-	0.54 ± 0.08
1	107927	4.1.93	2498	0.040 ± 0.001	0.78 ± 0.02
1	107931	18.3.93	1408	0.052 ± 0.004	0.88 ± 0.06
1	107934	25.4.93	1314	0.083 ± 0.003	0.63 ± 0.07
1	107940	20.6.93	1256	0.010 ± 0.001	0.13 ± 0.04
1	107943	29.8.93	1342	0.010 ± 0.001	2.59 ± 0.09
1	107950	7.1.94	1406	0.005 ± 0.002	< 1
1	107953	17.1.94	243	0.045 ± 0.002	1.4 ± 0.1
1	107955	24.4.94	1942	0.066 ± 0.005	< 1
1	107959	18.9.94	1782	0.005 ± 0.001	< 1
5	35675	7.1.91	550	0.020 ± 0.003	1.6 ± 0.1
5	35678	2.3.91	742	0.08 ± 0.02	1.47 ± 0.05
5	35680	11.5.91	352	0.20 ± 0.08	0.10 ± 0.03
5	98701	21.6.91	478	0.03 ± 0.02	0.11 ± 0.04
5	35685	8.11.91	506	0.02 ± 0.01	1.6 ± 0.04
5	35689	21.12.91	520	0.10 ± 0.01	1.4 ± 0.2
5	35695	26.1.92	405	< 0.1	2.4 ± 0.2
5	107903	8.3.92	581	< 0.01	2.3 ± 0.2
5	107910	2.5.92	393	0.504 ± 0.009	1.7 ± 0.3
5	107917	25.7.92	385	0.020 ± 0.001	3.6 ± 0.3
5	107920	25.10.92	1048	0.010 ± 0.001	0.9 ± 0.1
5	107923	13.12.92	1132	0.04 ± 0.01	1.5 ± 0.1
5	107929	16.1.93	1142	0.022 ± 0.008	0.86 ± 0.02
5	107933	13.3.93	1644	0.041 ± 0.001	2.02 ± 0.04
5	107930	9.4.93	1047	0.010 ± 0.001	0.24 ± 0.04

Table 9: Radionuclide levels in air from 1991 to 1994.(cont'd)

Station #	Sample #	Collection Date	Vol. (m^3)	^3H (Bq/m^3)	^7Be (mBq/m^3)
5	107936	4.6.93	1077	0.120 ± 0.004	0.91 ± 0.06
5	107942	24.7.93	890	0.010 ± 0.001	0.64 ± 0.07
5	107946	7.9.93	1103	0.02 ± 0.01	2.8 ± 0.3
5	107952	27.1.94	1209	0.041 ± 0.009	1.4 ± 0.1
5	107958	4.5.94	330	-	< 1
3	35671	31.1.91	5196	0.220 ± 0.005	0.10 ± 0.33
3	35681	19.9.91	4633	0.010 ± 0.001	1.33 ± 0.07
3	35684	21.1.91	1911	0.31 ± 0.01	1.77 ± 0.09
3	35688	22.12.91	536	0.23 ± 0.01	6.03 ± 0.27
3	35690	25.1.92	700	0.520 ± 0.002	6.44 ± 0.27
3	35691	23.2.92	424	0.51 ± 0.01	8.38 ± 0.34
3	35692	20.3.92	1962	0.091 ± 0.001	1.14 ± 0.08
3	107904	25.4.92	2259	0.070 ± 0.001	2.9 ± 0.1
3	107905	2.6.92	1863	0.63 ± 0.01	3.0 ± 0.1
3	107906	29.6.92	1082	-	2.0 ± 0.1
3	107907	23.7.92	1736	0.11 ± 0.01	2.5 ± 0.1
3	107911	20.8.92	1487	0.68 ± 0.01	1.4 ± 0.1
3	107912	18.9.92	1761	0.21 ± 0.01	2.22 ± 0.08
3	107913	20.10.92		0.98 ± 0.01	1.7 ± 0.1
3	107914	18.11.92	1185	0.71 ± 0.01	1.4 ± 0.1
3	107924	23.12.92	7827	0.24 ± 0.01	0.52 ± 0.02
3	107925	28.1.93	5545	0.16 ± 0.01	0.25 ± 0.03
3	107926	16.3.93	14517	0.78 ± 0.01	0.76 ± 0.07
3	107937	29.4.93	2919	1.02 ± 0.01	0.56 ±0.07
3	107938	19.5.93	4459	0.92 ± 0.02	1.4 ± 0.01
3	107939	7.7.93	11896	1.00 ± 0.01	1.28 ± 0.09
3	107945	16.10.93	18900	0.29 ± 0.01	1.3 ± 0.1
3	107947	15.1.94	5414	0.364 ± 0.006	1.92 ± 0.09
3	107948	20.2.94	6328	0.100 ± 0.001	1.02 ± 0.05
3	107949	24.3.94	5687	0.027 ± 0.001	2.04 ± 0.07
3	107957	11.5.94	547	0.265 ± 0.006	< 0.2
3	107961	28.11.94	3986	0.284 ± 0.009	< 0.1

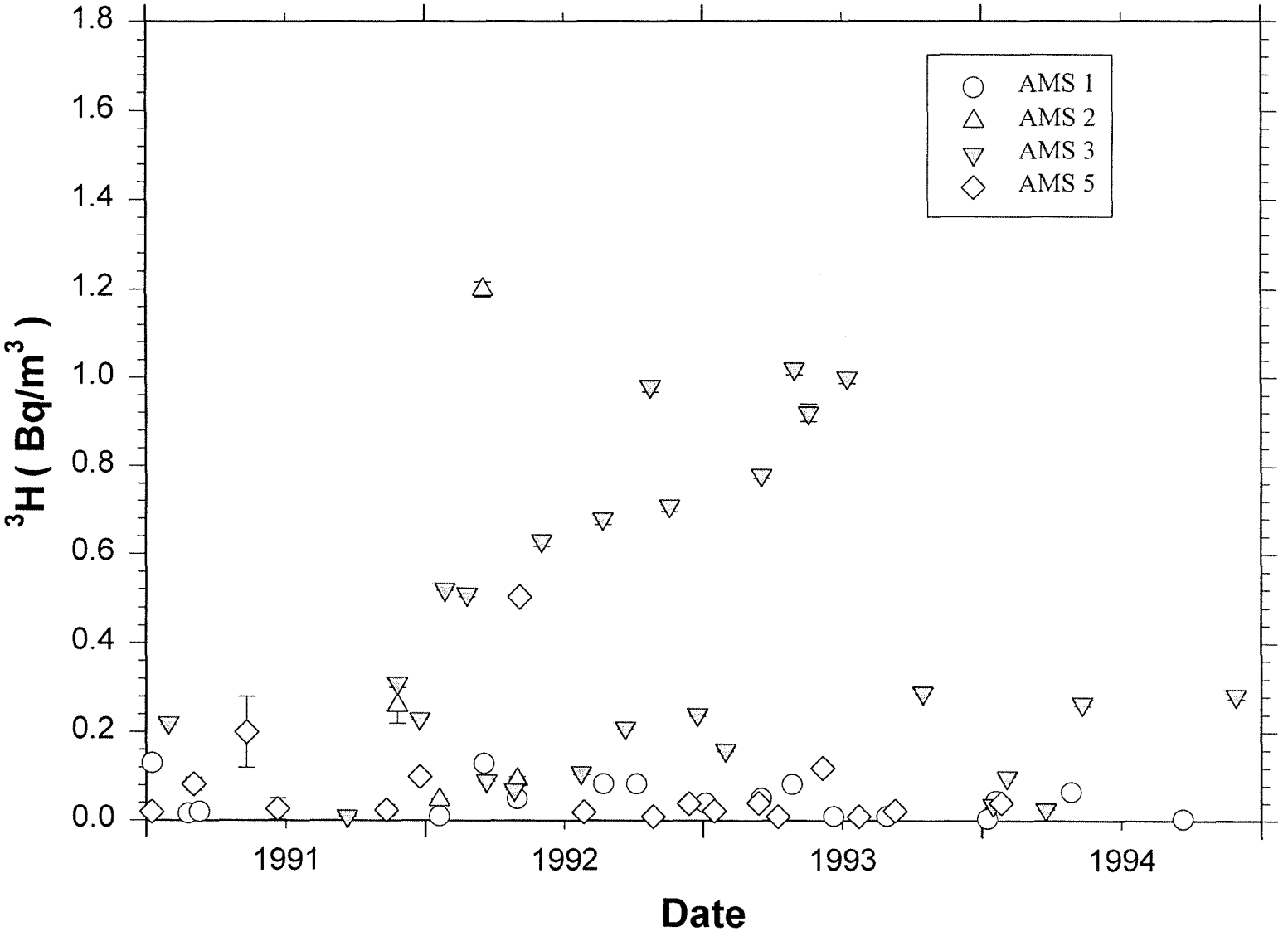

Figure 23: Tritium activities measured in air (Bq/m^3) from 1991 to 1994 for AMS 1, 2, 3 and 5.

are high and in the appropriate direction to carry releases over the AMS locations. Slightly higher tritium activities observed at AMS 1 reflect its relative proximity to the NGS compared to AMS 5 located in Digby N.S.

NBEPC operates an air monitoring station at the same location as AMS 3. The NBEPC results shown in Figure 24 are in reasonable agreement with those from AMS 3.

4.2.3 Air Filters and Cartridges

Air filters, which collect airborne particulate matter and air cartridges, which collect gaseous radionuclides, were analyzed for gamma-emitting radionuclides by direct counting on hyper pure germanium detectors (HPGe). No artificial isotopes, including ^{131}I, were detected on the charcoal cartridges and only ^{7}Be, a naturally occurring radionuclide, was detected on the filters.

Beryllium-7 activities increase in the spring when levels in the troposphere are augmented by inputs from the stratosphere (where it is produced during the annual mixing of the stratosphere and the troposphere (Olsen *et al*, 1985)). Differences between stations, normalized to individual precipitation rates, give an indication of the variance in local deposition rates.

The ^{7}Be results for 1991 to 1994 are given in Table 9 and illustrated in Figure 25. Beryllium-7 activities ranged from 0.1 to 8.4 mBq/m^3 and have an average of 1.4 mBq/m^3 for 1991 to 1994. The yearly average was 1.52 mBq/m^3 for 1991, 2.06 mBq/m^3 for 1992, 0.92 mBq/m^3 for 1993 and 1.14 mBq/m^3 for 1994. The average values for 1991 and 1992 are similar to those measured during previous years. The values for 1993 and 1994

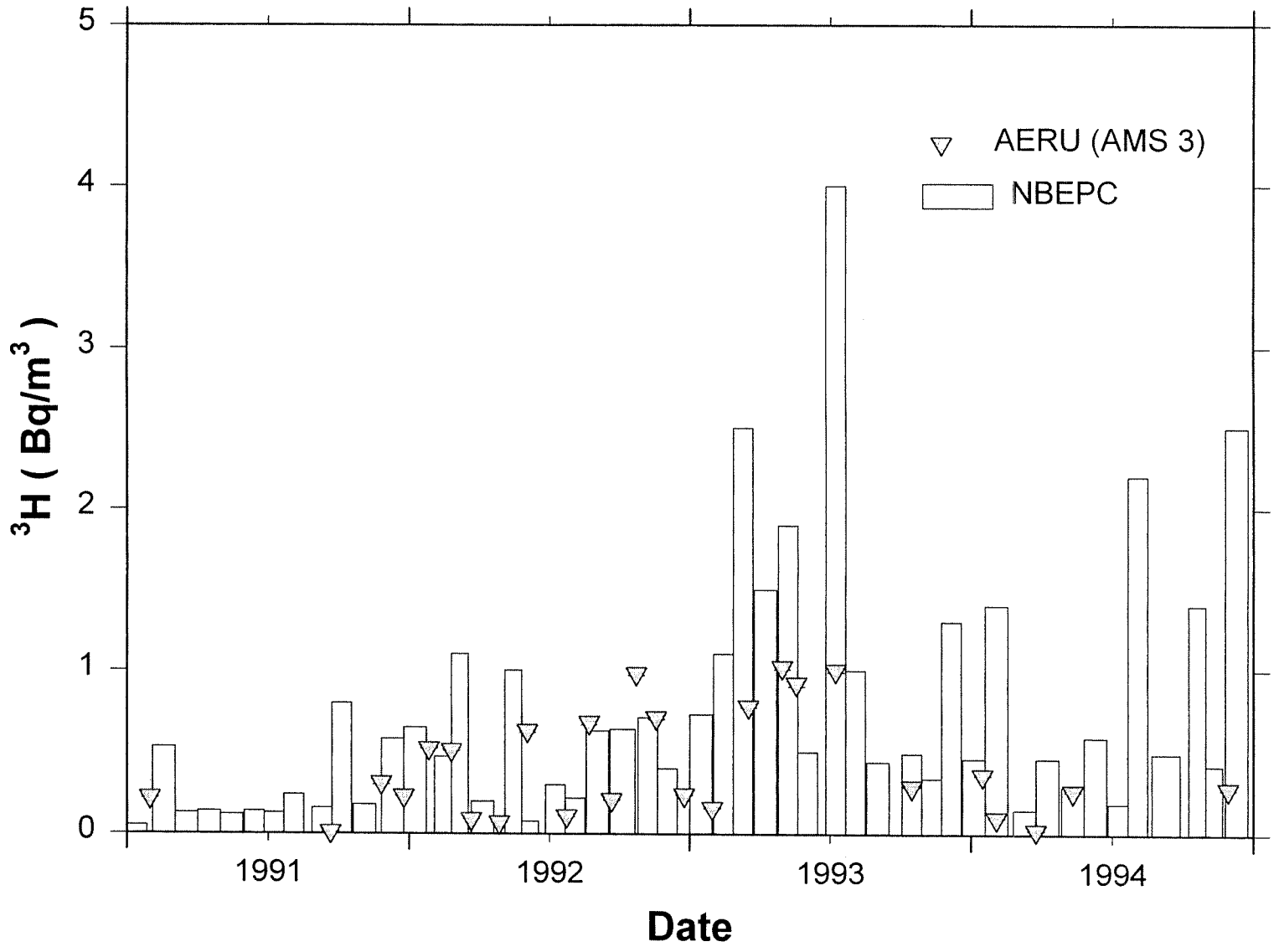

Figure 24: Tritium activities measured in air (Bq/m^3)from 1991 to 1994 at AMS 3. NBEPC measurements from the same location are included for comparison.

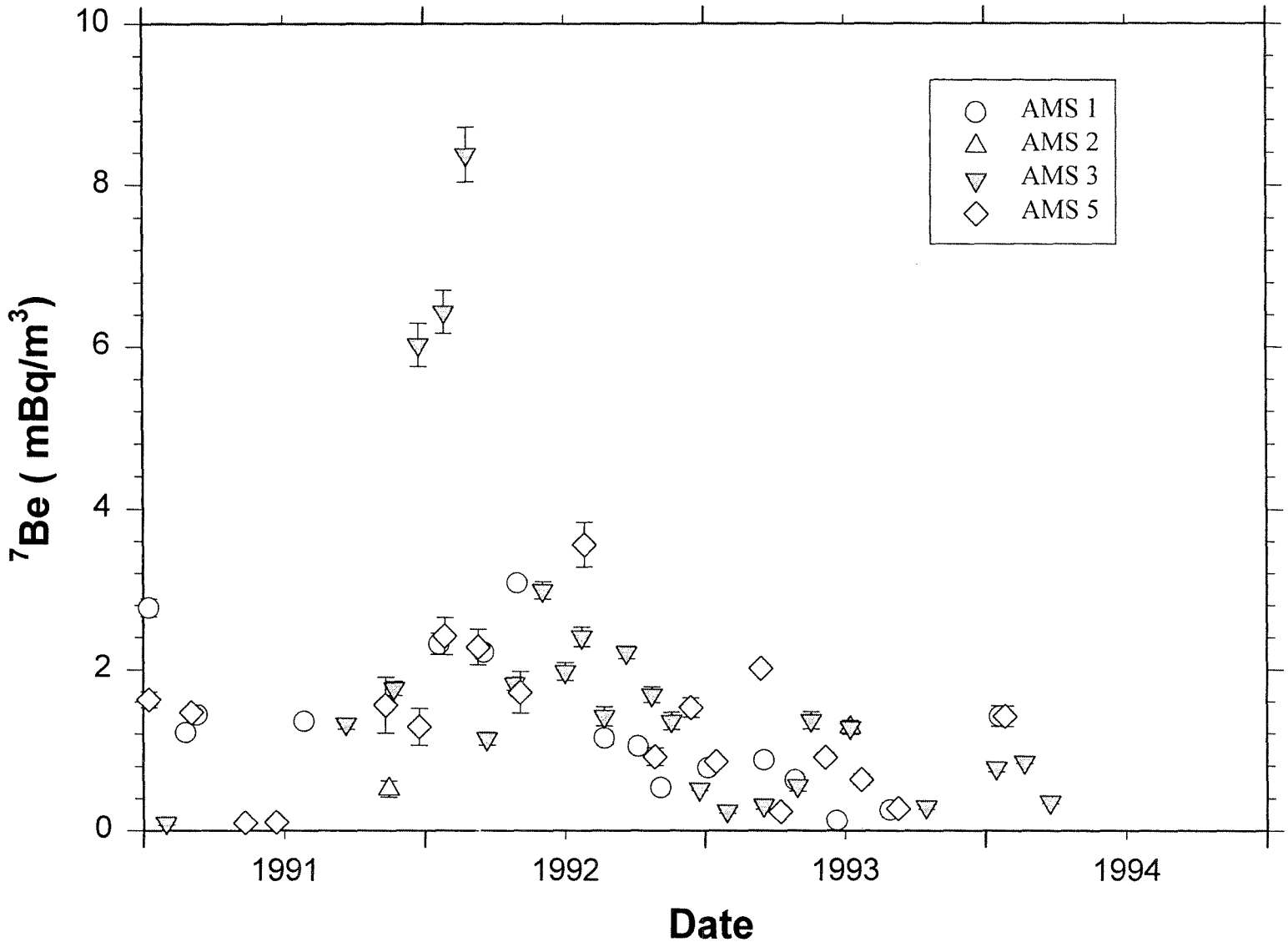

Figure 25: Beryllium-7 activities measured on air particles (mBq/m^3) from 1991 to 1994 for stations 1 to 5.

appear to be low compared with NBEPC results (Figure 24) and are the result of technical problems encountered with the air monitoring stations. Re-examination of the filter and cartridge data revealed ^{7}Be in the air cartridges. Beryllium-7 measured in the air cartridges is an artifact of bleed-through in the filters, which can occur at high flow rates, and result in the accumulation of particle-reactive radionuclides in the charcoal cartridge. Water in the collection line, either from condensation forming in the intake tubing or rainfall, wetting the filter, can also result in the loss of ^{7}Be from the filter to the cartridge. Delays between sample collection and sample counting resulted in the decrease in the ^{7}Be air cartridge signal due to radioactive decay. In 1993 and 1994, up to 50 % of the ^{7}Be activity was contained in the charcoal cartridge at AMS 3. The problem encountered at this station was a defective collection intake hose and has been corrected.

4.2.4 Time-Series Measurements 1981 to 1994.

Radioactivity levels have been measured in the three major components of the air monitoring program (particulates, gaseous ^{131}I and ^{3}H in water vapor) for the past 14 years. Results for samples collected from the pre-operational phase (1979 to 1982) have been combined with results from the operational phase (1983 to 1994) to construct a set of time series plots covering the duration of the monitoring program.

The ^{7}Be results exhibit no significant changes during the monitoring period and show little significant variance between stations as a function of time. The small decrease in ^{7}Be activities observed in recent years (Figure 26a and b) has been identified as a problem with flow rates at several of the stations as discussed above.

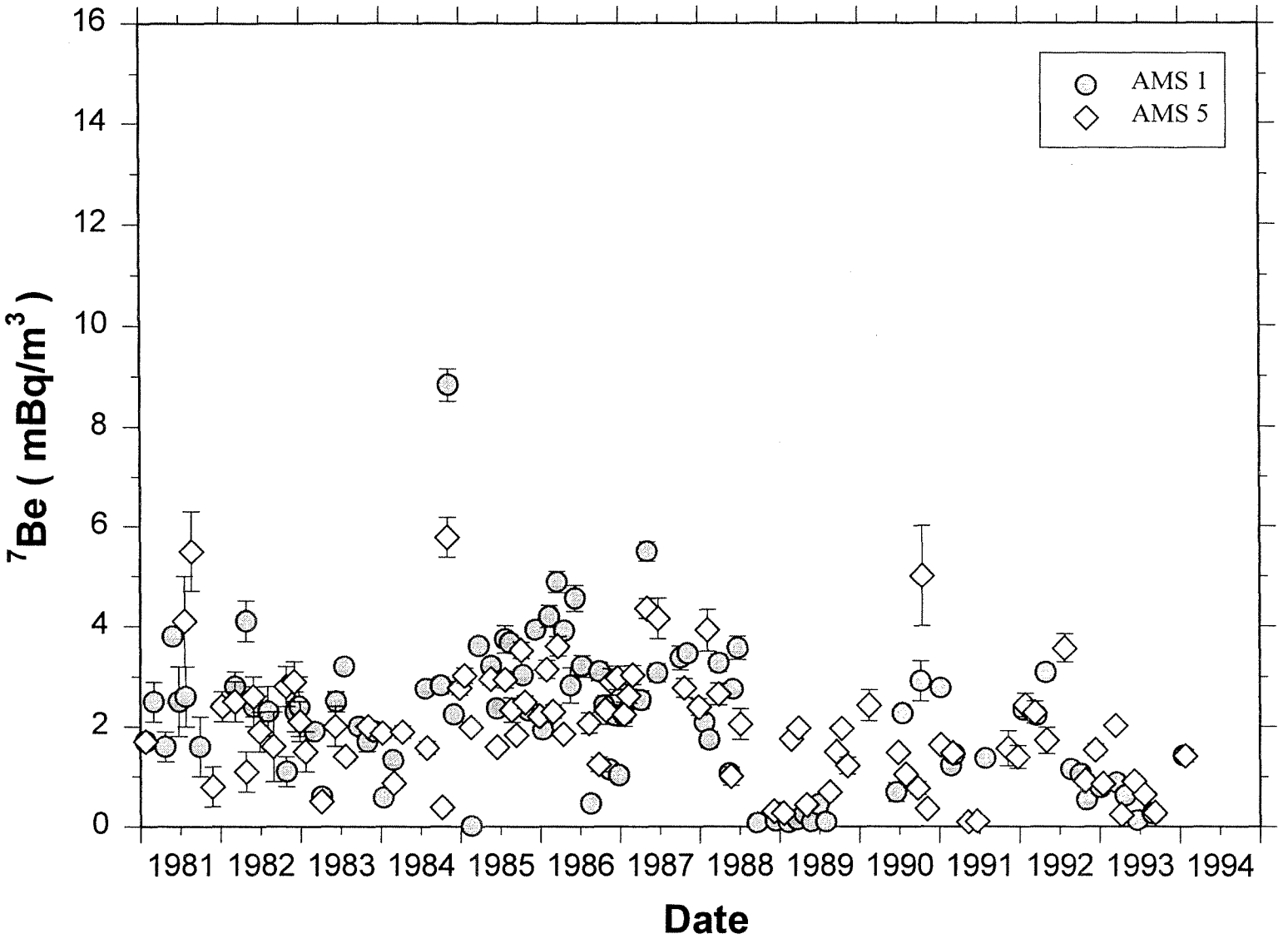

Figure 26A: Time series for ^{7}Be activities measured in air particulates (mBq/m^3) from 1981 to 1994 for stations 1 and 5.

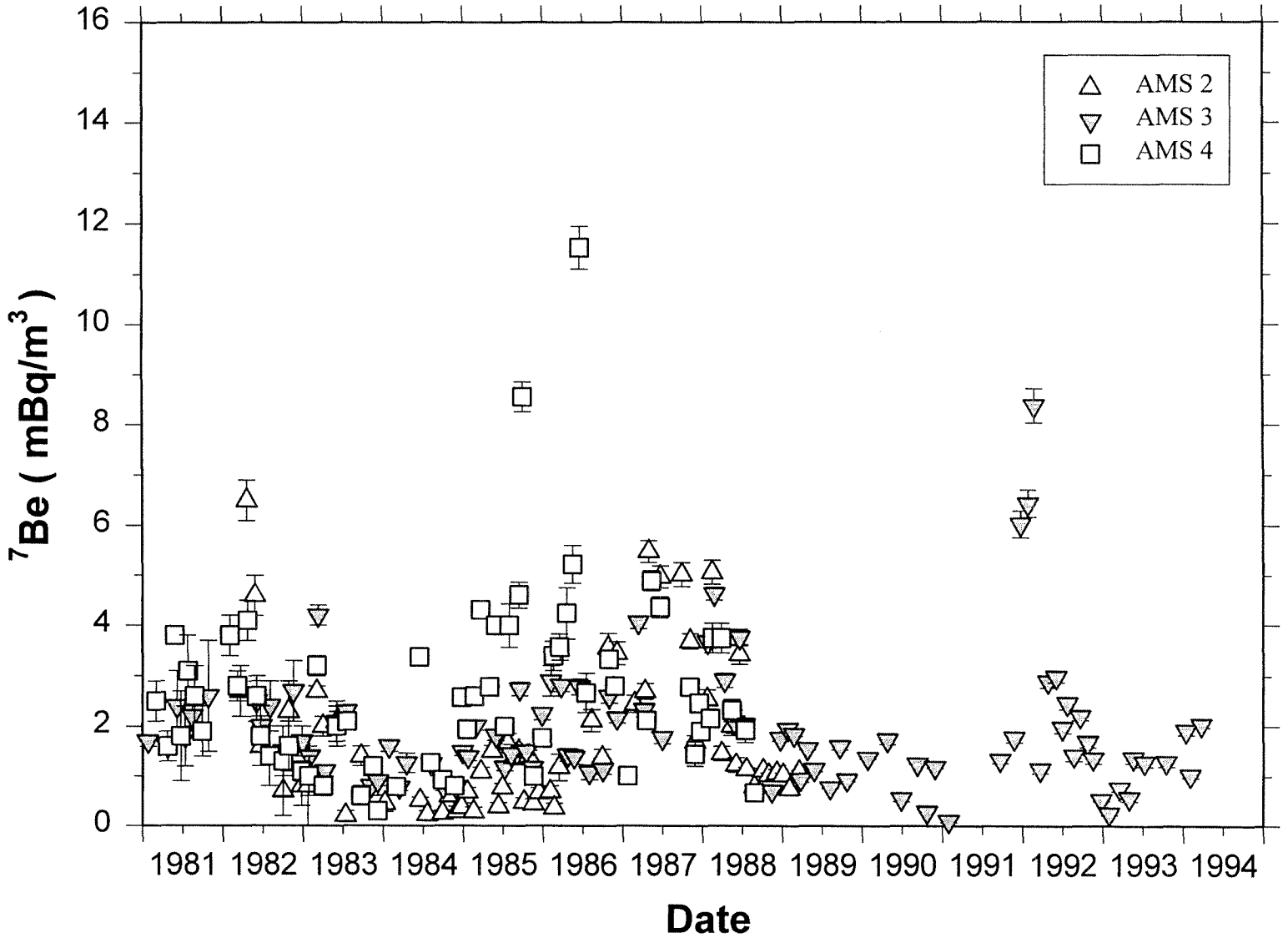

Figure 26B: Time series for ^{7}Be activities measured in air particulates (mBq/m^3) from 1981 to 1994 for stations 2,3 and 4.

The increase in the tritium emissions to the atmosphere from the NGS over this period is illustrated in Figure 27 (Sutherland *et al*, 1995). In 1983 32 TBq of ^{3}H (0.0016 % of the DEL of 20,000 TBq) was released which increased to 800 TBq in 1994. Increases in the amounts of tritium being released have been reflected by increases in the ^{3}H signal observed at the air monitoring stations as shown in Figures 28a and 28b (^{3}H in air) and Figures 29a and 29b (^{3}H in atmospheric moisture). At AMS 1, located approximately 20 km from the NGS there has been an increase from the pre-operational activity of 0.07 Bq/m^3 to 0.15 Bq/m^3 over the 14 year life of the monitoring program. At AMS 5, located in Digby N.S. the four year average for 1991 to 1994 was 0.072 Bq/m^3 showing no significant increase compared to the pre-operational activity of 0.07 Bq/m^3. However, as noted previously, occasionally elevated ^{3}H concentrations measured at AMS 5 may reflect some transport of NGS emissions across the Bay of Fundy towards Nova Scotia. The time series of ^{3}H concentrations in air for AMS 2, 3 and 4 is shown in Figure 28 b. Note that AMS 4, located at Welch's Cove was discontinued in 1986. These stations are located close to the reactor and tend to reflect the tritium release patterns from the NGS. At AMS 3 for example, ^{3}H concentrations have increased 10 fold from a pre-operational value of 0.07 Bq/m^3 to 0.7 Bq/m^3 in 1993. Tritium activities in atmospheric moisture (Bq/l) are shown in Figures 29a and 29b and show similar time series patterns to those for tritium concentrations in air.

In general, the time series records show minor increases in tritium levels in air at Musquash and Digby, N.S. since the start up of the reactor. Significantly larger increases

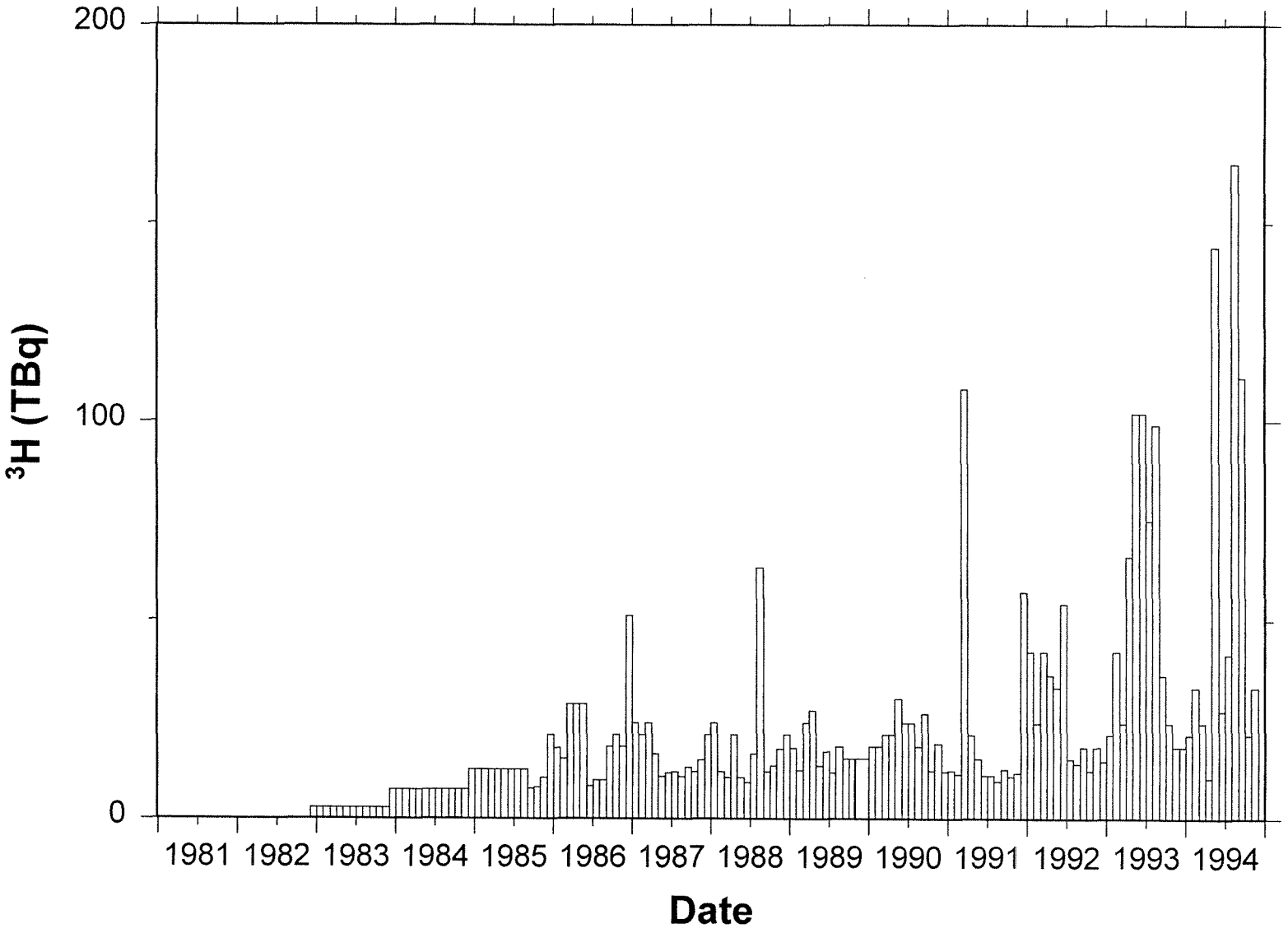

Figure 27: Monthly tritium emissions from 1981 to 1994. (NBEPC,1981 to 1995)

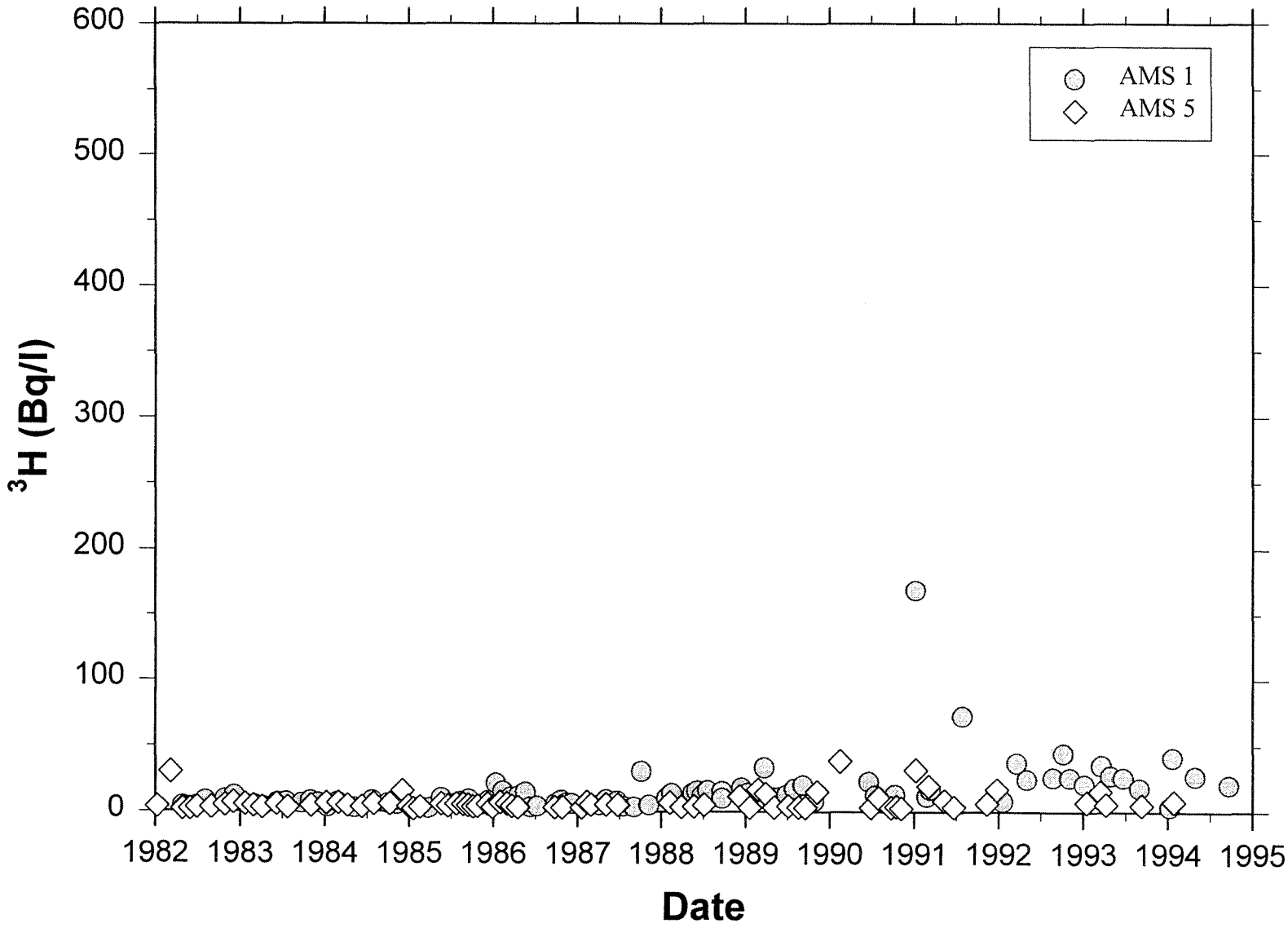

Figure 28A: Time series for tritium activities measured in water vapour (Bq/l) from 1982 to 1994 for stations 1 and 5.

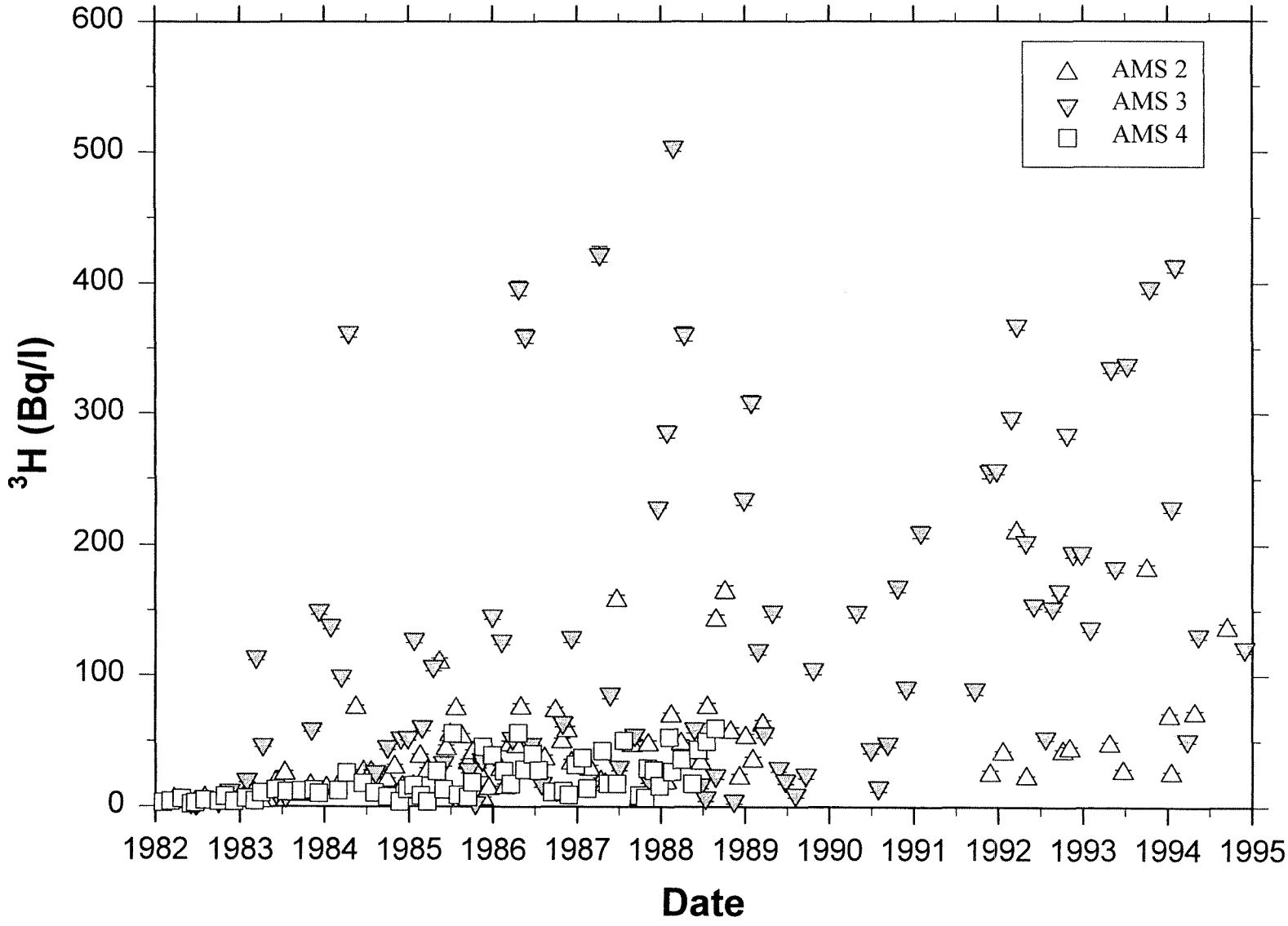

Figure 28B: Time series for tritium activities measured in water vapour (Bq/l) from 1982 to 1994 for stations 2,3 and 4.

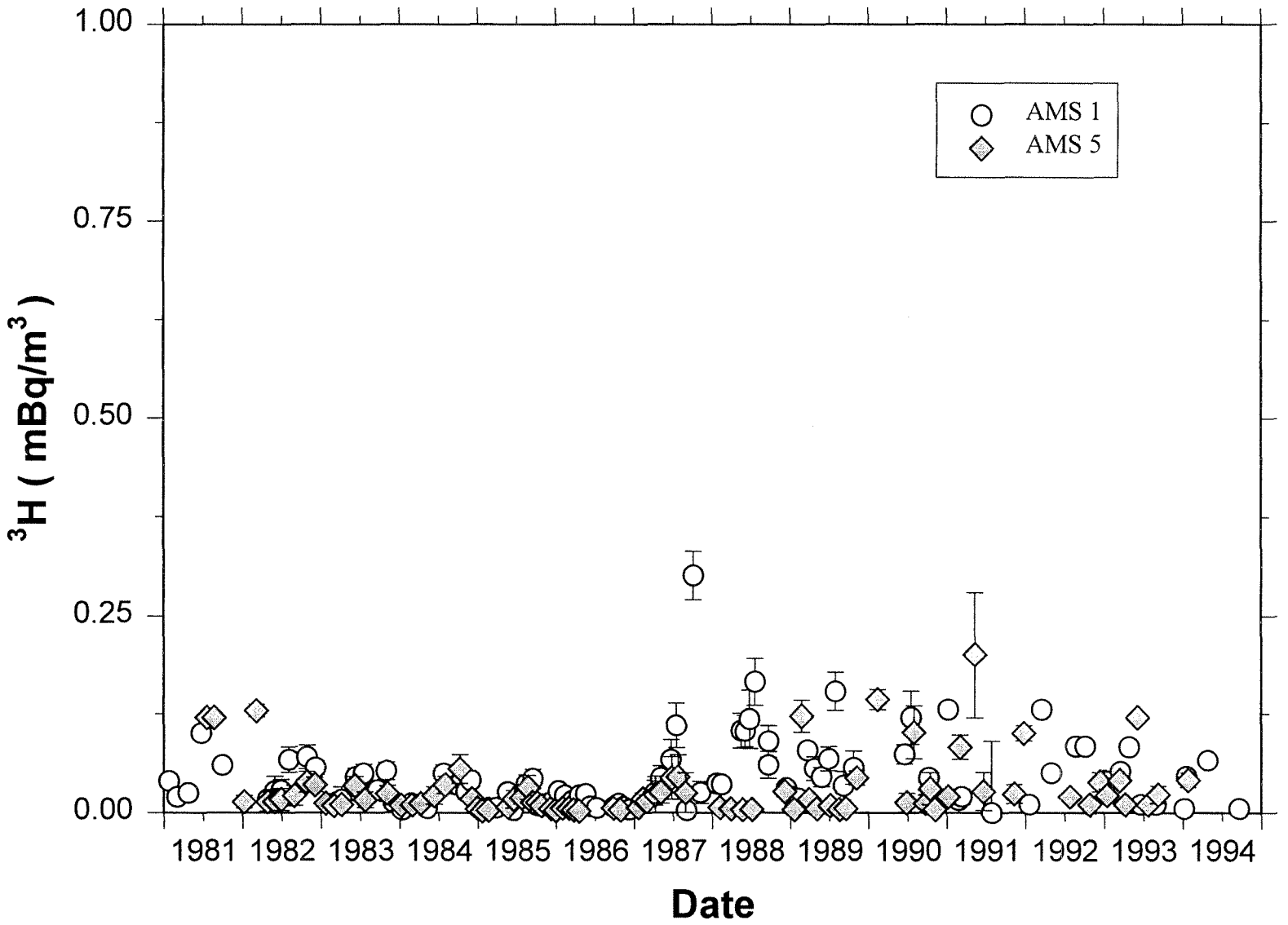

Figure 29A: Time series for ^{3}H activities measured in air (Bq/m^3) from 1981 to 1994 for stations 1 and 5.

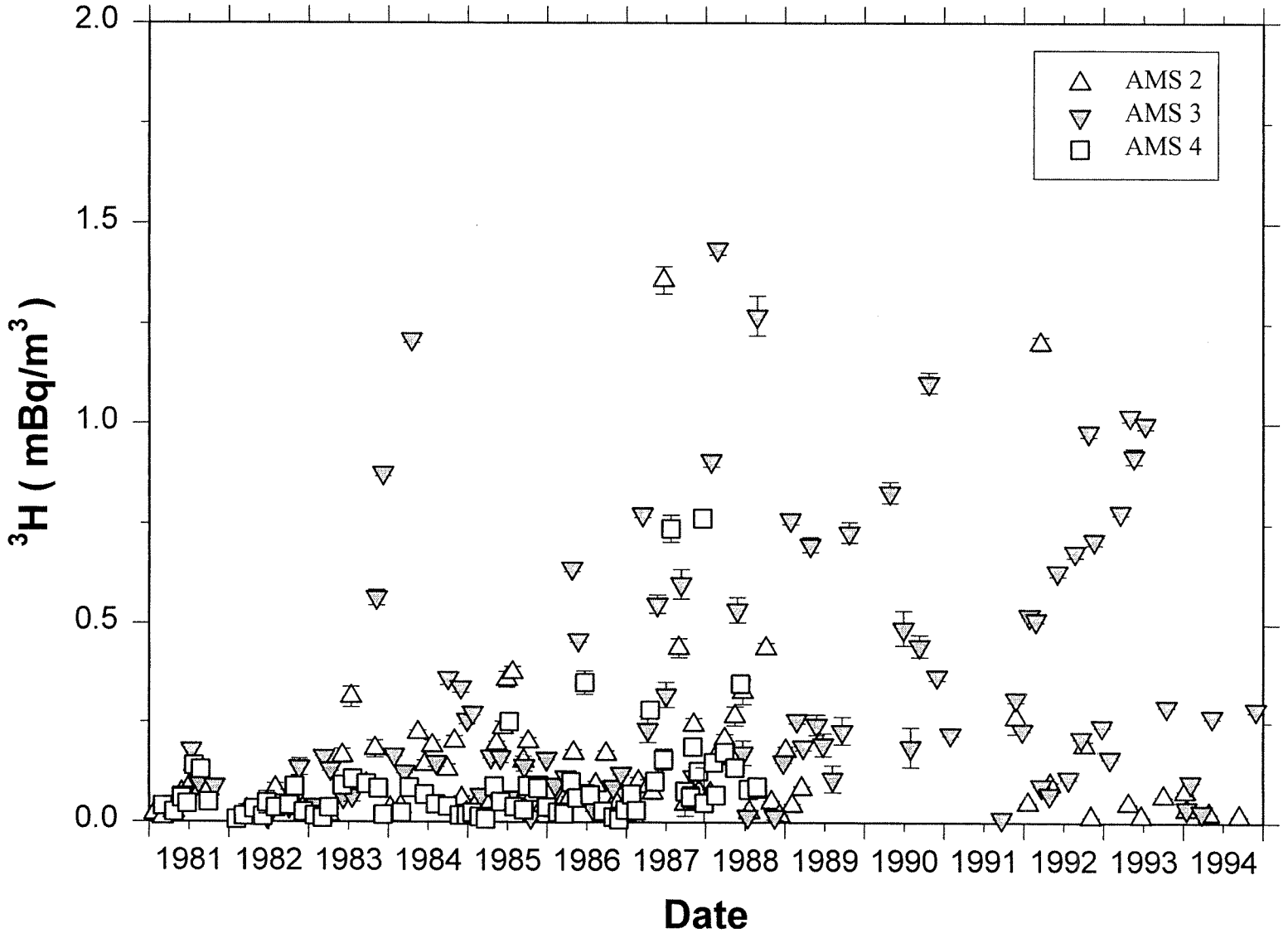

Figure 29B: Time series for ^{3}H activities measured in air (Bq/m^3) from 1981 to 1994 for stations 2,3 and 4.

were observed at Dipper Harbour and Point Lepreau that are clearly related to increasing gaseous emissions of tritium from the NGS.

5.0 MARINE BIOLOGY

The dispersion of radionuclides released into coastal waters depends upon the physical and chemical characteristics of the receiving water mass and on the chemical properties of the individual radionuclides. Oceanographic variables such as wave action, salinity, water temperature, nutrient levels, SPM concentrations and sediment type influence the types of organisms present in the receiving waters and effect the bioavailability of the chemical species released from the NGS.

Marine organisms can accumulate radionuclides and promote the transport of radioactivity to higher levels of the food chain. The accumulation rates and concentrations of radioactivity in marine organisms are characterized by biological half-lives and concentration factors respectively. Concentration factors for relevant radionuclides with respect to seawater for marine groups of interest (IAEA, 1985) are listed in Appendix 4.

5.1 Sampling, Sample processing and Analysis

Biological sample sites are indicated in Figure 30. Marine sites are located near the NGS cooling water intake (Indian Cove, I-16) and the outfall (Duck Cove, I-17) in order to assess releases from the Point Lepreau NGS. A site at Digby, N.S. (S-7) has been used to assess the transport of radionuclides across the Bay of Fundy. Samples of

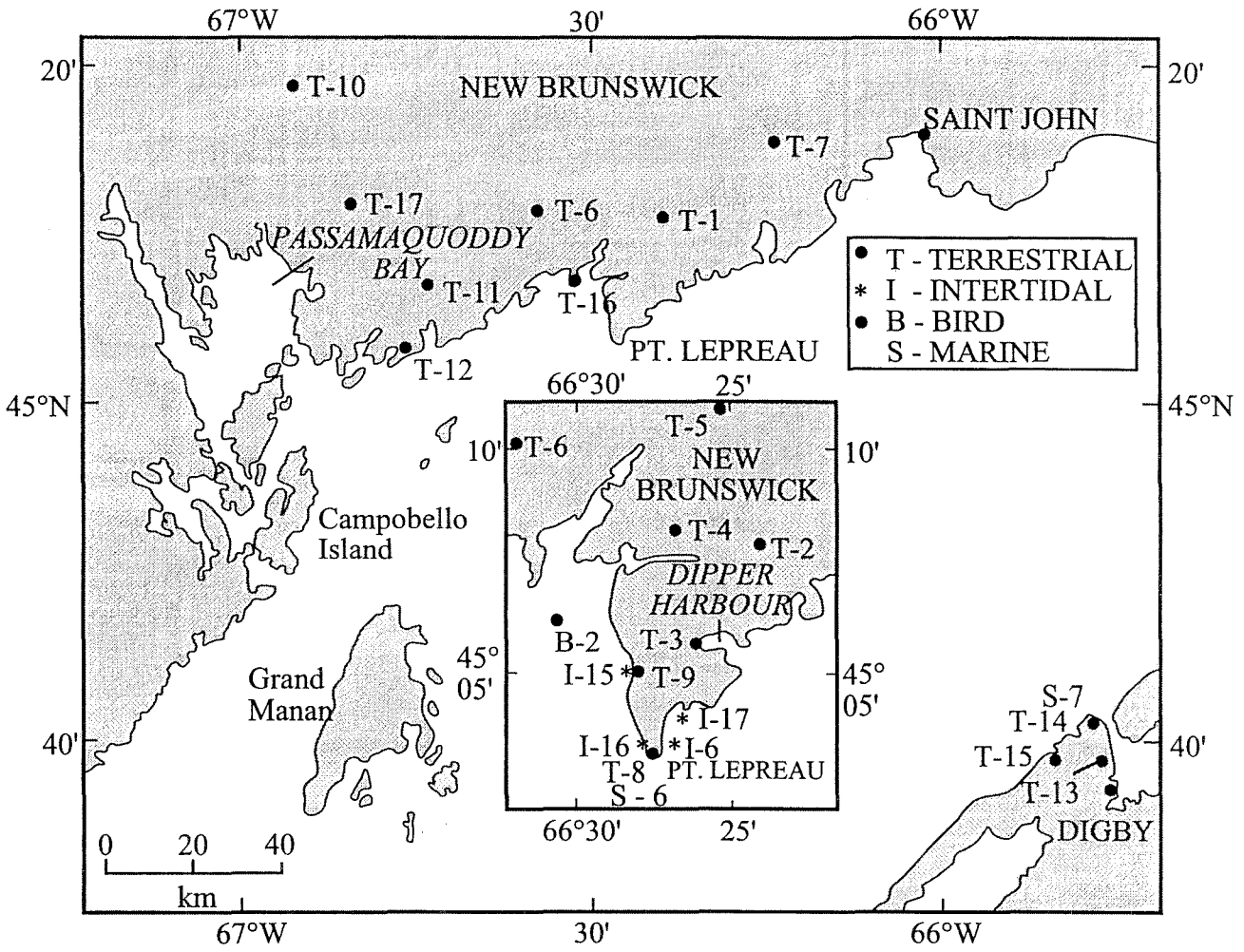

Figure 30: Sampling locations for biological samples

species considered representative of the area and known to accumulate radioactivity were collected mainly from the intertidal zone.

Samples were freeze dried, homogenized and analyzed directly in one of several different calibrated counting geometries for gamma-emitting radionuclides using an HPGe detector with Aptec OSQ Super analysis software. Detection limits for these geometries are given in Appendix 5. The tritium content of biological samples was determined using an azeotropic distillation method (Moghissi *et al.* 1973).

5.2 Marine Plants

AERU has maintained a yearly seaweed monitoring program as part of PLEMP. Samples of rockweed (*Fucus vesiculosis*), green algae (*Ascophyllum nodosom*), dulse (*Rhodymenia sp.*), a red algae and kelp (*Laminaria sp.*), a brown algae were collected from the intertidal zone at sites I-16 and I-17. Marine algae, particularly fucus and ascophyllum, have demonstrated their utility as bioindicators for radionuclides in the marine environment (Aarkrog 1985, Carleson and Erlandsson, 1991). The levels of ^{137}Cs, given in Table 10, have been consistently at or below AERU detection limits and within the ranges measured over the life of the pre- and post-operational program.

5.3 Marine Animals

Several species of marine animals were collected from the intertidal zone as part of the yearly sampling program. Species of marine molluscs analyzed included the blue mussel (*Mytilis edulis*) and periwinkle (*Littorina littorea*). Cesium-137 activities were below detection limits for all species (Table 10).

Table 10: Radionuclide results for marine plants and animals from 1991 to 1994.

Species	Collection Date	Sample Number	Site No.	^{137}Cs (Bq/Kg)	^{3}H Bq/l
Seaweed					
Fucus vesiculosis	19/06/91	98724	I-16	< 2	-
	19/06/91	98775	I-17	< 2	-
	23/09/92	107643	I-16	< 2	-
	23/09/92	107654	I-17	-	7 ± 2
	14/07/93	107736	I-16	< 2	1 ± 12
	14/07/93	107752	I-17	-	103 ± 4
	29/11/94	129509	I-16	< 2	2 ± 2
	29/11/94	129519	I-17	1 ± 1	-
Ascophyllum nodosom	19/06/91	98723	I-16	< 2	-
	19/06/91	98741	I-17	< 1	-
	23/09/92	107642	I-16	< 2	-
	23/09/92	107653	I-17	< 1	286 ± 5
	14/07/93	107737	I-16	< 2	8 ± 2
	14/07/93	107751	I-17	< 2	916 ± 9
	29/11/94	129510	I-16	< 2	< 2
	29/11/94	129517	I-17	< 2	-
Laminaria sp.	19/06/91	98722	I-16	< 3	-
	23/09/92	107647	I-16	< 9	-
	23/09/92	107656	I-17	-	6 ± 2
	14/07/93	107739	I-16	< 9	14 ± 2
	14/07/93	107753	I-17	< 6	-
	29/11/94	129505	I-16	-	-
	29/11/94	129505	I-16	-	-

Table 10 (cont'd): Radionuclide results for marine plants and animals from 1991 to 1994.

Species	Collection Date	Sample Number	Site No.	^{137}Cs (Bq/Kg)	^{3}H Bq/l
Rhodymenia palmata	19/06/91	98721	I-16	< 2	-
	14/07/93	107738	I-16	< 5	11 ± 2
Chondrus chrispis	23/09/92	107644	I-16	< 4	-
	23/09/92	107655	I-17	-	4 ± 2
	14/07/93	107738	I-16	-	-
	29/11/94	129508	I-16	< 5	-
Marine	**Animals**				
Littorina littorea	17/06/91	98719	I-16	< 1	-
	17/06/91	98771	I-17	< 1	-
	23/09/92	107646	I-16	< 1	-
	23/09/92	107659	I-17	< 1	-
	14/07/93	107741	I-16	< 1	8 ± 2
	14/07/93	107750	I-17	< 1	190 ± 4
	29/11/94	129506	I-16	< 2	2 ± 2
	29/11/94	129516	I-17	< 1	12 ± 2
Mytilis edulis	17/06/91	98720	I-16	< 1	-
	23/09/92	107645	I-16	< 1	-
	14/07/93	107740	I-16	< 1	11 ± 2
	29/11/94	129507	I-16	< 1	-

5.4 Tritium in Marine Organisms

In general, tritium freely exchanges with hydrogen in seawater and the bio-concentration of tritium is considered to be negligible in marine organisms. It should be noted, however, that tritium bound to organic compounds can be readily absorbed by marine organisms and only slowly exchanged with tritium in the water column. This process can produce tritium activities in organisms up to 20 times higher than those found in the surrounding water column (IAEA, 1981).

Samples of algae (*Ascophyllum nodosom*, *Fucus vesiculosis*, *Laminaria sp.*) and marine animals (*Littorina littorea*) and (*Mytilis edulis)* were analyzed for ^{3}H. Tritium activities measured continue to reflect the different concentrations of tritium present in the water at the intake (I16) and outflow (I17) locations. Tritium activities ranged from 2 to 14 Bq/l at Indian Cove, the cooling water intake location, while activities at Duck Cove, the outfall location, ranged from 6 to 916 Bq/l. Latter values represent transient increases in seawater tritium activities resulting from effluent releases from the NGS and the thermal plume impinging on the shoreline of Duck Cove. Studies of circulation patterns in Duck Cove indicate that under certain tidal conditions (i.e. half tide rising and high water) the thermal plume is swept away from the area, while under other tidal conditions (i.e. low tide and half tide falling) the plume becomes trapped in back eddies and remains in the vicinity of the outfall for longer periods of time (Nelson *et al* 1984). Although tritium levels in organisms in Duck Cove are elevated, they are below levels considered to be a radiobiological hazard.

6.0 FRESHWATER AND TERRESTRIAL PHASES

Radionuclides are injected into the terrestrial and freshwater aquatic environment from the Point Lepreau NGS via stack gas discharges to the atmosphere and from effluent releases to the cooling water outflow. In both cases, diffusion processes act to reduce radionuclide concentration as a function of distance from the source. Concurrently, depositional and adsorption phenomena act to concentrate radionuclides in the sediments. The high particle reactivity of some radionuclides leads to their rapid removal from the air-water continuum and plays an important role in their availability for biological uptake.

The location of the terrestrial sampling sites is given in Figure 30 and includes locations near Digby, N. S. used to assess the transport of radionuclides across the Bay of Fundy. Samples are processed and analyzed as described in Section 5.1.

6.1 Freshwater Systems

The distribution of radionuclides in the aquatic environment is governed by factors such as light intensity, temperature, redox conditions, particle uptake and sedimentation processes and frequently differs from distributions in the marine environment as a result of the differences in ionic strengths and the chemical composition of the two media.

Sampling has been undertaken at the seven sampling sites indicated in Figure 30. Site T3b is located 100 m upstream from site T3. One of the sites is on a small lake (T4) and the others are stream locations.

6.1.1 Water Column Results

Lake and streamwater samples have been collected during annual AERU field surveys and analyzed for both ^{137}Cs (particulate and dissolved) and ^{3}H. Large volume water samples were processed for ^{137}Cs from a site close to the reactor (T3b) and one at the Hansen Stream reservoir (T4) located approximately 10 km from the NGS (see Figure 30 for site locations). Cesium-137 activities were generally below the detection limit for both particulate and soluble fractions and the results are presented in Table 11. Cesium-137 levels measured in seawater at I16 and I17 (1.6 to 2.9 mBq/l) were much higher than those at freshwater locations (<0.5 mBq/l). Cesium tends to follow particle pathways through aquatic systems with bottom sediments acting as the main sink, but the overall distribution of ^{137}Cs depends on the size and physico-chemical characteristics of the aquatic system (Smith *et al*, 1982).

Tritium activities ranged from 4 to 108 Bq/l (Table 12) and were generally higher closer to the reactor. Figure 31 shows the ^{3}H distribution in freshwater samples collected during annual field trips. The dominant wind directions during sample collection tend to be from the northwest and southwest, distributing the atmospheric effluent from the reactor between T3 and T3b at Dipper Harbor and T8 and T9 at the tip of Point Lepreau where generally higher levels of ^{3}H were found. Tritium activities measured in fresh water samples collected from T8 and T9 are 1 to 8 times lower than activities measured in air samples collected at nearby AMS 3 during the same time period. Tritium labeled

Table 11: ^{137}Cs activities from Point Lepreau field trips from 1991 to 1994.

Collection Date	Sample Number	Sampling Location	^{137}Cs (mBq/l)	
			Soluble	Particulate
23/9/92	107617	T4	< 0.2	< 4
	107649	T3b	< 0.3	< 2
	107657	I17	2.9 ± 0.1	< 2
14/7/93	107716	T4	< 0.3	< 4
	107747	I17	1.6 ± 0.2	< 1
28/11/94	129525	T4	0.4 ± 0.4	0.5 ± 0.4
	129513	T3b	< 0.5	< 1
	129515	I17	2.4 ±0.3	0.4 ± 0.3

Table 12: Tritium activities in fresh water samples collected from 1991 to 1994.

Collection Date	Sample No.	Site No.	^{3}H (Bq/l)
23/09/92	107633	T1	6 ± 2
23/09/92	107611	T2	4 ± 2
23/09/92	107616	T4	10 ± 2
23/09/92	107638	T8	48 ± 2
23/09/92	107622	T9	34 ± 2
23/09/92	107648	T3b	161 ± 3
14/07/93	107754	T1	59 ± 3
14/07/93	107711	T2	4 ± 2
14/07/93	107720	T3	10 ± 2
14/07/93	107746	T3b	79 ± 3
14/07/93	107725	T4	4 ± 2
14/07/93	107731	T8	41 ± 3
14/07/93	107721	T9	28 ± 2
29/11/94	129511	T8	18 ± 2
29/11/94	129512	T3b	111 ± 4
29/11/94	129521	T1	7 ± 2
29/11/94	129524	T4	108 ± 4
29/11/94	129527	T9	37 ± 3
29/11/94	129529	T3	10 ± 2
29/11/94	129530	T2	6 ± 2

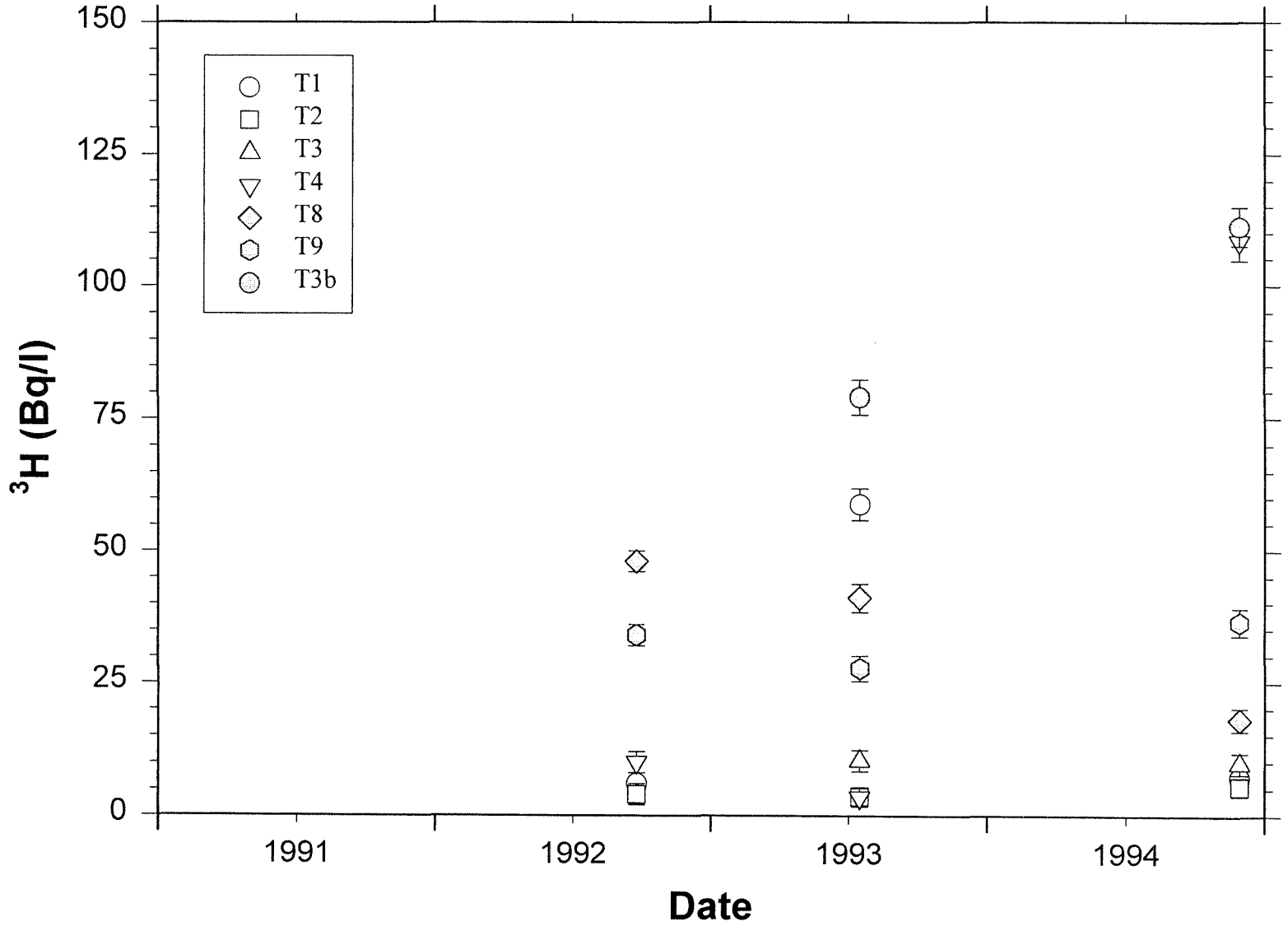

Figure 31: Tritium activities in fresh water collected from terrestrial sampling sites at Point Lepreau.

water vapor from the reactor is diluted by water from other sources as the reactor signal is dispersed through the aquatic environment. Tritium activities at T8, located 1 km from the NGS, averaged 36 ± 16 Bq/l compared to tritium activities at T1, located approximately 20 km from the NGS, of 24 ± 30 Bq/l. In general, tritium levels in fresh water at sites near the reactor are 2 to 3 times higher than those located further away.

6.1.2 Freshwater Plants

Freshwater plants collected and analyzed from 1991 to 1993 (Table 13) included horsetail (*Equisetum sp.*), a common plant found in wet areas in the Point Lepreau region and wild iris (*Iris veriscolor*). Cesium-137 activities in freshwater plants ranged from < 2 to 76 Bq/kg (average for iris of 10 Bq/kg and for horsetail of 8 Bq/kg). Cesium-137 levels in all freshwater plants were within ranges measured during the pre-operational phase of the program.

6.2 Terrestrial Systems

Biological uptake of fallout radioactivity is generally more efficient in the terrestrial environment compared to freshwater and marine systems due to the absence of a diluting medium such as water. The result is the accumulation of higher concentrations of fallout radionuclides in land-based plants and animals as shown in previous PLEMP studies (Ellis *et al,* 1984, 1992, Nelson *et al*, 1985, 1986, 1988).

6.2.1 Terrestrial Plants

Plant species collected from 1991 to 1994 included blueberry leaves

Table 13: Radionuclide results for Aquatic plants from 1991 to 1994.

Species	Collection Date	Sample No.	Site No.	^{137}Cs (Bq/kg)
Iris *(Iris verisicolor)*	17/06/91	98718	T8	4 ± 1
	14/07/93	107742	T8	15 ± 4
Horsetail (*Equisetum sp.*)	17/06/91	98703	T15	< 3
	17/06/91	98714	T8	< 2
	17/06/91	98736	T10	< 3
	17/06/91	98739	T1	< 4
	17/06/91	98735	T3	5 ± 1
	17/06/91	98728	T3a	8 ± 3
	17/06/91	98770	T9	< 4
	17/06/91	98748	T4	< 2
	17/06/91	98751	T6	2 ± 1
	23/09/92	107637	T1	7 ± 2
	23/09/92	107614	T2	2 ± 1
	23/09/92	107630	T3	2 ± 2
	23/09/92	107640	T8	76 ± 5
	23/09/92	107625	T9	3 ± 1
	23/09/92	107651	T3b	< 3
	21/09/92	107603	T13	4 ± 1
	21/09/92	107610	T15	4 ± 1
	14/07/93	107755	T1	2 ± 1
	14/07/93	107715	T2	7 ± 2
	14/07/93	107719	T3	4 ± 3
	14/07/93	107730	T4	4 ± 2
	14/07/93	107732	T8	28 ± 3
	14/07/93	107722	T9	3 ± 2
	12/07/93	107708	T13	< 10
	12/07/93	107705	T14	< 5
	12/07/93	107701	T15	6 ± 3

(*Vaccinium sp.*), alder (*Alnus rugosa*), conifer needles and two types of lichen; a ground lichen (*Cladonia sp.),* and an arboreal lichen (*Usnea sp.*), commonly known as Spanish moss or "old man's beard ".

6.2.2 Blueberry and Alder

Samples of blueberry and alder leaves were analyzed for gamma-emitting radionuclides and the results are presented in Table 14. The average ^{137}Cs activity of 12.3 Bq/kg for blueberry leaves and 9.1 Bq/kg for alder leaves (range of < 1 to 80 Bq/kg for both species) was within the range of ^{137}Cs levels measured during the pre-operational monitoring program and are associated exclusively with fallout.

6.2.3 Lichen

Lichen communities have long been recognized as concentrators of natural and artificial radionuclides. The accumulation of radionuclides is enhanced by the plant's persistent aerial parts, slow growth rate, long life span, high surface to mass ratio and its foliar absorption of nutrients. Modeling of radionuclide uptake by lichen at Point Lepreau (Ellis and Smith, 1987) has shown that ground lichen retains 10 to 30% of fallout deposition.

Arboreal lichen (*Usnea sp.*) and ground lichen (*Cladonia sp.*) samples were collected at sampling sites T1, T3 and T8 from 1991 to 1994 and results are presented in Table 15. Cesium-137 levels measured in *Cladonia sp.* ranged from 3 to 258 Bq/kg (average = 29, σ = 45 Bq/kg), which can be compared to the range of 18 to 64 Bq/kg measured in 1989/90, (mean = 43, σ = 15 Bq/kg). A slight reduction in ^{137}Cs activities in

Table 14: Radionuclide Results for Terrestrial Plants for 1991 to 1994.

Species	Collection Date	Sample No.	Site No.	^{137}Cs Bq/kg	^{7}Be Bq/kg
Blueberry (*Vaccinium sp.*)	17/06/91	98702	T-15	3 ± 1	< 510
	17/06/91	98717	T-8	< 5	< 73
	17/06/91	98738	T-1	< 3	< 1200
	17/06/91	98752	T-6	5 ± 1	< 686
	23/09/92	107635	T-1	< 2	< 802
	23/09/92	107613	T-2	< 2	< 102
	23/09/92	107619	T-4	80 ± 2	253 ± 40
	21/09/92	107605	T-13	8 ± 1	< 986
	14/07/93	107756	T-1	5 ± 2	-
	14/07/93	107714	T-2	4 ± 1	-
	14/07/93	107717	T-3	15 ± 2	-
	14/07/93	107748	T-3b	15 ± 1	-
	14/07/93	107727	T-4	22 ± 3	-
	14/07/93	107735	T-8	< 5	-
	12/07/93	107704	T-15	7 ± 2	-
Alder (*Alnus rugosa*)	17/06/91	98704	T-15	< 3	111 ± 20
	17/06/91	98706	T-14	< 1	< 423
	17/06/91	98710	T-13	< 2	< 28
	17/06/91	98716	T-8	25 ± 2	< 1050
	17/06/91	98772	T-10	3 ± 1	< 809
	17/06/91	98727	T-1	< 2	76 ± 14
	17/06/91	98734	T-3	< 1	104 ± 10
	17/06/91	98732	T-3a	6 ±1	79 ± 15

Table 14 (cont'd): Radionuclide Results for Terrestrial Plants for 1991 to 1994.

Species	Collection Date	Sample No.	Site No.	^{137}Cs Bq/kg	^{7}Be Bq/kg
Alder *(Alnus rugosa)*	17/06/91	98744	T-9	15 ±1	< 788
	17/06/91	98747	T-4	< 2	99 ± 14
	17/06/91	98750	T-6	< 2	< 580
	23/09/92	107636	T-1	< 2	134 ± 31
	23/09/92	107612	T-2	< 2	437 ± 55
	23/09/92	107631	T-3	< 1	< 549
	23/09/92	107621	T-4	17 ± 1	323 ± 22
	23/09/92	107641	T-8	7 ± 1	< 598
	23/09/92	107624	T-9	2 ± 1	< 582
	23/09/92	107650	T-3b	< 2	< 626
	21/09/92	107601	T-13	< 1	82 ± 25
	21/09/92	107607	T-14	< 2	< 63
	21/09/92	107608	T-15	< 2	< 64
	14/07/93	107757	T-1	< 5	-
	14/07/93	107712	T-2	13 ± 2	-
	14/07/93	107718	T-3	25 ± 1	-
	14/07/93	107744	T-3b	< 4	-
	14/07/93	107728	T-4	7 ± 2	-
	14/07/93	107733	T-8	11 ± 2	-
	14/07/93	107724	T-9	6 ± 2	-
	12/07/93	107709	T-13	63 ± 2	-
	12/07/93	107706	T-14	< 5	-
	12/07/93	107702	T-15	< 5	-

Table 15: Radionuclide results for Lichen collected from 1991 to 1994.

Species	Collection Date	Sample No.	Site No.	^{137}Cs (Bq/kg)	^{7}Be (Bq/kg)
Cladiona sp.	12/06/91	98803	T8	4 ± 1	173 ± 15
	12/06/91	98806	T3	32 ± 2	457 ± 22
	12/06/91	98805	T1	< 3	719 ± 27
	14/08/91	98760	T8	6 ± 1	-
	14/08/91	98759	T3	43 ± 1	-
	14/08/91	98758	T1	39 ± 3	-
	31/10/91	98829	T8	8 ± 2	295 ± 119
	31/10/91	98822	T3	28 ± 3	-
	6/04/92	98810	T8	14 ± 3	378 ± 37
	6/04/92	98812	T3	34 ± 7	463 ± 65
	6/04/92	98814	T1	15 ± 2	401 ± 24
	24/05/92	107535	T8	< 4	-
	24/05/92	107537	T3	13 ± 1	539 ± 9
	1/09/92	107520	T8	15 ± 2	-
	1/09/92	107519	T3	34 ± 3	< 33
	1/09/92	107518	T1	68 ± 2	703 ± 135
	24/05/92	107539	T1	28 ± 3	452 ± 193
	8/10/92	107542	T8	33 ± 14	828 ±141
	8/10/92	107544	T1	21 ± 8	392 ± 89
	27/01/93	107777	T8	< 2	-
	27/01/93	107780	T1	8 ± 1	-
	19/07/93	122902	T8	7 ± 1	-

Table 15: Radionuclide results for Lichen collected from 1991 to 1994 cont'd.

Species	Collection Date	Sample No.	Site No.	^{137}Cs (Bq/kg)	^{7}Be (Bq/kg)
Cladiona sp.	19/07/93	122904	T1	258 ±10	-
	26/10/93	107774	T3	< 8	-
	26/10/93	107772	T8	13 ± 4	-
	26/10/93	107775	T1	9 ± 4	-
	23/03/94	14578	T8	13 ± 4	-
	23/03/94	14579	T1	25± 8	-
	8/07/94	107995	T8	4 ± 3	-
	8/07/94	107998	T1	58 ± 8	-
Usnea sp.	12/06/91	98802	T8	27 ± 2	203 ± 25
	12/06/91	98801	T3	43 ± 2	275 ± 26
	12/06/91	98804	T1	34 ± 2	301 ± 27
	14/08/91	98755	T8	9 ± 1	-
	14/08/91	98754	T3	39 ± 1	-
	14/08/91	98756	T1	36 ± 2	-
	31/10/91	98825	T8	41 ± 5	-
	31/10/91	98807	T3	19 ± 4	-
	6/04/92	98809	T8	21 ± 3	117 ± 49
	6/04/92	98811	T3	20 ± 3	171 ± 25
	24/05/92	107536	T8	< 8	-
	24/05/92	107540	T3	32 ±6	-

Table 15: Radionuclide results for Lichen collected from 1991 to 1994, cont'd.

Species	Collection Date	Sample No.	Site No.	^{137}Cs (Bq/kg)	^{7}Be (Bq/kg)
Usnea sp.	24/05/92	107538	T1	35± 3	-
	1/09/92	98757	T8	18 ± 1	-
	1/09/92	107522	T3	37 ± 4	-
	1/09/92	107521	T1	21 ± 4	-
	8/10/92	107541	T8	11 ± 4	< 79
	8/10/92	107543	T1	28 ± 4	< 175
	27/01/93	107778	T8	4 ± 1	-
	27/01/93	107779	T1	6 ± 1	-
	19/07/93	122901	T8	7 ± 2	-
	19/07/93	122903	T1	41 ± 5	-
	26/10/93	107771	T8	4 ± 4	-
	26/10/93	107774	T1	9 ± 5	-
	23/03/94	14577	T1	27 ± 8	-
	8/07/94	107994	T8	5 ± 2	-
	8/07/94	107997	T1	8 ± 5	-

Usnea sp. from 24 ± 7 Bq/kg to 22 ± 7 Bq/kg was also observed. Cesium-137 levels in lichen have decreased during the lifetime of the operational monitoring program for *Cladonia sp.,* (Figure 32 a) and for *Usnea sp.,* (Figure 32 b). The Point Lepreau NGS has not contributed any measurable ^{137}Cs to lichen and ^{137}Cs activities have coincidentally decreased since the reactor startup due to radioactive decay and the decrease in atmospheric fallout from nuclear tests.

In general, levels of ^{137}Cs are higher in *Cladonia sp.* than in *Usnea sp.* (Figures 32a and 32b) as a result of a longer biological half-life for cesium in the former (Ellis and Smith, 1987, Martin and Koranda, 1971). Radionuclide activities are similar at the different sites and small differences have been shown to be consistent with changes in ^{7}Be activities. The relationship between ^{7}Be, a naturally-occurring radionuclide, formed in the stratosphere, and fallout ^{137}Cs permits the estimate of lichen collection efficiency for atmospheric fallout radionuclides (Ellis and Smith, 1987, Nelson *et al*, 1988). Unfortunately, delays between sampling and analysis have led to high detection limits for ^{7}Be in many cases, making the use of ^{137}Cs /^{7}Be ratios difficult. Arboreal lichens such as *Usnea sp.* obtain their nutrients directly from the atmosphere resulting in similar isotopic ratios in lichen and the atmosphere. The accumulation of radionuclides in ground lichen, such as *Cladonia sp.* occurs via several pathways such as soil and rain, leading to fractionation and delays in uptake owing to different isotopic half-lives and residence times in preceding environmental reservoirs.

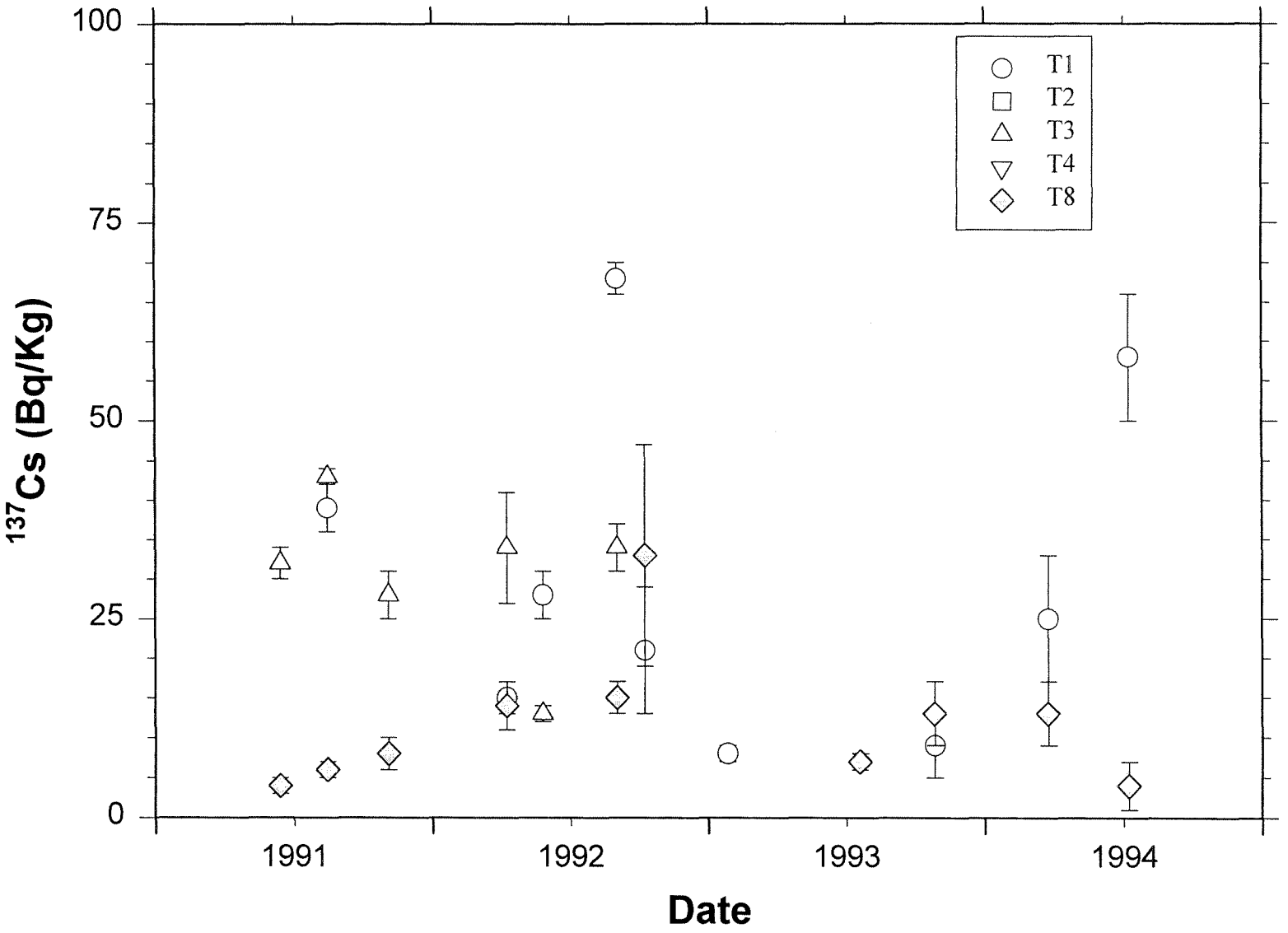

Figure 32A: Cesium-137 activities in ***Cladonia sp.*** from 1991 to 1994.

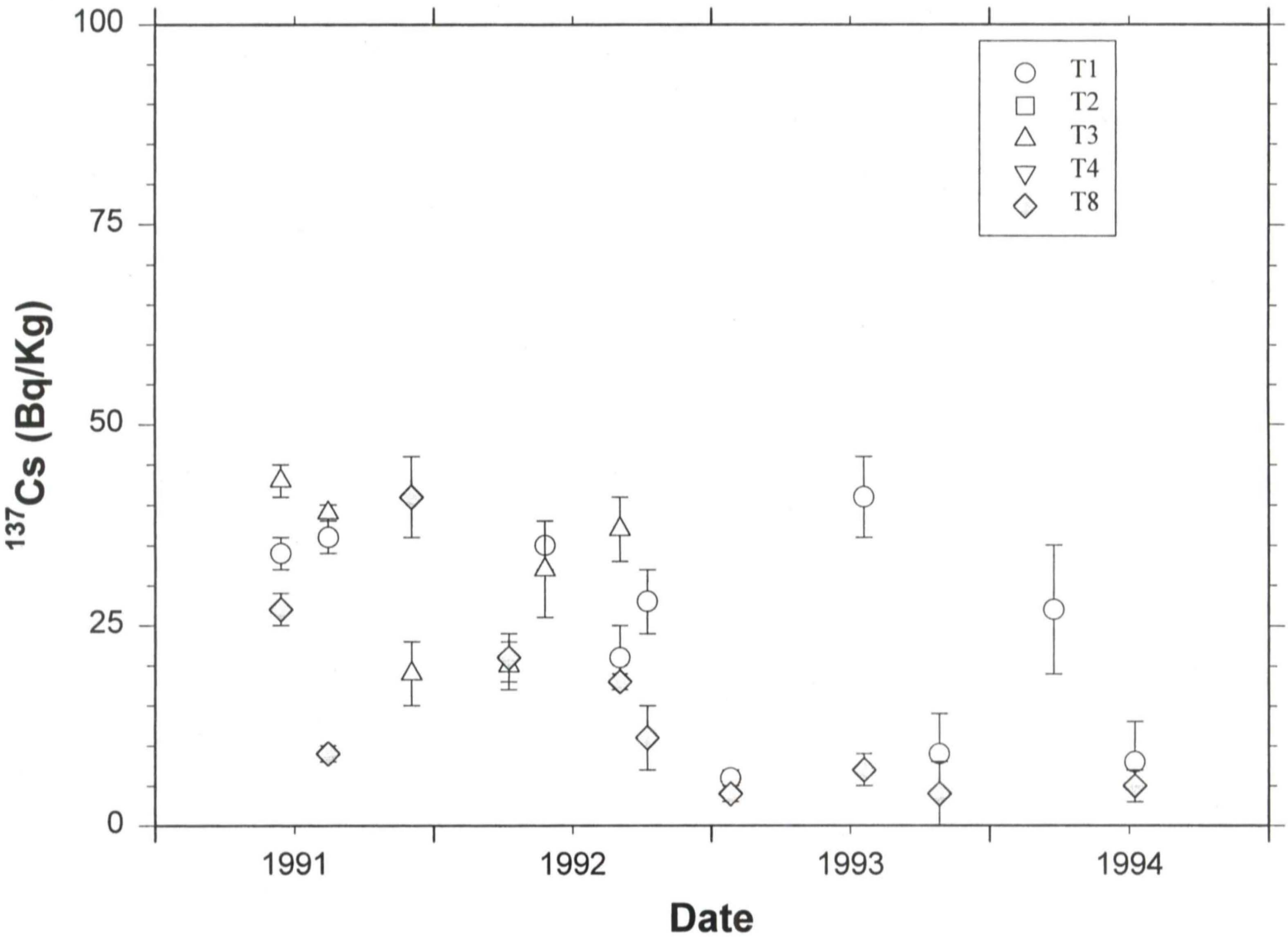

Figure 32B: Cesium-137 activities in ***Usnea sp.*** from 1991 to 1994.

^{137}Cs (Bq/Kg)
100
75
50
25
0
T1
T2
T3

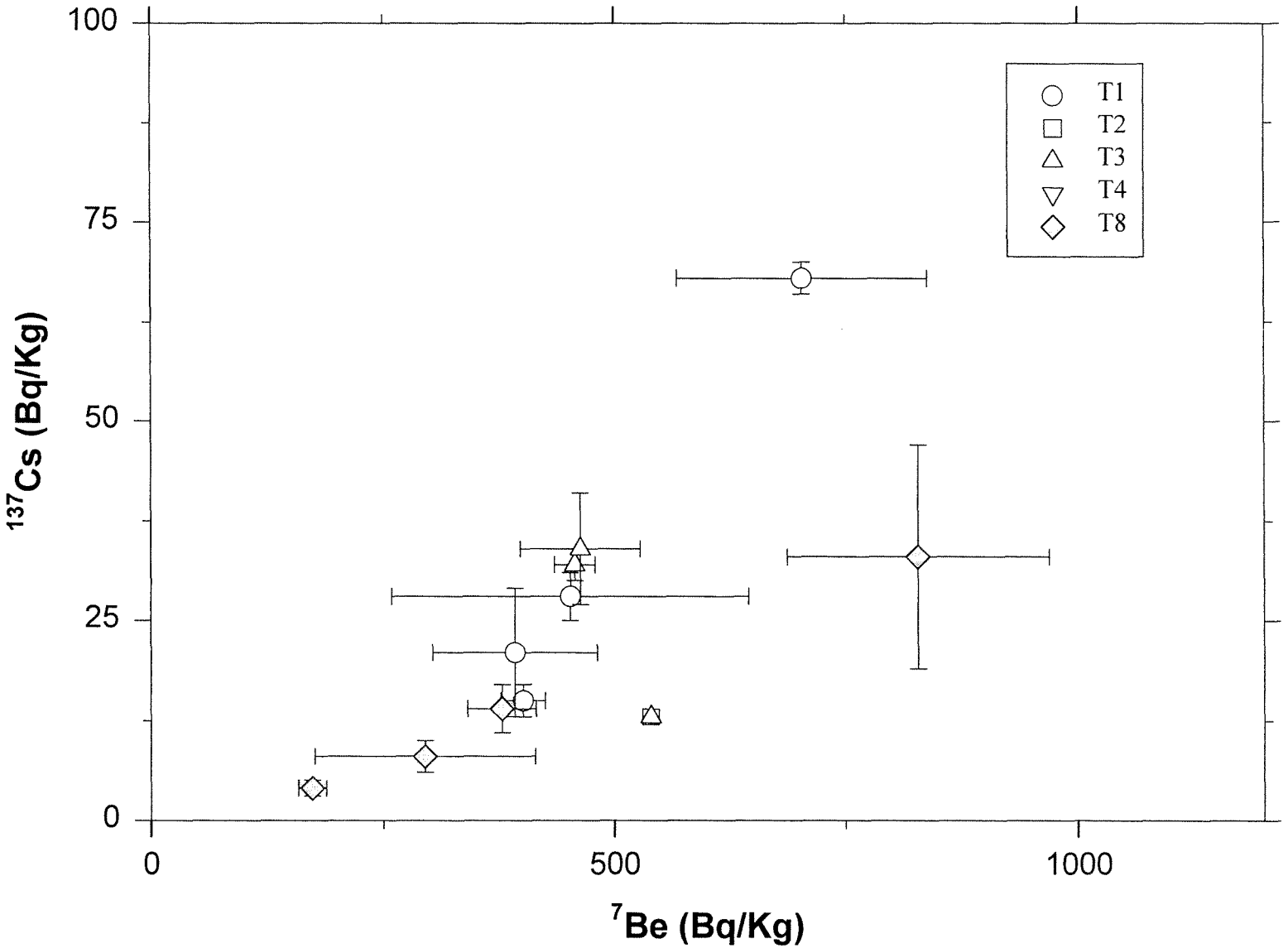

Figure 33A: ^{137}Cs vs ^{7}Be in ***Cladonia sp.*** from 1991 to 1994.

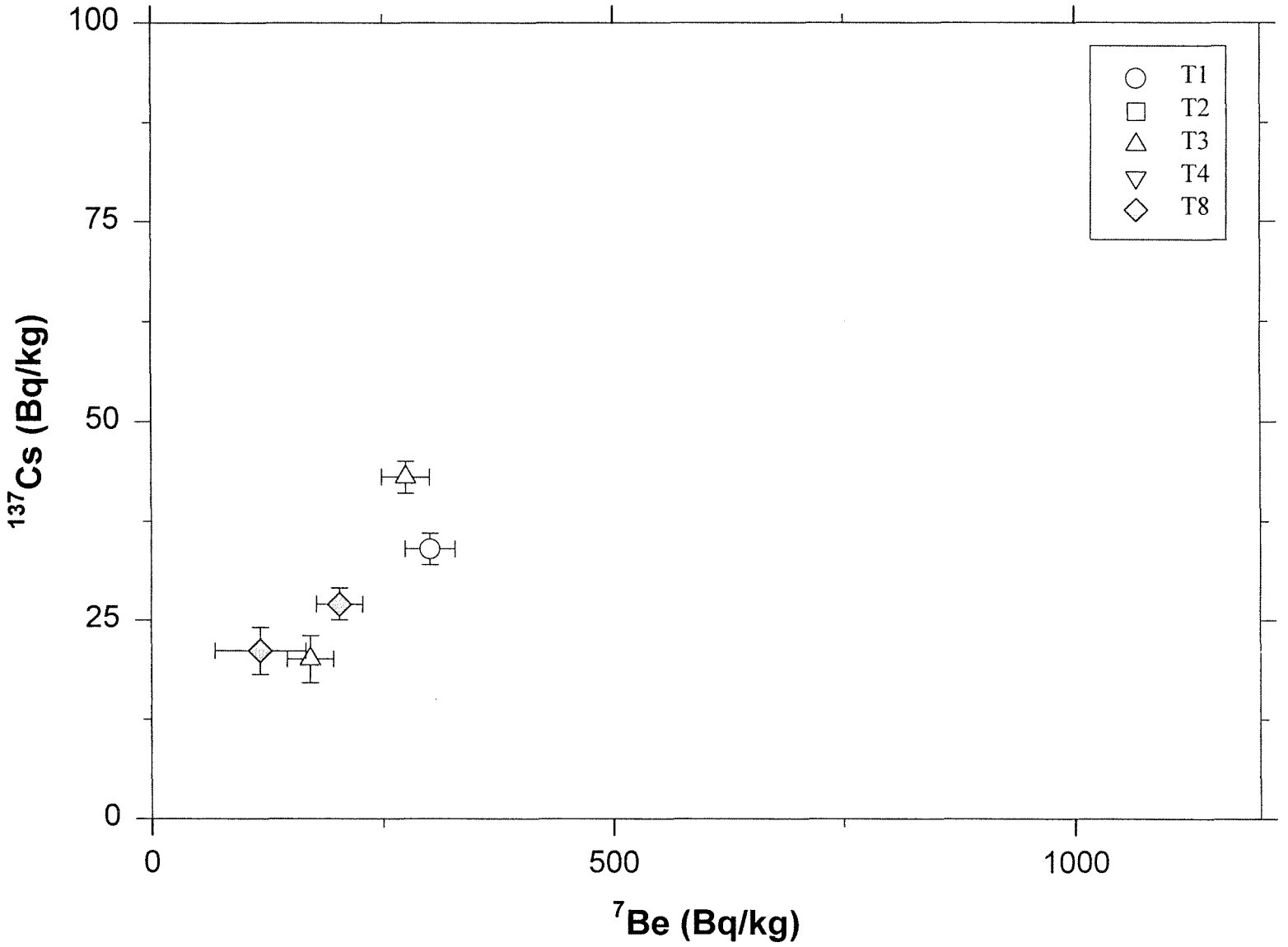

Figure 33B: ^{137}Cs vs ^{7}Be in ***Usnea sp.*** from 1991 to 1994.

6.3 Tritium in Terrestrial Systems

The majority of tritium from the reactor enters the environment in the form of tritiated water (HTO). Absorption of HTO by plants occurs through exchange between atmospheric moisture and foliar water (Belot, 1986). Water is also absorbed through the root or rhyzoid system by the same process and at rates similar to the uptake of natural water (Murphy *et al*, 1982). Tritium activities measured in conifer needles collected from 1991 to 1994 are presented in Table 16. The wide range of tritium activities measured, (from 2 to 613 Bq/l), reflect the variability in atmospheric tritium levels observed throughout the sampling area.

Conifer needle samples were collected from three of the locations (T1, T3 and T8) at more frequent intervals from 1991 to 1994 to provide a time series and the results are shown in Figure 34. Site T8 is located 0.5 km southwest of the NGS and is closest to the release source. Tritium activities in conifer needles are highest here and tend to be maximized during the winter months when the site is downwind from the reactor source. Site T3 is located approximately 10 km to the northeast of the reactor. ^{3}H activities are highest in the spring and summer when releases from the NGS are transported to the site by the prevailing southwesterly winds. Results for T1 located 20 km from the NGS remain comparable to values of 8 Bq/l, measured during the pre-operational program, with several exceptions (Figure 34). Tritium activities measured above background at T1 are related to higher tritium emissions from the NGS during the spring and summer when the prevailing winds are from the southwest transporting NGS emissions towards T1. The increase in the yearly average tritium activity from 8 Bq/l during the pre-operational

Table 16: Tritium Results for Conifer Needles Collected in 1991.

Collection Date	Sample No.	Site No.	^{3}H (Bq/l)
12/06/91	107506	T8	32 ± 4
12/06/91	107508	T3	68 ± 2
12/06/91	107505	T1	< 2
17/06/91	98705	T15	2 ± 2
17/06/91	98707	T14	55 ± 4
17/06/91	98709	T13	442 ± 5
19/06/91	98715	T8	496 ± 5
19/06/91	98774	T10	14 ± 5
20/06/91	98726	T1	489 ± 2
20/06/91	98733	T3	351 ± 3
20/06/91	98729	T3a	32 ± 4
20/06/91	98743	T9	101 ±2
20/06/91	98746	T4	59 ± 4
20/06/91	98753	T6	471 ± 2
8/07/91	107513	T8	55 ± 8
8/07/91	107512	T3	30 ± 2
14/08/91	107509	T8	64 ± 2
14/08/91	107510	T3	22 ± 2
14/08/91	107511	T1	35 ± 2
31/10/91	107515	T8	51 ± 3
31/10/91	107516	T3	244 ± 2
31/10/91	107517	T1	3 ± 2

Table 16 (cont'd): Tritium Results for Conifer Needles Collected in 1992 and 1993.

Collection Date	Sample No.	Site No.	^{3}H (Bq/l)
24/05/92	107501	T1	122 ± 3
21/09/92	107602	T13	2 ± 2
21/09/92	107606	T14	2 ± 2
21/09/92	107609	T15	1 ± 1
23/09/92	107634	T1	6 ± 2
23/09/92	107615	T2	< 2
23/09/92	107632	T3	24 ± 3
23/09/92	107620	T4	11 ± 2
23/09/92	107639	T8	7 ± 2
23/09/92	107623	T9	5 ± 2
23/09/92	107652	T3b	104 ± 4
8/10/92	129609	T8	66 ± 3
8/10/92	129610	T1	4 ± 2
12/07/93	107710	T13	4 ± 2
12/07/93	107707	T14	6 ± 2
12/07/93	107703	T15	9 ± 2
14/07/93	107758	T1	8 ± 2
14/07/93	107713	T2	29 ± 3
14/07/93	107716	T3	76 ± 3
14/07/93	107745	T3b	225 ± 5
14/07/93	107729	T4	9 ± 2
14/07/93	107734	T8	32 ± 3
14/07/93	107723	T9	79 ± 3
19/07/93	128887	T8	116 ± 3
19/07/93	128888	T1	24 ± 2
20/10/93	107773	T8	323 ± 6
20/10/93	107776	T1	3 ± 2

Table 16 (cont'd): Tritium Results for Conifer Needles Collected in 1994.

Collection Date	Sample No.	Site No.	^{3}H (Bq/l)
23/03/94	14575	T8	613 ± 8
23/03/94	14576	T1	3± 2
8/07/94	107996	T8	3 ± 2
8/07/94	107999	T1	3 ± 2
28/11/94	129503	T13	3 ± 2
28/11/94	129502	T14	< 1
28/11/94	129501	T15	1 ± 2
29/11/94	129522	T1	3 ± 2
29/11/94	129530	T2	2 ± 2
29/11/94	129528	T3	21 ± 3
29/11/94	129514	T3b	110 ± 4
29/11/94	129524	T4	108 ± 4
29/11/94	129504	T8	56 ± 3
29/11/94	129526	T9	17 ± 3

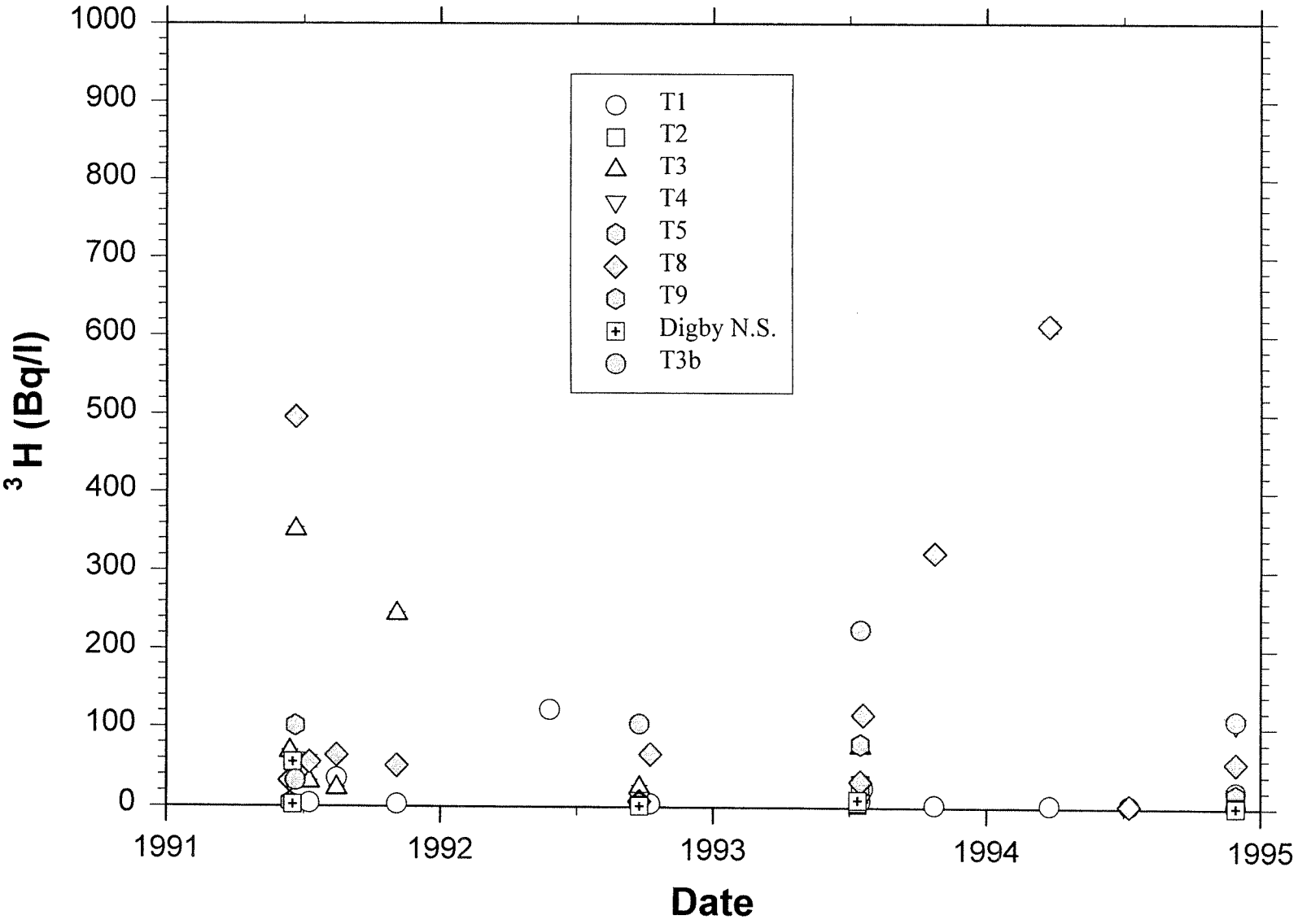

Figure 34: Tritium in conifer needles collected from 1991 to 1994.

program to values in excess of 100 Bq/l for 1991 to 1994 reflects the general increase in the quantity of ^{3}H being released from the NGS (Figure 2).

6.4 Time Series Results for 1984 to 1994.

Radionuclide levels measured during the past 14 years have been used to construct time series plots for data collected from the aquatic and terrestrial phases for both the pre-operational and operational stages of PLEMP.

6.4.1 Lichen

Three species of lichen have been collected as part of PLEMP. *C. Arbuscula,* and *C. Rangiferna*, both ground lichen (referred to as *Cladonia sp.*), have been collected since the start of the monitoring program in 1980 and *Usnea sp.*, was added to the monitoring program in 1984.

The changes in ^{137}Cs activity on a semilogarithmic scale as a function of time for both *Cladonia sp.* and *Usnea sp.* are shown in Figures 35a and 35b respectively. Cesium-137 activities for *Cladonia sp* have decreased from a mean average of 119 Bq/l. in 1984 to 30 Bq/kg for samples collected from 1991 to 1994. Cesium-137 activities for *Usnea sp.* decreased from a mean value of 35 Bq/kg in 1984 to 22 Bq/kg for the 1991 to 1994 period. These results mainly reflect the decrease in ^{137}Cs activities due to radioactive decay and the biological half-life of ^{137}Cs in lichen.

The short-term efficiency for each lichen sample as an integrator, or sampling device for fallout radioactivity, can be estimated from its ^{7}Be concentration. Since the

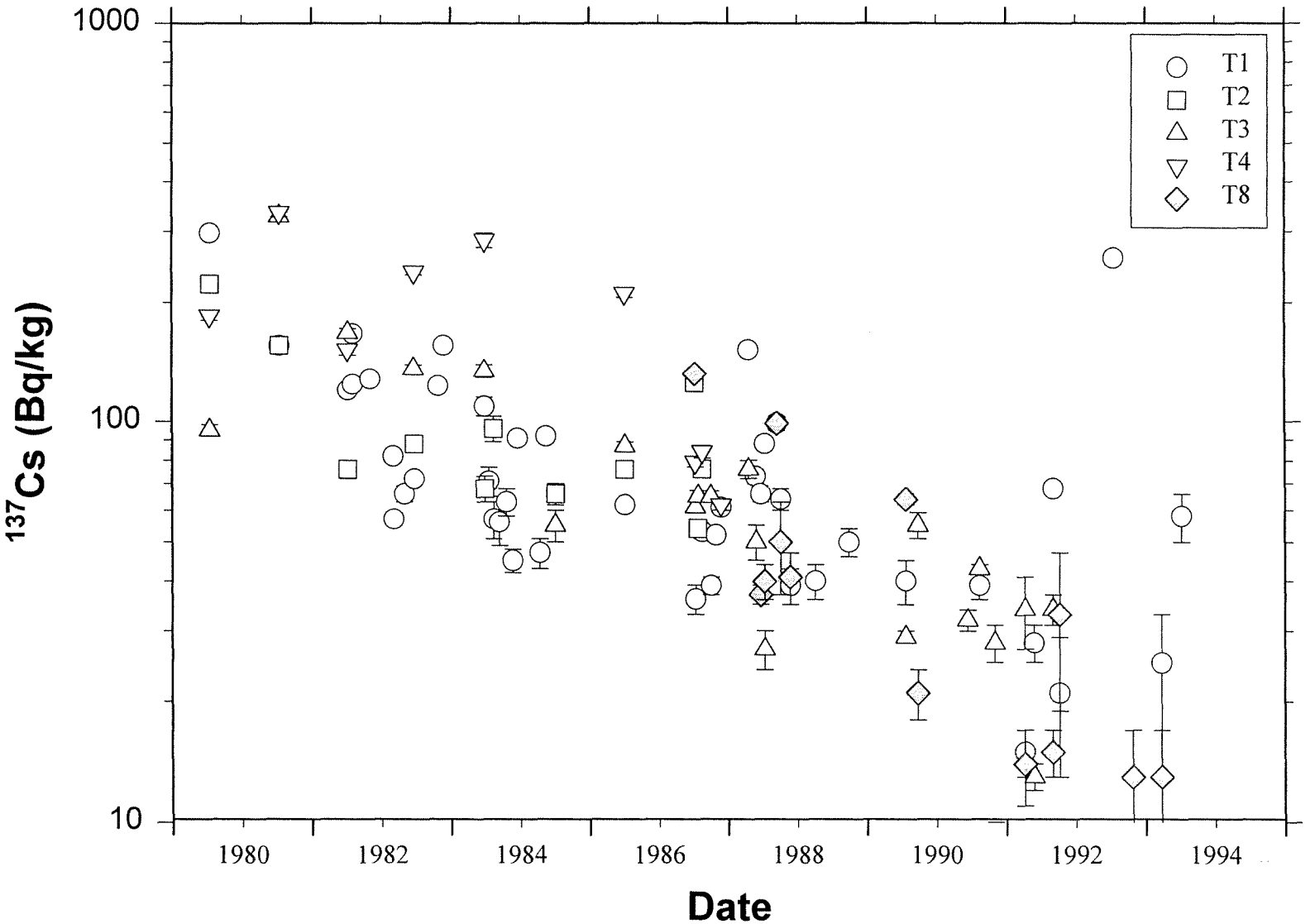

Figure 35A: Cesium-137 activities in ***Cladonia sp.*** from 1980 to 1994.

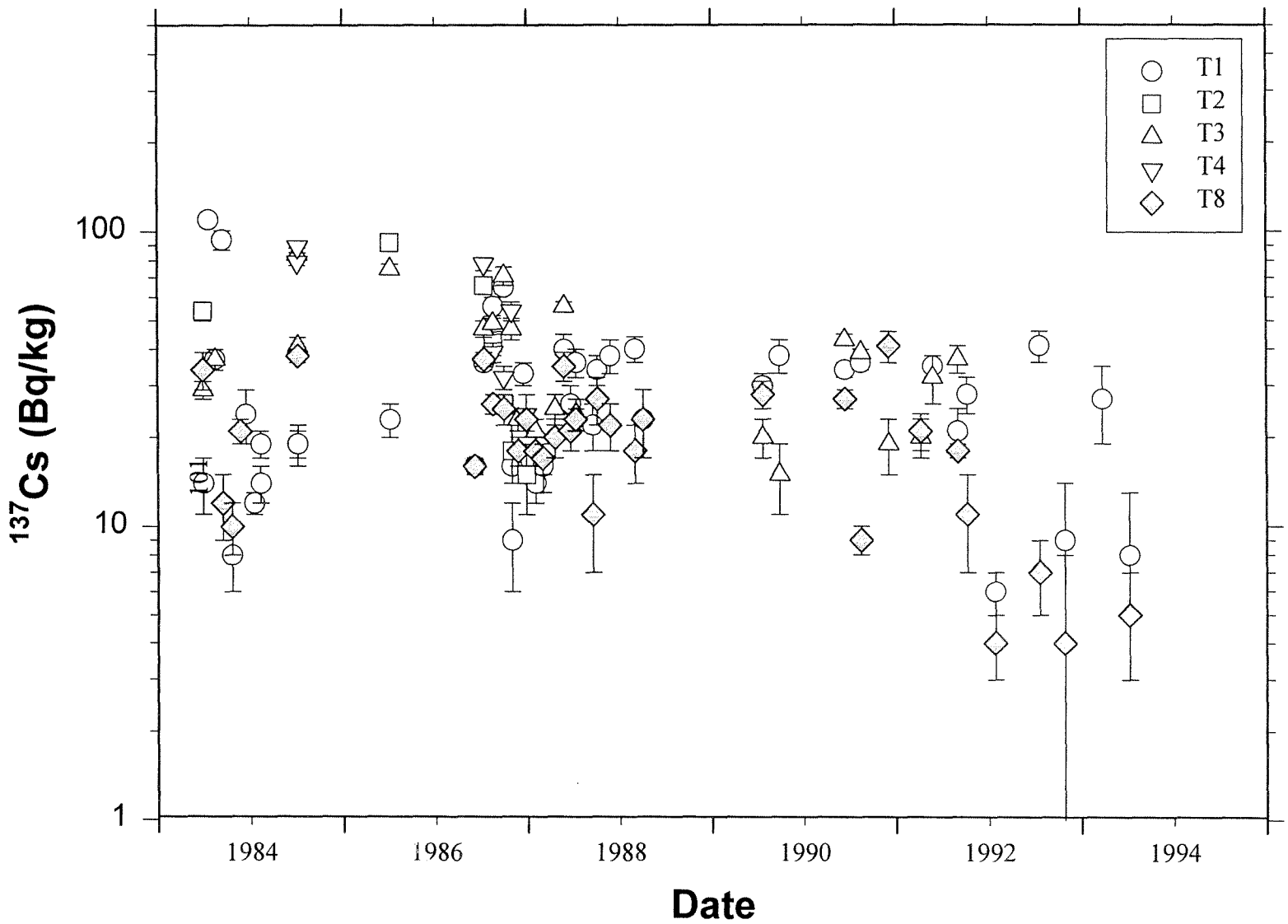

Figure 35B: Cesium-137 activities in ***Usnea sp.*** from 1984 to 1994.

atmospheric flux of ^{7}Be is comparatively constant, lichen samples high in ^{7}Be should have higher concentrations of other fallout radionuclides. The correlation of ^{137}Cs and ^{7}Be in *Cladonia sp.* ($r^2 = 0.001$; n=64; Figure 36a) is poor because radionuclide uptake in this type of lichen occurs from multiple reservoirs (soil, runoff, air, etc.). A better correlation is observed for ^{137}Cs and ^{7}Be for *Usnea sp.* ($r^2 = 0.1$, n = 42; Figure 36b) which collects radionuclides directly from the atmosphere.

6.4.2 Tritium in Biological Samples

Tritium activities have been measured in freshwater and terrestrial plant samples since 1980. Conifer needles were added to the monitoring program in 1986 to provide a sample matrix that could be collected throughout the year in order to assess levels of tritium in the terrestrial ecosystem.

Freshwater samples were collected annually for tritium analysis from sites shown in Figure 30 and the results are presented in Figure 37. Tritium activities have increased above the pre-operational average value of 8 Bq/l (Figure 37), at sites T8, T9 and T3b located nearest the NGS. Figure 38 shows comparisons between ^{3}H activities in water vapor collected at AMS 1 and AMS 3 and in water samples collected from the nearest terrestrial sampling sites. In all cases ^{3}H activities in water vapor were higher than in water samples reflecting the dilution of the tritium signal as it is transported from atmospheric to aquatic phases of the environment. Tritium activities were generally 2 to 10 times higher in atmospheric water vapour compared to freshwater from nearby sites.

Tritium activities measured in blueberry leaves and conifer needles collected from 1983 to 1994 are shown in Figure 39. Tritium levels in conifer needles were higher than

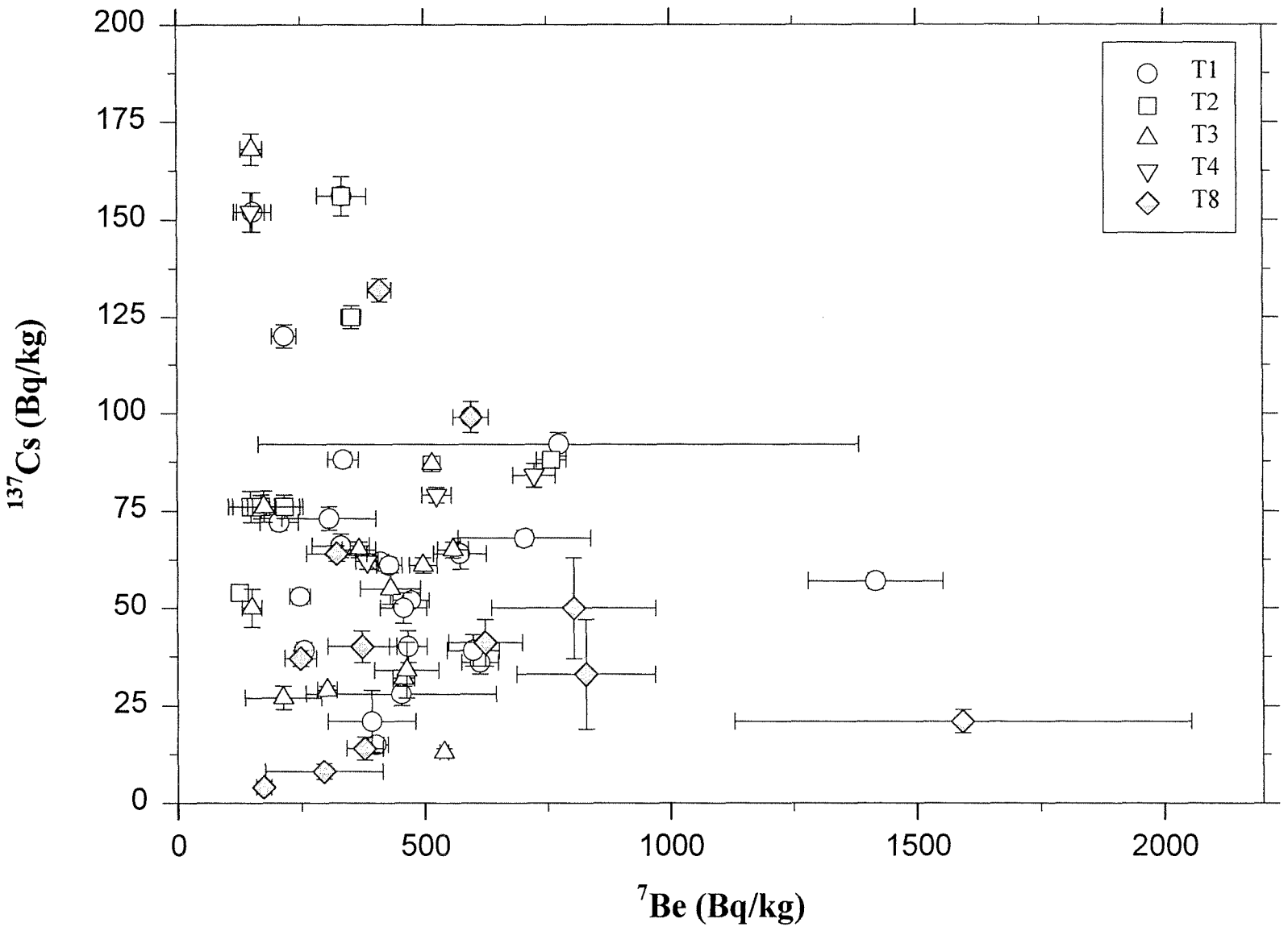

Figure 36A: ^{137}Cs vs ^{7}Be in ***Cladonia sp.*** from 1980 to 1994.

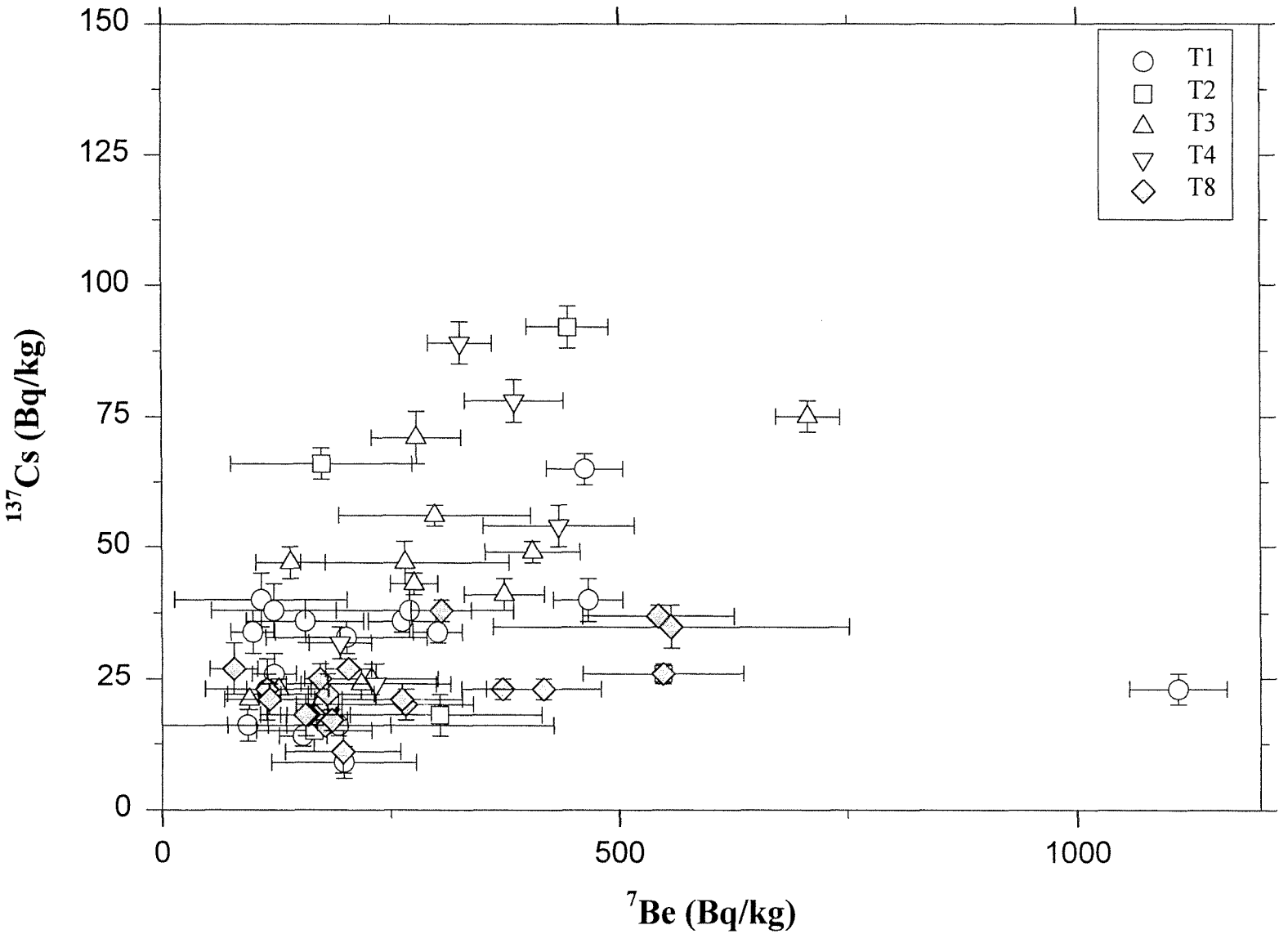

Figure 36B: ^{137}Cs vs ^{7}Be in ***Usnea sp.*** from 1980 to 1994.

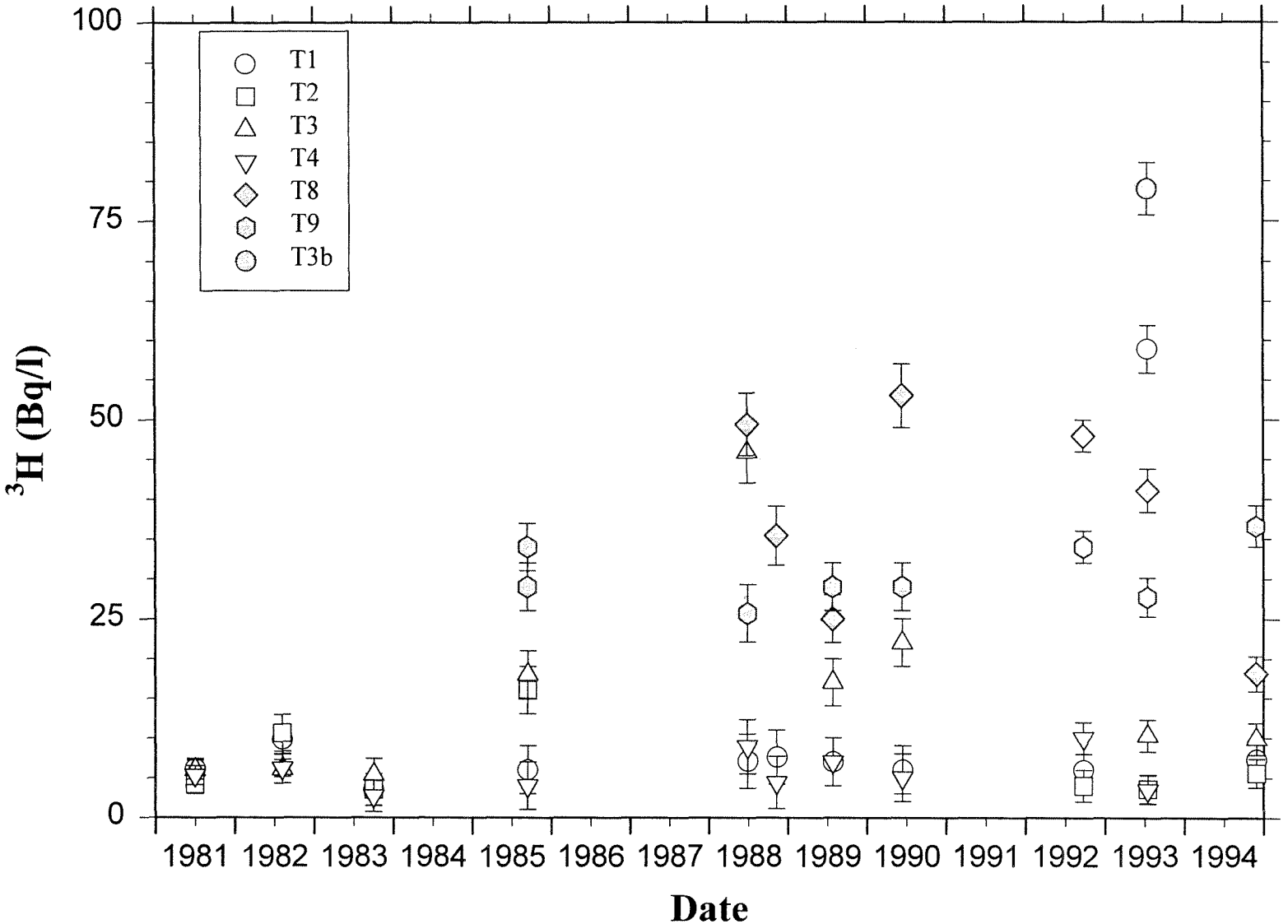

Figure 37: Tritium activities in fresh water collected from terrestrial sampling sites at Point Lepreau from 1981 to 1995.

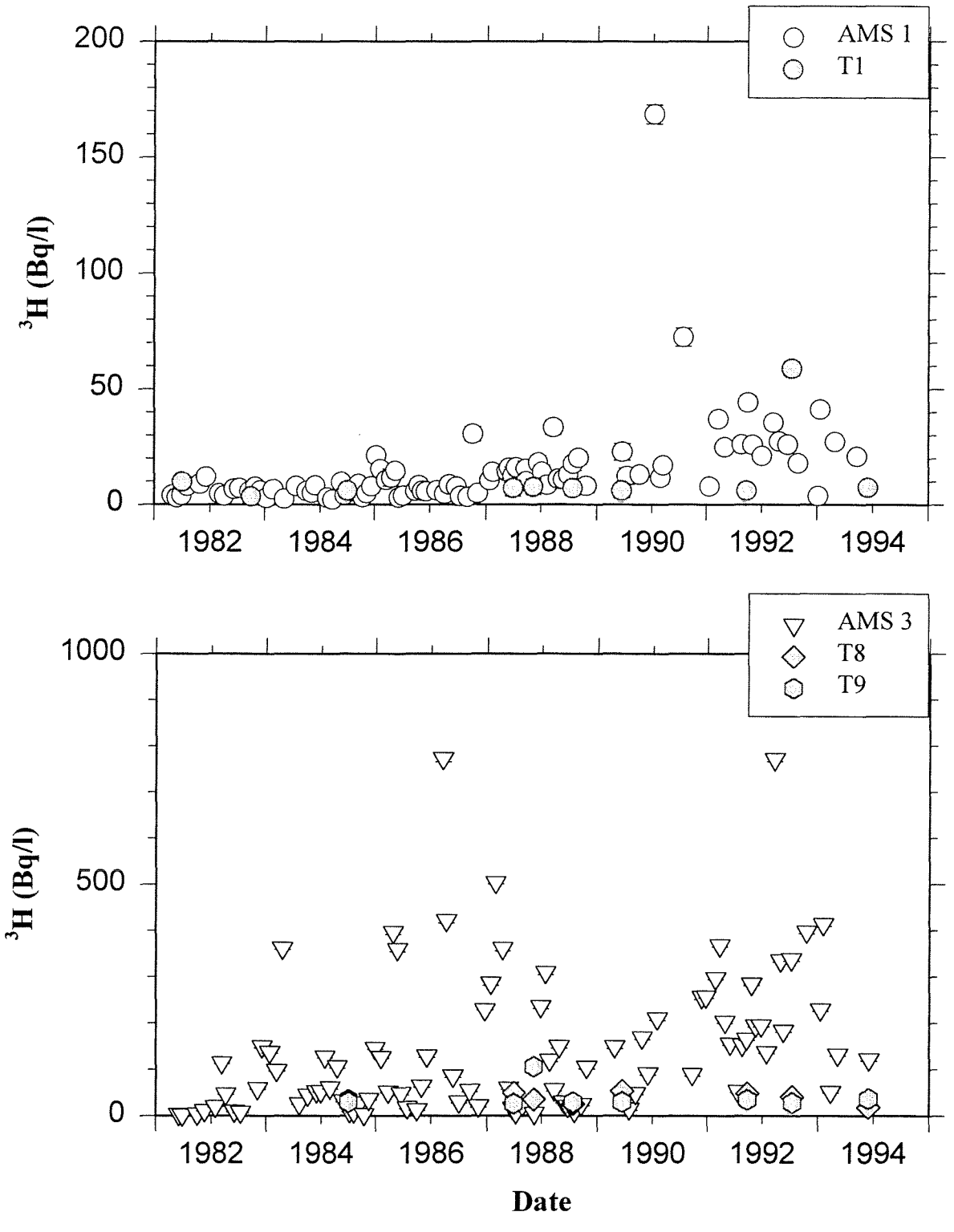

Figure 38. Comparison of tritium in terrestrial water samples and in water vapour at a site near the NGS (AMS 3,T8) and 20 km from the site, (AMS 1, T1).

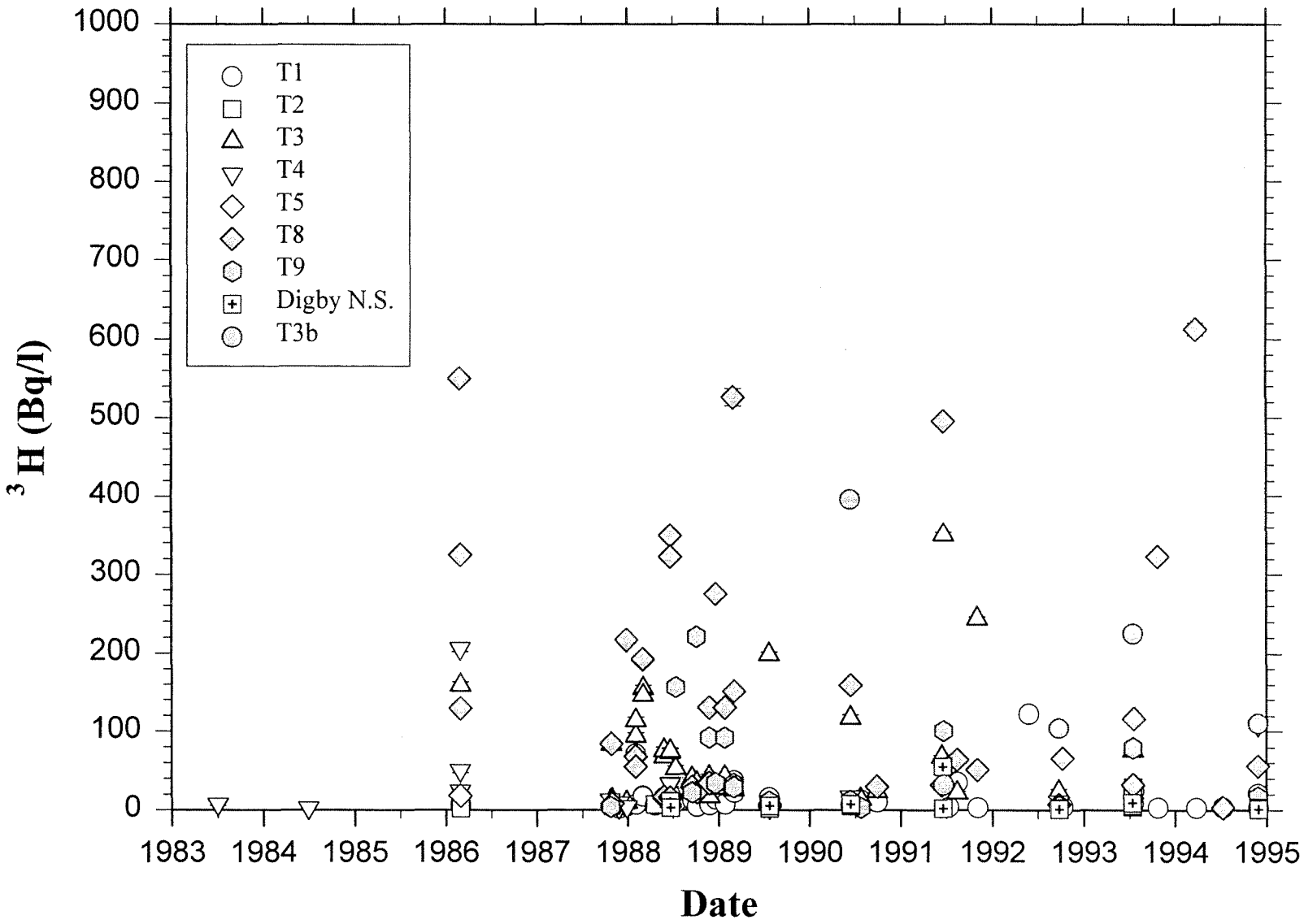

Figure 39: Tritium in terrestrial plant samples collected from 1983 to 1995. Tritium results for the period 1983 - 1986 are for blueberry leaves and tritium results for the period from 1986 - 1995 are for conifer needles.

tritium levels in water samples from common sampling sites, but exhibit a similar time series distribution. Tritium activities were highest at those sites closest to the NGS (T3, T8, T9 and T3b) with the highest value of 600 Bq/l measured at T8. At those sites farther from the NGS tritium activities have remained close to pre-operational levels. Tritium activities for conifer needles and for water vapor collected from nearby atmospheric monitoring sites are illustrated in Figure 40. Since the conifer needles directly intercept atmospheric water vapor tritium levels are comparable in both sample matrices. In the absence of atmospheric water vapour samples, conifer needles provide a reasonable proxy for estimating tritium transport in water vapour.

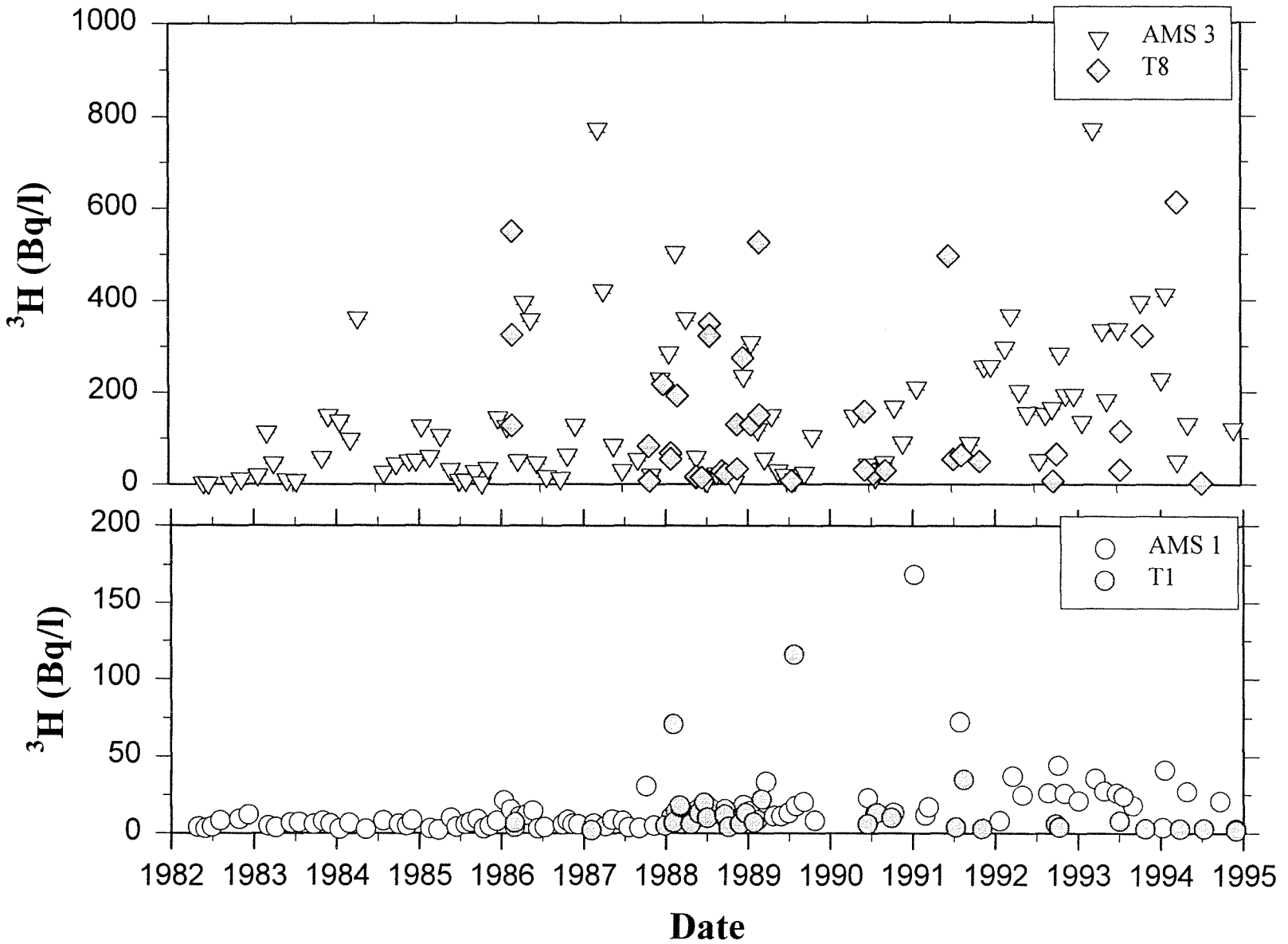

Figure 40: Comparison of tritium in conifer needles (dark) and in water vapour (white) at a site near the NGS (AMS 3, T8) and 20 km from the site (AMS 1, T1).

7.0 Laboratory Intercomparison Program

The AERU laboratory participates in several ongoing intercomparison programs in order to maintain a check on the laboratory's analytical performance. Two major programs run by the United States Environmental Protection Agency (USEPA) and the International Atomic Energy Agency (IAEA) provide a variety of sample matrices for blind intercomparison studies. The results of both programs are published and distributed to all participants.

The USEPA distributes an assortment of intercomparison samples throughout the calendar year to provide a routine check on a variety of sample matrices. The results for 1991 to 1994 are presented in Table 17. The agreement between AERU and USEPA results is generally good for most types of samples analyzed.

In addition the IAEA has provided a series of sediment and marine biota samples, in their blind intercomparison program. The results from this program are presented in Table 18. Results again indicate generally good agreement between IAEA and AERU results. A calibration error, in 1994, for the tracer used in the ^{210}Pb analytical procedure was discovered and corrected as a result of the intercalibration exercises

Table 17: Results for intercalibration samples from EPA.Units for air filters are pCi and for water samples are pCi/l.

Sample Type	Collect. Date	Nuclide	EPA Value	AERU Value	AERU SD	All Labs SD	AERU/ EPA
Air Filter	29.3.91	^{137}Cs	40	46	2	10	1.2
	30.8.91	^{137}Cs	30	33	3	5	1.1
	27.3.92	^{137}Cs	10	9	1	2	0.9
	26.8.94	^{137}Cs	15	17	1	3	1.1
Water	21.6.91	^{3}H	12480	11396	376	940	0.9
Water	15.2.91	^{131}I	75	82	2	6	1.1
	7.8.92	^{131}I	45	38	4	4	0.8
	8.10.93	^{131}I	117	68	6	11	0.6
	7.10.94	^{131}I	79	85	4	7	1.1
Water	16.4.91	^{134}Cs	24	20	1	3	0.8
		^{137}Cs	25	28	1	2	1.1
	14.4.92	^{134}Cs	24	23	12	2	1.0
		^{137}Cs	22	26	1	2	1.2
		^{60}Co	56	21	1	3	0.4
	20.10.92	^{134}Cs	5	7	1	2	1.4
		^{137}Cs	8	8	1	1	1.0
		^{60}Co	15	22	2	2	1.5
	20.4.93	^{134}Cs	27	28	2	2	1.0
		^{137}Cs	32	36	2	3	1.1
		^{60}Co	39	48	3	3	1.2
	19.10.93	^{134}Cs	12	10	2	2	0.8
		^{137}Cs	10	13	3	2	1.3
		^{60}Co	10	10	2	2	1.0

Table 17: Results for intercalibration samples from EPA. Units for air filters are pCi and for water samples are pCi/l. (cont'd)

Sample Type	Collect. Date	Nuclide	EPA Value	AERU Value	AERU SD	All Labs SD	AERU/ EPA
Water	19.4.94	^{134}Cs	34	28	1	3	0.8
		^{137}Cs	29	32	1	2	1.1
		^{60}Co	20	18	2	2	0.9
Water	7.6.91	^{133}Ba	62	62	3	6	1.0
		^{65}Zn	108	122	6	8	1.1
		^{106}Ru	149	170	6	14	1.1
		^{134}Cs	15	16	1	2	1.1
		^{137}Cs	14	19	1	2	1.4
		^{60}Co	10	12	2	2	1.2
	4.10.91	^{133}Ba	98	87	4	7	0.9
		^{65}Zn	73	59	5	7	0.8
		^{106}Ru	199	141	8	21	0.7
		^{134}Cs	10	6	1	2	0.6
		^{137}Cs	10	12	2	2	1.2
		^{60}Co	29	31	1	3	1.1
	5.6.92	^{133}Ba	98	114	2	7	1.2
		^{65}Zn	99	122	6	7	1.2
		^{106}Ru	141	157	6	12	1.1
		^{134}Cs	15	14	3	2	0.9
		^{137}Cs	15	16	2	4	1.1
		^{60}Co	20	23	1	2	1.2
	12.11.93	^{133}Ba	79	83	2	6	1.1
		^{65}Zn	150	178	4	9	1.2
		^{106}Ru	201	182	24	18	0.9
		^{134}Cs	59	58	5	5	1.0
		^{137}Cs	40	45	3	3	1.1
		^{60}Co	30	38	1	2	1.3

Table 18: Results for intercalibration samples from IAEA.

Sample #	Nuclide	IAEA Value (Bq/kg)	AERU Value (Bq/kg)	AERU SD (Bq/kg)	AERU / IAEA
IAEA 367	^{137}Cs	195	187	7	1.0
1991	^{230}Th	19	19	2	1.0
	$^{239/240}Pu$	38	33	3	0.9
IAEA 368	^{137}Cs	0.34	< 4		
1991	^{210}Pb	23	26	2	1.1
	$^{239/240}Pu$	31	30	2	1.0
IAEA 134	^{137}Cs	49.8	46	4	0.9
1992	^{60}Co	4.5	5	3	1.1
	^{40}K	212	168	13	0.8
	^{228}Th	3	3.4	0.2	1.1
	$^{239/240}Pu$	15	17	1	1.1
IAEA 135	^{137}Cs	1108	1024	14	0.9
1992	^{60}Co	4.8	5	3	1.0
	^{40}K	560	529	46	0.9
	^{228}Th	38	72	4	1.9
	$^{239/240}Pu$	213	245	21	1.2
IAEA 300	^{226}Ra	56.5	33	3	0.6
1993	^{210}Pb	360	296	14	0.8
	^{210}Po	340.5	324	18	1.0
	$^{239/240}Pu$	3.55	3.5	0.2	1.0
	^{238}Pu	0.15	0.14	0.04	0.9
	^{137}Cs	1066.6	1067	18	1.0
	^{134}Cs	66.6	39	3	0.6

Table 18: Results for intercalibration samples from IAEA. (cont'd)

Sample #	Nuclide	IAEA Value (Bq/kg)	AERU Value (Bq/kg)	AERU SD (Bq/kg)	AERU / IAEA
IAEA 315	^{226}Ra	14.2	8	1	0.6
1993	^{210}Pb	30.2	30	2	1.0
	^{210}Po	30.1	30	2	1.0
	$^{239/240}$Pu	70.0	61	4	0.9
	^{238}Pu	9.9	8.8	0.8	0.9
	^{137}Cs	541.0	533	10	1.0
	^{134}Cs	12.0	8	1	0.7
	^{60}Co	144.0	165	7	1.2
IAEA 326	^{228}Ac	40.2	33	2	0.8
1994	^{134}Cs	4.6	4.5	0.4	1.0
	^{137}Cs	137.5	154	1	1.1
	^{40}K	575.4	634	9	1.1
	^{210}Pb	45.6	62	4	1.4
	$^{239/240}$Pu	0.50	0.5	0.1	1.1
	^{106}Ru	4.0	< 8	-	-
	^{135}Sb	2.4	< 3	-	-
	^{228}Th	39.0	30	4	0.8
IAEA 327	^{228}Ac	38.6	36	2	0.9
1994	^{241}Am	0.22	0.23	0.07	1.0
	^{134}Cs	1.8	1.8	0.5	1.0
	^{137}Cs	25.1	25	2	1.0
	^{40}K	616.4	681	13	1.1
	^{210}Pb	52.7	75	5	1.4
	$^{239/240}$Pu	0.58	0.63	0.05	1.1
	^{106}Ru	3.0	< 9	-	-
	^{135}Sb	7.4	< 3	-	-
	^{228}Th	38.2	33	2	0.9

8.0 Conclusions

No environmental increases in ^{137}Cs activities have been observed as a result of releases from the NGS. Levels of ^{137}Cs measured in the Bay of Fundy result from atmospheric fallout from the nuclear weapons testing and have decreased to an average of 2.55 mBq/l due to radioactive decay and gradual dilution with Atlantic water and freshwater. Levels of ^{137}Cs measured in terrestrial and freshwater plants have decreased as a result of radioactive decay of previously deposited material and decreased inputs from atmospheric testing.

Tritium continues to be the only radionuclide released by Point Lepreu that was detected in the environment during this time period.

Small increases in the tritium activity in air for AMS 5 located in Digby N.S. indicate that there is some transport of radioactivity across the Bay of Fundy of no ecological or human health risk.

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The working group for the Point Lepreau Environmental monitoring program is composed of scientists from different government departments (Appendix 1), all of whom have contributed to the development and operation of this program. In particular, we would like to thank Bill Richards (Atmospheric Environment Services, Fredericton, N.B.) who supervised the meteorological aspects of PLEMP. We also thank members of Environment New Brunswick (Fredericton, N.B.), who provided many of the terrestrial and aquatic samples; namely K. Brown, W. Sexsmith and M.Boldon. J. Abriel, G. Folwarczyna and C. Anstey provided the analytical support in the AERU radiochemical laboratory and Dr. J. M. Bewers (Fisheries and Oceans) has provided continued support and many helpful suggestions through all stages of the program.

Residents of Point Lepreau, N.B. provided great assistance in the operation of the air monitoring stations including Mr. and Mrs. G. Thompson (Dipper Harbour), and the staff of the New Brunswick Department of Transport depot at Musquash, particularly E. Thompson. Mr. M. Durkee provided similar support at Digby, N.S. Appreciation is also extended to members of the N. B. Electric Power Commission's Health Physics Department who helped with the deployment, maintenance and operation of air monitoring equipment and provided information regarding reactor operation, namely Dr. J. Paciga, J. McCulley, J. O'Donnell and C. Nason.

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APPENDIX 2: PLEMP REPORTS

Bishop F.J., Ellis KM. and Smith, J.N. and Bewers, J.M. (1980). Pre-operational environmental monitoring report for the Point Lepreau, N.B. nuclear generating station. Bedford Institute of Oceanography Report Series - BI-R-801.

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APPENDIX 3: Conversion Factors for Radionuclide Units:

1 Becquerel (Bq)	=	60 dpm
	=	27 pCi
1 Bql/l	=	2.7×10^{-11} Curies (Ci)
	=	8.3 tritium units (TU)
1 Ci	=	3.7×10^{10} Bq
1mCi	=	3.7×10^{7} Bq
1pCi	=	3.7×10^{-2} Bq
1dpm	=	0.0167 Bq
1 dpm	=	0.45pCi
1TU	=	0.12Bql/l
1TU	=	7.2 dpm/l
1mCi/Km^2	=	37 Bq/m^2

APENDIX 4: Concentration Factors for Radionuclides from Seawater for Various Marine Groups (IAEA, 1985).

Radio-nuclide	Half-life	Plankton	Macro-Algae	Crustacean	Mollusc	Pelagic Fish
^{141}Ce	33.0 d	9×10^4	5×10^3	1×10^3	5×10^3	5×10^1
^{144}Ce	284.4 d	9×10^4	5×10^3	1×10^3	5×10^3	5×10^1
^{58}Co	71.2 d	5×10^3	1×10^4	5×10^3	5×10^3	1×10^3
^{60}Co	5.3 y	5×10^3	1×10^4	5×10^3	5×10^3	1×10^3
^{51}Cr	27.7 d	2×10^3	2×10^3	5×10^2	8×10^2	2×10^2
^{134}Cs	5.2 y	2×10^1	5×10^1	3×10^1	3×10^1	1×10^2
^{137}Cs	30.2 y	2×10^1	5×10^1	3×10^1	3×10^1	1×10^2
^{55}Fe	2.6 y	6×10^4	3×10^4	5×10^3	3×10^4	3×10^3
^{131}I	8.1 d	1×10^3	1×10^3	1×10^1	1×10^1	1×10^1
^{54}Mn	321.6 d	6×10^3	6×10^3	5×10^2	5×10^3	4×10^2
^{95}Nb	35.2 d	1×10^3	3×10^3	2×10^2	1×10^3	3×10^1
^{103}Ru	39.4 d	2×10^5	2×10^3	1×10^2	2×10^3	2×10^0
^{106}Ru	368.0 d	2×10^5	2×10^3	1×10^2	2×10^3	2×10^0
^{65}Zn	244.1 d	3×10^4	2×10^4	5×10^4	3×10^4	1×10^3
^{95}Zr	65.0 d	6×10^4	3×10^3	2×10^2	5×10^3	2×10^1

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